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Informatics Society

Aims and Scope

The purpose of this journal is to provide an open forum to publish high quality research papers in the areas of informatics and related fields to promote the exchange of research ideas, experiences and results.

Informatics is the systematic study of Information and the application of research methods to study Information systems and services. It deals primarily with human aspects of information, such as its quality and value as a resource. Informatics also referred to as Information science, studies the structure, algorithms, behavior, and interactions of natural and artificial systems that store, process, access and communicate information. It also develops its own conceptual and theoretical foundations and utilizes foundations developed in other fields. The advent of computers, its ubiquity and ease to use has led to the study of informatics that has computational, cognitive and social aspects, including study of the social impact of information technologies.

The characteristic of informatics' context is amalgamation of technologies. For creating an informatics product, it is necessary to integrate many technologies, such as mathematics, linguistics, engineering and other emerging new fields.

Guest Editor's Message

Yoh Shiraishi

Guest Editor of Seventeenth Issue of International Journal of Informatics Society

We are delighted to have the seventeenth and special of the International Journal of Informatics Society (IJIS) published. This issue includes selected papers from the Seventh International Workshop on Informatics (IWIN2013), which was held at Stockholm, Sweden, Sep 1-4, 2013. The workshop was the seventh event for the Informatics Society, and was intended to bring together researchers and practitioners to share and exchange their experiences, discuss challenges and present original ideas in all aspects of informatics and computer networks. In the workshop 24 papers were presented at five technical sessions. The workshop was complete in success. It highlighted the lasts research results in the area of networking, business systems, education systems, design methodology, groupware and social systems.

Each paper submitted IWIN2013 was reviewed in terms of technical content and scientific rigor, novelty, originality and quality of presentation by at least two reviewers. From those reviews 15 papers are selected for publication candidates of IJIS Journal. This issue includes seven papers of them. The selected papers have been reviewed form their original paper presented in IWIN and accepted as publication of IJIS. The papers were improved based on reviewers' comments.

We hope that the issue would be interest to many researchers as well as engineers and practitioners in this area.

We publish the journal in print as well as in an electronic form over Internet. This way, the paper will be available on a global basis.

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User's Communication Behavior in a Pseudo Same-room Videoconferencing System BHS

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Abstract - This paper presents user's communication behavior in a pseudo same-room videoconferencing named "Being Here System," in comparison with a conventional videoconferencing. The system extracts the remote person's figure and superimposes it on the local site's front view in a large display in real-time. This method makes the local person feel as if the remote person was before him/her in his/her spatial environment. To investigate the influence of the system on user's communication, the recorded video of the system evaluation experiment was analyzed. This revealed that the system significantly affected user's communication behavior such as turn taking, speech overlap, and gaze directions [1].

Keywords: Videoconferencing, presence, video overlay, telecommunication, Kinect application

1 INTRODUCTION

Communication can be carried out in face-to-face (F2F) or through media. In F2F communication, the exchange of information, thoughts, and feelings is made when the participants exist in the same physical space at the same time. In this communication, nonverbal cues (e.g., eye contact, facial expression, body movement, interpersonal distance, etc.) may influence the way the message is interpreted by the receiver. In contrast, although mediated communication including videoconferencing provides people with many advantages given the increased globalization and the need for rapid knowledge transfer across borders and time zones, the absence of nonverbal cues may make communication difficult. Hence communication process is affected in mediated communication. A person may feel less presence of remote participants in mediated settings, and he/she may fail to interpret other people's behavior correctly and/or accurately. Therefore, one of the design goals of a videoconferencing system is to create a medium setup that is as close as possible to F2F.

Many studies have suggested that generating a life-sized view is likely to enhance the user's sense of presence [8, 12, 13, 24, 11, 16]. Here "presence" or "sense of presence" refers to the user's feeling of connection to the remote person with whom they are interacting [18]. The life-sized view makes it easy to read the other person's behavior that is essential for smooth communication.

Figure 1: A user talks to a remote user through BHS.

Large displays can be used to achieve a life-sized view. However, this means that a considerable region of the local person's front view is replaced by the remote site's background, which makes no integration or continuity in the local person's front view. This may decrease the user's sense of co-presence. Meanwhile, the remote site's background in some environments might be 'cluttered' with static or movable objects. This may either be a distraction or be more engaging, giving a greater sense of the other person's environment [5].

"Being Here System (BHS)" is a system to achieve pseudo same-room videoconferencing system using a large display [23]. The system provides the communication environment where the remote user's life-sized figure is visually situated in the local site (Fig. 1) and vice versa. The display shows the local site's front view, which would otherwise have been obstructed by the display, as a background. In this way, the user feels as if the remote user is present before him/her in the same room. In other words, the user feels co-presence of the other remote user. BHS was initially evaluated by a questionnaire filled by users after performing a videoconferencing experiment. The questionnaire results revealed that BHS achieved higher sense of co-presence of remote users than the conventional videoconferencing system.

In this paper, we further investigated the user's behaviors when communicating using BHS. The motivated question is whether BHS affects verbal and/or nonverbal communication structure. The considered verbal communication parameters in this study are turn taking, speech time, and speech overlap. Regarding nonverbal

[1] This research was partially supported by the JSPS Grant-in Aid for Scientific Research 26330218.

parameters, gaze direction is considered. The communication behavior analysis revealed that BHS has significantly affected users' conversational behaviors.

2 RELATED WORKS

2.1 Media Space Systems

There have been various studies done on remote communication and media spaces, and a host of systems have been developed over time. Many of these studies have been devoted to proposing and/or implementing methods aimed at enhancing the sense of presence in videoconferencing.

One early system called "Hydra" sought to enhance the sense of presence by supporting directional gaze cues and selective listening in 4-way videoconferencing [27]. A multi-party videoconferencing system called "MAJIC" was constructed by Okada et al. to support eye contact [24]. In this system, life-sized video images of participants were projected onto a large curved transparent display. Another line of research focused on the seating arrangement in video-mediated meetings, in order to enhance the sense of presence [12]. The system was designed for multiple participants so that the video image of any remote participant be always placed where a viewer need to make no effort to see it. A different approach to enhance the sense of presence was introduced by Morikawa et al. [20]. In this study, a system called "HyperMirror" was constructed, in which all participants were meant to feel as if they were sharing the same virtual space. To provide a greater sense of presence than had been achieved with conventional desktop videoconferencing, Gibbs et al. created the "TELEPORT" system [8], which was based on special rooms, called display rooms, in which one wall was a "view port" into a virtual extension. A side-by-side media space concept was proposed to enhance the presence feelings, which was suggested to be more appropriate for side-by-side style interactions such as collaborative writing and training [28]. Other effective attempts to enhance the presence feelings involved movable displays [22] and movable cameras [21].

It is natural to devote more attention to people present before one, since the felt presence of remote people is considerably weaker [32]. To overcome this inclination, robotic means have been employed to convey the sense of presence in videoconferencing, enhancing the remote people's felt presence. In this regard, a study by Sakamoto et al. investigated the effect of using a humanoid robot system as a telecommunication medium [26]. Another study, by Yankelovich et al., introduced a system called "Porta-Person" to enhance the sense of social presence for remote-meeting participants [32]. This goal was achieved by providing a high-fidelity audio connection and a remotely controlled telepresence display with video or animation. In the same manner, Venolia et al. developed a telepresence device, called "Embodied Social Proxy (ESP)", which represented a remote coworker at roughly human-scale [29]. In this system, they found that the physical presence of the ESP was a powerful reminder of the presence of the remote worker in the meetings.

The studies and implemented systems above focused primarily on creating a high-presence media space. Our study, in turn, makes its own contribution to this field. To mimic real situations, the remote person's figure should be presented locally, without his/her remote background. Typically, this can be achieved by using mixed-reality (MR) technology and special head-mounted display (HMD) equipment [11, 4, 15]. Using HMD for some people might be encumbering and uncomfortable. This setup is likely to decrease the sense of presence. In contrast, our proposed system can be easily implemented in both sites, allowing both participants to experience the same effects.

2.2 Commercial Videoconferencing

In commercial videoconferencing business firms, many solutions have been introduced under the name "Telepresence" technology for high presence feelings. Telepresence is defined as an illusion that a mediated experience is not mediated [18]. In videoconferencing experience, telepresence gives you the feeling as if the remote participants are in the same room with you. To create the same-room illusion, some commercial telepresence solutions use a combination of technology elements, such as utilizing large displays for life-sized dimensions and hidden high-definition cameras strategically placed to create the appearance of a direct eye contact, and environmental design, such as consistent furniture arrangements across locations. The life-sized dimensions allow participants to see facial expressions, make eye contact, and read body language. Such solutions are: Cisco TelePresence TX9000 Series [1], Polycom® RealPresence™ Immersive [2], TANDBERG[3], PeopleLink TelePresence[4], etc.

In one hand these solutions simulate high presence meeting environments as if the other people were sitting across the table in the same room. But on the other hand these solutions are very expensive, require large-spaces, and have to be installed in a fixed environment with pre-installed matching furniture in both sides to achieve maximum telepresence feelings. In contrast, BHS can be implemented using an affordable equipments and can be installed easily almost anywhere.

2.3 Verbal and Nonverbal Communication Analysis

It's well known that in F2F communication, people switch speaking and listening by using a complicated mechanism of verbal and nonverbal cues [2]. A major nonverbal cue in speaking involves the use of eye contact [1]. In F2F communications, failure to maintain eye contact is commonly considered to be a sign of deception, and leads to feelings of mistrust [2]. Vertegaal et al. concluded that gaze is an excellent predictor of conversational attention in multiparty conversations [30]. A study by Karmer et al.

[1] http://www.cisco.com/en/US/products/ps12453/

[2] http://www.polycom.com/products/telepresence/_video/

[3] http://www.tandberg.com/

[4] http://www.peoplelink.in/telepresence.html

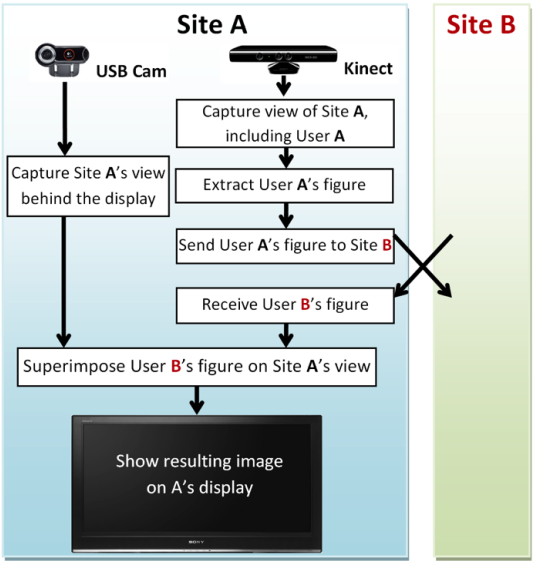

Figure 2: The process diagram of BHS.

proposed a method of measuring people's sense of presence in videoconferencing system based on linguistic features of their dialogues [17]. This study shows that 30% of the variance in self-reported presence can be accounted for by a small number of task-independent linguistic features.

The seating arrangements on group video communication affect participant's behaviors as well. A study by Inoue et al. presented a videoconferencing system "HERMES" that integrates F2F and video-mediated meetings [12]. In This study they observed that participants tended to pay much attention to the monitor when using lined-up seating arrangement. This problematic behavior solved by the combination of round seat arrangement and multiple monitors. Another study by Yamashita et al. revealed that seating arrangements affect speaker switches without verbal indication of the next speaker [31]. This study found that in some seating arrangement, the participants shared a higher sense of unity and reached a slightly better group solution.

Our study as well examined the proposed high-presence videoconferencing system for any verbal and/or nonverbal effects on communication comparing with a conventional videoconferencing system.

3 BEING HERE SYSTEM

A videoconferencing system "Being Here System (BHS)" was constructed to achieve pseudo same-room environment to the users. The two sites, 'Site A' and 'Site B', were connected over a local network to permit the exchange of live video. Each site was equipped with a display installed upright 70 cm above the floor, a USB camera, a Kinect™ RGB-D camera, a computer connected to the network, a speaker and a microphone, and a chair. The user was seated at 1.2 m distant from the display since this was considered to be appropriate distance for F2F meetings [10].

The process diagram of BHS is shown in Fig 2. We used the USB camera to capture the local site's front view, that is, the region concealed behind the display. The USB camera was placed behind the display in the center, and the camera's angle and zoom were calibrated so that the region behind the

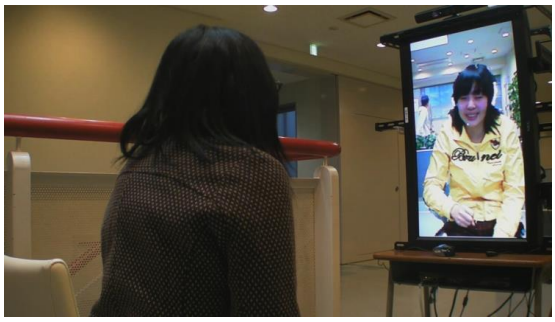
Figure 3: The 30 inch portrait display setup.

display was exclusively captured. This captured image (640 by 480 pixels) was used as a background for the display.

To capture the site view and extract the user's figure from it at run-time, the Kinect was used, which was placed centrally over the display and focused on the person's face. OpenNI API was used to analyze the Kinect image depth data by identifying the user in the scene and replacing the background with a transparent color. The resulted image was transmitted to the other site at 15 frames per second.

The final step in the process was to superimpose the received remote user figure onto the local front view. This was accomplished by merging the extracted user's figure and the background. Finally, the processed video was presented on the large display.

With this simple system architecture, the system is supposed to be expanded to the multi-point conferencing easily. This is a noteworthy feature that other existing systems have not achieved because of their limited spatial alignment and/or expensive customized devices.

4 SYSTEM EVALUATION

An experiment was conducted to evaluate BHS. The main objective of this experiment was to study the influence of BHS on user's communication behavior in comparison with conventional videoconferencing. Two remote sites, Site A and B, were constructed. In Site A, a large flat-panel display (46 inches) was used (Fig. 1), while in Site B, a 30-inch display was used. The 30-inch display was fixed in a vertical portrait position, presenting a life-sized image of an adult's upper body (Fig. 3). We used the portrait mode to study the effects of different background sizes.

4.1 Conditions

Two videoconferencing modes, "***Conventional mode***" where the remote site view was displayed in the local site's display and "***Superimpose mode***" where the remote person's figure was extracted and superimposed on the local site's front view, were established.

In the experiment, we considered the following videoconferencing conditions:

- Large Superimpose (***LS***): superimpose mode via large display.
- Portrait Superimpose (***PS***): superimpose mode via portrait display.

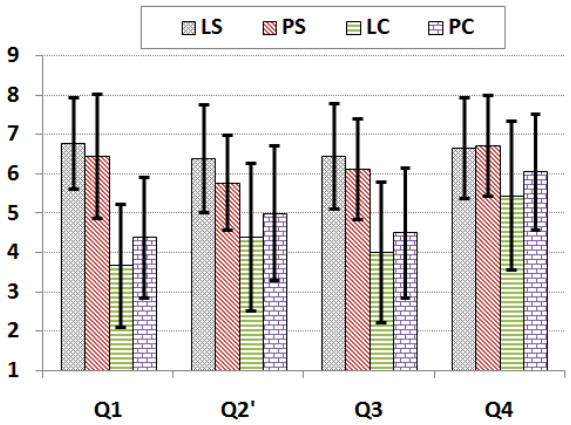

Figure 4: The participants' average sense of presence results *(Note: Q2' result is the positive form of the original Q2).*

- Large Conventional (***LC***): conventional mode via large display.
- Portrait Conventional (***PC***): conventional mode via portrait display.

4.2 Participants

Nine pairs, 7 females and 11 males whose ages ranged from 23 to 36 years old and who were familiar with each other, took part in the experiment. Among them, 17 participants had experience using videoconferencing systems. Most used the videoconferencing principally to talk to remote family members and/or remote close friends.

4.3 Procedure

One of the pair used the system at Site A, while the other used Site B. Before performing the videoconferencing tasks, the participants were asked to complete a basic demographic survey. After this, the experimenter introduced the system to the participants. The experiment began with a familiarization session. Each participant performed four videoconferencing sessions to test the conditions. In each session, participants were instructed to talk about a selected general topic for approximately 10 minutes. After that they were asked to complete the questionnaire about the system. The four general topics were:

Study life in X city: discuss with the other person the pros and cons of studying in X city; how long you have been in X city; why you choose X university, compare X city with other cities you have been in, etc.

Buying a new laptop: discuss the laptop's specifications; the suggested shops; prices; usage; etc.

Planning a trip: for the coming summer vacation, discuss the trip's options; where to go; locally or abroad; cost; weather; attraction; etc.

Plans after graduation: discuss with the other person your plans after graduation, the possibility of pursuing a higher degree; work options, etc.

The conditions orders were randomized to ensure that the order of the tested conditions would not affect the result.

4.4 Questionnaire

In the questionnaire, we asked participants to evaluate each of the statements according to the feeling they experienced during the videoconferencing session. To investigate the participants' sense of co-presence in each condition, the following statements were used [10]:

- ***Q1***: "I felt as if the other person existed in the same room."
- ***Q2***: "I didn't feel as if I were talking with the other person in the same room."
- ***Q3***: "I felt as if I were facing the other person in the same room."

The perceptual distance between the participants is an aspect of the sense of co-presence. To evaluate this, the following statements were used:

- ***Q4***: "I felt that the distance between me and the other person was comfortable for chatting."
- ***Q5***: "I felt that the distance between me and the other person was around:_____ "

All of these statements, except Q5, were rated on a 9-point Likert scale, where 1 = strongly disagree, 3 = disagree, 5 = neutral, 7 = agree, and 9 = strongly agree.

4.5 Videotaping

Two cameras were used to record the experiment sessions at HD 720 resolution (1280 by 720 pixels). The first camera was placed over the display facing the participant in order to capture his/her facial expressions, gestures, and postures. The second camera was installed upright 1 m above the floor beside participant in order to capture him/her from the side and the display content.

5 RESULTS

5.1 Questionnaire

Figure 4 shows the average results of the participants' sense of the other person's presence while videoconferencing, under the four conditions. A comparison was done using two-factor ANOVA test. The first factor is the videoconferencing mode (i.e. Conventional and Superimpose). The second factor is the used display (i.e. Large and Portrait). We found main effect of videoconferencing mode over the participants' sense of other person's presence as if in the same room (Q1: $F(1,68) = 55.26$, $p<0.01$, Q2': $F(1,68) = 14.08$, $p<0.05$, Q3: $F(1,68) = 31.71$, $p<0.01$). This indicates that the superimposed videoconferencing mode enhanced the presence feelings more than the conventional videoconferencing mode. On the other hand, the results shows no main effect of the used display (Q1: $F(1,68) = 0.31$, Q2': $F(1,68) = 0.0$, Q3: $F(1,68) = 0.06$). The result also shows that there is no interaction between the used mode and display (Q1: $F(1,68) = 2.31$, Q2': $F(1,68) = 2.73$, Q3: $F(1,68) = 1.34$).

Moreover, we found main effect of videoconferencing mode over the feeling of comfortable distance between the user and the other person (Q4: $F(1,68) = 7.14$, $p<0.01$), while no main effect of the used display (Q4: $F(1,68) =$

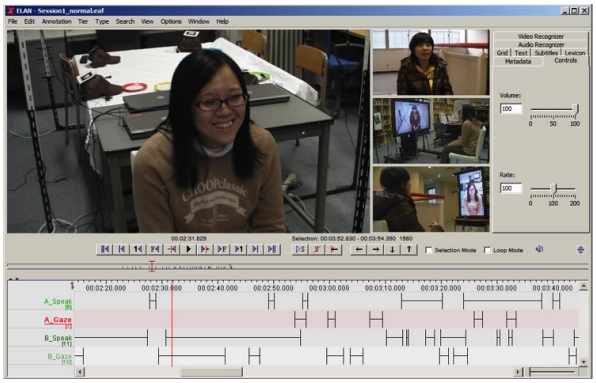

Figure 5: Screenshot of one of the ELAN's annotated video.

0.89). The result also shows there is no interaction between the used mode and display (Q4: F(1,68) = 0.62). This indicates that the superimposed videoconferencing mode enhanced the feeling of comfortable distance between the user and the other person. In addition, participants who used the superimpose videoconferencing mode were able to estimate the distance more accurately. The average estimated distances were as follows:

- LS: 1.3 m (s.d. = 0.6).
- PS: 1.3 m (s.d. = 0.6).
- LC: 2.2 m (s.d. = 1.2).
- PC: 1.8 m (s.d. = 1.0).

(The actual distance between the participant and the display was 1.2 m).

5.2 Communication Behavior

Communication behavior was analyzed quantitatively using the recorded video. ELAN[1] was used to annotate the video. A total of 36 recorded videos from 9 pairs by 4 conditions were annotated for user's communication behaviors such as speech and gaze. The middle 2 minutes of each session was analyzed, which resulted in a total of 72 minutes data. Figure 5 shows a screenshot of one of the ELAN's annotated video.

The following aspects were used for the analysis:

- ***Speech***: happens when a person speaks for at least 1.5 seconds [14].
- ***Turn taking***: is defined as the manner in which orderly conversation normally takes place. The principles of turn-taking were first described by sociologists Sacks et al. in [25]. In this study, we adopted the same turn definition with [27] as the person's number of continuous segment of speech between silent intervals for at least 1.5 seconds.
- ***Overlap***: is a simultaneous speech by two persons. This might happen when taking turns or when responding to other person's speech while talking.
- ***Gaze***: happens during a conversation when a person look at the other [1].

[1] http://tla.mpi.nl/tools/tla-tools/elan/

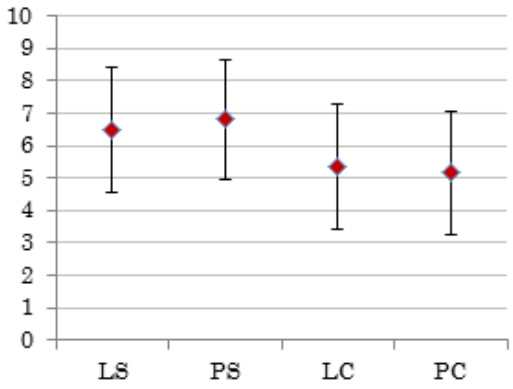

Figure 6: The participants' average number of turn taking per minute.

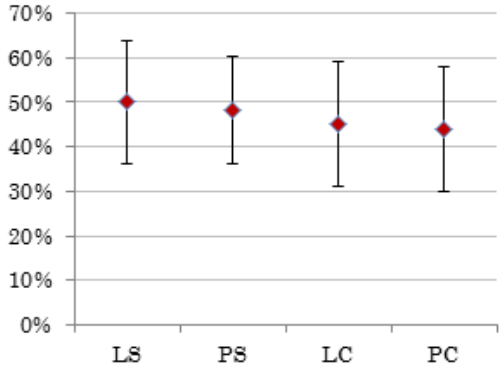

Figure 7: The participants' average speech rate.

- ***Gaze aversion***: this term is defined for the analysis in this paper. It happens when a person averts his/her gaze from the other.

5.3 Speech

Figure 6 shows the average results of the participants' number of turn taking per minute under the four videoconferencing conditions. A comparison among the conditions was done using one-way repeated-measures ANOVA test. We found significant difference in the number of turn taking ($F(3,51) = 6.49$, $p<0.05$). From Tukey's HSD post-hoc test, the superimpose conditions were significantly different from the conventional conditions.

Figure 7 shows the average results of participants' percentage of individual speech. We found no significant difference between the conditions ($F(3,51) = 0.48$).

Figure 8 shows the average results of the participants' percentage of speech overlap. We found significant difference in the percentage of speech overlap ($F(3,51) = 11.69$, $p<0.01$). The superimpose conditions were significantly different from the conventional conditions.

5.4 Gaze

Figure 9 shows the average results of the participants' number of gaze aversion per minute. We found a significant

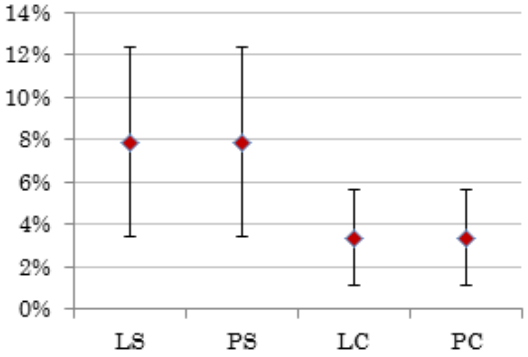

Figure 8: The participants' average percentage of speech overlap.

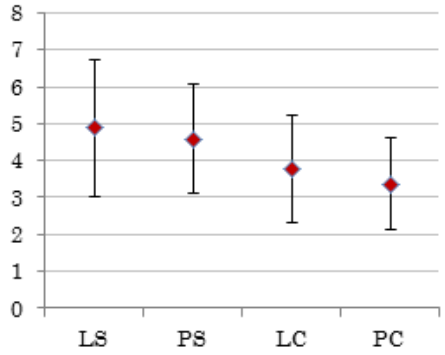

Figure 9: The participants' average number of gaze aversion per minute.

difference in the number of gaze aversion ($F(3,51) = 4.83$, $p<0.05$). The superimpose conditions were significantly different from the conventional conditions.

6 DISCUSSION

6.1 Display Size

We expected that the results could be different depending on the display sizes because of the different background sizes. One participant mentioned that the portrait display's frame concealed a relatively large area of the front view compared with the large display, which may be related to the study by Bi et al. on the effects of bezels of large tiled display that the bezels affected tunnel steering [3].

The results were, however, very similar between different display sizes. More regions are concealed in the large display conditions. It is expected that the superimpose mode can compensate this by displaying the front view as a background of the display. Actually the large superimpose condition and the portrait superimpose condition obtained the similar results. This indicates that the display size has no major effect as long as the displayed background is integrated with the actual front view.

In the conventional modes, the large display shows remote site more, which might decrease the sense of co-presence compared to the portrait display. This was not observed in the communication behaviors. The small differences of questionnaire results between the large conventional condition and the portrait conventional condition could be explained by this, although the differences are not statistically significant.

6.2 Communication Behavior

In this paper it was shown that the superimpose mode significantly affected participants' verbal and nonverbal communication behaviors. The superimpose conditions increased the number of turns by around 130% more than the conventional conditions (Fig. 6). The participants' average percentage of speech wasn't affected by the tested conditions (Fig. 7). This result is consistent with a related research by Sellen, which compared face-to-face and video-mediated conversations to find no difference in speech rate [27]. Each participant spoke 48% of the session time on average in our experiment. We found that the percentage of speech overlap in the superimpose conditions were twice more than the conventional conditions (Fig. 8). Because Cohen's study [7] and Sellen's study [27] found that face-to-face imposes more simultaneous speech compared with video conditions, this can be one of the evidences that our proposed superimpose mode could be closer to the F2F than the conventional mode.

Gaze is an important aspect of nonverbal communication [6, 9, 27]. We investigated the gaze directions and counted the number of gaze aversion in this study. The result shows that the participants tended to avert their gazes more when they used the superimposed conditions compared with the conventional conditions (Fig. 9). In F2F conversations, people use more gaze when they are further apart [1]. This means that the participants who used the superimposed conditions might feel closer to the other person.

6.3 Multipoint BHS

BHS was a point-to-point conferencing system. However, the system was supposed to be expanded to the multi-point conferencing easily considering its simple architecture, as noted in Section 3. Figure 10 shows a schematic diagram of the multi-point BHS which does not need a network, though obviously the system can be expanded to multi-point using a multicast network.

To examine its feasibility, the actual multipoint BHS was implemented (Fig. 11). It can be observed that the multipoint BHS provides higher sense of co-presence than the conventional multipoint videoconferencing (Fig. 12), even from the figures.

7 CONCLUSION

In BHS, the pseudo same-room effect is achieved by superimposing the remote person's figure, which is extracted from the remote site view using the Kinect RGB-D camera, with the local front view on a large display. BHS effectively reduced the psychological distance between the remote participants.

In this study, we investigated user's verbal and nonverbal communication behaviors while using BHS, in comparison with a conventional videoconferencing. The analysis of the

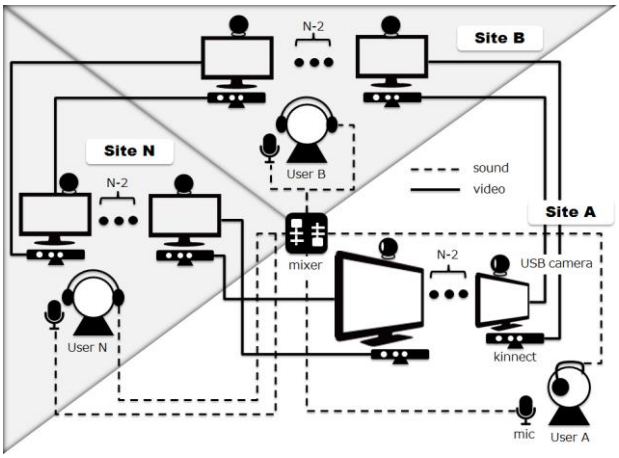

Figure 10: Design of Multipoint BHS.


Figure 11: Multipoint BHS.


Figure 12: Conventional multipoint videoconferencing.

recorded video revealed that using BHS significantly affected user's communication behavior. This result suggests that considering the local site front view as a background is one practical way to create the same-room illusion, which facilitates communication.

REFERENCES

[1] M. Argyle, Bodily Communication, 2nd Edn, Routledge, (1988).
[2] E. Bekkering, and J. Shim, "Trust in videoconferencing," Commun. ACM, Vol. 49, No. 7, pp.103–107 (2006).
[3] X. Bi, S. Bae, and R. Balakrishnan, "Effects of interior bezels of tiled-monitor large displays on visual search, tunnel steering, and target selection," In Proceedings of the 28th international conference on Human factors in computing systems, CHI'10, ACM, pp.65–74 (2010).
[4] M. Billinghurst, and H. Kato, "Out and about real world teleconferencing," BT Technology Journal, Vol. 18, pp.80–82 (2000).
[5] D. Chatting, J. Galpin, and J. Donath, "Presence and portrayal: video for casual home dialogues," In Proceedings of the 14th annual ACM international conference on Multimedia, MULTIMEDIA'06, ACM, pp.395–401 (2006).
[6] M. Chen, "Leveraging the asymmetric sensitivity of eye contact for videoconference," In Proceedings of the SIGCHI conference on Human factors in computing systems: Changing our world, changing ourselves, CHI'02, ACM, pp.49–56 (2002).
[7] K. Cohen, "Speaker interaction: video teleconferences versus face-to-face meetings," In Proceedings of Teleconferencing and Electronic Communications, pp.189–199 (1982).
[8] S. Gibbs, C. Arapis, and C. Breiteneder, "Teleport towards immersive copresence," Multimedia Systems, Vol. 7, No. 3, pp.214–221 (1999).
[9] D. Grayson, and A. Monk, "Are you looking at me? eye contact and desktop video conferencing," ACM Trans. Comput.-Hum. Interact, Vol. 10, No. 3, pp.221–243 (2003).
[10] Y. Ichikawa, K. Okada, G. Jeong, S. Tanaka, and Y. Matsushita, "Majic videoconferencing system: experiments, evaluation and improvement," In Proceedings of the fourth conference on European Conference on Computer-Supported Cooperative Work, ECSCW'95, Kluwer Academic Publishers, pp.279–292 (1995).
[11] T. Inoue, "Mixed reality meeting system enabling user to keep and share interpersonal distance in the real world," Journal of Information Processing Society of Japan, Vol. 50, No. 1, pp.246–253 (2009).
[12] T. Inoue, K. Okada, and Y. Matsushita, "Integration of face-to-face and video-mediated meetings: Hermes," In Proceedings of the international ACM SIGGROUP conference on Supporting group work: the integration challenge, GROUP'97, ACM, pp.405–414 (1997).
[13] T. Ishida, A. Sakuraba, and Y. Shibata, "Proposal of high realistic sensation system using the large scale tiled display environment," In Proceedings of Network-Based Information Systems (NBiS), pp.444–449 (2011).
[14] J. Jaffe, and S. Feldstein, "Rhythms of Dialogue," Academic Press, New York, (1970).
[15] T. Kantonen, C. Woodward, and N. Katz, "Mixed reality in virtual world teleconferencing," In 2010 IEEE Virtual Reality Conference (VR), pp.179–182 (2010).
[16] E. Koh, "Conferencing room for telepresence with remote participants," In Proceedings of the 16th ACM international conference on Supporting group work, GROUP'10, ACM, pp.309–310 (2010).
[17] A. Kramer, L. Oh, and S. Fussell, "Using linguistic features to measure presence in computer-mediated communication," In Proceedings of the SIGCHI conference on Human Factors in computing systems, CHI'06, ACM, pp.913-916 (2006).

[18] M. Lombard, and T. Ditton, "At the heart of it all: The concept of presence," Computer-Mediated Communication, Vol. 3, No. 2, (1997).
[19] M. Mantei, R. Baecker, A. Sellen, W. Buxton, T. Milligan, and B. Wellman, "Experiences in the use of a media space," In Proceedings of the SIGCHI conference on Human factors in computing systems: Reaching through technology (CHI'91), pp.203–208 (1991).
[20] O. Morikawa, and T. Maesako, "Hypermirror: toward pleasant-to-use video mediated communication system," In Proceedings of the 1998 ACM conference on Computer supported cooperative work (CSCW'98), pp.149–158 (1998).
[21] H. Nakanishi, K. Kato, and H. Ishiguro, "Zoom cameras and movable displays enhance social telepresence," In Proceedings of the 2011 annual conference on Human factors in computing systems (CHI'11), pp.63–72 (2011).
[22] H. Nakanishi, Y. Murakami, and K. Kato, "Movable cameras enhance social telepresence in media spaces," In Proceedings of the 27th international conference on Human factors in computing systems (CHI'09), pp.433–442 (2009).
[23] M. Nawahdah, and T. Inoue, "Being Here: Enhancing the Presence of a Remote Person through Real-Time Display Integration of the Remote Figure and the Local Background," Transactions of the Virtual Reality Society of Japan, Vol. 17, No. 2, pp.101-109 (2012).
[24] K. Okada, F. Maeda, Y. Ichikawa, and Y. Matsushita, "Multiparty videoconferencing at virtual social distance: Majic design," In Proceedings of the 1994 ACM conference on Computer supported cooperative work (CSCW'94), pp.385–393 (1994).
[25] H. Sacks, E. A. Schegloff, and G. A. Jefferson, "Simplest Systematics for the Organization of Turn-Taking for Conversation," Language Vol. 50, No. 4, pp. 696–735 (1974).
[26] D. Sakamoto, T. Kanda, T. Ono, H. Ishiguro, and N. Hagita, "Android as a telecommunication medium with a human-like presence," In Proceedings of the ACM/IEEE international conference on Human-robot interaction (HRI'07), pp.193–200 (2007).
[27] A. J. Sellen, "Speech patterns in video-mediated conversations," In Proceedings of the SIGCHI conference on Human factors in computing systems (CHI'92), pp.49–59 (1992).
[28] P. Tanner, and V. Shah, "Improving remote collaboration through side-by-side telepresence," In Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems (CHI EA'10), pp.3493–3498 (2010).
[29] G. Venolia, J. Tang, R. Cervantes, S. Bly, G. Robertson, B. Lee, and K. Inkpen, "Embodied social proxy: mediating interpersonal connection in hub-and-satellite teams," In Proceedings of the 28th international conference on Human factors in computing systems (CHI'10), pp.1049–1058 (2010).
[30] R. Vertegaal, R. Slagter, G. van der Veer, and A. Nijholt, "Eye gaze patterns in conversations: there is more to conversational agents than meets the eyes," In Proceedings of the SIGCHI conference on Human factors in computing systems (CHI'01), pp.301–308 (2001).
[31] N. Yamashita, K. Hirata, S. Aoyagi, H. Kuzuoka, and Y. Harada, "Impact of seating positions on group video communication," In Proceedings of the 2008 ACM conference on Computer supported cooperative work (CSCW'08), pp.177–186 (2008).
[32] N. Yankelovich, N. Simpson, J. Kaplan, and J. Provino, "Porta-person: telepresence for the connected conference room," CHI'07 extended abstracts on Human factors in computing systems, pp.2789–2794 (2007).
[33] Y. Noguchi, T. Inoue, "Study on Placement and Presentation of Multiple Avatars in MR-based Distributed Meeting," Information Processing Society of Japan (IPSJ) Journal, Vol.48, No.1, pp54-62 (2007).

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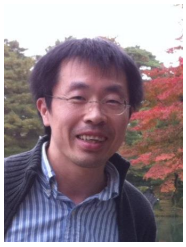

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A DTN Routing Scheme Based on Publish/Subscribe Model

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Abstract - Delay Tolerant Networking (DTN) is attractive as an effective communication method in unstable network environments where frequent disconnections occur easily. DTN routing is based on the store-carry-forward paradigm. So far, various DTN routing schemes corresponding to the temporal and spatial characteristics of contacts between nodes have been proposed. However, name resolution between a source and a destination is difficult in a network environment that consists of only wireless terminals such as DTN. In this paper, we present a DTN routing scheme based on the publish/subscribe model that enables flexible communication by using topics of information. In the proposed scheme, messages are sorted by the subscription lists and the contact condition of nodes in order to deliver to destinations with a short delay. We compare the performance of the proposed scheme with that of existing schemes through simulations.

Keywords: Delay Tolerant Networking, Store-Carry-Forward, Publish/Subscribe Model.

1 INTRODUCTION

Recently, as a development of near field communication technology and mobile devices, network services are becoming available in areas where a communication infrastructure is not set up and disaster areas. However, if nodes move frequently in such environments, frequent disconnections occur easily, so users cannot use the networks continuously.

Delay Tolerant Networking (DTN) is attractive as an effective communication method in such unstable network environments [1]. DTN is intended to optimize communication performance and share network resources. To reach these goals, source nodes, relay nodes, and destination nodes work together and control the transmission of information. DTN has been primarily studied as a technology to be applied to communication in the sea, space, and disaster areas, etc. However, in recent years, the number of applications and experiments that use DTN technology is increasing, such as communication in developing countries and the delivery of local news and advertising.

DTN routing is based on the Store-Carry-Forward paradigm [2]. In this paradigm, each node moves while keeping messages until it becomes possible to communicate with other nodes. When it meets the other nodes, it forwards replications of the message to them.

Generally, in DTN routing schemes, the message delivery delay is shorter as the number of replications of a message increases. This is because the chance that the relay nodes having the replication meet the destination node is increased. However, buffer consumption of the relay nodes is larger as the replications of a message increase. Because of these properties, there is a trade-off between message delivery delay and buffer consumption.

So far, various DTN routing schemes have been proposed in order to resolve this trade-off and to transmit information effectively. Existing schemes are classified into several communication models. An example of these models is one-to-one communication models based on the host address. This communication model requires the name resolution between a source and a destination. However, the name resolution based on the host address is difficult in a network environment that consists of only wireless terminals such as DTN. Other examples of the models are the information dissemination-based communication model and information collection-based communication model for targeting all users. These models can be realized without the name resolution between a source and a destination. However, communication between the specified nodes is not possible. Therefore, in the DTN routing based on the existing communication models, each user in the network cannot select and get the information they wants.

In this paper, we present a DTN routing scheme based on the publish/subscribe model [3] that enables flexible communication by using topics of the information. The proposed scheme can communicate without checking each host address between sources and destinations because the name resolution is achieved on the basis of the topics of information. In addition, we proposed an algorithm that sort messages by the subscription lists and the contact condition of nodes in order to deliver to destinations with a short delay.

We compare the performance of the proposed scheme with that of existing schemes through simulations and show the effectiveness of the proposed scheme.

2 RELATED TECHNOLOGY

In this chapter, we discuss the functions of DTN routing and the publish/subscribe model as techniques related to our research. In addition, we discuss existing research on applying publish/subscribe model to DTN routing.

2.1 DTN Routing

Functions of DTN routing based on Store-Carry-Forward are classified into selecting relay nodes, selecting messages, and managing the buffer. In this section, we discuss the details of the three functions.

(1) Selecting relay nodes

With this function, each node selects the relay nodes to forward messages preferentially from several nodes within the communication range. The following is typical DTN routing schemes.

- Epidemic Routing [4]
  Each node forwards the replications of the message to all nodes that it contacts. In this scheme, many replications of a message are generated, so the message delivery delay is short but buffer consumption is large.
- Two-Hop Forwarding [5]
  Source nodes forward the replications of the message to all nodes that they contact, but relay nodes forward the replications of the message to only destination nodes. In this scheme, few replications of a message are generated, so the message delivery delay is long but buffer consumption is small.
- Spray and Wait [6]
  In this scheme, the limit on the number of replications that can be generated from a message is set. After this limit is reached, each node waits to make contact with the destination nodes. In this scheme, the limited on the number of replications is set, so it is possible to control the trade-off between message delivery delay and buffer consumption.
- PRoPHET [7]
  The relay nodes that are most likely to meet the destination node is selected from records of past communications of each node, and they receive the replication.

(2) Selecting Messages

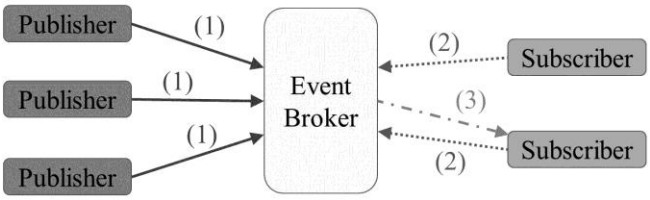
With this function, the order to send messages is decided. It is expected that the session between nodes breaks down before each node forwards all messages to communication partners in DTN routing. Therefore, when they meet other nodes, they decide which message preferentially is forwarded from their buffer in order to improve the communication performance. Examples of the algorithm are FIFO (First In First Out), which messages in the order from oldest received time, and LIFO (Last In First Out), which messages in the order from newest received time.

(3) Buffer Management

In this scheme, each node decides which message is removed in their buffer if the capacity of their buffer is exceeded because of an accumulation of messages. Examples of the algorithm are FIFO and LIFO as well as the function that select messages. In addition, another approach is to use recovery schemes that remove messages that are no longer needed after reaching destination nodes [8].

2.2 Publish/Subscribe Model

The publish/subscribe model [3] is a communication model that implements asynchrony between senders and receivers. The structure of this model is shown in Fig. 1. It consists of three systems: publishers to send information, subscribers to receive information, and an event broker to relay information between publishers and subscribers. Publishers send the event broker the information they want to provide in the network. Subscribers send the event broker requests for information they want to get from the network. An event broker checks the requests from subscribers and the information from publishers and sends subscribers the information that matches the requests.



Publisher: Sending the event broker information …(1)

Subscriber: Sending the event broker requests …(2)

Event Broker: Sending subscribers the information that matches the requests …(3)

Figure 1: publish/subscribe model

Using a communication model based on the name resolution based on the host address is difficult in a network environment that consists of only wireless terminals such as DTN. In contrast, the publish/subscribe model can communi-cate without checking the host address between sources and destinations because the event broker achieves the name resolution based on the topics of information. Therefore, this model has the following advantages.

- It is not necessary that senders and receivers are synchronized temporally and geographically. Therefore, when the senders send messages, receivers do not need to be in the network.
- It is not necessary that senders and receivers notify their presence to each other because information is distributed on the basis of the content and topic of information.
- One-to-many communication, many-to-many is possible.

2.3 Publish/Subscribe-based DTN Routing

DTN assumes unstable network environments where frequent disconnections occur easily. The publish/subscribe model achieves asynchrony between the sender and the receiver. Therefore, these technologies are considered compatible, so the combination of them is attractive. In this section, we discuss related researches on DTN routing schemes based on the publish/subscribe model.

Kure proposed a routing scheme in which all nodes have the functions of the publishers, subscribers, and event brokers in DTNs constructed in disaster areas [9]. In the affected areas, all users who own a wireless terminal can be subscribers and publishers. In addition, special nodes that mediate between publishers and subscribers do not exist in the network all the time. Assuming these cases, each node processes communication on the basis of functions of subscribers, publishers, and event brokers. With the function of publishers, the nodes that generated messages forward the replications to all nodes in communication range at the present moment. With the function of subscribers, the nodes forward requests that contain the topics of information they want to all nodes that they meet. In addition, the requests

that they receive from other nodes in the past are forwarded. With the function of event brokers, if the nodes receiving the requests have messages corresponding to the request in their buffer, they propagate the messages by Epidemic Routing and deliver them to the node requesting. This routing scheme makes it possible for all the nodes in disaster areas to share the information with request and response. However, messages to be forwarded to the relay nodes are sorted by FIFO. Therefore, it is not always possible to deliver messages efficiently to all the destination nodes in the network.

Janico proposed a communication process (DPSP) for when two nodes meet [2]. The sequence of the communication based on DPSP is shown in Fig. 2. When two nodes establish a session, they first exchange their subscription lists that contain the topics of information they want (1). Then each node builds a queue of the replications of the message from the local storage in order to forward the messages to the partner (2). After building the queues, the messages whose probability to be delivered is not improved when they are replicated to the partner are removed (3). This process has the effect of reducing the buffer usage of the relay nodes. Then, each node sorts the messages in their queue by their priority (4). After that, the nodes send the messages from the queues until the queues are empty or the session breaks down (5).

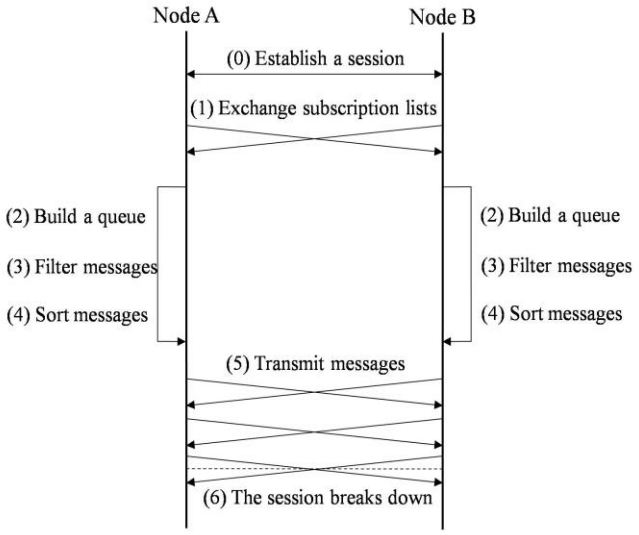


Figure 2: Communication process based on DPSP

In addition, Janico discussed several approaches for (3) filtering and (4) sorting the messages. Janico believed that message delivery rate and delivery delay are optimized by using these approaches properly depending on the network environment such as the message creation interval and the number of nodes. However, it is difficult for either approach to maintain consistently high communication performance without depending on the changes of the network environment. In addition, when the messages are sorted on the basis of the subscription lists, the communication performance of each topic may be uneven because of the difference in the number of subscribers.

3 RESEARCH TASK

In this paper, we aim to establish a flexible system in which each user can select and get the information they wants in a network environment that consists of only wireless terminals. Therefore, we need to discuss the efficiency of DTN routing based on the publish/subscribe model that communicates with topics of information. The challenge of this routing scheme is ensuring that the messages of each topic are delivered to subscribers with high probability and a short delay.

The capacity of each node's buffer and the time that it can communicate with other nodes are limited in a DTN environment. We need to improve the efficiency of message delivery under these constraints. In addition, our task is to reduce the bias in the communication performance of each topic without depending on the number of subscribers.

4 PROPOSED SCHEME

In this chapter, we propose a DTN routing scheme based on the publish/subscribe model detailed in section 2.3 and chapter 3. In the following, we discuss the assumed network environment and give a summary of the proposed scheme.

4.1 Assumed Environment

The proposed scheme is assumed to distribute information in a DTN that consists of only mobile nodes. Examples of the applications are services to deliver information on events, advertisements in the surrounding areas and news with high locality.

The nodes in the network are mobile phones, tablet devices, laptops, etc. All the nodes in the network can distribute information (messages) and receive it. Each message that is distributed in the network is belongs to a topic. Topic types are determined in advance, and new topics are not added. Each message is completed as one packet, and it is removed when TTL (Time To Live) expires.

4.2 Summary of Proposed Scheme

In the proposed scheme, all nodes have functions of publishers, subscribers, and event brokers that are based on the publish/subscribe model. Each node relays messages on the basis of the subscription lists and the contact condition of communication partners in order to deliver each message to the nodes subscribing to them. A use case diagram of the proposed scheme is shown in Fig. 3.

Each node generates messages on topics that are specified as publishers. The header of a message is shown in Table 1. The nodes register the topics in which they have an interest in their subscription lists as subscribers. The elements of the subscription list are shown in Table 2. The nodes can set the order to receive messages and the priorities of the topics when registering the topics.

The nodes that receive messages and subscription lists relay the messages to the nodes that they meet as event brokers. The messages are sorted on the basis of the subscription list and contact condition of each node. In addition, each node delivers the messages matching the

topics in the communication partner's subscription lists as event brokers.

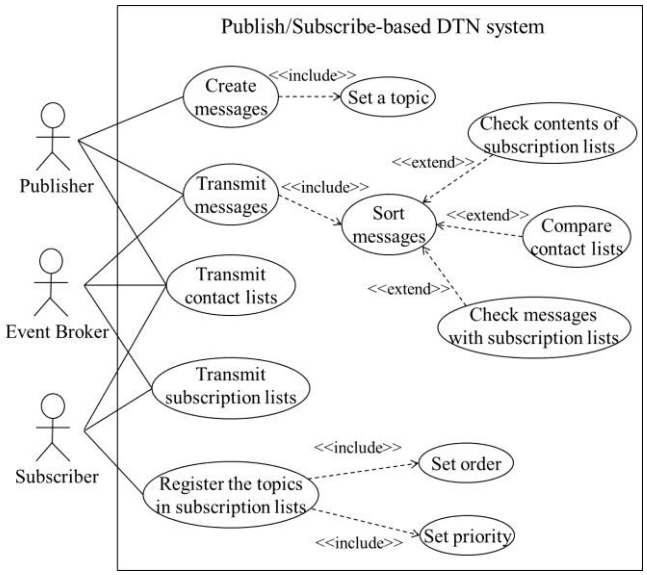


Figure 3: Use case diagram

Table 1: Header of a message

Element	Detail
From	Address of the node that generates a message
TopicID	Topic ID to which a message belongs
MsgID	Message ID, which contains a sequence number of a message to be counted independently for each node
CreateTime	Time that a message was generated
ReceivedTime	Time that a node received a message
TTL	TTL (Time To Live) of the message

Table 2: Elements of the subscription list

Element	Detail
SubID	Unique ID that a subscription list has
TopicID	Topic ID to which a message belongs
Order	Order in which to receive the message, which is selected from the ascending *CreateTim*e of a message or descending
Priority	Priority of a topic
ContactCnt	Number of times that a node meets other nodes registered to the same topic

End to end communication is realized by each node processes communication on the basis of the above functions when it meets other nodes. The communication process between two nodes is shown in Fig. 4.

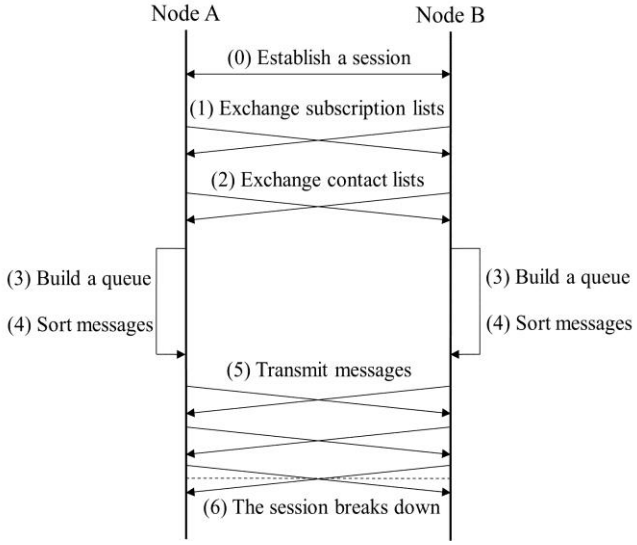


Figure 4: Communication process between two nodes

When two nodes meet, they first exchange their subscription lists (1). The subscription lists contain topics of information for each node and the nodes that it met in the past want.

After exchanging the subscription lists, they exchange their contact lists (2). The contact lists contain the average value of the contact time (i.e., how long each node is in contact with other nodes) and the average value of inter-contact time (i.e., the time between the end of a previous contact and the beginning of a new contact). They judge which of their contact condition is better by comparing their contact lists each other.

Then each node builds a queue of messages from the local storage to forward to the partner (3). After building the queue, the nodes sort the messages by the subscription lists and the contact lists (4). The details of this sorting algorithm are discussed in Section 4.3. After that, the nodes send the messages from the queues until the queues are empty or the session breaks down (5).

4.3 Sorting Messages

In a DTN environment, the session between nodes may break down before each node forwards all messages to a communication partner. Therefore, in the proposed scheme, the messages are sorted and transferred to the communication partner in the order of the highest priority.

The sorting of messages has two steps. In the first step, the priority of the topics to which the message belongs is determined (sorting topics). In the second step, the priority of messages that belong to the same topic is determined (sorting messages). Each node forwards the messages in the order that is determined through these steps.

In the proposed scheme, the messages are forwarded to the communication partner in three phases on the basis of the subscription lists and the contact lists. The procedure of forwarding the messages is shown in Fig. 5.

(a) Forwarding the subscribed messages

Each node forwards messages belonging to the topics that the communication partner registers. The sorting of topics

is done in ascending the *Priority* that the partner sets when registering the topic. The sorting of messages follows the *Order* that the partner sets when registering the topic.

(b) Relaying messages on the basis of the contact lists

Each node forwards the messages belonging to the topics in the subscription lists with the nodes that the partner met in the past. First, two nodes compare each contact condition by using the contact lists. Then, the messages with low reachability are relayed to the node whose contact condition is better, while the messages with high reachability are relayed to the node whose contact condition is worse. The messages of all topics are evenly propagated in the network by this process.

$V_{contact}$ is defined below as the indicator for evaluating the contact condition.

$$V_{contact} = \frac{T_{contact}}{T_{inter}} \quad (1)$$

In general, the number of messages that can be transferred during contact tends to increase as contact time $T_{contact}$ increases. The number of opportunities that for the node to contact with other nodes tends to increase as inter-contact time T_{inter} decreases. Therefore, a node whose $V_{contact}$ is large can communicate with many nodes for a long period of time. In this phase, as a result of comparing each node's $V_{contact}$, a node whose $V_{contact}$ is large relays messages with step (b-i), and a node whose $V_{contact}$ is small relays the messages with step (b-ii).

(b-i) A node whose $V_{contact}$ is large forwards messages with high delivery probability to a node whose $V_{contact}$ is small. The sorting of topics is done in descending *ContactCnt* in the partner's subscription lists. If some topics have the same *ContactCnt*, the topics are sorted in descending *Priority*. The sorting of messages follows FIFO.

(b-ii) A node whose $V_{contact}$ is small forwards messages with low delivery probability to a node whose $V_{contact}$ is large. The sorting of topics is done in ascending *ContactCnt* in the partner's subscription lists. If some topics have the same *ContactCnt*, the topics are sorted in ascending *Priority*. The sorting of messages follows FIFO.

(c) Forwarding the unregistered messages

The node forwards the messages that the partner's subscription lists are unregistered to. The messages are sorted by FIFO without sorting topics.

Both the messages of the popular topic and those of the unpopular topic are evenly propagated in the network by sorting the messages on the basis of the contact lists, not only the subscription lists. Therefore, the proposed scheme makes it possible for messages to be delivered to all subscribers more evenly than by sorting the messages on the basis of only the subscription lists.

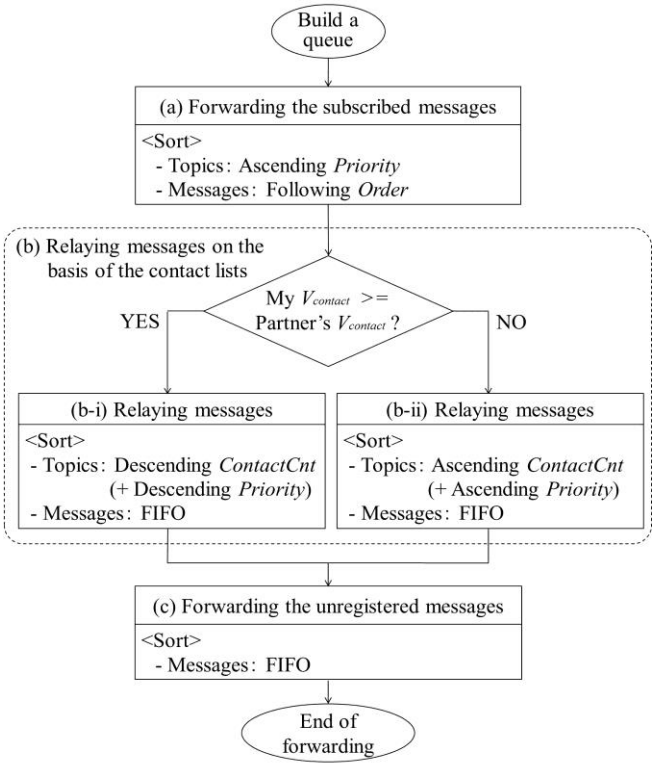


Figure 5: Procedure of forwarding messages

In addition, the messages are removed by FIFO if the capacity of their buffer is exceeded because of an accumulation of messages. This is because it is considered that the oldest message that each node has is relayed to other nodes sufficiently.

5 EXPERIMENTAL EVALUATION

5.1 Experiment Environment

We implemented the proposed scheme on the network simulator The ONE (The Opportunistic Network Environment Simulator) [11] and compared the performance of the proposed scheme with that of existing schemes in order to evaluate the effectiveness of the proposed scheme. The ONE is a simulator that was developed for evaluating of routing and application protocols in DTN environments.

The structure of the network that was used in this simulation is shown in Fig. 6, and the simulation parameters that are shown in Table 3. There are three types of message topics that are distributed in the network: topics A, B, and C. There are 240 nodes that subscribe to topic A, and half of them move in Cluster P, and the other half move in Cluster S. There are 120 nodes that subscribe to topic B, and half of them move in Cluster Q, and the other half move in Cluster S. There are 40 nodes that subscribe to topic C, and half of them move in Cluster R, and the other half move in Cluster S.

Therefore, the nodes that subscribe to the same topic frequently contact with each other in Clusters P, Q, and R, and the nodes that subscribe to a different topic frequently contact with each other in Cluster S. In the simulation, it was evaluated whether messages belonging to each topic are

delivered to the nodes whose contact condition is different in the network.

A node is assumed pedestrian and moves by Random Waypoint. A message is assumed advertisements and news and is generated by a node selected randomly from all nodes. The message size is determined by a normal distribution when the message is generated. Messages are generated until 30 minutes before the end of the simulation time. A communication standard of a node is assumed Bluetooth.

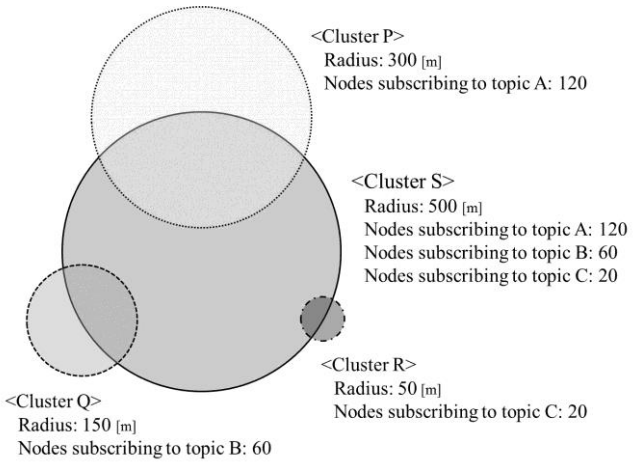


Figure 6: Structure of network

Table 3: Simulation parameters

Simulation time	12 [hour]
Moving speed of node	1.8 - 5.4 [km/h]
Wait time	0 - 120 [sec]
Communication range	10 [m]
Communication speed	250 [kbps]
Buffer size	50 [MB]
Message size	0.5 - 3.0 [MB]
Message creation time	11.5 [hour]
TTL	120 [min]

5.2 Evaluation Policy

In the experiment, the proposed scheme is compared with the existing schemes in terms of average message delivery rate and average delivery delays as the message creation interval changed. In addition, the standard deviation of each scheme was compared in order to evaluate the effect that the number of subscribers has on the communication performance. The definition of each evaluation indicator is the following.

- Message delivery rate (Avg.)
  The rate of the subscribing nodes who received each generated message.
- Message delivery delay (Avg.)
  The average time between the creation and arrival of the message that was delivered to the subscribing node.

The existing schemes compared with the proposed scheme are Epidemic Routing, Two-Hop Forwarding, and Subscription-based Routing (SBR). The SBR is basically the same mechanism as the proposed scheme, but the messages are sorted on the basis of only the subscription lists without the contact lists. Therefore, the messages are forwarded to all nodes in the order of (a), (b-i), and (c) in Fig. 5. In addition, the messages are sorted by FIFO in Epidemic Routing and Two-Hop Forwarding.

5.3 Results of Experiment and Discussion

The average message delivery rate is shown in Fig. 7, and the average message delivery delay is shown in Fig. 8.

As shown in Fig. 7, the average message delivery rate of the proposed scheme was always more than 99% in parallel with Epidemic Routing and SBR. It is considered that the DTN routing scheme based on the publish/subscribe model can reliably forward messages to each subscribing node through this result.

As shown in Fig. 8, the average message delivery delay of the proposed scheme was about 80 - 100 seconds shorter than that of Epidemic Routing and SBR, and about 400 seconds shorter than that of Two-Hop Forwarding. This is because messages with a lower priority were propagated actively by the nodes with good contact condition.

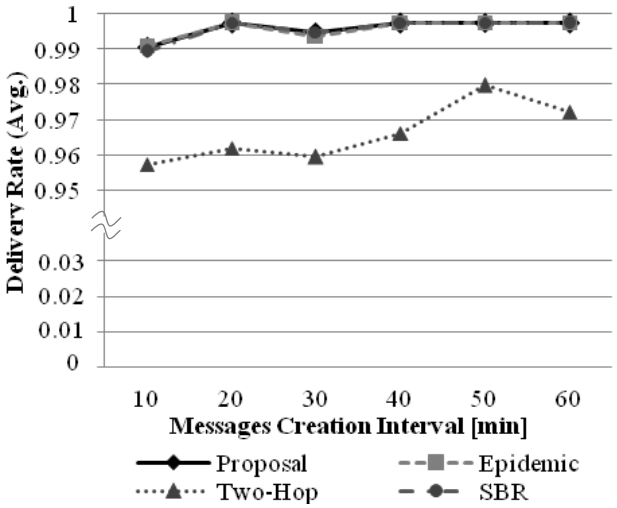


Figure 7: Message delivery rate (Avg.)

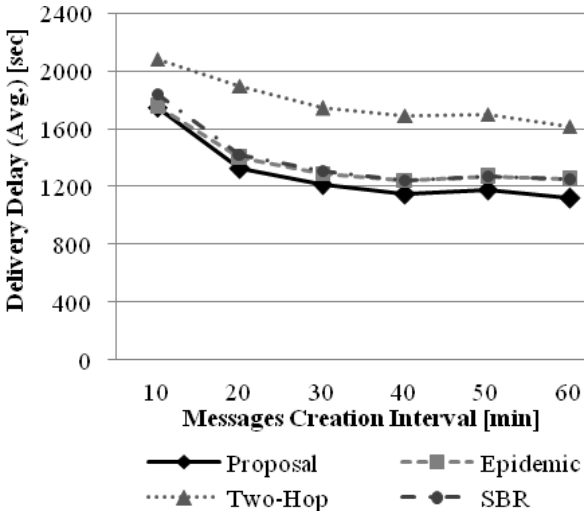


Figure 8: Message delivery delay (Avg.)

In addition, the standard deviation of the message delivery delay of the proposed scheme, Epidemic Routing, and SBR are shown in Fig. 9. The standard deviation of the proposed scheme was smaller than that of other schemes as the message creation interval decreased. It is considered that the proposed scheme prevents an increase in the message delivery delay due to the number of subscribing nodes because each message is relayed in accordance with the priorities and the contact condition even if the message is generated frequently.

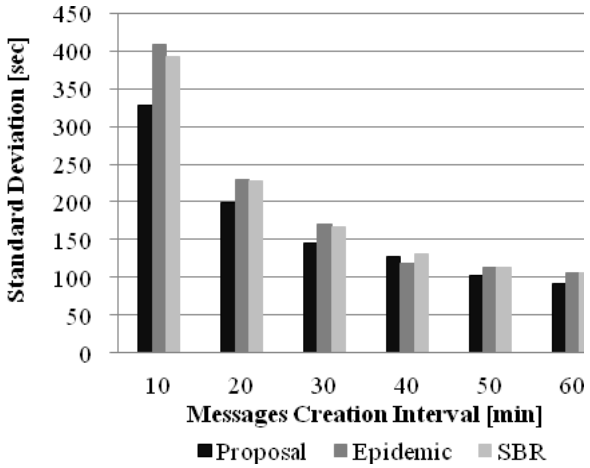


Figure 9: Standard deviation of message delivery delay

6 CONCLUSION

In this paper, we proposed a DTN routing scheme based on the publish/subscribe model with the aim of establishing a flexible system with which each user can select and get the information they wants in the network environment that consists of only wireless terminals. We compared the performance of the proposed scheme with that of existing schemes on the network simulator The ONE in order to evaluate the effectiveness of the proposed scheme. Through the results of the experiment, the proposed scheme was confirmed to deliver messages to subscribing nodes with high probability. In addition, message delivery delay of the proposed scheme was about 80 - 100 seconds shorter than that of the existing schemes, and its dependence on the number of subscribing nodes was low.

It is considered that the effectiveness of the proposed scheme increased as the simulation map had a high characteristic of the mobility of nodes, because the messages are sorted by the contact condition of the nodes, although the mobility model of the nodes was set for Random Waypoint in this experiment. Therefore, we will implement a map and a mobility model that are closer to the real world and evaluate the effectiveness of the proposed scheme. In addition, our challenge is also to study approaches that reduce buffer consumption.

REFERENCES

[1] S. Farrell, and V. Cahill, Delay and Disruption Tolerant Networking, Artech House (2006).

[2] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, and H. Weiss, "Delay tolerant network architecture," IETF RFC 4838 (2007).

[3] P. Th. Eugster, P. Felber, R. Guerraoui, and A-M. Kermarrec, "The Many Faces of Publish/Subscribe," ACM Computing Surveys, Vol.35 No.2, pp.114-131 (2003).

[4] A. Vahdat, and D. Becker, "Epidemic routing for partially-connected ad hoc networks," Duke Technical Report CS-2000-06 (2000).

[5] Z. Zhang, "Routing in intermittently connected mobile ad hoc networks and delay tolerant networks: Overview and challenges," IEEE Communications Surveys & Tutorials, Vol.8, No.1, pp.24-37 (2006).

[6] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Spray and Wait: An efficient routing scheme for intermittently connected mobile networks," Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking, pp.252-259 (2005).

[7] Z. Haas, and T. Small, "A new networking model for biological applications of ad hoc sensor networks," IEEE/ACM Transactions on Networking, Vol.14, No.1, pp.27-40 (2006).

[8] K. Kure, and H. Esaki, "Pub/Sub based Information Acquisition System over Disaster Area DTN," Proceedings of the DICOMO2010 Symposium, pp.1352-1359 (2010). *(in Japanese)*

[9] J. Greifenberg, and D. Kutscher, "Efficient Publish/Subscribe-Based Multicast for Opportunistic Networking with Self-Organized Resource Utilization," Proceedings of 22nd International Conference on Advanced Information Networking and Applications (AINAW2008), pp.1708-1704 (2008).

[10] A. Lindgren, A. Doria, and O. Schelén, "Probabilistic routing in intermittently connected networks," ACM SIGMOBILE Mobile Computing and Communications Review, Vol.7, No.3, pp.19-20 (2004).

[11] A. Keränen, J. Ott, and T. Kärkkäinen, "The ONE Simulator for DTN Protocol Evaluation," Proceedings of the 2nd International Conference on Simulation Tools and Techniques (SIMUTools'09), pp. 1-10 (2009).

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Improvement of Attribute Correlation Method and Proposal of Collaborative Attribute Method in Text Recommender Systems for E-Learners

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Abstract -E-learning is used in various places. However, many systems do not show advantages, such as online exams, and simply enumerate the teaching material, etc. In our An Individual Reviewing System (abbreviated AIRS), contents of each user are optimized according to recommendations using Collaborative Filtering (what we call CF). This system multiplies the load to the user by smoothly improving study efficiency. However, this CF method has disadvantages in that if insufficient data is available, recommendations may show poor accuracy. This is what we call Cold-Start problem. In this paper, to solve this Cold-Start problem, firstly we provided a solution of Attribute Correlation Method that uses metadata which are belonged to users. And, we experimented with this Attribute Correlation Method, but the good results were not obtained. Secondly, in order to improve this Attribute Correlation Method, we proposed a new approach (called Collaborative Attribute Method) is to address this Cold-Start problem and showed the experimental results.

Keywords: Recommender System, Web Digital Texts, E-Learning, Cold-Start Problem.

1 INTRODUCTION

E-learning, in which students can learn anywhere, at any time, has been coming into broader use in universities, corporate training and other settings. However, many existing systems simply make teaching materials available and conduct online testing, without providing the full range of unique learning advantages available through e-Learning.

One example of the existing systems is an individualized reviewing system (called AIRS). With AIRS, provision of content is tailored to the specific learner. This system uses an algorithm that helps students learn efficiently, based on the student's own historical data and the historical data of other learners, as described in [1].

The first other example is a bidirectional recommendation system. This system extracts the relationship among the learning web digital texts with historical logs and recommends an effective web digital text for learners, as discussed in [2].

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The second other example is a recommendation system that recommends the optimum learning texts based on data mining of learning historical data. This system is called a collaborative learning recommendation system that mines the data of similar users sharing non-favorite subjects using historical logs and user attribute data, as discussed in [3].

However, among the existing systems mentioned above, there is a common disadvantage that the systems cannot handle recommendation before any historical data have been accumulated. This is a so-called Cold-Start problem.

To solve the Cold-Start problem, firstly we proposed Attribute Correlation Method using the background data of the user, and evaluated the usefulness of this approach, as mentioned in [4]. However, the results did not show this method to be particularly useful.

Secondly, in order to improve this Attribute Correlation Method, we proposed another solution to the Cold-Start problem in our research. So, we adopted the following approach;

· We proposed Attribute Correlation Method using the background data of the user.

· We tested subjects using Attribute Correlation Method, and evaluated the results.

· We examined whether this Attribute Correlation Method is effective or not.

· We proposed a new method (what we call Collaborative Attribute Method, described later), after considering improvements to this Attribute Correlation Method.

2 RELATED RESEARCH

Research in systems that anticipate user preferences and recommend contents is currently advancing, with a number of Web services using this approach. For instance, with the EC services used by Amazon [5], products are recommended that are likely to appeal to the user, based on the user's product page viewing history y, purchasing history and other data. Many of these systems use collaborative filtering (CF), as shown in [6]. In terms of education, however, research in the use of CF as opposed to education based on classroom lectures and other realistic environments is being conducted, as discussed in [7], but there are few cases in which this has actually been incorporated into e-Learning systems. With AIRS, learning content is recommended to the learner. With CF, however, a Cold-Start problem exists, in which the user has to use the

contents to some extent, or no history can be obtained, and this makes it impossible to provide recommendations with a high level of accuracy, as described in [8]. This poses a drawback for users who want to use the system to solve questions in content learned through lectures and other means, or to review content already acquired. The research presented here proposes Attribute Correlation Method, which focuses on the Cold-Start problem.

3 COLLABORATIVE LEARNING RECOMMENDATIONS

Collaborative learning recommendations are recommendations carried out through the same procedure as CF. Hereafter the user will be referred to as the "learner", and the historical data as "learning history ".The procedure for making collaborative learning recommendations comprises the following sequence of steps.

3.1 Extraction of Similar Learners

Other learners who have preferences similar to those of the learner for whom contents are to be recommended are extracted as "similar learners". A database of the learning histories of learners is compiled, and correlations are drawn between learners based on that database, with learners being sorted in sequence based on the size of the correlation coefficient. Higher-order learners with a particularly large correlation are extracted as similar learners.

3.2 Extraction of Recommendation Contents

The actual content to be recommended is extracted from among the learners extracted as similar learners. The learning histories of similar learners are used to identify difficulties encountered by those persons, and analogies are drawn based on the way that those difficulties were overcome in order to extract relevant content.

3.3 Presentation of Recommendation Results

The extracted content is presented to the user via the system. This involves the system interface, and will not be addressed here.

4 ATTRIBUTE CORRELATION METHOD

As described above, collaborative learning recommendations are formulated by selecting recommended content based on the history of the learner. For this reason, similar learners cannot easily be extracted for learners who do not already have a learning history, or learners for whom a certain level of learning history has not been compiled (hereafter, we will call these "new learners"). As a result, it will not be possible to present highly accurate recommendation results. Given this, we propose a method of extraction in which background data for new learners is compiled and treated as attribute data, and learners with attribute data similar to that of the learner for whom recommendations are being provided are extracted as persons with similar attributes.

4.1 Overview

A primary reason for the Cold-Start problem that occurs in the collaborative learning recommendation method is that new learners do not have extensive histories, making it difficult to identify similar learners, as described in Section 3.2. In other words, this problem could possibly be solved if correlations between new learners and existing learners could be evaluated by other means. Figure 1 shows an overall flowchart incorporating the proposed method.

4.2 Attribute Data

Attribute data are acquired from meta-data, for example, age, sex, hobbies and preferences, strong subjects, weak subjects, and other personal data. This data is certain to be available for new learners, even if they do not have a learning history.

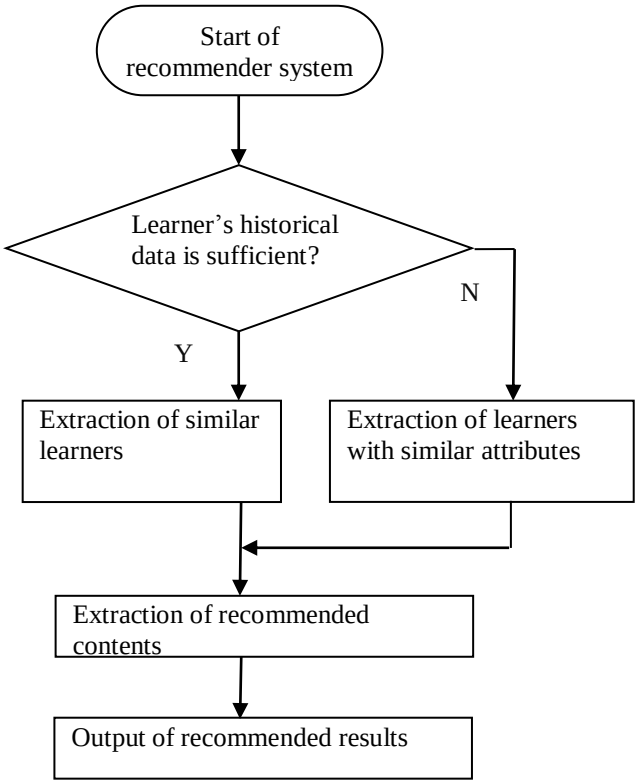

Figure 1: Attribute correlation method flow chart.

4.3 Systematization of Attribute Data

In attribute data, there is relevance among data items. For example, no relevance can be identified in a high school education between writing and physics, but a certain degree of relevance can be found between items that are both in a science curriculum, such as mathematics IA and physics. Systematizing attribute data within itself and expressing it is believed to be a necessary step, the reason being that one can envision that there will be little attribute data that can be compared to the learning history and used.

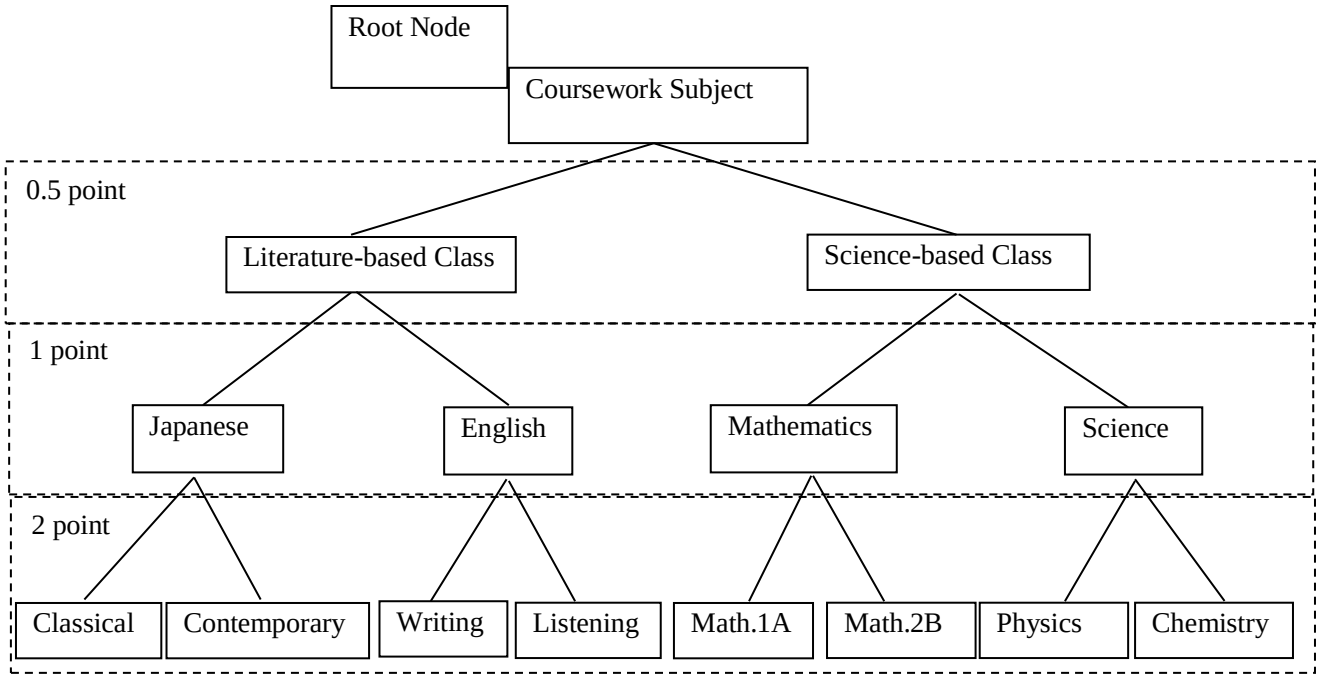

Figure 2: Hierarchy of attribute data.

With learning attributes, taking, for instance, a high school education as an example, coursework subjects are classified into root nodes, with science-based classes and literature-based classes as sub-nodes. These sub-nodes are further classified into generalized coursework classifications. Even more detailed names and definitions of classes are provided at the next layer, and a hierarchical structure is created. Moving further down the hierarchical layers, data become more specific, and thus carry greater weight as information. This weight can be expressed in terms of points: the first layer directly beneath the root node is counted as 0.5 points; and underlying layers are counted as 1, 2, and 4 points respectively, so that each layer has double the weight of the layer just above. This is done to increase the estimated value of the deeper layers. Figure 2 shows an example of the systematization of attribute data pertaining to learning. Here, only those types of attributes necessary for the evaluation, such as "learning" and "occupation", are created.

4.4 Extraction of the Degree of Attribute Data Similarity and Users with Similar Attributes

Conformances of attributes between new learners and all other learners are compared, and scores of all of the attributes are added together. A ranking is then created, with the highest scores at the top, and learners with particularly high conformance values are taken as learners with similar attributes. In the example shown in Table 1, Learner N is strong in the subject of physics, and thus has information in science and in science-category classes, which are upper-level nodes. Learner X matches completely, so 2 points are assigned, while Learner Y matches only in science-category subjects, and is thus assigned 0.5 points. Consequently, at this stage, Learner X will be a learner with similar attributes. The available attributes continue to be added up in this way. Ultimately, learners with the highest scores are extracted as learners with similar attributes.

4.5 Relationship between Similar Learners and Users with Similar Attributes

Table 1: Attribute table

	Science-category class	Natural Science	Physics	Chemistry	Math-ematics
N	0.5	1	2	0	0
X	0.5	1	2	0	0
Y	0.5	0	0	0	1

The flowchart in Figure 3 shows that when a sufficient learning history is available, Attribute Correlation Method is bypassed and recommendations are based on the normal algorithm for collaborative learning recommendations. This is because it can be surmised that Attribute Correlation Method will not produce better results by extracting similar learners based on learning history. This is because the recommended content itself is used as the history when extracting similar learners. In comparison, the background information of the learner, which has no direct relation, is used with attribute correlation. When these two approaches are compared, the learning history

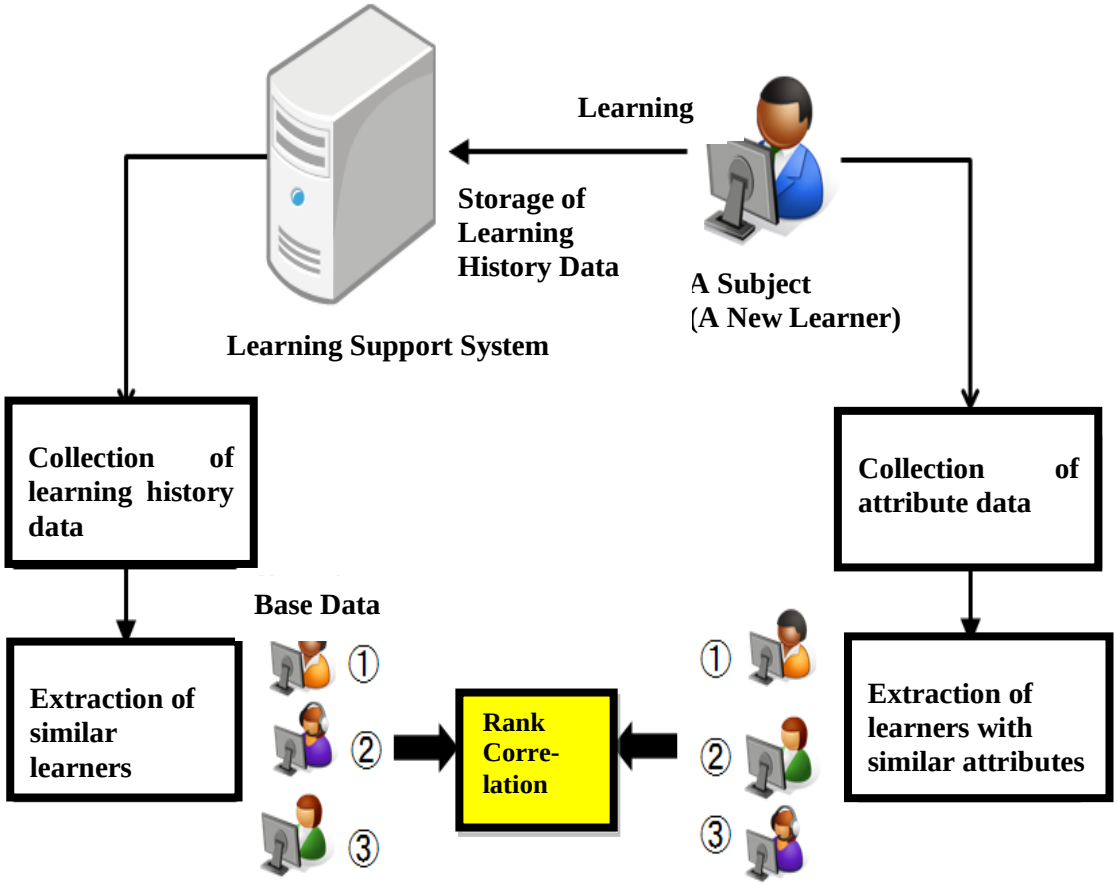

Figure 3： Outline of experiment.

clearly constitutes pure information in terms of the system. For example, in order to recommend books to a person who has not read any books to date, the thinking is incorporated that books will be recommended that may appeal to that person's preferences, based on elements such as other interests and skills. The primary aim of this method is to solve the Cold-Start problem.

4.6 Testing

Testing was conducted on subjects to clarify the outcomes of the proposed method. The following two items were evaluated.

· Is the proposed method effective?

· Was the hypothesis pertaining to attribute data selection proven?

4.6.1 Hypothesis Pertaining to the Selection of Attribute Data

As described in Section 3.1, attribute data serve as the meta-data for learners. However, not all of the personal data of learners is necessarily required. For example, if one were recommending exercises to help a person stay fit, physical information such as height and weight would be important, but this type of information is not necessary when recommending novels. In other words, it was theorized that attributes that are relevant to the content being recommended will probably demonstrate a high correlation. Here, because we are creating a recommendation system to be used in an education support system, information relating to learning will demonstrate a high correlation compared to attributes that are not particularly related to learning.

4.6.2 Test Method

***Advance preparation*:** To prepare for testing, courses from a high school curriculum were systematized as attributes related to learning, and hobbies were systematized as attributes other than learning-related attributes. The reason for choosing hobbies as attributes was that learners acquire and actively choose hobbies, as opposed to inherent information such as height, so these were assumed to closely reflect learner preferences. High school courses were selected as learning attributes in order to eliminate differences based on school year, since the students taking part in the testing were university students. As no models existed that were systematized with respect to hobbies, systematization was done based on speculation. For high school courses, however, we referred to the “Senior High School Education Guidelines” issued by the Ministry of Education, Culture, Sports, Science and Technology, as shown in [9]. Attribute hierarchies were

each organized into three layers, with the objective of suppressing any bias created by differences in scores occurring as a result of changes in the weight of scores based on the depth of the hierarchy layer. Attribute data obtained as a result consisted of two attributes and three hierarchical layers.

***Subjects*:** Subjects were grouped into two groups comprising a total of 18 students, and a questionnaire was conducted prior to the testing. Participants answered the following two questions.

· What were your strong subjects when you were in high school? (Learning attributes)

· What are your current hobbies? (Hobby attributes)

Attributes of subjects were compiled based on the questionnaire. As a large number of attributes could be selected, the questionnaire was conducted in a self-reporting format, but in cases where the student did not respond correctly, that student was asked the question again by the tester, for the purpose of normalizing the attribute information. Subsequently, the following three items pertaining to the contest of the test were explained to the subjects, and testing was conducted.

· Learning time would be 15 minutes.

· Content would be in the form of a database.

· An achievement test would be performed after the study time had ended.

Moreover, the database comprising the content was something that could not be learned in its totality in 15 min, so subjects were asked to select portions that they did not understand, and to focus on those items when learning. This was done in order to avoid having subjects start at the beginning and study the contents in sequential order. The achievement test was also designed to increase the motivation of subjects to study efficiently in a short period of time, and would not affect the test evaluation itself.

***Test content*:** For this test, we used the text content to study the relational algebra operations of database technology with AIRS. The relational algebra operations cover the nine topics listed below.

· Selection Operation
· Projection Operation
· Summation Operation
· Intersection Operation
· Difference Operation
· Division Operation
· Cartesian Product Operation
· Join Operation
· Natural Join Operation

Figure 4 shows the examples of contents on Projection Operation and Join Operation.

***Analysis method*:** Figure 3 shows a schematic for the testing. The degree of similarity (similar learners) was calculated based on the learning history obtained from the 15-min period of learning, and the degree of similarity (learners with similar attributes) was calculated based on the compiled attribute data. The two were then compared and evaluated. Specifically, the same number of rank correlations was acquired as the number of subjects, and correlations were acquired in relation to the rankings of similar learners and learners with similar attributes obtained from each of the two similarity scales noted above. The Jaccard coefficient was used to calculate the degree of similarity based on learning history, as described in [10], and Kendall's rank coefficient correlation was used to calculate the rank correlation, as shown in [11]. Attribute Correlation Method is designed only to address new learners. The degree of similarity based on learning history shows a high degree of reliability, and so was used as the reference. In other words, the aim was to obtain the rank correlation between the ranking for the degree of similarity based on learning history (similar learners) and the degree of similarity calculated based on the proposed method (learners with similar attributes), so if the average of all subjects was high, reliability in terms of the extraction of similar learners would be seen as high, and the approach could be considered effective.

4.6.3 Test Results

Table 2 and Table 3 show test results for the two groups. The figures represent mean and standard deviation for the group as a whole, calculated based on the rank correlation between the ranks of learners with similar attributes and those of learners with similar learning histories. As the rank correlation is a correlation coefficient, values were taken from between -1 and 1. The closer the value is to 1, the stronger the correlation. The closer the value is to -1, the stronger the inverse correlation. The closer the value is to 0, the weaker the correlation. As can be seen from the two tables, the average was |0.1| or less for both, so no correlation was demonstrated, and no significant results were obtained. Moreover, with respect to learning attributes and hobby attributes, the only differences were due to error, so the hypothesis was negated. Except for one item, standard deviations were all≤0.2 as well, indicating that this conclusion is appropriate.

Table 2: Experimental results for group 1

	Learning Attribute	Hobby Attribute	Whole Attributes
Average	-0.077	-0.044	-0.095

Table 3: Experimental results for group 2

	Learning Attribute	Hobby Attribute	Whole Attributes
Average	0.1032	0.0238	-0.0397

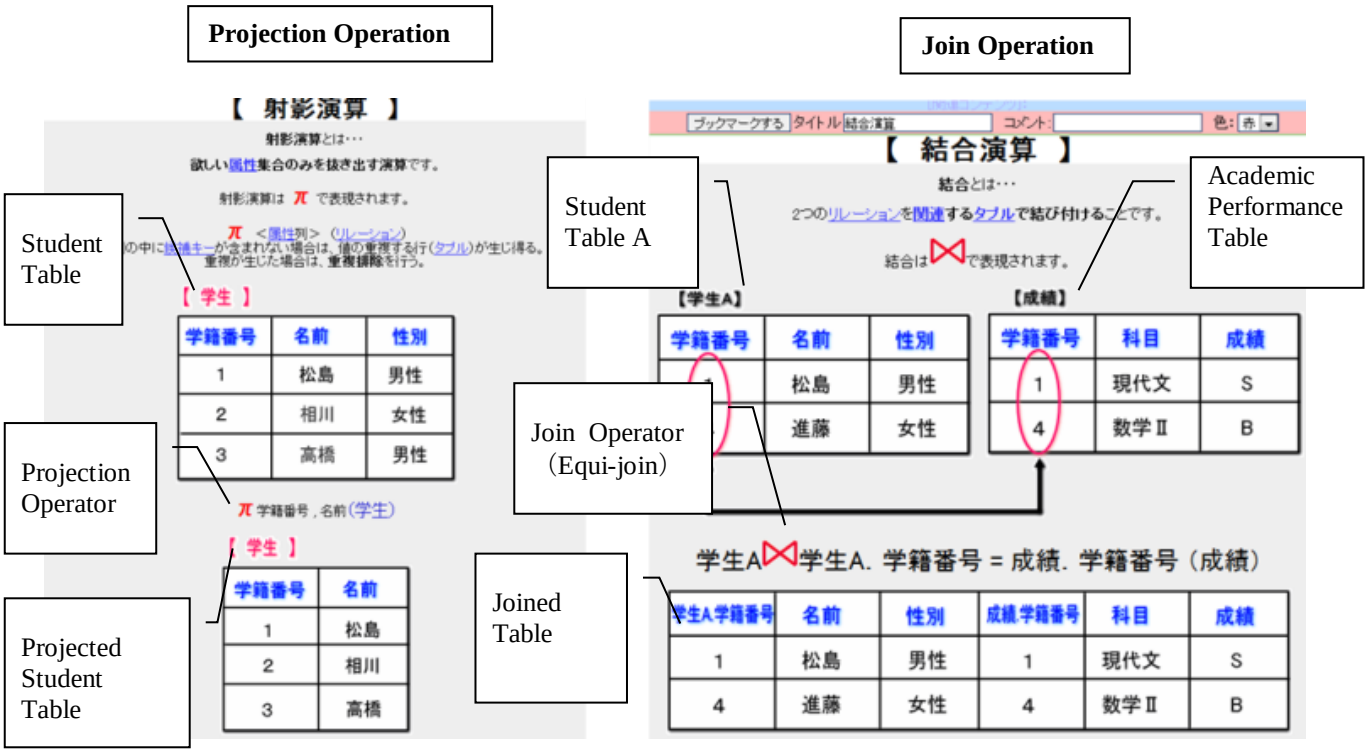

Figure 4: Examples of test content.

4.6.4 Discussion

Considering the causes of the results produced, the possibility arises that the amount of attribute data was insufficient. In that light, looking at the individual data for each subject, in the rankings based on attribute correlation, it was seen that rankings at the same ratio occurred for many subjects. Among these, there were a number of cases in which hobby attributes ended up being the same numeric values as those for other subjects as a whole, and no ranking correlations could be determined. However, despite the small volume of sample data, the fact that the average value for correlation coefficients was close to zero cannot be ignored. One other problem was that the relationship between the content being recommended and the attribute data was not clear. As indicated in Section 4.5, the reliability of attribute data is unclear, from an objective standpoint.

5 COLLABORATIVE ATTRIBUTE METHOD

In Collaborative Attribute Method of testing described in Section 4.6, usefulness could not be confirmed, for the reasons described in Section 4.6.4. Given that, we used the background information as attribute data. Collaborative Attribute Method is proposed here as a method for extracting new learners

.

5.1 Overview

Using the background information of the learner as attribute data is the same approach used in Attribute Correlation Method. This Attribute Correlation Method consisted of systematizing this data before use, but the data are not systematized in the method proposed here, but rather used as is. The degree of similarity between learners is surmised with reference to the degree of similarity between learners based on learning history, and to the attribute data.

5.2 Degree of Similarity between Attribute Data

The degree of similarity between attribute data was calculated in advance. Here, we take Learner I and Learner J, for whom a certain amount of learning history has been compiled. Attribute data for these two users were acquired when they were new learners, so we already have degrees of similarity in learning histories and respective attribute data at this stage. Amounts of attribute data are not determined in particular, but let us assume in this example that we have two attribute data: A and B. Taking the degree of similarity in learning histories between these two persons as X, we can say that the combination of attributes for these two persons, for some reason, has similarity X. If this combination is also seen among other learners, we take the average. These degrees of similarity are then accumulated in a database. Figure 5 shows a schematic diagram of this.

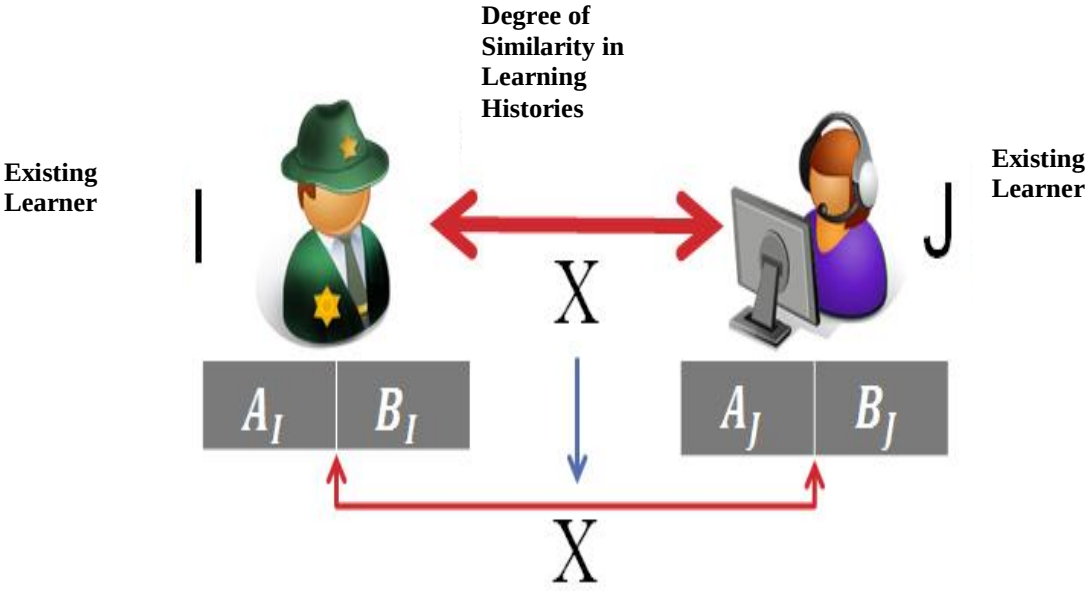

Figure 5: Calculating the similarities between attribute data.

5.3 Deriving the Degree of Similarity

When actually making recommendations for new learners for whom no degree of learning history similarity exists, we refer to similarities between attribute data that have been accumulated, and extract learners having combinations with the highest degrees of similarity between attribute data as learners with similar attributes, as shown in Figure 6. Content is then recommended based on these users.

5.4 Differences between This Method and the Attribute Correlation Method

In Attribute Correlation Method, attributes are systematized and the number of points is totaled. In Collaborative Attribute Method, however, similarities between attributes are measured using similarities in learning histories, which are reliable, as a resource. As a result, the data can be expected to be more reliable. Conversely, because the approach taken is similar to that in CF, recommendations will similarly be less accurate if only small amounts of data have been accumulated.

5.5 If the Amount of Attribute Data Accumulated Is Insufficient

As indicated in Section 5.4, this method also involves accumulated attribute data, and there are concerns that the extraction of persons with similar attributes will be less accurate if insufficient information is available. If the amount of attribute data accumulated by forming combinations of attributes of a learner for whom recommendations are being made is smaller than a stipulated amount, attributes A and B are split and calculated, as shown in Figure 7.

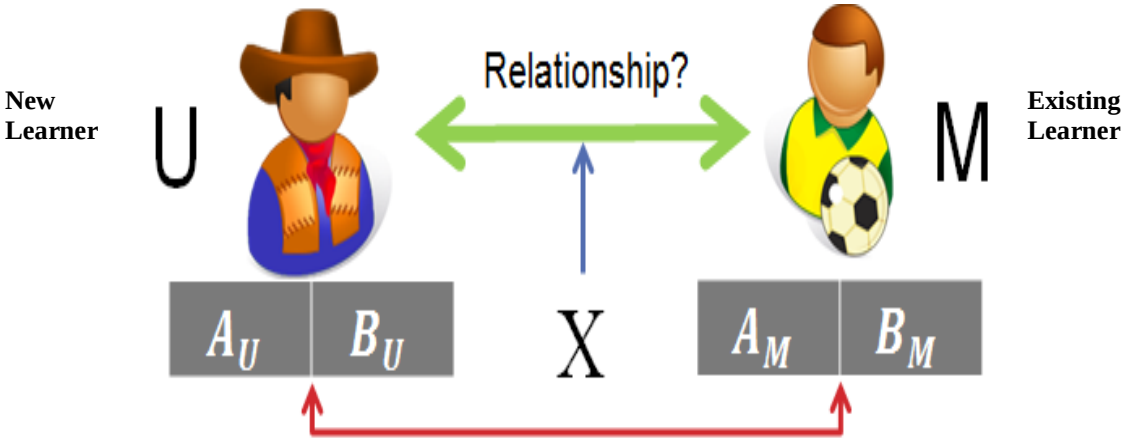

Figure 6: Extracting the attribute analogy.

Now, assume that we want to find the similarity of A_X and A1. We load combinations that include and from a table of attribute data similarities that have been accumulated, and we take the similarity of each of these and divide the number of points by the ratio of the number of elements. For example, if the ratio of the number of elements of A and the number of elements of B is 1:2, and the similarity between A_XB_a, and A_1B_n is 0.6, this result of 0.6 would be divided by 1/3 to obtain a result of 0.2. This would be carried out for the number of combinations A_X of and A1, and the average of all values would be taken. This would be done as many times as there are combinations of the attributes of A and B, and recommendation content would be extracted from users having the combinations with the highest values.

5.6 Experimental Results

We experimented with Collaborative Attribute Method using the same data as those in Section 4.6. Table 4 shows the results of rank correlations. We can see that this Collaborative Attribute Method provides better results than Attribute Correlation Method in Table 4, but they are not so high values. Some values of the rank correlations which are above 0.4 exist among the results before averaging. So, we can expect the averaged rank correlation will be higher if we can collect more data.

Table 4: Experimental results of rank correlation with Collaborative Attribute Method

	Rank Correlation
Average	0.188
Average	0.237

6 CONCLUSION

In the testing described in Section 4.6, the usefulness of Attribute Correlation Method was not able to be proved. This was attributed to the fact that the relationship between attribute data and learning history is not understood, and Collaborative Attribute Method is proposed in which similarities in learning history are referenced and attributes are used. At the same time, however, this method has not yet been perfected and still has scope for improvement. In addition, it may simply be that not enough testing has been conducted on Attribute Correlation Method. In the future, we intend to continue conducting testing on Attribute Correlation Method, and to develop, implement and test Collaborative Attribute Method.

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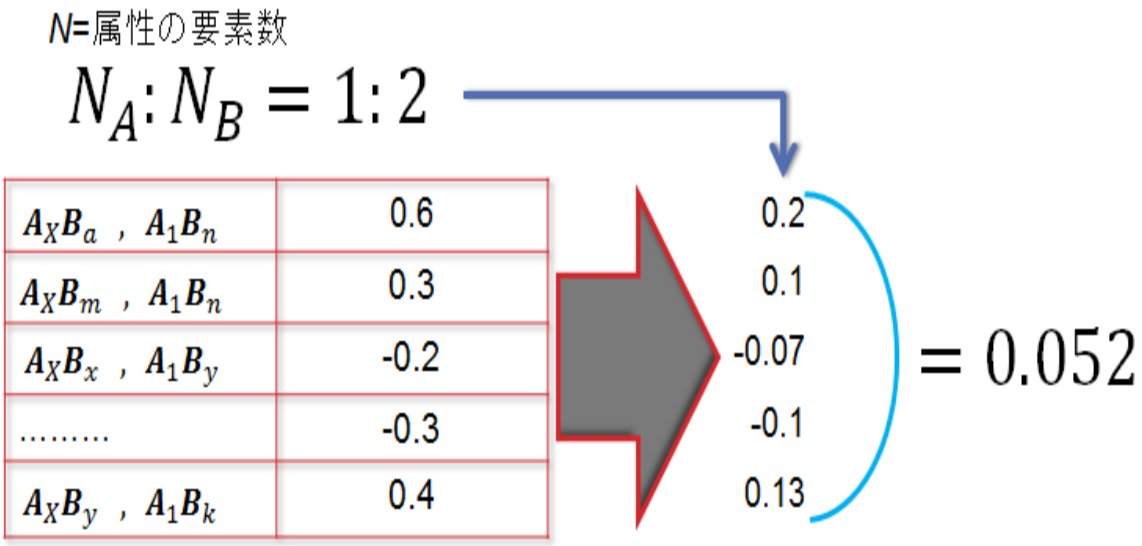

Figure 7: Algorithm for split attributes.

REFERENCES

[1] M. Yamaguchi, Y. Takahashi, T. Matsuzawa, T. Takahashi, and S. Dohi, "Development and Evaluation of e-Learning System AIRS with Multi-Expression Contents," IEICE-ET2006-118, Vol.106, No.583, pp.69-74 (2007).

[2] Y. Wada, S. Matsuzawa, M. Yamaguchi, and S. Dohi, "Bidirectional Recommendation Technology for Web Digital Texts, Journal of Digital Information Management," vol. 8, no. 4, pp. 240–246 (2010).

[3] Y, Wada, Y. Hamadume, S. Dohi, and J. Sawamoto, "Technology for Recommending Optimum Learning Texts Based on Data Mining of Learning Historical Data," International Journal of Information Society IJIS., vol. 2, no.3, pp.78–87 (2011).

[4] Y. Wada, T. Segawa, J. Sawamoto, and H. Sato, "RESEARCH ON RECOMMENDER FUNCTIONS FOR LEARNING SUPPORT SYSTEMS," 2nd International Conference on Applied and Theoretical Information Systems Research (2012).

[5] Amazon: http://www.amazon.com

[6] P. Resnick, N. Iacovou, M. Suchak, P. Bergstorm, and J. Riedl, "GroupLens: An Open Architecture for Collaborative Filtering of Netnews," Proc. ACM Conf. on computer Suspend Coparative Work, pp.175-186 (1994).

[7] S. Kitamura, "Consistency between Theoretical Interests in Collaborative Learning Studies and Methods of Statistical Analysis: A Review of Statistics for Hierarchical Data," Japan Society for Educational Technology (ISSN 1349-8290), vol.33 , no.3 , pp.342-352 (2010).

[8] A. Schein, A. Popescul, L. Unger, and D. Pennock, "Methods and Metrics for Cold-Start Recommendations," 25th Annual ACM SIGIR Conf., pp253-260 (2002).

[9]http://www.mext.go.jp/b_menu/shuppan/sonota/990301d.htm

[10]T. Segaran, "Programming Collective Intelligence Building Smart Web 2.0 Applications," O'REILLY (ISBN 978-4-87311-364-7), (2008).

[11]H. Iwasa and H. Yadohisa, ISBN 978-4-7980-2396-0, pp.352 (2009-10).

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New Metrics for Program Specifications Based on DbC

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Abstract - For realizing dependable and maintainable software, Design by Contract (DbC) is a useful approach. DbC utilizes constraints as contracts between the caller and the callee routines in programs. Verifiers for the programs are able to check whether the given source code satisfies the given constraints. However, it is difficult to measure the exhaustiveness for a specification, *i.e.*, how well the constraints cover the ideal specification for the source code. This paper proposes Variable Coverage, a simple set of metrics to check the exhaustiveness of specification for source code in Java and other object-oriented programming languages. The proposed coverage observes the occurrence of variables in the constraints, such that the variables are also used in the target method/-constructor. We applied the metrics to three actual programs to evaluate the ability of Variable Coverage to find variables that should have been referred in specifications as important variables. As a result, the shortage of JML annotations found in the target programs shows the usefulness of the proposed metrics.

Keywords: DbC, Coverage, Specification,Testing, Metrics

1 INTRODUCTION

Formal methods [1], which are mathematical techniques for the specification, development and verification of software and hardware systems, have attracted much attention because they are said to play important roles for designing software, especially since the size of software has increased. The larger the program size, the more frequently the software testing misses the corner case. Formal methods can perform exhaustive checking. In various industries, such as public transportation systems, real and large programming projects have been successful by using formal methods [2]. Formal methods are classified into three technologies: deductive methods, model checking, and model-based simulation or testing.

Design by Contract (DbC) [3] is a well-known approach for clarifying the responsibility between callers and callees. Java Modeling Language (JML) [4]–[6] is a specification language for Java based on DbC. A program based on DbC can be verified with static checking and runtime checking. For example, ESC/Java2 [7] and jml4c [8] are such tools for Java. As an example in another language, Spec# [9] is a superset of C#, and the static checker for Spec#, developed by Microsoft, uses Boogie [10].

However, it is difficult to determine whether the specification is well-written (exhaustive). If the specification is low exhaustive, the correctness of the program is not clear. In runtime checking, as an example, a runtime checker produces a violation when the source code and its specification do not match. No violation is reported by the runtime checkers if the code has no specification, because no constraint has been specified. Consequently, we cannot do anything about the quality of the source code.

Some papers have studied coverage metrics for hardware verification. Chockler et al. [11] summarized coverage metrics for simulation-based verification, such as code coverage and assertion coverage. To generate a test efficiently, Moundanos et al. [12] proposed functional coverage as the amount of control behaviors covered by a test suite using abstraction techniques. Nevertheless, few coverage metrics can be applied to general-purpose programming languages at the implementation level. This includes Java and JML.

In this paper, we propose Variable Coverage as coverage metrics for formal specifications at the implementation level. Variable Coverage consists of the coverage for the pre-condition, post-condition, assignable and invariant.

In experiments, we used a prototype that measures the Variable Coverage of three kinds of programs. As a result, we found a shortage of JML annotations in the target programs. The result shows the usefulness of our proposed metrics.

The paper is organized as follows. Section 2 provides definitions of important terms and Section 3 introduces related work. Section 4 shows our proposed method, Variable Coverage, followed by experiments and discussion in Sections 5 and 6, respectively. Finally, Section 7 concludes this paper.

2 PRELIMINARIES

This section provides some concepts and definitions.

2.1 Design by Contract

Design by Contract (DbC) was proposed by Bertrand Meyer [3]. In DbC, suppliers (callee routines) and clients (caller routines) make contracts with each other. The clients should satisfy the pre-conditions, and the suppliers should satisfy the post-conditions under the pre-conditions. This mechanism makes it easier to identify bugs.

Some programming languages support DbC as a standard, and others have a specification language that is separate from the core grammar of the language. Eiffel [13] supports DbC as the standard. C# and Java have no standard contract system but some specification languages are proposed separately. Spec# [9] is a superset of C# to describe contracts. For Java, JML [4] is the de-facto standard specification language.

2.2 Constraints

The pre-condition for a routine (method) is a set of Boolean constraints. It should be `true` prior to the routine execution.

Clients are responsible to meet the pre-condition.

The post-condition for a routine is a set of Boolean constraints. It should be `true` after the routine execution, provided that its associated pre-condition holds. Suppliers are responsible to meet the post-condition under the pre-condition.

The routine is permitted to assign values to only the variables specified in Assignable. The constraints help the developers to detect side effects.

Invariant is a set of Boolean constraints. Invariants should be always `true`. Depending on the target of a constraint, invariants are divided into class invariant and loop invariant. This paper deals with only the class invariant.

2.3 Java Modeling Language

JML is a specification language based on DbC for Java. JML supports the pre-condition, post-condition, assignable and invariant. We explain them through class `BankAccount`, an account for a customer of a bank, as an example.

Figure 1 is the source code of class `BankAccount` with JML.

```
1  public class BankAccount {
2
3    private int balance;
4    // @invariant balance >= 0;
5
6    // @ensures balance == 0;
7    // @assignable balance;
8    public BankAccount() {
9      this.balance = 0;
10   }
11
12   // @requires amount >= 0;
13   // @requires balance >= amount;
14   // @ensures  balance == \old(balance) -
         amount;
15   // @assignable balance;
16   public void withdraw(int amount) {
17     this.balance -= amount;
18   }
19
20   // @requires amount >= 0;
21   // @ensures  balance == \old(balance) +
         amount;
22   // @assignable balance;
23   public void deposit(int amount) {
24     this.balance += amount;
25   }
26
27   // @ensures \result == balance;
28   // @assignable \nothing;
29   public int getBalance() {
30     return this.balance;
31   }
32
33   // @pure
34   public void inquiry() {
35     System.out.println("Balance is " + this.
           balance);
36   }
37
38 }
```

Figure 1: Source Code of Class BankAccount with JML

Pre-conditions Keyword `@requires` expresses the pre-condition. In Fig. 1, methods `withdraw` and `deposit` have pre-conditions in lines 12,13 and 20.

Post-conditions Keyword `@ensures` expresses the post-condition. The constructor and methods `withdraw`, `deposit` and `getBalance` have post-conditions. Line 6 in Fig. 1 means that field `balance` is 0 after the instance creation.

Assignables `@assignable` expresses the assignable. The following `@assignable` classes, fields that can be assigned, are listed. If every field is prohibited to be assigned, then `@assignable \nothing` is used, as in line 28 in Fig. 1. To shorten the code, `@pure` is equivalent to `@assignable \nothing`.

Invariants The JML description of invariants is `@invariant`. Also, attribute `a` with `@non_null` is equivalent to `@invariant a != null`. In Fig. 1, line 4 is an invariant clause that means field `balance` must be 0 or more at any time.

2.4 Global Variables

Generally, the term "global variables" is not used in object-oriented programming language. In this paper, as a matter of convenience, we define global variables as follows.

Definition 2.1 (Global Variables)
When a method m is a member of class c, a global variable g is defined as:

- g is not a member of c, and
- g is visible from m.

Figure 2 shows an example of a global variable. The variable `font` of class `Config` is a global variable for method `draw`.

```
1  public class Config {
2    public static Font font;
3  }
4
5  public class Customer {
6    public void draw(Graphics g) {
7      g.setFont(Config.font);
8      g.drawString("An example for a global
           variable", 10, 10);
9      ...
10   }
11 }
```

Figure 2: An Example of a Global Variable

3 RELATED WORK

This section introduces some of the work related to this paper.

3.1 Program Verification

ESC/Java [14], an Extended Static Checker for Java, was the practical usable checker among the early verifiers. Currently, its successor version, ESC/Java2 [15] is widely used and supports JML2.

Also supporting the newer Java, Mobius [16] has attracted increased attention as a program verification environment (PVE) that includes static checkers, runtime checkers, and verifiers. It is provided as an Eclipse [17] plug-in. ESC/Java2 is also integrated into Mobius.

3.2 Verification Coverage

Coverage metrics for formal verification are called verification coverage primarily in the hardware field. Verification coverage falls into two categories: syntactic coverage and semantic coverage [11]. As syntactic coverage, code coverage for model-based simulation is the metric derived from software testing [18]. The ratio of executed code during a simulation is code coverage. As simple coverage, line coverage is the code of a block without control transition.

Coverages depending on a control flow graph (CFG) are branch coverage, expression coverage, and path coverage.

Semantic coverage is categorized into assertion coverage and functional coverage. Assertion coverage is the measuring method by which users determine variables to observe. Assertion coverage measures what assertions are covered with a given set of input sequences [11].

To generate a test suite to be analyzed, Moundanos et al. [12] proposed functional coverage, which is the amount of control behavior covered by a test suite using abstraction techniques.

3.3 Assertion Density

Assertion density is the number of assertions per line of code [19]. Without sufficient assertion density, the full benefits of assertions are not realized. Assertions must be verified for behaviors as design intents, *i.e.*, statements of properties.

4 VARIABLE COVERAGE

This section defines Variable Coverage, our proposed method.

4.1 Motivation

Formal verification checks the consistency between source code and its contracts based on the Class Correctness formula. Chockler et al. [11] stated that "Measuring the exhaustiveness of a specification in formal verification has a similar flavor as measuring the exhaustiveness of the input sequences in simulation-based verification for hardware." To apply this idea to software, the input sequences of a method/constructor correspond to variables. Consequently, we propose a coverage metric that observes variables.

4.2 Policies

We propose a set of metrics that supports these policies:

1. Our metric checks all variables as input and output.
   It is oriented with verification coverage.

2. Our metric is simple.
   The execution of measuring the coverage requires a relatively short time. The metric targets developers who describe assertions in JML. Our metric should be checked for a short time on a frequent basis when the developers want to conduct checks.

3. Our metric uses only static information.
   Using only static information (source code and JML) without an execution trace enables the measurement of coverage for a part of incomplete code.

4.3 Constraints Development Process with Variable Coverage

Quickly measuring Variable Coverage (hereafter, VC) enables a high frequency of measurements. Implementators can improve the constraint descriptions by the iterative process:

Step 1 Implementators describe assertions.

Step 2 VC is measured.

Step 3 Iterate Step 1 if the implementators do not find all of their assertions.

We call such an iteration "Quick VC revise."

4.4 Definition of Variable Coverage

VC consists of four kinds of metrics: coverage for the pre-condition, post-condition, assignable and invariant. Tables 1 and 2 show the VC metrics for a single constraint and multiple constraints, respectively.

4.4.1 The Coverage for Pre-conditions

Pre-conditions should check all input variables, *i.e.*, parameter of the method, attributes and global variables referred in the method. Thus, the coverage for pre-conditions consists of Parameters Coverage and Referred Attributes Coverage.

Definition 4.1 (PrPC)
Let $P(m)$ and $P_{held-by-pre}(m)$ be a set of parameters defined in method m and held by a pre-condition in method m, respectively. Equation (1) defines $PrPC(m)$, Parameters Coverage for pre-conditions of method m.

$$PrPC(m) = \frac{\mid P_{held-by-pre}(m) \mid}{\mid P(m) \mid} \tag{1}$$

In Fig. 3, both $\mid P_{held-by-pre}(m) \mid = \mid \{age\} \mid = 1$ and $\mid P(m) \mid = \mid \{name, age\} \mid = 2$ hold. Hence, we have $PrPC(m) = 1/2$.

Definition 4.2 (PrAC)
Let $A_{referred}(m)$ and $A_{held-by-pre}(m)$ be a set of attributes referred in method m and held by the pre-condition in method

Table 1: Variable Coverage (single constraint)

Coverage Name	Constraint	Target Variables	Measuring Unit
PrPC	Pre-Condition	Parameters	Method
PrAC		Refered attributes	Method
PrGC		Refered global variables	Method
PoRC	Post-Condition	Return value	Method
PoAC		Assigned attributes	Method
PoGC		Assigned global variables	Method
AAC	Assignable	Assigned attributes	Method
IAC	Invariant	Attributes	Class

Table 2: Variable Coverage (multiple constraints)

Coverage Name	Constraint	Target Variables	Measuring Unit
PrIAC	Pre-condition + invariant	Refered attributes	Method
PoIAC	Post-condition + invariant	Assigned attributes	Method

```
1 //@ requires age >= 0;
2 // no requires holds 'name'
3 public Customer(String name, int age){
4   this.name = name;
5   this.age = age;
6 }
```

Figure 3: An Example to Explain Parameters Coverage for Pre-condition

m, respectively. Equation (2) defines $PrAC(m)$ as the Referred Attributes Coverage for pre-conditions of method m.

$$PrAC(m) = \frac{\mid A_{held-by-pre}(m) \mid}{\mid A_{referred}(m) \mid} \tag{2}$$

Definition 4.3 (PrGC)
Let $G_{referred}(m)$ and $G_{held-by-pre}(m)$ be a set of global variables referred in method m and held by the pre-condition in method m, respectively. Equation (3) defines $PrGC(m)$ as the Referred Global Variables Coverage for pre-conditions of method m.

$$PrGC(m) = \frac{\mid G_{held-by-pre}(m) \mid}{\mid G_{referred}(m) \mid} \tag{3}$$

4.4.2 The Coverage for Post-conditions

Post-conditions observe output variables that have an effect outside of the method, such as the return value, attributes and global variables assigned in the method. Hence, the coverage for a post-condition is composed of Return Value Coverage, Assigned Attributes Coverage and Assigned Global Variables Coverage.

Definition 4.4 (PoRc)
Equation (4) defines $PoPC(m)$ as the Parameters Coverage for post-conditions of method m.

$$PoRC(m)=\begin{cases} 1 & \text{(return value is held by post-condition)} \\ 0 & \text{(otherwise)} \end{cases} \tag{4}$$

Definition 4.5 (PoAC)
Let $A_{assigned}(m)$ and $A_{held-by-post}(m)$ be a set of attributes assigned in method m and held by the post-condition in method m, respectively. Equation (5) defines $PoAC(m)$ as the Assigned Attributes Coverage for post-conditions of method m.

$$PoAC(m) = \frac{\mid A_{held-by-post}(m) \mid}{\mid A_{assigned}(m) \mid} \tag{5}$$

Definition 4.6 (PoGC)
Let $G_{assigned}(m)$ and $G_{held-by-post}(m)$ be a set of global variables assigned in method m and held by the post-condition in method m, respectively. Equation (6) defines $PoGC(m)$ as the Assigned Global Variables Coverage for post-conditions of method m.

$$PoGC(m) = \frac{\mid G_{held-by-post}(m) \mid}{\mid G_{assigned}(m) \mid} \tag{6}$$

4.4.3 The Coverage for Assignables

Assignable constraints are written on methods or constructors. Some variables are assigned in the method or constructor, including attributes that have their scope outside of the method. Thus, the coverage for assignables includes Assigned Attributes Coverage.

Definition 4.7 (AAC)
Let $A_{assigned}(m)$ and $A_{held-by-asgn}(m)$ be a set of attributes assigned in method m and held by the assignable in method m, respectively. Equation (7) defines $AAC(m)$ as the Assigned Attributes Coverage for the assignable of method m.

$$AAC(m) = \frac{\mid A_{held-by-asgn}(m) \mid}{\mid A_{assigned}(m) \mid} \tag{7}$$

4.4.4 The Coverage for Invariants

Class invariants are described in a class. The variables owned by the classes are attributes. Hence, coverage for invariants has Attributes Coverage for invariants.

Definition 4.8 (IAC)
Let $A(c)$ and $A_{held-by-inv}(c)$ be a set of attributes owned by class c and held by the invariants in class c, respectively. Equation (8) defines $IAC(c)$ as the Attributes Coverage for invariants of class c.

$$IAC(c) = \frac{\mid A_{held-by-inv}(c) \mid}{\mid A(c) \mid} \tag{8}$$

4.4.5 The Coverage for Pre-conditions and Invariants

Definition 4.9 (PrIAC)
Let us assume that Class c owns method m. Also, let $A_{referred}(m)$, $A_{hold-by-pre}(m)$, and $A_{hold-by-inv}(c)$ be a set of attributes referred in method m, held by the pre-condition in method m, and held by invariants in class c, respectively. Equation (9) defines $PrIAC(m)$ as the Referred Attributes Coverage for pre-conditions and invariants of method m.

$$PrIAC(m) = \frac{PrIACNR(m)}{\mid A_{referred}(m) \mid} \tag{9}$$

where $PrIACNR(m) =$
$\mid A_{referred}(m) \cap (A_{held-by-pre}(m) \cup A_{held-by-inv}(c)) \mid$

4.4.6 The Coverage for Post-conditions and Invariants

Definition 4.10 (PoIAC)
Let us assume that Class c owns method m. Let $A_{assigned}(m)$, $A_{hold-by-post}(m)$, and $A_{hold-by-inv}(c)$ be a set of attributes referred in method m, held by the post-condition in method m, and held by the invariants in class c, respectively. Equation (10) defines $PoIAC(m)$ as the Assigned Attributes Coverage for post-conditions and invariants of method m.

$$PoIAC(m) = \frac{PoIACNR(m)}{\mid A_{assigned}(m) \mid} \tag{10}$$

where $PoIACNR(m) =$
$\mid A_{assigned}(m) \cap (A_{held-by-post}(m) \cup A_{held-by-inv}(c)) \mid$

4.4.7 Ignored Variables

Constants are ignored when measuring the coverage because such variables do not affect the communication among methods. For example, in Java, the variables described by `final` modifier are ignored.

5 EVALUATION

This section gives our experimental evaluations and the results.

5.1 Overview

We performed experiments using our prototype tool to evaluate our proposed coverage metrics. We measured (1) execution times, and (2) numeric results of our proposed coverage. Here is the experimental environment; HP Z800 Workstation (Xeon E5607 dual core 2.27 GHz, 2.26 GHz and main memory 32 GB), Windows 7 Professional for 64 bits with Service Pack 1 and Java Version 1.7.

5.2 Target Programs

We applied our approach to three programs: The Warehouse Management Program (WMP) [20], HealthCard (HC) [21], [22], and the Syllabus Management System for a university (SMS). Table 3 summarizes the target programs including the size of the programs and available assertion types of each program.

Table 3: Target Programs

Target Program	N	Available JML Assertions
WMP	53	requires,ensures, assignable,invariant
HC	197	requires,ensures,assignable
SMS	562	requires,ensures

N = The number of target methods and constructors

WMP was developed by an ex-member of our research group. This program has requires, ensures, assignables and invariants, and they all passed the static checker, ESC/Java2.

HC is a medical appointment application written as a master's thesis by Ricardo Rodrigues at the University of Madeira. The application is based on JavaCard, the platform of IC card devices. In general, the embedded systems need stricter quality because it is difficult to update their software. HC has two versions: a running version and a JML version. We utilize the JML version as the experimental target because the JML version contains more JML descriptions than does the running version. The HC program has no `@invariant` in JML because `model` is used instead of `@invariant`. Thus, in this evaluation, Attributes Coverage for invariants is not measured.

SMS is implemented in Java by a software company as an educational resource for the IT Specialist Program Initiative for Reality-based Advanced Learning (IT Spiral), a national educational project lead by MEXT. Members of our research group added only pre-conditions and post-conditions in JML to the system, and the system produced no violations by jml4c, a runtime checker.

We added the standard libraries (*e.g.*, `java.lang.Object`) with JML descriptions [15] to the target programs. Thus, the contracts of the superclass or interface are added to the class that inherits a class or implements an interface. For example, the contracts of `java.lang.Object#toString()` are added to all the `toString()` methods. Additionally, the results of coverage do not include the methods of the standard libraries. Furthermore, we excluded abstract classes, interfaces, test classes and the main method because they should not necessarily have contracts.

The JML annotations on each experimental target are described based on judgements of each developer. Hence, there is no common policy for describing annotations between the experimental targets.

5.3 Results of Execution Times

Table 4 shows the results of the execution times. We measured three execution times for each program and show their average in the table.

Table 4: Execution Times

Target Program	Execution Time
WMP	9.3 sec
HC	16.0 sec
SMS	14.0 sec

5.4 Results of Variable Coverage

Tables 5, 6, and 7 show the results of the coverages for pre-conditions, for post-conditions, and for assignables, respectively.

Table 5: Results of Coverage for Pre-conditions

Target Program	PrPC	PrAC	PrIAC
WMP	99.17%	9.09%	96.97%
HC	79.22%	46.24%	NA
SMS	41.82%	2.77%	NA

Table 6: Results of Coverage for Post-conditions

Target Program	PoRC	PoAC	PoIAC
WMP	100.00%	94.12%	100.00%
HC	84.11%	48.39%	NA
SMS	99.68%	99.38%	NA

Table 8 shows the results of the coverage of invariants for WMS.

6 DISCUSSION

This section discusses the experimental results and the threats to validity.

6.1 Warehouse Management Program

The following method does not cover Parameter Coverage for pre-conditions:

```
StockManagement.Request#
Request(java.lang.String, int,
   StockManagement.Customer, java.util.Date,
   byte).
```

We found that parameter `rqst` is not covered by `requires` in the source code of the constructor `Request`. The byte-type parameter `rqst` means the request state instead of Enum, as `SHORTAGE=0`, `SATISFYED=1`, `DELIVERED=2`, `WAIT=3`. Therefore, the constraints of class `Request` in JML are lacking because the attribute `rqst` must be any of 0 to 3.

Table 6 shows that every return value is held by its post-conditions. No problem was found when we read the source code and JML.

The following method does not cover the Assigned Attributes Coverage for post-conditions:

```
StockManagement.ReceiptionDesk#
   ReceiptionDesk().
```

Developers who described the source code and JML seemed to recognize the shortage of post-conditions, because the comment "ensures are included in invariants" is in the source code (Fig. 4).

Table 7: Results of Coverage for Assignables

Target Program	AAC
WMP	100.00%
HC	41.94%
SMS	NA

Table 8: Results of Coverage for Invariants (WMP)

Class Name	P	IAC
ContainerItem	3 / 3	100.00%
Customer	3 / 3	100.00%
Item	2 / 2	100.00%
ReceiptionDesk	2 / 2	100.00%
Request	4 / 6	66.67%
StockState	NA	NA
Storage	3 / 3	100.00%

P=The number of attributes held by invariants / the Number of attributes

```
1 //ensures are included in invariants.
2 //@ public behavior
3 //@   assignable requestList, storage;
4 public ReceiptionDesk() {
5   requestList = new LinkedList();
6   storage = new Storage();
7 }
```

Figure 4: Constructor ReceptionDesk That Is Not Covered by Post-conditions

In the source code of class `ReceptionDesk` (Fig. 5), attributes `requestList` and `storage` are held by invariants.

Also, the result of Assigned Attributes Coverage for post-conditions and invariants is 100%. Even if Assigned Attributes Coverage for post-conditions is low, we can conclude that the source code does not have a problem because the value of Assigned Attributes Coverage for post-conditions is high. Hence, VC helps us to clarify that the source code does not have a problem.

As in the case of class `ReceptionDesk`, it is difficult to know the reason why post-conditions are omitted in a general case. One solution is the designer should describe a comment or some keyword when the post-conditions are included in the class invariants.

Table 7 shows that all assigned attributes are held by assignables. Therefore, we can see that every assignable is described correctly in WMP.

Table 8 shows that Attributes Coverage for invariants of most of classes is 100%, but the coverage of class `Request` is 66%. Class `Request` has six attributes, but two of them are not held by invariant constraints. We found that attributes `deliveringDate` and `requestState` in class `Request` are the cause. `deliveringDate` is defined as the `java.util.Date` type field, which is the date of delivery. Any field of type `java.util.Date` except for `deliveringDate` in class `Request` has a constraint "the

```
public class ReceiptionDesk {
  private /*@ spec_public non_null @*/ List
      requestList;
  private /*@ spec_public non_null @*/ Storage
      storage;
  //@ public invariant \typeof(requestList) ==
      \type(Request);
    ...
}
```

Figure 5: Invariants in Class ReceptionDesk

Table 9: Extracted Results of Coverage for HC

T	N	PrPC	PrAC	PoRC	PoAC	AAC
(1)	197	79.22 %	46.24 %	84.11%	48.39%	41.94 %
(2)	38	82.61%	42.86 %	88.89%	NA	NA

T=The Type of Targets
N=The Number of Targets
(1):All methods and constructors
(2):Except for constructors, setters and getters

field is not null." Thus, the implementor has no insight into the constraints of `deliveringDate` because `deliveringDate` can be null before delivery. The same is true with respect to field `requestState`. Figure 6 shows our recommended revised version of constraints based on the results.

```
1  public class Request implements Comparable {
2    private /*@ spec_public non_null @*/ Date
         receiptionDate;
3    private /*@ spec_public non_null @*/ String
         itemName;
4    private /*@ spec_public @*/ int amount;
5    private /*@ spec_public non_null @*/
         Customer customer;
6
7    private byte requestState;
8    private Date deliveringDate;
9    //@invariant
10     (requestState != delivered &&
           deliveringDate == null) ||
11     (requestState == delivered &&
           deliveringDate != null);
12   ...
13 }
```

Figure 6: Class Request with Recommended JML Revisions

6.2 HealthCard

From the manual inspection we conclude that the JML assertion for HC is described in the following way. No constructors have a JML description because the JML description is on the interface. Setters and getters have no JML description. We discuss constructors, setters and getters later. Table 9 lists the results of HC except for constructors, setters and getters.

According to Table 9, the following methods have no preconditions with their parameters even though they are neither setters/getters nor constructors:

- `commons.CardUtil#byte[] clone(byte[])`
- `commons.CardUtil#void cleanField(byte[])`
- `commons.CardUtil #boolean validateObjectArrayPosition (java.lang.Object[], short)`
- `commons.CardUtil #short countNotNullObjects (java.lang.Object[])`

The parameters of the methods are array type, and any caller or any callee does not guarantee that each of the parameters is not null. We found the shortage of JML descriptions by applying Variable Coverage. In addition, the methods do not check whether the parameters inside are null. `NullPointerException` is thrown when the parameter array is `null`. The result shows that these methods have potential bugs.

Also, this program has a method with comments in natural language instead of JML constraints. Figure 7 shows the source code of method `validateObjectArrayPosition` of class `CardUtil`. Line 1 in the figure indicates that the developers know the lack of JML descriptions. We consider, as future work, that we could infer contracts from useful comments.

```
1  //Returns false if position points to a null
       value or if position is out of bounds.
2  //@ assignable \nothing;
3  public /*@ pure @*/ static boolean
       validateObjectArrayPosition (Object[]
       array, short position) {
4    if(position < 0 || position >=
         countNotNullObjects(array))
5      return false;
6    else
7      return true;
8  }
```

Figure 7: Comments Instead of Contracts

For Referred Attributes Coverage for pre-conditions, the results of 23 methods are not full coverage. The results of 8 of 23 of the methods with `toString` are eliminated because their source code has the comment, "Testing code."

For the other 15 methods, we explain the method `validateAllergyPosition`. It does nothing other than call utility method `validateObjectArrayPosition` of class `CardUtil` (Fig. 8).

```
1  public boolean validateAllergyPosition(short
       position){
2    return CardUtil.validateObjectArrayPosition(
         this.allergies, position);
3  }
```

Figure 8: Source Code of Method validateAllergyPosition

It is preferable that contract violations are produced in a previous step than over a later step because it is easier to identify bugs. Thus, methods `validateAllergyPosition`

and validateVaccinePosition should be written with more JML descriptions.

For Return Value Coverage for post-conditions, analogous with pre-conditions, the following methods have no post-conditions even though they have neither setters/getters nor constructors:

- commons.CardUtil#byte[] clone(byte[])
- commons.CardUtil #short countNotNullObjects (java.lang.Object[])
- commons.CardUtil #boolean validateObjectArrayPosition (java.lang.Object[],short)

The JML descriptions of the methods can be improved. For method clone, we recommend the post-condition @ensures \result != null. Also, we recommend the post-condition for method validateObjectArrayPosition idea in Figure 9, based on its comment "//Returns false if position points to a null value or if position is out of bounds."

```
/*@ ensures
    (\result == false)  ==>
    (array == null ||
     position <= 0 || position >=
         countNotNullObjects(array))
  @*/
```

Figure 9: Recommended Post-condition of Method validateObjectArrayPosition

For method countNotNullObjects, we suggest @ensures \result >= 0;.

About the Assigned Attributes Coverage for post-conditions, the result is not available because no methods assign attributes.

No methods assign attributes except constructors, setters and getters.

In general, constructors and setters tend to change the attributes. Although every getter does not change the attributes, its return value is used by other methods. To guarantee the behavior of the class, constructors, setters and getters should have JML descriptions.

We recommend that developers describe the JML description of constructors, setters and getters, as in Figure 10. For setters, developers should write pre-conditions that mean that the parameters equal the attributes assigned. For getters, developers should write post-conditions that means that the return value equals the attributes returned.

6.3 Syllabus Management System

The parameters of 207 methods are not held by pre-conditions; 144 of them are setters, and 63 are others. As an instance of setters, Figure 11 shows the source code of method setJugyouKamoku of class JikanwariJugyouKamokuDTO.
When parameter jugyouKamoku is null, the attribute jugyouKamoku is set to null.

```
public class Person {
  private String name;

  //@requires name != null;
  //@ensures this.name == name;
  public Person(String name) {
    this.name = name;
  }

  //@requires name != null;
  //@ensures this.name == name;
  public void setName(String name) {
    this.name = name;
  }

  //@ensures \result == this.name;
  //@assignable nothing;
  public String getName() {
    return this.name;
  }

}
```

Figure 10: Recommended Source Code with JML of Setter and Getter

If method setJugyouKamoku is called again, the null reference occurs at line 2. Thus, the pre-condition should have the jugyouKamoku != null constraint for parameter jugyouKamoku.

```
1 //@ ensures  this.jugyouKamoku.equals(
      jugyouKamoku);
2 public void setJugyouKamoku(final JugyouKamoku
       jugyouKamoku) {
3   this.jugyouKamoku = jugyouKamoku;
4 }
```

Figure 11: An Example for Setter of SMS

Only the following method does not have full coverage for Return Value Coverage for post-Conditions:
service.UserServiceImpl#
boolean authenticate(java.lang.String,
java.lang.String, entity.UserKubun)
The method authenticate of class UserServiceImpl returns true or false depending on its parameters. We found no post-condition in its source code, but whether constraints are needed or just forgotten is difficult to distinguish. Therefore, for such a method, we recommend writing explicit contracts to single out oversights:
ensures \result == true|false;.

For Assigned Attributes Coverage for post-conditions, the result of the following method is not held by post-conditions:
entity.Soshiki # void add(entity.Soshiki)
Figure 12 shows the source code of the method add of class Soshiki. The post-condition in line 3 calls the getter method getKaiSoshiki. From the source code of the getter (Figure 13), the getter just returns the attribute kaiShoshiki without changing it. We recommend using ensures this.kaiSoshiki.contains(soshiki); instead of line 3.

Calling the setter of the attribute in the methods is the same as assigning the attribute. For example, line 5 in Figure 14 is

```
1 //@ requires soshiki != null;
2 //@ ensures this.getKaiSoshiki().contains(
      soshiki);
3 public void add(final Soshiki soshiki) {
4   if (getKaiSoshiki() == null) {
5     this.kaiSoshiki = new LinkedHashSet<
          Soshiki>();
6   }
7   soshiki.setJouiSoshiki(this);
8   getKaiSoshiki().add(soshiki);
9 }
```

Figure 12: Added Source Code of Method of Class Soshiki

```
1 //@ ensures (this.kaiSoshiki != null) ? (this.
      kaiSoshiki.size() == \result.size()) && (
      \forall Soshiki s; this.kaiSoshiki.
      contains(s); \result.contains(s)) : \
      result == null;
2 // anotation OneToMany(cascade = CascadeType.
      ALL, targetEntity = Soshiki.class,
      mappedBy = "jouiSoshiki")
3 public Set<Soshiki> getKaiSoshiki() {
4   return this.kaiSoshiki;
5 }
```

Figure 13: Source Code of Method getKaiSoshiki of Class Soshiki

equivalent to assigning the attribute `SESSION`. Assigned Attributes Coverage should also be extended to a target calling the setter of the attribute.

```
1 public static Session currentSession() {
2   Session s = SESSION.get();
3   if (s == null) {
4     s = SESSION_FACTORY.openSession();
5     SESSION.set(s);
6   }
7   return s;
8 }
```

Figure 14: Example of the Unmonitored Case of Assigning an Attribute

6.4 The cost of writing additional annotations

The case studies revealed that the proposed metrics could contribute to detect shortage of JML annotations. However, it may require a certain amount of effort to fix the shortage of the annotations. We believe that the amount of annotations is important to evaluate the safety of software systems. We also propose our method considering the scalability. It should be easy to calculate for real software. However, redundant annotations should not increase the safety even though they require a certain amount of effort to be described. Hence, it is necessary to judge whether the shortage of annotations detected by the proposed metrics really required to be fixed.

7 CONCLUSION

This paper proposed Variable Coverage, a set of metrics for the exhaustiveness of specification with source code based on Design by Contract. Our proposed coverage observes variables depending on constraints. We applied our approach to three programs to evaluate the ability of Variable Coverage to find variables that should have been referred in specifications as important variables. As a result, we found a shortage of JML annotations in the target programs, and this shows the usefulness of our proposed metrics.

Future work includes inferring the constraints. The first approach is suggesting constraints from the comments in the source code. The second approach is using the modifiers of a method; static methods should not have assignable clauses except for static variables. This means no attributes are permitted to be assigned, because static methods do not change the internal state, (*i.e.*, attributes). Such a modifier helps to generate helpful assertions.

8 FUTURE WORK

In order to reduce the verification time, we proposed the metrics that only consider the amount of annotations. However, we plan to make the proposed metrics take the quality of annotations into account. Currently, the proposed metrics consider only the amount of annotations. They do not consider the quality of the annotations. Hence, the high values of the proposed metrics may not be directly linked to the safety of software systems. Therefore, it will improve the usefulness of the proposed metrics to consider the quality of annotations. We add these explanations in Section 8 as our future work.

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REFERENCES

[1] E.M. Clarke, and J.M. Wing, “Formal Methods: State of the Art and Future Directions,” ACM Computing Surveys, Vol.28, No.4, pp.626–643 (1996).

[2] J.R. Abrial, “Formal Methods in Industry,” Proceeding of the 28th international conference on Software engineering - ICSE ’06, pp.761–768 (2006).

[3] B. Meyer, “Applying ‘Design by Contract’,” IEEE Computer, Vol.25, No.10, pp.40–51 (1992).

[4] G.T. Leavens, A.L. Baker, and C. Ruby, “JML: A Notation for Detailed Design,” Behavioral Specifications of Businesses and Systems, pp.175–188 (1999).

[5] P. Chalin, P.R. James, and G. Karabotsos, “JML4: Towards an Industrial Grade IVE for Java and Next Generation Research Platform for JML,” Proceeding VSTTE ’08 Proceedings of the 2nd international conference on Verified Software: Theories, Tools, Experiments, eds. N. Shankar, and J. Woodcock, Vol.5295, pp.70–83 (2008).

[6] D.R. Cok, “OpenJML: JML for Java 7 by extending OpenJDK,” Proceeding NFM’11 Proceedings of the Third international conference on NASA Formal methods, pp.472–479 (2011).

[7] D.R. Cok, and J.R. Kiniry, "ESC/Java2: Uniting ESC/-Java and JML," International Workshop on Construction and Analysis of Safe Secure and Interoperable Smart Devices CASSIS 2004, Vol.3362, pp.108–128 (2004).
[8] A. Sarcar, "A New Eclipse-Based JML Compiler Built Using AST Merging," 2010 Second World Congress on Software Engineering, pp.287–292 (2010).
[9] M. Barnett, K.R.M. Leino, and Schulte, "The Spec# Programming System: An Overview," Construction and Analysis of Safe, Secure, and Interoperable Smart Devices, eds. G. Barthe, L. Burdy, M. Huisman, J.L. Lanet, and T. Muntean, Vol.3362, pp.49–69 (2005).
[10] M. Barnett, B.Y.E. Chang, R. DeLine, B. Jacobs, and K.R.M. Leino, "Boogie: A Modular Reusable Verifier for Object-Oriented Programs," 4th International Symposium, FMCO 2005, Vol.4111, pp.364–387 (2006).
[11] H. Chockler, O. Kupferman, and M. Vardi, "Coverage Metrics for Formal Verification," International Journal on Software Tools for Technology Transfer, Vol.8, No.4-5, pp.373–386 (2006).
[12] Dinos Moundanos, J.A. Abraham, and Y.V. Hoskote, "Abstraction Techniques for Validation Coverage Analysis and Test Generation," IEEE Transactions on Computers, Vol.47, No.1, pp.2–14 (1998).
[13] B. Meyer, Eiffel : The Language (Prentice Hall Object-Oriented Series), Prentice Hall (1991).
[14] C. Flanagan, K.R.M. Leino, M. Lillibridge, G. Nelson, J.B. Saxe, and R. Stata, "Extended Static Checking for Java," ACM SIGPLAN Notices, Vol.37, No.5, pp.234 (2002).
[15] KindSoftware, "ESC/Java2" .
[16] J. Kiniry, P. Chalin, C. Hurlin, B. Meyer, and J. Woodcock, "Integrating Static Checking and Interactive Verification: Supporting Multiple Theories and Provers in Verification," in VERIFIED SOFTWARE: THEORIES, TOOLS, EXPERIMENTS, eds. B. Meyer, and J. Woodcock, Vol.4171 of Lecture Notes in Computer Science, pp.153–160 (2008).
[17] E. Foundation, "Eclipse" .
[18] S. Tasiran, and K. Keutzer, "Coverage Metrics for Functional Validation of Hardware Designs," IEEE Design & Test of Computers, Vol.18, No.4, pp.36–45 (2001).
[19] H. Foster, D. Lacey, and A. Krolnik, Assertion-Based Design, SpringerSecond edition (2004).
[20] M. Owashi, K. Okano, and S. Kusumoto, "Design of Warehouse Management Program in JML and Its Verification with ESC/Java2 (in Japanese)," The Transactions of the Institute of Electronics, Information and Communication Engineers D, Vol.91, No.11, pp.2719–2720 (2008).
[21] R.M.S. Rodrigues, "JML-Based formal development of a Java card application for managing medical appointments," University of Madeira (2009).
[22] R.M.S. Rodrigues, "HealthCard" .

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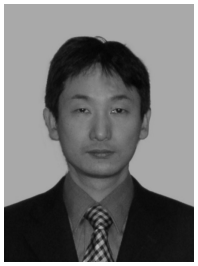

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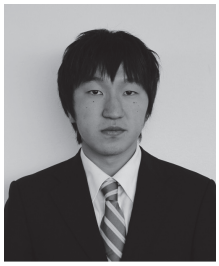

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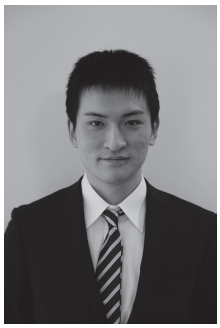

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Verification of a Control Program for a Line Tracing Robot using UPPAAL Considering General Aspects

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Abstract - The demand for embedded systems have increased in our society. Ensuring the safety properties of these systems has also become important. Model checking is a technique to ensure such systems. Our target is formal verification of hybrid systems which contain both continuous and discrete behaviors. For the goal, we have studied properties of a line tracing robot built using LEGO Mindstorms with a control program written in LeJOS. We have already presented verification of safety properties of a control program for the application using model checker UPPAAL. In the previous study, we were in a preliminary stage and set limitations. In this presentation, we extend our previous study. In general, a real course can be expressed in combinations of straight and arc courses. First, we verify properties of the same control program for arc courses. Next, in case of the line tracer can not keep track, we analyze turning angle using counter examples. Above-mentioned two approaches are necessary from the standpoint of design phase.

Keywords: Embedded Systems, Formal Verification, Timed Automaton

1 INTRODUCTION

The demand for embedded systems have increased in our society. In these circumstances, it is important to ensure safety properties of embedded systems. Formal methods are mathematical based techniques for verification and development. Model checking is one of formal methods and is widely used in order to ensure properties. Model checking techniques take model and logical formula as their input. Given a model that represents a system under consideration, model checking automatically determines whether or not the model satisfies a given property by exhaustively searching for the state space of the model.

There are various kinds of model checking techniques. Most model checking techniques are based on the finite state machine. For example, a conventional model checking is based on Kripke structure and only deals with discrete variables. However, some embedded systems require time properties in their specification. Several models have been proposed to deal with such real-time systems. One of such approaches is the timed automaton [1]. Timed automaton uses clock variables which range over real numbers. Therefore, timed automaton model can naturally represent the behavior of real-time systems. One of major verifier for timed automaton is UPPAAL [2] in which extended timed automata is used to construct models. UPPAAL can deal with bounded integer variables and guard expressions on transitions which allow expressions of constraints on variables.

Embedded systems sometimes consist of continuous and discrete dynamics. Such systems are called hybrid systems [3]. We are motivated to verify the behavior of embedded control systems. Especially if these embedded systems are considered to be hybrid systems. For the goal, we have presented verification of safety property of a control program for a line tracing robot using model checker UPPAAL. In the previous study, we were in a preliminary stage and set limitations. For example, we only considered a straight line as a course.

In this study, we extend our previous study. First, we verify that the same control program can trace an arc course. This is because a real course can be expressed in combination of straight and arc courses. Therefore, verifying the tracer for arc courses should be important to show applicability of model checking. Next, if the line tracer is not able to run along an arc course, we analyze turning angle using counter examples. Above-mentioned approaches will be useful to check performance properties in the design phase.

The roadmap of this paper is as follows. Sec. 2 outlines the foundations of our work and briefly describe our previous study. Sec. 3 show specification of a line tracer, and its implementation is described in Sec 4. Then, formal models used in verification are described in Sec. 5. Verification results are presented in Sec. 6, and Sec. 7 offers some discussion of these results. Finally, Sec. 8 provides a concluding summary and outline our future work.

2 PRELIMINARIES

In this section, we outline the background to our work and briefly show our previous study.

2.1 Model Checking

Model checking [4] is an automatic formal verification technique. Given a model that represents a system under consideration, and a logical formula that represents a property to be verified, model checking automatically determines whether or not the model satisfies a given property by exhaustively searching for the state space of the model. There are various kinds of model checking depending on expressive power

of model and logical formula. In this study, we use timed automata to express models and Computation Tree Logic (CTL) for formulas. We use a model checker UPPAAL which takes timed automata as models and CTL formulas as property.

2.1.1 Timed Automata

A timed automaton is an extension of the conventional automaton with clock variables and constraints for expressing real-time dynamics. These are widely used in the modeling and analysis of real-time systems.

Definition 1 (constraints) *We use the following constraints on clocks.*

1. *C represents a finite set of clocks.*
2. *Constraints $c(C)$ over clocks C are expressed as inequalities in the following BNF (Bacchus Naur Form).*

$$E ::= x \sim a \mid x - y \sim b \mid E_1 \wedge E_2,$$

where $x, y \in C, \sim \in \{\leq, \geq, <, >, =\}$, and $a, b \in \mathbb{R}_{\geq 0}$, in which $\mathbb{R}_{\geq 0}$, is a set of all non-negative real numbers.

Time constraints are used to mark edges and nodes of the timed automata and for describing the guards and invariants.

Definition 2 (timed automaton) *A timed automaton $\mathscr{A}$ is a 6-tuple (A, L, l_0, C, T, I), where*

- *A: a finite set of actions;*
- *L: a finite set of locations;*
- *$l_0 \in L$: an initial location;*
- *C: a finite set of clocks;*
- *$T \subseteq L \times c(C) \times A \times 2^C \times L$ is a set of transitions. The second and fourth items are called a guard and clock resets, respectively; and*
- *$I : L \to c(C)$ is a mapping from location to clock constraints, called a location invariant.*

A transition $t = (l_1, g, a, r, l_2) \in T$ is denoted by $l_1 \overset{a,g,r}{\to} l_2$.

A map $v : C \to \mathbb{R}_{\geq 0}$, is called a clock assignment (or clock valuation). We define $(v + d)(x) = v(x) + d$ for $d \in \mathbb{R}_{\geq 0}$ and some $x \in C$.

For guards, resets and location invariants, we introduce some notation for clock valuations. For each guard $g \in c(C)$, a function $g(v)$ stands for the valuation of the guard expression g with the clock valuation v. For each reset r, where $r \in 2^C$, we introduce a function denoted by $r(v)$, and let $r(v) = v[x \mapsto 0], x \in r$. For each location invariant I, we shall introduce a function denoted by $I(l)(v)$, which stands for the valuation of the location invariant $I(l)$ of location l with the clock valuation v.

The dynamics of a timed automaton may be expressed via a set of states and their evaluations. Changes from one state to a new state may be as a result of either the firing of an action or an elapsed time.

Definition 3 (state of timed automaton) *For a given timed automaton $\mathscr{A} = (A, L, l_0, C, T, I)$, let $S = L \times \mathbb{R}^C_{\geq 0}$ be the complete set of states of $\mathscr{A}$, where $\mathbb{R}^C_{\geq 0}$ is a complete set of clock evaluations on C.*

The initial state of $\mathscr{A}$ can be given as $(l_0, 0^C) \in S$. For a transition $l_1 \overset{a,g,r}{\to} l_2$, the following two transitions are semantically defined. The first one is called an action transition, while the latter one is called a delay transition.

$$\frac{l_1 \overset{a,g,r}{\to} l_2, g(v), I(l_2)(r(v))}{(l_1, v) \overset{a}{\Rightarrow} (l_2, r(v))}, \qquad \frac{\forall d' \leq d \quad I(l_1)(v + d')}{(l_1, v) \overset{d}{\Rightarrow} (l_1, v + d)}$$

The semantics of a timed automaton can be interpreted as a labeled transition system.

Definition 4 (semantics of a timed automaton) *For a timed automaton $\mathscr{A} = (A, L, l_0, C, T, I)$, an infinite transition system is defined according to the semantics of $\mathscr{A}$, where the model begins with the initial state. By $\mathscr{T}(\mathscr{A}) = (S, s_0, \overset{\alpha}{\Rightarrow})$, the semantic model of $\mathscr{A}$ is denoted, where $\alpha \in A \cup \mathbb{R}_{\geq 0}$.*

Definition 5 (run of a timed automaton) *For a timed automaton $\mathscr{A}$, a run σ is finite or infinite sequence of transitions of $\mathscr{T}(\mathscr{A})$.*

$\sigma = (l_0, \nu_0) \overset{\alpha_1}{\Rightarrow} (l_1, \nu_1) \overset{\alpha_2}{\Rightarrow} (l_2, \nu_2) \overset{\alpha_3}{\Rightarrow} \cdots$

2.1.2 Computation Tree Logic

In model checking, properties are written as logical formulas. Computation Tree Logic (CTL) [5] is a temporal logic suited to dealing with such formulas. Using CTL we are able to describe properties relating to behaviors of a program for a line tracer robot.

Let AP be a set of atomic propositions. The syntax of CTL is defined as follows:

$$\begin{aligned}\varphi ::= \quad & \bot \mid \top \mid p \mid \neg\varphi \mid \varphi \vee \varphi \mid \varphi \wedge \varphi \mid \varphi \to \varphi \\ & \mid \mathtt{AX}\varphi \mid \mathtt{EX}\varphi \mid \mathtt{A}\Diamond\varphi \mid \mathtt{E}\Diamond\varphi \mid \mathtt{A}\Box\varphi \mid \mathtt{E}\Box\varphi \\ & \mid \mathtt{A}[\varphi_1 \ \mathtt{U} \ \varphi_2] \mid \mathtt{E}[\varphi_1 \ \mathtt{U} \ \varphi_2],\end{aligned}$$

where p is an atomic proposition in AP. The symbols $\bot$, $\top$, $\neg$, $\vee$, $\wedge$ and $\to$ have their usual meanings. The symbols X ("next"), $\Diamond$ ("eventually"), $\Box$ ("globally"), and U ("until") are temporal operators. The symbols A ("always") and E ("exists") are path quantifiers. Intuitively, temporal operators represent statements of a path, and path quantifiers represent statements on one or more paths which are branching forwards from a state. In a CTL formula, temporal operators are preceded by a path quantifier. Due to space limitation, we omit semantics. Please refer to Emerson [5] for details of the semantics of CTL.

For example, a safety property that "variable x is less than 10 for all paths" is written as a CTL formula $\mathtt{A}\Box(x < 10)$.

2.1.3 UPPAAL

UPPAAL [2], is a popular model checker for extended timed automata. It supports model checking for both conventional and timed automata. UPPAAL allows verification of expressions described in an extended version of CTL. Note that, a property to be verified is called a query in the field of verification of timed automaton. Given a model and a query,

UPPAAL checks whether or not the model satisfies the query. If the query does not hold, UPPAAL returns a counter example. A counter example is a run of the model, and presents sequence of locations that query does not hold. In addition, UPPAAL supports local and global integers and primitive operations on integers, such as addition, subtract and multiplication with constants. Such expressions are also allowed on the guards of transitions. System models can be created from multiple timed automata which are synchronized via a CCS (Common-Channel Signaling)-like synchronization mechanisms. An important point is that, with the exception of clocks, the extended timed automaton used in UPPAAL cannot deal with real valued variables. We, therefore, have to round real values to integer values when we model the target systems.

2.2 Results from a Previous Study

In this subsection, we briefly mention about our previous study [6], [7]. The question at the core of our research is formal verification of embedded systems as hybrid systems. For that goal, our first step is verifying time-related properties of a real embedded application using UPPAAL. We set our application to a line tracing robot constructed by LEGO Mindstorms [8] with a control program written in Java base language LeJOS [9].

We presented verification of safety properties of the program for line tracing robot in terms of design verification. In the verification, we constructed two models expressed by timed automata, one for the control program and one for the motion control depending to the course. To construct these models, it is required that behaviors have to be modeled in discrete steps except for time clock. Sampling and quantization techniques are applied for the purpose. We showed experimental results of verification and presented model checking has power to check behaviors. We considered time-delay in the verification. However, the study was in preliminary stage because we set some limitations, such as no disturbance and handling only straight lines. Even limitations were set, we think that our previous study showed applicability of model checking for verifying real embedded systems.

3 SPECIFICATION

The whole system of line tracer consists of two parts; courses and a line tracer. We describe specifications in this section.

3.1 Course

For a line tracer robot, a *course* is a black line painted on white ground. Assume that course width w is constant. In general, a real course can be expressed in combination of straights and arcs. We verified that our control program can trace a straight course in our previous study. Therefore, we consider arc courses in this study. An arc course is expressed by radius r and central angle α.

3.2 Line Tracer

A *line tracer* is a vehicle which traces a course. In this study, we fix a line tracer that consists of a body, two motors, and two color sensors. Figure 1 illustrates the relationships between constants and state variables. Table 1 summarizes state variables associated with the line tracer. Additionally, $\overrightarrow{los}$ and $\overrightarrow{ros}$ are vectors from the gravity center (x, y) to left sensor and right sensor, respectively.

Table 1: State Variables of a Line Tracer

variable	description
(x, y)	coordinate of the center
θ	direction
$lsensor$	sensed value of the left sensor
$rsensor$	sensed value of the right sensor
(x_{sl}, y_{sl})	coordinate of the left sensor
(x_{sr}, y_{sl})	coordinate of the right sensor
v_l	revolution speed of the left wheel
v_r	revolution speed of the right wheel
lw	half width of the tracer

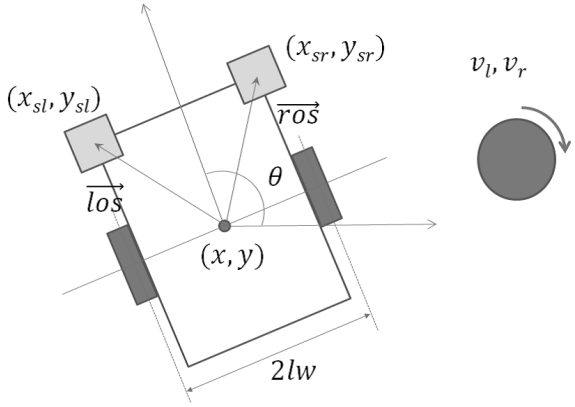

Figure 1: Constants and State Variables

A color sensor can discriminate colors. In this study, we assume that read value of the color sensor is two-valued, black and white, by setting threshold. Then the line tracer reads colors of the course using two color sensors, and determines its motion by changing left or right wheel speeds. Table 2 shows the controller logic associated with read values of two color sensors. If, for example, the left sensor and the right sensor sense white and black respectively, then the line tracer will "turn right". This is done by setting left wheel speed to high speed HS and right wheel speed to low speed LS. Note that there are delays in sensors and actuators, for example sleeping time before next sense-act loop and motor reaction.

Table 2: Logic for Color Sensors

		RightSensor	
		black	white
LeftSensor	black	go straight	turn left
	white	turn right	go straight

4 IMPLEMENTATION

LEGO Mindstorms NXT [8] is a kit for assembling robots and machines with various actuators and sensors. The default programming language for LEGO NXT is Mindstorms, but there are other languages such as NXC (Not eXactly C) [10] and LeJOS [9] which supply various classes for NXT sensors and actuators. We use LeJOS for making the control program of the tracer. This is because Mindstorms is GUI base language and does not suit for modeling. Instead, LeJOS is Java based language and is easier to construct models from a program.

Figure 2 shows our implemented controller program written in LeJOS. In this research, we use the same program used in our previous study mentioned in Sec. 2.2. Then, we try to verify that the program can trace arc courses.

5 MODEL

The line tracer system described in Sec. 3 is converted into two models; `Controller` model and `Motion` model. We introduce these models in this section,

Both `Controller` model and `Motion` model are expressed in timed automata. However, most of the state variables used in a line tracer have real values, and UPPAAL can only handle integer variables except for clock. Therefore, it is required to approximate state variables for discrete values to construct models in timed automata. We presented approximation of the state variables by applying sampling and quantization techniques in our previous study. In this study, we use the same models. Please refer papers [6], [7] for detail information of discretization techniques. Note that, we have modeled in the relative scale in this study. Therefore, units are not specified.

5.1 `Controller` Model

`Controller` model is a timed automaton which represents controller program for the line tracer. Fig. 3 shows `Controller` model which corresponds to the implementation in Sec. 4. Please refer to Table 1 which summarizes variables used in `Controller` model.

As described in Sec. 3, `Controller` decides motor speeds according to the four possible combinations of read values of the two color sensors. From the initial location represented as double circle, there are four transitions. Each of the transition corresponds to a pair of real value of sensors.

5.2 `Motion` Model

`Motion` model is a timed automaton which represents motions of the line tracer's coordinates of the gravity center and read values of color sensors. The line tracer keep on moving while the control program does not work because of delay or sleep time. Therefore, coordinates of center should be updated as independent of the `Controller` model to express behavior of the tracer. Fig. 4 shows the timed automaton which updates states variables at regular, discrete time intervals. The automaton of `Motion` model periodically calls functions updateX, updateY, updateTheta, up-

```
import lejos.nxt.*;
public class Controller {
  public static void main(String[] args)
        throws Exception {
    int rid,lid;
    final int HS = 420, LS = 120, BLACK = 7,
    MS = 360, HSEC = 500;
    Color colorR ,colorL;
    ColorSensor sensorR =
      new ColorSensor(SensorPort.S3);
      // 1(S3):right
    ColorSensor sensorL =
      new ColorSensor(SensorPort.S4);
      // 2(S4):left
    Motor motor = new Motor();
    motor.B.setSpeed(MS);
    motor.C.setSpeed(MS);
    Thread.sleep(HSEC);
      // wait for devices to be stable
    motor.B.forward();
    motor.C.forward();
    while(true) {
      rid = sensorR.getColorID();
      lid = sensorL.getColorID();
      if (lid == BLACK
         && rid != BLACK) {
        motor.C.setSpeed(LS);
        motor.B.setSpeed(HS);
      } else if (lid != BLACK
                && rid == BLACK) {
        motor.C.setSpeed(HS);
        motor.B.setSpeed(LS);
      } else if (lid == BLACK
                && rid == BLACK) {
        motor.C.setSpeed(HS);
        motor.B.setSpeed(HS);
      } else if (lid != BLACK
                && rid != BLACK) {
        motor.C.setSpeed(HS);
        motor.B.setSpeed(HS);
      }
      if (Button.readButtons()
          == Button.ENTER.getId())
        break;
    }
  }
}
```

Figure 2: Controller Program in LeJOS

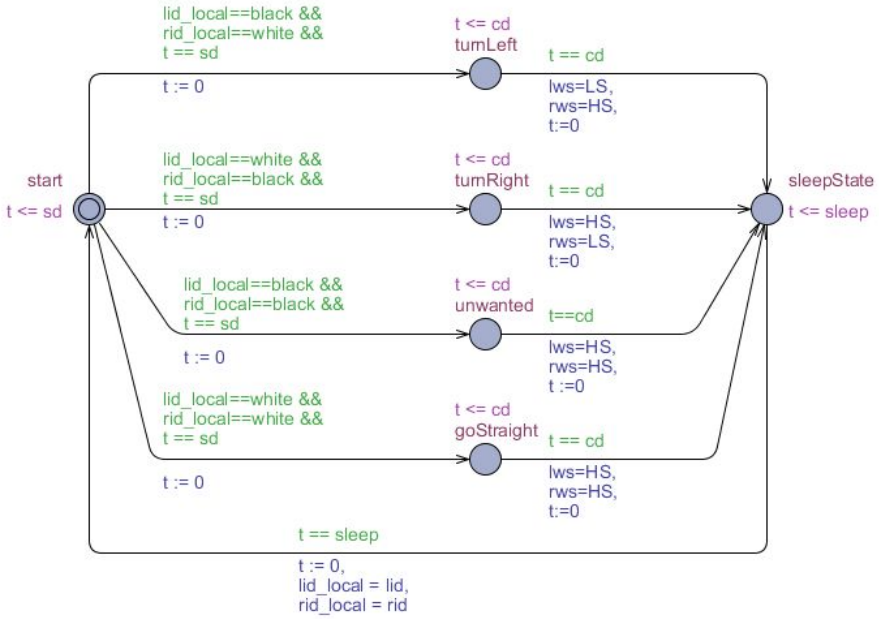

Figure 3: `Controller` Model

dateLSensor, and updateRSensor which update state variables x, y, θ, lid and rid, respectively. Note that, lid and rid are two-valued variables associated with read values of the sensors.

Read values of sensors depend on the coordinates of gravity center, the angle of the line tracer, and the course. Gravity center and angle are expressed by integer variables in this model. It is also required discretely handling of the course. There will be two methods for handling. First one is quantization, mapping the continuous course to discrete values. Second one is equation representation, the course is expressed in a formula. In this study, we adopt the second method. Let (s_x, s_y) be the coordinates of left or right sensor. Then, the read value of the sensor is decided to be black if (s_x, s_y) satisfies the following formula. Otherwise, the read value is decided to be white.

$$\left(r - \frac{w}{2}\right)^2 \leq s_x^2 + s_y^2 \wedge s_x^2 + s_y^2 \leq \left(r + \frac{w}{2}\right)^2$$

where r is radius of a circle course, and w is line width.

6 EXPERIMENTAL RESULTS

described in Sec. 5. In this section, we verify correctness of the control program. Verifications were performed using UPPAAL 4.0.13 running on Windows 7 (64 bit), Intel Core i5-2400, 3.10GHz, with 8GB memory.

6.1 Verification of Specification

A line tracer is expected to trace a course. First, we verify whether or not the controller program satisfies the property. Therefore, what we need to verify is, i) the tracer runs along the course within a certain range, and ii) the tracer keeps on taking its route, i.e., does not get stuck.

To verify these requirements, we need to fix some initial values. Let initial values be as follows.

- coordinates of gravity center $(x, y) = (r, 0)$
- direction of the tracer $\theta = 90°$
- width of the course $w = 100$

In addition, we set the following values associated with the tracer.

- half width of the tracer $lw = 60$
- distance between center and a sensor $ds = |\overrightarrow{los}| = |\overrightarrow{ros}| = 180$
  The angle between $\overrightarrow{los}$ and $\overrightarrow{ros}$ is 60 degrees.
- high / low wheel speeds $HS = 12, LS = 6$
- sensing interval is 1, and sensing delay is 1

Note that, sensing interval and sensing delay are modeled as an unit time of UPPAAL. It should be also noted that the parameters used in verification are not the same as those used in implementation.

We then check the correctness of the line tracer by verifying the following queries.

1. $\mathtt{A}\Box$ (*firstquadrant* $\rightarrow$ *inrange*)
   where *firstquadrant* is $x \geq 0 \wedge y \geq 0$, *inrange* is $\left(r - \frac{w}{2} - ds\right)^2 \leq x^2 + y^2 \wedge x^2 + y^2 \leq \left(r + \frac{w}{2} + ds\right)^2$, and ds is a distance between center and a sensor, *i.e.,* $ds = |\overrightarrow{ros}| = |\overrightarrow{los}|$.

2. $\mathtt{E}\Diamond\, (x < 0 \wedge y > 0)$

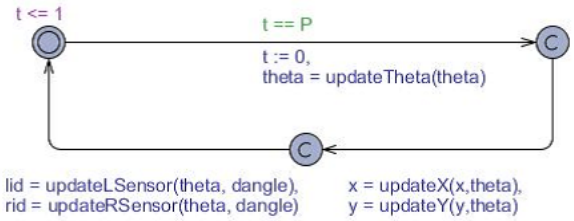

Figure 4: `Motion` Model

Query 1 represents that the gravity center of the tracer is always located within a certain range, $w/2 + ds$, from the line in the first quadrant. Note that we consider the gravity center (x, y) in this query, therefore ds is added to the allowable distance from the course. Here, target domain is limited to the first quadrant, because if the whole area is set to be a target, state explosion problem occurs. In addition, even if the target area is restricted, query 1 can not be verified because of the state explosion problem.

To solve these problems, we slightly modified `Motion` model. We added a new location named `STOP` to `Motion` model. If the gravity center goes outside the first quadrant, then transit to the location `STOP`. This modification works on verification of query 1. Instead, we also have to modify query 1 considering the new location `STOP`. New query $1'$ is as follows.

$$1'. \quad \mathtt{A}\Box\,(\textit{firstquadrant} \rightarrow \textit{inrange} \ \vee \mathtt{M.STOP})$$

where `M` is the variable name for `Motion` model in UPPAAL and `M.STOP` represents the location `STOP` in `Motion` model.

It is easily understand that the verification result for query $1'$ depends on the radius of the arc course. We verified query $1'$ by changing radius r. As a result, query $1'$ holds if $r \geq 277$ and does not hold if $r \leq 266$.

Query 2 is reachability checking that the line tracer eventually reaches to the second quadrant. This query is necessary to check behavior of the tracer, because query 1 only describe the distance from the course and does not describe movement. It makes no sense to check query 2 if query $1'$ does not hold. According to the above-mentioned results for query $1'$, we verified query 2 for $r \geq 277$. Then, we obtain verification results that query 2 holds for $r \geq 277$.

Ideally, conjunction of the two queries should be verified at once. Unfortunately, UPPAAL does not allow nesting of path quantifiers in a formula. Therefore we verified the queries one by one. However, when we consider both two queries together, it is possible to judge whether or not the tracer satisfies the specification. Note that, we verified dependency of radius by hand, but it is possible to be automated by generating UPPAAL model.

6.2 Analysis of Turning Angle

It is easily understand that verification results of query $1'$ depend on wheel speeds of the tracer. For example, if the tracer moves slowly, it will be able to keep on tracing longer. However, verification results of query $1'$ and query 2 do not describe distance from the initial position.

We calculate turning angle of the tracer by analyzing counter examples of query $1'$ for various wheel speeds. For that purpose, high wheel speed HS and low wheel speed LS are changed into $HS' = C_{ms}HS$ and $LS' = C_{ms}LS$ where C_{ms} is a coefficient. Then, we verify query $1'$ for some C_{ms}. When the query does not hold, we obtain a counter example which consists of a sequence of locations in evidence. UPPAAL has a function to generate the shortest trace as a counter example. By analyzing the counter example, it is possible to calculate the coordinate where the tracer turns off from the course. As an example, let radius r be fixed to 250. This is because that we know the tracer is not able to keeps on track in the first quadrant from the verification results in Sec. 6.1. Then, we think about intersection of the course and orbit of the tracer. Let the intersection be P, coordinates of before turning off be Q, and coordinates of after turning off be Q'. Then, P is an intersection of circle $x^2 + y^2 = (r \pm (w/2 + ds))^2$ and a line passing through Q and Q'.

Table 3 shows C_{ms}, Q, Q', P and α, where α (deg) is angle between x-axis and line passing through the origin and point P, obtained from the shortest counter examples. Note that there are no results for $C_{ms} = 1/2$ in Table 3, because query $1'$ holds. It is not surprisingly that verification results depend on wheel speeds. Query $1'$ holds for $C_{ms} = 1/2$ should be reasonable because this setting means slower move that arrows the tracer keeping on track. Fig. 5 shows a result of the orbit of the tracer obtained from the counter example, intersection P, and turning angle α for $C_{ms} = 2/3$ and $r = 250$. From the results except for $C_{ms} = 1/2$, central angle α is roughly constant. This result can be interpreted that angle α is the minimum turning radius for $r = 250$. This results seems natural, however, it indicates that model checking can be applied to analyze properties relating to turning angles.

7 DISCUSSION

In this section, we discuss our experiments and future work.

7.1 Discussion on the Experiments

We briefly return to our basic focus on our research question. We are motivated to know applicability of formal ver-

Table 3: Speed Dependency and Turning Angle ($r = 250$)

C_{ms}	Q	Q'	P	α (deg)
1/2	—	—	—	90 <
2/3	(214, 428)	(213, 435)	(213.7, 429.8)	63.6
1	(262, 394)	(262, 405)	(262.0, 402.2)	56.9
2	(310, 360)	(314, 384)	(310.9, 365.7)	68.5
3	(310, 336)	(213, 396)	(310.9, 365.7)	68.5
4	(306, 306)	(213, 384)	(310.9, 365.7)	68.5

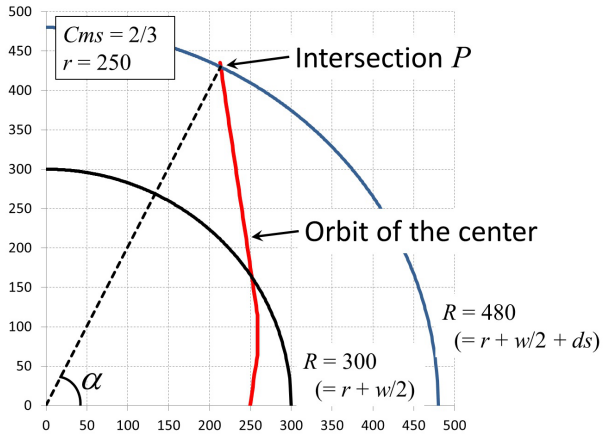

Figure 5: Orbit of the Tracer, Intersection, and Turning Angle

ification to real embedded systems, especially control continuous systems. Continuous systems are essentially hybrid systems, but we set our first target to verifying time-related properties. We also set another research question that we want to know applicability of verification techniques from the view point of design verification.

In this study, we divided the circle course into an arc course, the first quadrant, because of the state explosion problem. Here, we consider possibility of verification for tracing the entire route of the circle. To tackle this problem, straightforward modeling seems unpromising according to the verification results in Sec. 6. To reduce the size of state space, one possibility is applying abstraction techniques such as data mapping and predicate abstraction. Another possibility will be combination of theorem proving and model checking.

Experimental results combined with our previous study, behavior of a line tracer is verified based on specification and a control program. We think our verification results indicate usefulness of model checking. However, there are still problems remained to verify real embedded system. One problem is scalability. Through our studies, parameters used in verification are not the same as those used in implementation and differ from LEGO Mindstorms kit in size. However, we believe that our parameter settings are acceptable to show applicability of model checking. The reason why we adjust parameters is the state explosion problem. If we set parameters as the same as real used values, the size of state space becomes too large, and model checker cannot respond in a reasonable time or it exhausts its available memory. This problem is widely known in the field of model checking.

Another problem is that we are not yet consider effects of errors and distributions. When we think of real embedded system, behaviors of the systems are disordered by disturbances or errors. It is natural that disturbances and error probabilistically occur. However, timed automaton is not suited for probabilistic event. Here, we give a little more thought to the tracer constructed by LEGO Mindstorms as a real embedded system. It is reported in [11] that motor speed of LEGO Mindstorms kit is approximately proportional to the parameter, but has error. Through this study, we have tried to handle errors associated with wheel speeds. We assumed that wheel speed includes a certain amount of error. If such error exists, errors are cumulated and make an impact on the position of the tracer. We confirmed that such errors affect to the result of verification. Unfortunately, we have not yet obtained systematic results.

7.2 Related Work

In this section, we briefly describe related work on formal verifications associated with control engineering.

One of similar researches is verification of real-time control program using UPPAAL [12]. In this paper, the authors constructed a brick sorter system using LEGO RCX and wrote control programs in Not Quite C (NQC). The paper presents verification of safety and liveness properties by automatic translation from the control program into UPPAAL models. Through the research, abstraction and reduction techniques are applied to construct discrete models from continuous systems. This approach is similar to ours, however, the brick sorter system is essentially a discrete system even though it contains time dependencies.

As with many control systems, a line tracer can be considered as a hybrid system by describing their movements using differential equations and their control programs in discrete time. It is generally accepted that real embedded systems are too big to fully verify. Therefore, it is usual to focus on important behaviors. As an example of hybrid approaches, paper [13] described the verification of the behaviors of a line tracer by constructing a model using hybrid I/O automata and correctness proofs. In that paper, the authors presented verification of safety property, that is, a line tracer should move along a straight line and never run off. However, the authors noted that some time details, such as time delay between two motors, were not considered

In verification of robotics, a survey of model checking of the control system of NASA robotics systems is reported [14]. In this survey, the authors summarize various techniques for verification and show verification of a robot control system. Safety and liveness properties are verified, but these properties were not related to continuous dynamics. Even though the survey does not cover the handling of continuous dynamics, it is a good resource. As a similar area, the verification of a real vehicle is presented [15]. Even though our aim is the verification of continuous systems, our approach in reflects those above, *i.e.*, conversion to timed automata using quantization and sampling.

8 CONCLUSION

In our previous study, we have verified that a line tracer runs along a straight line. In this research, we used the same control program for the tracer and showed the same models can keep track on arc courses. These are verified using UPPAAL with timed automata and logical formulas. We also presented that if the tracer cannot run from the first quadrant to the second quadrant, it is possible to calculate turning angle by analyzing counter examples.

We hope to extend this study to the analysis of more real embedded systems including disturbances and errors. To that purpose, expressive power of timed automaton is not sufficient as described in Sec. 7. We plan to express models in probabilistic timed automata (PTAs). We also intend to use the latest version of probabilistic model checker PRISM [16] which supports PTAs.

Another direction of future work includes a PID controller (proportional-integral-derivative controller), which is a widely used feedback control system. We used simple specification to control the line tracer, but PID control is widely used in control systems and control engineering. When PID control is applied to a line tracer, it enables smooth motion. However, PID control is essentially hybrid system, which continuous and discrete dynamics are mixed with time progression. Several approaches have been proposed to handle hybrid systems. One of these approach is hybrid automata [17] which is a formal model for describing discrete-continuous systems.

REFERENCES

[1] R. Alur, and D.L. Dill, "A theory of timed automata," Theoretical Computer Science, Vol.126, No.2, pp.183–235 (1994).

[2] J. Bengtsson, and W. Yi, "Timed Automata: Semantics, Algorithms and Tools," in Lectures on Concurrency and Petri Nets, Advances in Petri Nets (4th ACPN'03), Vol.3098 of Lecture Notes in Computer Science (LNCS), pp.87–124 (2004).

[3] A. Schild, and J. Lunze, Control design by means of embedded maps, in Handbook of Hybrid Systems Control, eds. J. Lunze, and F. Lamnabhi-Lagarrigue, chapter 6.5, pp.231-247, Cambridge University Press (2009).

[4] E.M. Clarke, O. Grumberg, and D. Peled, Model Checking, MIT Press (1999).

[5] E.A. Emerson, "Temporal and Modal Logic", Handbook of Theoretical Computer Science, Vol.B, chapter 16, pp.995–1072, Elsevier (1990).

[6] K. Okano, T. Sekizawa, H. Shimba, H. Kawai, K. Hanada, Y. Sasaki, and S. Kusumoto, "Verification of Safety Property of Line Tracer Program using Timed Automaton Model," International Workshop on Informatics (IWIN2012), pp.136–142 (2012).

[7] K. Okano, T. Sekizawa, H. Shimba, H. Kawai, K. Hanada, Y. Sasaki, and S. Kusumoto, "Verification of Safety Properties of a Program for Line Tracing Robot using a Timed Automaton Model," Special Issue of the International Journal of Informatics Society (IJIS), Vol.5, No.3, pp.147–155 (2014).

[8] LEGO Mindstorms NXT official website, `http://www.legoeducation.jp/mindstorms/`.

[9] LeJOS Java for LEGO Mindstorms, `http://lejos.sourceforge.net`.

[10] NXC Tutorial, `http://bricxcc.sourceforge.net/nbc/nxcdoc/NXCtutorial.pdf`.

[11] K. Yamabe, "Measurement of Performance Characteristic of LEGO NXT using LeJOS," (2011), (undergraduate thesis in Osaka Gakuin University, written in Japanese).

[12] T.K. Iversen, K.J. Kristoffersen, K.G. Larsen, M. Laursen, R.G. Madsen, S.K. Mortensen, P. Pettersson, and C.B. Thomasen, "Model-Checking Real-Time Control Programs - Verifying LEGO MINDSTORMS Systems Using UPPAAL," In Proc. of 12th Euromicro Conference on Real-Time Systems, pp.147–155 (2000).

[13] A. Fehnker, F.W. Vaandrager, and M. Zhang, "Modeling and Verifying a Lego Car Using Hybrid I/O Automata," Models, Algebras, and Logic of Engineering Software, Vol.191, pp.385–402 (2003).

[14] N. Sharygina, J. Browne, F. Xie, and V. Levin, "Lessons learned from model checking a NASA robot controller," Formal Methods in Systems Design Journal, pp. 241–270 (2004).

[15] M. Proetzsch, K. Berns, T. Schuele, and K. Schneider, "Formal Verification of Safety Behaviours of the Outdoor Robot RAVON," Fourth International Conference on Informatics in Control, Automation and Robotics (ICINCO), pp. 157–164 (2007).

[16] M. Kwiatkowska, G. Norman, and D. Parker, "PRISM 4.0: Verification of Probabilistic Real-time Systems," Proc. 23rd International Conference on Computer Aided Verification (CAV'11), eds. G. Gopalakrishnan, and S. Qadeer, Vol.6806, pp.585–591 (2011).

[17] T.A. Henzinger, "The Theory of Hybrid Automata," In Proceedings of the 11th Annual Symposium on Logic in Computer Science, pp.278–292 (1996).

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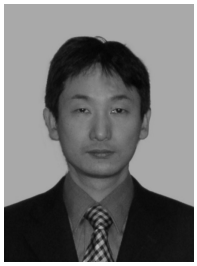

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A Proposal of P2P Content Delivery System for Supporting Streaming Applications

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Abstract - Streaming large files such as video and audio contents from the internet has become an increasingly common practice with users and content providers. Content delivery presents serious challenge for content providers, with the increased cost of hosting and transmitting large video files, the existing client server system is experiencing problems. The high server load incurred by the client model is costing hosts considerable resources. Peer to Peer (P2P) technology alleviates some of these problems by distributing transfer work among multiple hosts (peers). P2P works by sending and receiving data directly with other peers that are participating in the network. It distributes resources and load across the network. This can solve the problem of the client server system resource overload. The purpose of this research is to propose a method which is suitable for streaming using P2P and solve the problem of client server system's resource overload. We aim to realize stable video streaming, low latency playback, and reduction of the number of breaks due to buffering protocol.

Keywords: Content delivery, Streaming, Peer to Peer network, BitTorrent, BiToS.

1 INTRODUCTION

[1]The video and audio content delivery service using the internet, such as YouTube [1] and NicoNico Douga [2], has become an increasingly common practice, and it is capturing the attention from broad directions, such as political use and commercial use, etc. Moreover, by the development of broadband service and improvement of terminal performance of individual use, it is expected that the video and audio content as a medium for disseminating information continues to grow. In the prediction and investigation of Cisco [3], it is expected that two-thirds of the world's mobile data traffic will be video by 2017. Mobile video will increase 16-fold between 2012 and 2017, accounting for over 66 percent of total mobile data traffic by the end of 2017. As streaming large files such as video and audio content from the internet has become an increasingly common practice with users and content providers, the content delivery presents serious challenge for content providers, with the increased cost of hosting and transmitting large video files, the existing client server system is experiencing problems. The high server load incurred by the server-client model is costing hosts considerable resources.

Peer to Peer (P2P) technology alleviates some of these problems by distributing transfer work among multiple hosts (peers). BitTorrent [4] is one of the most popular P2P protocols. File transfer operates by splitting the file into many pieces. Peers transfer the pieces out of order in a distributed fashion then re-assemble the original file. The order of the pieces transferred is determined by the RarestFirst algorithm [5, 6]. However, it is bad for streaming because pieces are transferred out of order and it is hard to predict the next piece. BiToS (BitTorrent Streaming) [7] was proposed to solve the streaming P2P problems of BitTorrent. This allowed somewhat smoother playback, but there were still delays or pauses (breaks). And some new methods to shorten breaks' time and reduce the number of times of breaks are called for.

We propose a method which is suitable for streaming using P2P. The emphasis must be placed on reduction of the number of breaks in playback. To this end, we must do something different if there is a gap in download pieces between current playback position and the next available piece. Improved peer and piece selection methods, such as special priority for pieces near playback position may hopefully alleviate the problems with BiToS and RarestFirst algorithm. Specifically, if the piece closest to the playback position is not yet downloaded then the proposed method will set an emergency priority. Within the high priority group we must request missing pieces from the peer with the fastest connection. In order to verify the proposed method's effectiveness when compared to the established methods of RarestFirst and BiToS, we performed simulations and experiments.

The rest of this paper is organized as follows: In section 2, we describe detailed algorithm of BitTorrent and BiToS. In section 3, we present our proposed solution for better peer and piece selection. In section 4, details of the implementation on software simulator is described. In section 5, we report experimental evaluation of our proposed method. Finally, the paper is concluded in section 6.

2 BITTORRENT AND BITOS

BitTorrent is one of the most popular P2P protocols. Holding, sending, and receiving of all content are performed by only the peers. The tracker manages information about peers in a swarm; it coordinates initial connections and

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keeps a table of connected hosts and the download/upload statistics of each peer (Fig.1).

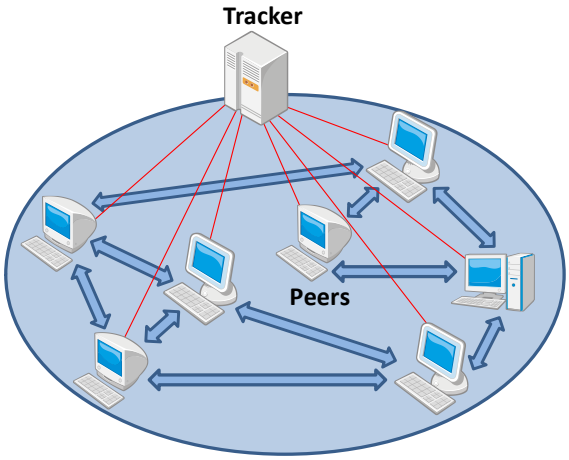


Figure 1: Network configuration of BitTorrent.

As shown in Fig.2, BitTorrent uses swarming techniques in which the torrent file (the content that is distributed), is split in pieces. A user who wants to upload a file first acts as a seed and distributes content information through BitTorrent nodes. Peers (leecher) can simultaneously download pieces from other peers. While the peer is downloading pieces of the file, it uploads the pieces that it has already acquired to its peers. Each time the peer has a new piece, it advertises this information to its peer set (the peers that the peer is connect to).

Peers transfer the pieces out of order in a distributed fashion then re-assemble the original file. This distributed method is suitable for large-capacity content delivery.

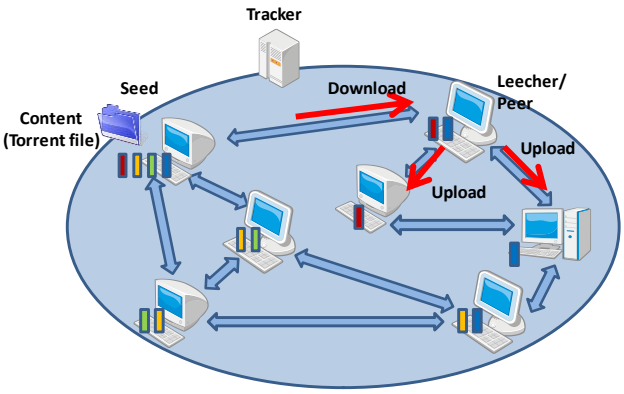


Figure 2: File transfer operates by splitting the file into many pieces

The order of the pieces transferred is determined by the RarestFirst algorithm. This algorithm tells peers to send the least common pieces amongst the swarm first, causing convergence faster. RarestFirst transfer makes P2P very efficient when compared to the random out of order method. However, it is bad for streaming because pieces are transferred out of order and it is hard to predict the next piece. Streaming requires in-order transfer for smooth playback. The method proposed in this paper aims to provide more predictable transfer to allow for smooth playback.

BiToS was a previous attempt to solve the streaming P2P problems (Fig.3). It was a research to reduce the number of breaks when streaming using BitTorrent. The BiToS method changed from RarestFirst so that pieces near deadline mark have higher priority than later pieces. This allowed somewhat smoother playback, but there were still pauses. BiToS method works by assigning a priority to two groups of pieces. If the probability of selecting a piece from the high priority group is "*p*" then low priority group probability is "*1-p*". The parameter "*p*" represents the balance between the immediate need for a piece and the future need. Within each priority group we simply use RarestFirst method.

Currently downloading pieces in high priority group and low priority group are moved to the group of received pieces after they are downloaded. If a piece cannot meet its playback deadline, then it will not be asked to be downloaded (or its download can be aborted) and will be marked Missed. A peer at any given time can have at maximum a fixed number of currently downloading pieces. The number of pieces (cardinality) of the higher priority group remains fixed. Using BiToS, we receive pieces closer to the playback position sooner. This is more suitable for content delivery than pure RarestFirst method.

However within each group the RarestFirst method is still used, so there may be breaks if the priority group has not rare pieces close to the playback position. This means pieces are still sent out of order within each priority group. This causes gaps in playback when the playback position reaches a missed piece.

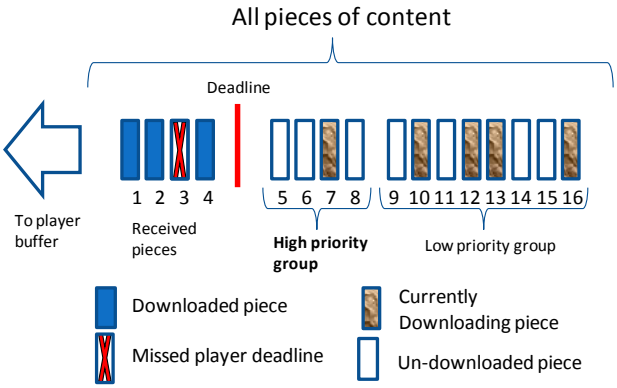


Figure 3: Outline of BiToS piece selection method.

3 PROPOSED SOLUTION

To propose a method which is suitable for streaming using P2P, emphasis must be placed on the reduction of the number of breaks in playback. To this end, we must do something different if there is a gap in download pieces between our deadline position and the next available piece. Here, the deadline is the time limit after that, the received piece is not useful and will be discarded.

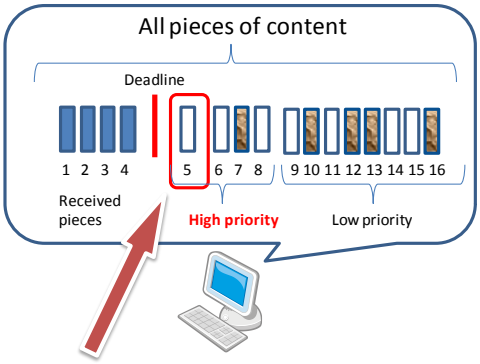


Figure 4: Introduction of emergency priority.

Improved peer and piece selection methods, such as special priority for pieces near deadline position may hopefully alleviate the problems with BiToS and RarestFirst. Specifically, if the piece closest to the deadline position is not yet downloaded then the proposed method will set an emergency priority (Fig. 4). Within the high priority group we must request emergent pieces from the peer with the fastest connection (Fig. 5).

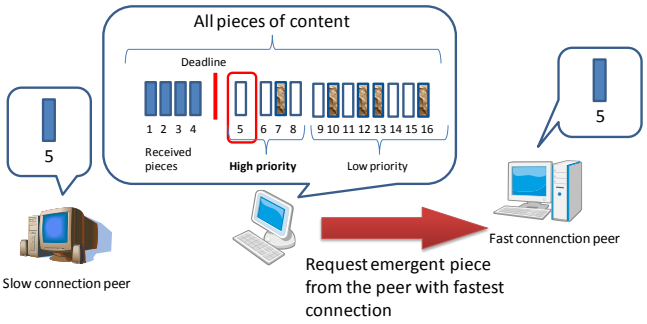


Figure 5: Request emergent pieces from the peer with the fastest connection.

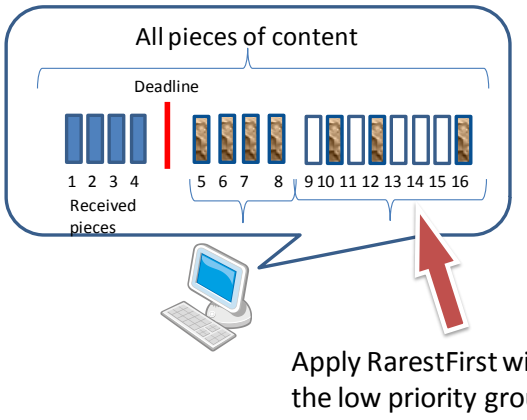


Figure 6: Enough buffered content then download pieces from a lower priority group.

If there is enough buffered content then the new method may download pieces from a lower priority group using simple RarestFirst (Fig. 6). Thus it is still possible to contribute to the distribution of rare pieces on low priority groups and improve convergence speed.

The proposed method solves the problem of BiToS where pieces close to playback position are not always chosen. This leads to a more stable delivery and smooth playback.

4 IMPLEMENTATION ON A SOFTWARE SIMULATOR

In order to verify the proposed method's effectiveness when compared to the established methods of RarestFirst and BiToS, it is necessary to perform simulations and experiments. One such proposed experiment is to provide a peer that implements each method on a software simulator. We used General Purpose Simulator for P2P network (GPS) [8] which is capable of simulating BitTorrent algorithm.

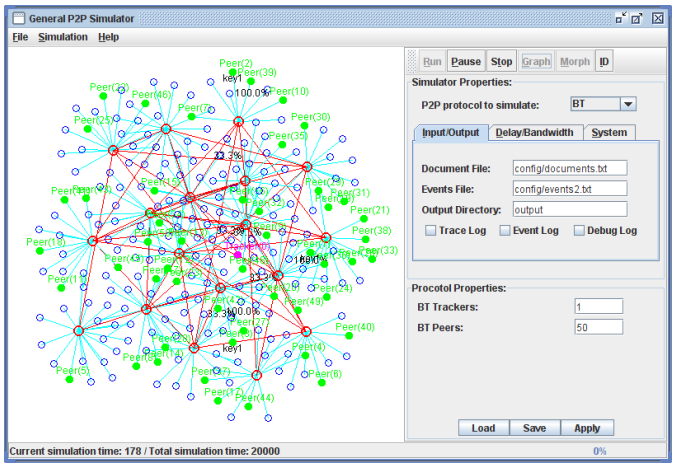


Figure 7: Display image of the simulation by General Purpose Simulator for P2P network.

As for the software structure of GPS, various search protocols such as Chord [9], CAN [10], etc. are located on top of the physical network layer at the bottom of the structure. The layer of P2P algorithms come on the search layer. Some Hybrid P2P algorithms including BitTorrent exist in the same layer as the search layer, because they don't use provided general search protocols like Chord etc. but they mostly implement original search protocols using the server systems.

The methods of previous works and our proposed method are implemented on top of the P2P algorithms layer, and they can be switched according to the experimental situation. However, it is not possible to make peers who adopt different methods on the same network at present.

Moreover, in the operation of the various methods, since it is necessary to acquire the information of the playback position, and to measure the number of times of breaks and duration and frequency of breaks, which is the evaluation indices, we added virtual video player part on top of the P2P algorithm layer.

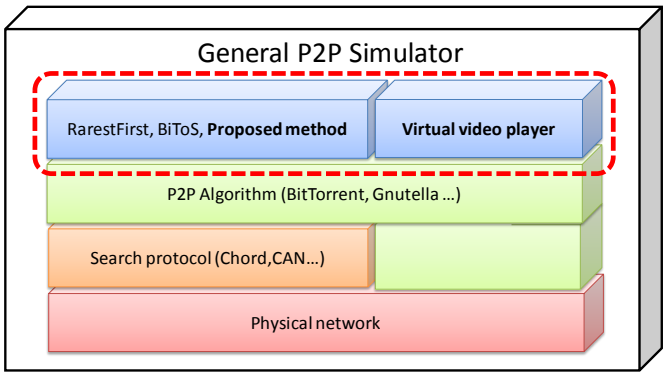


Figure 8: Software structure of GPS.

5 EXPERIMENTS

The peer and piece selection method proposed by this research, RarestFirst and BiTos are compared by measuring evaluation indices such as the number of breaks and the total duration of breaks under various video download conditions.

5.1 Outline of the Experiment

First, the peer who had all the pieces (original content) is generated on the simulator. Then a peer who does not have any piece participates one at a time to the network with certain interval and starts content downloading. Playback is started when the head piece of the content is downloaded at the peer. All the peers continue remaining in the network until the last peer completes the download. All the peers who participated to the network complete the download of whole content and finish the playback then the simulation stops.

The transmission speed of peers are classified into two types such as high speed and low speed, and randomly assigned to each peer. In the communication between low-speed peers, bandwidth is set to 5Mbps, between a high-speed peer and a low-speed peer 10Mbps, and between high-speed peers 15Mbps.

Simulations are iterated 10 times for each method respectively, and the results are compared on the average basis.

5.2 Contents and Parameters used for the Simulation

The details of parameters used for the simulation are shown in Table 1. The content sizes are two kinds, 128 MB and 256 MB.

The size per one piece, in consideration of the size length used widely when dividing a file by BitTorrent, is set as 1 MB. Even if the content size is the same, the playback time differs according to the content quality, high and low image quality. We experiment two cases of playback time, i.e., 0.5 seconds and 4 seconds per one piece, supposing two content qualities.

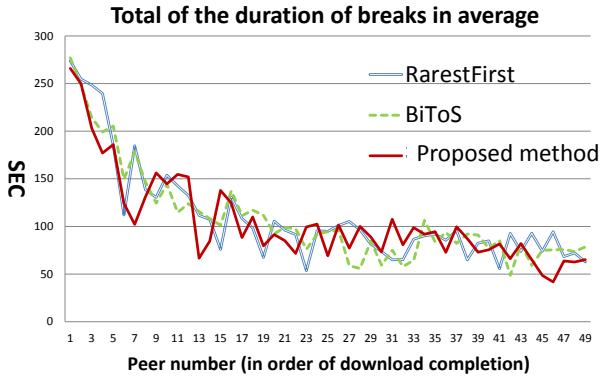
Table 1: Details of the contents and parameters used for the simulation

Content size (Mbyte)	128MB		256MB	
Size of a piece (Mbyte)	1MB			
Playback time per a piece (sec)	4	0.5	4	0.5
Number of peers	50			
Participating interval of new peers (sec)	60			
Ratio of the high priority group (%)	5			
Probability of selecting a piece from high priority group (%)	90			

5.3 Experimental Results and Evaluation

5.3.1 Content Size 128MB , 4 Seconds of Playback Time per One Piece

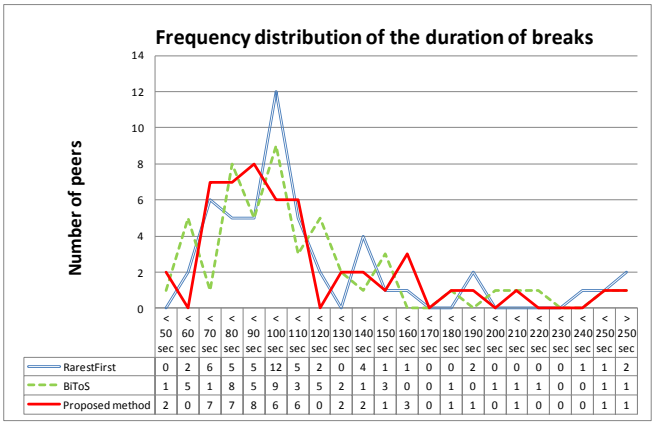
The experimental result in case of content size is 128 MB and the playback time per one piece is 4 seconds is shown here. Fig.9 is a graph of the total of the duration of breaks in average at each peer and total average of all peers during the playback by each method. The total duration of breaks at the peer which completed download earlier is large and decreases as the number of peers increases for all methods. This is because when few peers are in the network, the number of downloadable peers is small, but it increases as more peers participate to the network and the feature of P2P algorithm that a download speed rises using a communication line effectively as the number of peers increase is shown here. From the graph, significant difference is not seen as a whole by each method, but when the total average of all peers was taken for each method, it turned out that the total of the duration of breaks in average is the shortest in our proposed method (105.2) than RarestFirst (110.0) or BiToS (108.3).



Total average (seconds)		
RarestFirst	BiToS	Proposed method
110.0	108.3	105.2

Figure 9: Total of the duration of breaks in average at each peer and total average of all peers (Content size 128MB, 4 seconds of playback time per one piece).

Figure 10 shows the frequency distribution of the duration of breaks at each peer for each method. In our proposed method, many peers have shorter duration of breaks compared to other methods. For example, as shown in Table 2, 24 peers have duration of brakes less than 90 seconds in our method compared to 18 in RarestFirst and 20 in BiToS. Therefore it could be assumed that many peers have achieved shorter download time of the content as a whole.



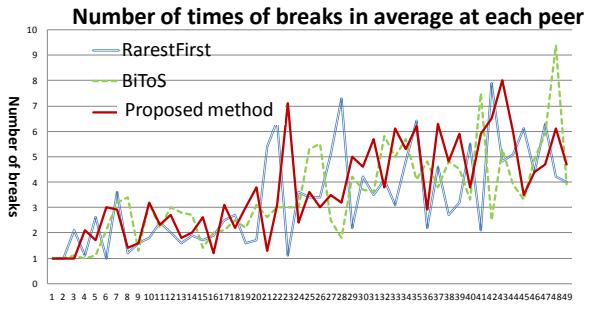
	< 50 sec	< 60 sec	< 70 sec	< 80 sec	< 90 sec	< 100 sec	< 110 sec	< 120 sec	< 130 sec	< 140 sec	< 150 sec	< 160 sec	< 170 sec	< 180 sec	< 190 sec	< 200 sec	< 210 sec	< 220 sec	< 230 sec	< 240 sec	< 250 sec	> 250 sec
RarestFirst	0	2	6	5	5	12	5	2	0	4	1	1	0	0	2	0	0	0	0	1	1	2
BiToS	1	5	1	8	5	9	3	5	2	1	3	0	0	1	0	1	1	1	0	0	1	1
Proposed method	2	0	7	7	8	6	6	0	2	2	1	3	0	1	1	0	1	0	0	0	1	1

Figure 10: Frequency distribution of the duration of breaks at each peer in average (Content size 128MB, 4 seconds of playback time per one piece).

Table 2: Accumulated number of peers of duration of brakes less than 90 and 110

	RarestFirst	BiToS	Proposed method
<90 sec	18	20	24
<110 sec	35	32	36

On the other hand, about the number of times of breaks, as shown in Fig.11 of number of times of breaks in average at each peer and total average, no method is stable and no significant difference is seen in average here.

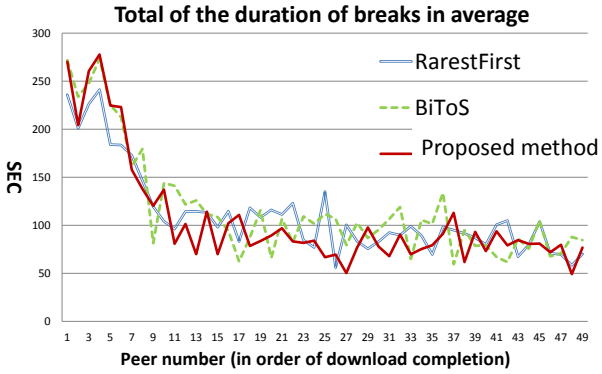


Total average (Times)		
RarestFirst	BiToS	Proposed method
3.3	3.4	3.7

Figure 11: Number of times of breaks in average at each peer and total average (Content size 128MB, 4 seconds of playback time per one piece).

5.3.2 Content Size 128MB , 0.5 Seconds of Playback Time per One Piece

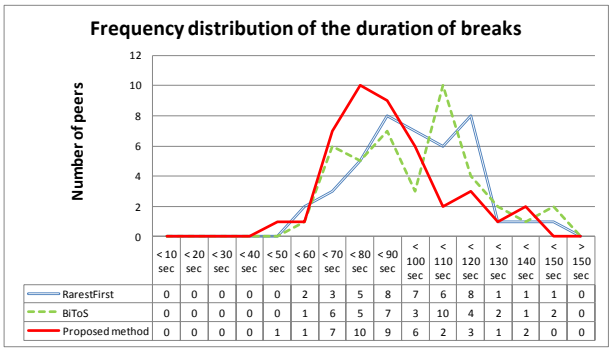
The experimental result in case of content size is 128 MB and the playback time per one piece is 0.5 seconds is shown here. Form the graph of Fig.12, the total duration of breaks in average at each peer and total average of all peers during the playback shows similar trend as the case of 4 seconds of playback time per one piece, and it turned out that the total of the duration of breaks is the shortest in average in our proposed method (106.3) than RarestFirst (110.9) or BiToS (116.2).



Total average of all peers (seconds)		
RarestFirst	BiToS	Proposed method
110.9	116.2	106.3

Figure 12: Total of the duration of breaks in average at each peer and total average of all peers (Content size 128MB, 0.5 seconds of playback time per one piece).

Fig.13 shows the frequency distribution of the duration of breaks at each peer for each method. In our proposed method, many peers have shorter duration of breaks compared to other methods. For example, 34 peers have duration of brakes less than 100 seconds in our method compared to 25 in RarestFirst and 22 in BiToS.

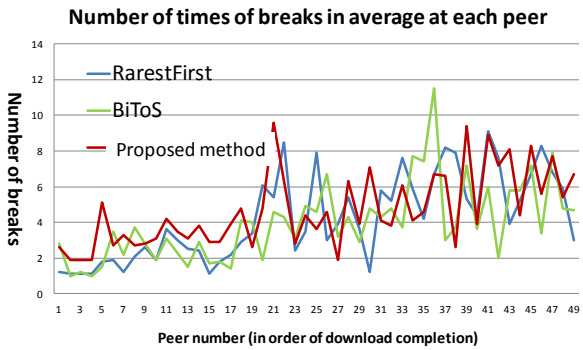


	< 10 sec	< 20 sec	< 30 sec	< 40 sec	< 50 sec	< 60 sec	< 70 sec	< 80 sec	< 90 sec	< 100 sec	< 110 sec	< 120 sec	< 130 sec	< 140 sec	< 150 sec	> 150 sec
RarestFirst	0	0	0	0	0	2	3	5	8	7	6	8	1	1	1	0
BiToS	0	0	0	0	0	1	6	5	7	3	10	4	2	1	2	0
Proposed method	0	0	0	0	1	1	7	10	9	6	2	3	1	2	0	0

Figure 13: Frequency distribution of the duration of breaks at each peer in average (Content size 128MB, 0.5 seconds of playback time per one piece).

On the other hand, about the number of times of breaks, , as shown in Fig.14 of number of times of breaks in average

at each peer and total average, no big difference is seen among methods just like the case of 4 seconds of playback time per one piece.

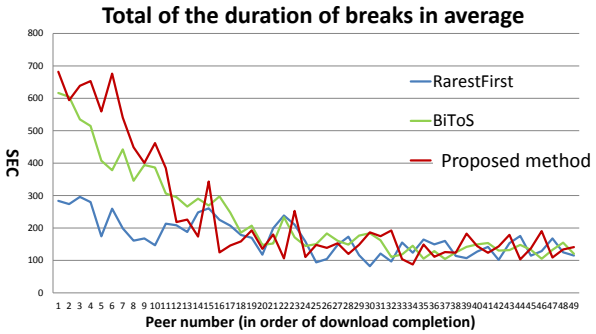


Total average (Times)		
RarestFirst	BiToS	Proposed method
4.2	4.0	4.7

Figure 14: Number of times of breaks in average at each peer and total average (Content size 128MB, 0.5 seconds of playback time per one piece).

5.3.3 Content size 256MB, 4 seconds of playback time per one piece

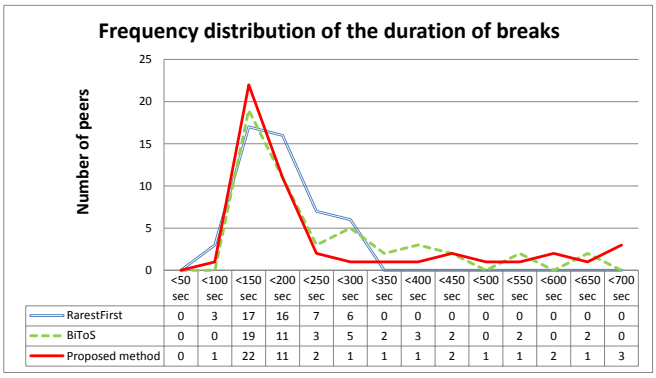
The experimental result in case of content size is 256 MB and the playback time per one piece is 4 seconds is discussed here. The proposed method has shown poor performance here and the total duration of breaks in average at each peer is the largest (Proposed metod:244.0, RarestFirst:169.8, BiToS:231.5) as shown in Fig.15.



Total average of all peers (seconds)		
RarestFirst	BiToS	Proposed method
169.8	231.5	244.0

Figure 15: Total of the duration of breaks in average at each peer and total average of all peers (Content size 256MB, 4 seconds of playback time per one piece).

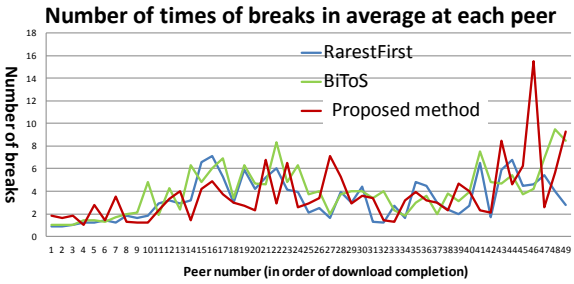
Figure 16 shows the frequency distribution of the duration of breaks at each peer for each method. For example, the number of peers of less than 150 seconds of duration of breaks is 23 in our method compared to 20 in RarestFirst and 19 in BiToS.



	<50 sec	<100 sec	<150 sec	<200 sec	<250 sec	<300 sec	<350 sec	<400 sec	<450 sec	<500 sec	<550 sec	<600 sec	<650 sec	<700 sec
RarestFirst	0	3	17	16	7	6	0	0	0	0	0	0	0	0
BiToS	0	0	19	11	3	5	2	3	2	0	2	0	2	0
Proposed method	0	1	22	11	2	1	1	1	2	1	1	2	1	3

Figure 16: Frequency distribution of the duration of breaks at each peer in average (Content size 256MB, 4 seconds of playback time per one piece).

As shown in Fig.17, the number of times of breaks in average at each peer and total average, no big difference is seen among methods (Proposed method: 3.7, RarestFirst: 3.3, BiToS: 4.0).



Total average (Time)		
RarestFirst	BiToS	Proposed method
3.3	4.0	3.7

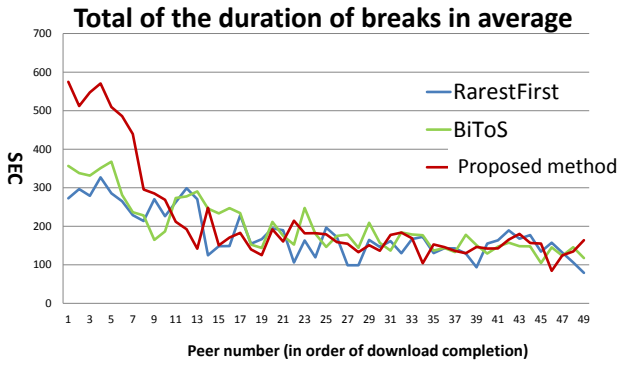
Figure 17: Number of times of breaks in average at each peer and total average (Content size 256MB, 4 seconds of playback time per one piece).

5.3.4 Content size 256MB, 0.5 seconds of playback time per one piece

The experimental result in case of content size is 256 MB and the playback time per one piece is 0.5 seconds is discussed here. Here also the proposed method performed poorly in terms of total duration of breaks in average as shown in Fig.18.

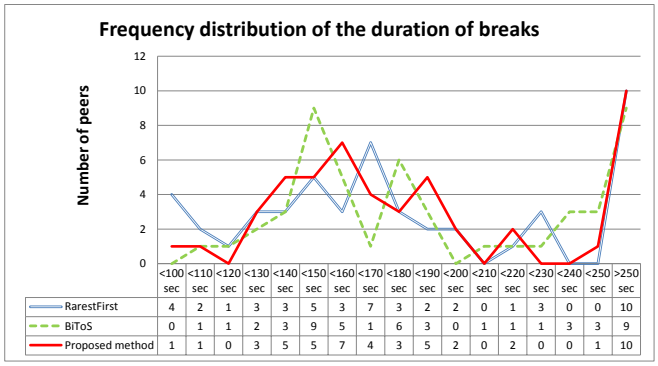
The frequency distribution of the duration of breaks shows the distribution is high in the area of 130-200 seconds and over 250 seconds area in all methods as shown in Fig.19.

As shown in Fig.20, the number of breaks in average is the smallest in our method (Proposed method: 4.0, RarestFirst: 4.1, BiToS: 4.5), but no significant difference is seen by methods here also.



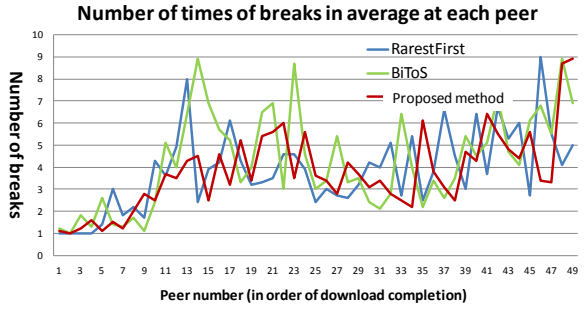
Total average of all peers (seconds)		
RarestFirst	BiToS	Proposed method
180.5	198.0	218.1

Figure 18: Total of the duration of breaks in average at each peer and total average of all peers (Content size 256MB, 0.5 seconds of playback time per one piece).



	<100 sec	<110 sec	<120 sec	<130 sec	<140 sec	<150 sec	<160 sec	<170 sec	<180 sec	<190 sec	<200 sec	<210 sec	<220 sec	<230 sec	<240 sec	<250 sec	>250 sec
RarestFirst	4	2	1	3	3	5	3	7	3	2	2	0	1	3	0	0	10
BiToS	0	1	1	2	3	9	5	1	6	3	0	1	1	1	3	3	9
Proposed method	1	1	0	3	5	5	7	4	3	5	2	0	2	0	0	1	10

Figure 19: Frequency distribution of the duration of breaks at each peer in average (Content size 256MB, 0.5 seconds of playback time per one piece).



Total average (Times)		
RarestFirst	BiToS	Proposed method
4.1	4.5	4.0

Figure 20: Number of times of breaks in average at each peer and total average (Content size 256MB, 0.5 seconds of playback time per one piece).

5.4 Consideration

In case of content size 128MB, in both cases of 4 and 0.5 seconds of playback time per one piece, the number of times of breaks is rather small in all peers and no significant difference was seen by each method. It is considered that since the communication with sufficient bandwidth is secured by any method because the size of the content is small enough for the environment with assumed number of peers and line speed. On the other hand, there is less number of times of breaks in case the playback time per one piece is 4 seconds rather than the case of 0.5 second. This indicates that long playback contents with low image quality have less frequent breaks. About the duration of breaks, in both cases of 4 and 0.5 seconds of playback time per one piece, the average duration of breaks is the smallest by our proposed method. In many peers, average duration of breaks distributes between 50 and 120 seconds. In case of 0.5, the duration came between 50 and 100 in most of peers by our method, and our proposed method performed better than other methods.

In case of content size is 256MB, in cases of 4 and 0.5 seconds of playback time per one piece, average number of times of breaks is smallest by RarestFirst and by our method respectively, but no significant difference is seen among methods. This is because the content size is rather large and pieces are too many for the assumed environment in this case. For the duration of breaks, in both cases of 4 and 0.5 seconds of playback time per one piece, the average duration of breaks is the largest by our method. And from the frequency distribution of the duration of breaks, distribution of short breaks is almost same by all methods, but breaks of long duration are seen in many peers by our method. This is considered that when the system downloads pieces with emergency priorities, download requests from other peers also swarm about a certain peer and causes a long waiting time for the download request.

6 CONCLUSION

The purpose of this research is to propose a method which is suitable for video streaming using P2P while solving the problem of client server system resource overload in the content delivery market. The research has proposed a new method of peer and piece selection in a P2P streaming environment using BitTorrent. The proposed simulations examine the effectiveness of the new methods for improving on the established BiToS and RarestFirst methods. It is the research's sincerest hope that the proposed method alleviates some of the current challenges facing streaming content delivery.

REFERENCES

[1] YouTube : http://www.youtube.com/
[2] NicoNico Douga : http://www.nicovideo.jp/
[3] Cisco®, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2012–2017," (2013).

[4] B. Cohen, “Incentives build robustness in bittorrent,” In 1st Workshop on the Economics of Peer-2-Peer Systems, Berkley, CA (2003).
[5]BitTorrentSpecifications. https://wiki.theory.org/BitTorrentSpecification .
[6]Arnaud Legout, G. UrvoyKeller, and P. Michiardi, “Rarest First and Choke Algorithms Are Enough,” IMC '06 Proceedings of the 6th ACM SIGCOMM conference on Internet measurement, pp.203–216 (2006).
[7] A. Vlavianos, M. Iliofotou, and M. Faloutsos, “BiToS: Enhancing Bittorrent for Supporting Streaming Applications,” INFOCOM 2006, Proc. of 25th IEEE International Conference on Computer Communications, pp.1–6 (2006).
[8] Weishuai Yang, Nael Abu-Ghazaleh, “GPS: A General Peer-to-Peer Simulator and its Use for Modeling BitTorrent,” Proceedings of 13th Annual Meeting of the IEEE International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS '05) (2005).
[9] I. Stoica, et al. “Chord: A scalable peer-to-peer lookup service for Internet applications,” In Proceedings of ACM SIGCOMM, Volume 31 Issue 4, pp.149-160 (2001).
[10] S. Ratnasamy, P. Francis, M. Handley, R. Karp, and S. Shenker, “A scalable content-addressable network,” In Proceedings of ACM SIGCOMM, Volume 31 Issue 4, Pages 161-172 (2001).

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A Design Method of Optimal H_2 Integral Servo Controller for Torsional Vibration System

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Abstract -This paper proposes a design method of optimal H_2 integral servo controller. The optimal H_2 integral controller is to establish a way to find the admissible controller such that the controlled plant is stabilized and guarantee to track a constant reference signal while minimizing the close-loop system H_2 norm from the disturbance to the controlled output. In this paper the derivative state constrained optimal H_2 integral servo controller is proposed for oscillatory system with a constant disturbance. This design method has the advantage that it can be applied to reduce the vibration of the two-inertia system. The effectiveness of proposed controller is evaluated by experiments.

Keywords: Optimal controller, Integral servo, Torsional vibration

1 INTRODUCTION

In sense of optimal control, the state feedback approaches for a linear dynamical system which not only stabilizes but also dampens the output responses of closed-loop system is generally required [1]. It is also required that the output of a system has no steady-state error for a desired input even if the parameter variations or disturbances exist. Consequently, the integral servo problem was initiated by H. W. Smith and E. J. Davison [2], in which they proposed the state and output integral feedback approaches by the differential state transformations, and gave the feedback control which contains a feed forward based on the measurable disturbance by the affine transformation. In addition, the optimal regulator control theory was primarily proposed by R.E. Kalman [3] to minimize the quadratic performance index of state variables and inputs. By using the regulator theory, the design method of an optimal tracking system by introducing the integral action for the system was obtained and reported by T. Takeda and T. Kitamori [4]. However, it is difficult to select the proper values of the weighting matrices of performance index in the optimal servo problem to mitigate under damped responses of dynamic systems. Besides, the optimal H_2 servo problem is to find the optimal control such that the output tracks the desired trajectory, minimizing the tracking error cost and state excitation cost in the sense of an optimal H_2 control [5]-[6]. On the other hand, Anderson and Moore [7] introduced an optimal controller with a prescribed degree of stability affecting the locations of all closed-loop poles. However, it does not necessarily reduce the under damping of the closed-loop system. Recently, the optimal H_2 control for oscillatory system minimizing a performance criterion involved time derivatives of state vector was formulated to mitigate the vibration responses of dynamic systems [9]-[13].

In this paper, the theorem of the derivative state constrained optimal H_2 integral servo controller is obtained by the standard H_2 control framework [8]. The proposed controller is applied to reduce the vibration of the two-inertia system. The verification of the effectiveness of the proposed controller to reduce the vibration responses and to reject the constant disturbance is shown by experiments.

2 H_2 INTEGRAL SERVO PROBLEM

In order to obtain the optimal H_2 integral servo controller, the following controlled plant equations are given as

$$\begin{aligned} &\frac{d}{dt}x(t) = Ax(t) + B_2u(t) + d_0,\ x(0) = x_0, \\ &y(t) = C_2x(t), \end{aligned} \tag{1}$$

where $x(t) \in R^n$, $u(t) \in R^{m2}$, $d_0 \in R^1$ and $y(t) \in R^{p2}$ denote the state vector, the input vector, the constant disturbance and the output vector, respectively. The integral $x_I(t) \in R^{p2}$ of the error vector $e(t) \in R^{p2}$ between the reference input $r(t) \in R^{p2}$ and controlled output $y(t)$ is defined as

$$x_I(t) = \int_0^t e(\tau)d\tau,\ e(t) = r(t) - y(t). \tag{2}$$

Using Eq. (1) and Eq. (2), the augmented controlled plant is then given by

$$\begin{aligned} &\frac{d}{dt}\begin{bmatrix} x(t) \\ x_I(t) \end{bmatrix} = \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix}\begin{bmatrix} x(t) \\ x_I(t) \end{bmatrix} + \begin{bmatrix} B_2 \\ 0 \end{bmatrix}u(t) + \begin{bmatrix} d_0 \\ r(t) \end{bmatrix}, \\ &y(t) = \begin{bmatrix} C_2 & 0 \end{bmatrix}\begin{bmatrix} x(t) \\ x_I(t) \end{bmatrix}. \end{aligned} \tag{3}$$

In order to the steady state tracking error $\lim_{t\to\infty} e(t)$ should be vanished, the derivative augmented state vector defined as $\dot{x}_I(t)$ which should be vanished for approaching $t \to \infty$. The derivative augmented system is given by combining of the derivative state equation of Eq. (3) with design parameter matrices as

$$P(s):\begin{cases}\dfrac{d}{dt}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}=\begin{bmatrix}A & 0\\ -C_2 & 0\end{bmatrix}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}+\left[\begin{array}{cc|cc|cc}B_1 & 0 & 0 & 0 & 0 & 0\\ 0 & B_{1I} & 0 & 0 & 0 & 0\end{array}\right]\dot{w}(t)+\begin{bmatrix}B_2\\ 0\end{bmatrix}\dot{u}(t)\\ \dot{z}(t)=\begin{bmatrix}C_1 & 0\\ 0 & C_{1I}\\ 0 & 0\\ 0 & 0\end{bmatrix}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}+\begin{bmatrix}0 & 0\\ 0 & 0\\ D_{11} & 0\\ 0 & D_{11I}\end{bmatrix}\begin{bmatrix}\ddot{x}(t)\\ \ddot{x}_I(t)\end{bmatrix}+\begin{bmatrix}0\\ 0\\ 0\\ D_{12}\end{bmatrix}\dot{u}(t))\\ \begin{bmatrix}\dot{y}(t)\\ y_I(t)\end{bmatrix}=\begin{bmatrix}C_2 & 0\\ 0 & I\end{bmatrix}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}+\left[\begin{array}{cc|cc|cc}0 & 0 & 0 & 0 & D_{21} & 0\\ 0 & 0 & 0 & 0 & 0 & D_{21I}\end{array}\right]\dot{w}(t),\end{cases} \tag{4}$$

where $B_1, B_{1I}, C_1, C_{1I}, D_{11}, D_{11I}, D_{12}, D_{21}$ and D_{21I} are denoted the design parameter matrices. $y_I(t) \in R^{p2}$ is added to obtain the proposed integral servo controller.

The disturbance $\dot{w}(t) = \left[\dot{w}_1{}^T(t) \quad \dot{w}_2{}^T(t) \;\vdots\; \ddot{x}^T(t) \quad \ddot{x}_I{}^T(t) \;\vdots\; \dot{w}_3{}^T(t) \quad \dot{w}_4{}^T(t)\right]^T$ is continuously differentiable in time. By definition of the optimal H_2 integral servo problem, the augmented general plant is given by

$$\hat{P}(s):\begin{cases}\dfrac{d}{dt}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}=\begin{bmatrix}A & 0\\ -C_2 & 0\end{bmatrix}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}+\breve{B}_1\dot{w}(t)+\begin{bmatrix}B_2\\ 0\end{bmatrix}\dot{u}(t)\\ \dot{z}(t)=\breve{C}_1\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}+\breve{D}_{12}\dot{u}(t))\\ \begin{bmatrix}\dot{y}(t)\\ \dot{y}_I(t)\end{bmatrix}=\begin{bmatrix}C_2 & 0\\ 0 & I\end{bmatrix}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}+\breve{D}_{21}\dot{w}(t),\end{cases} \tag{5}$$

where

$$\breve{B}_1=\left[\begin{array}{cc|cc|cc}B_1 & 0 & AD_{11} & 0 & 0 & 0\\ 0 & B_{1I} & -C_2D_{11} & 0 & 0 & 0\end{array}\right],$$

$$\breve{D}_{21}=\left[\begin{array}{cc|cc|cc}0 & 0 & C_2D_{11} & 0 & D_{21} & 0\\ 0 & 0 & 0 & D_{11I} & 0 & D_{21I}\end{array}\right],$$

$$\breve{C}_1=\left[\begin{array}{cc}C_1 & 0\\ 0 & C_{1I}\\ \hline D_{11}A & 0\\ -D_{1I}C_2 & 0\\ \hline 0 & 0\end{array}\right],\quad \breve{D}_{12}=\left[\begin{array}{c}0\\ 0\\ \hline D_{11}B_2\\ 0\\ \hline D_{12}\end{array}\right].$$

Statement of Derivative State Constrained H_2 integral servo problem:

Let $r(t)$ denote the step reference vector. Derivative State Constrained Optimal H_2 servo integral problem is to find an admissible optimal integral controller such that the controlled plants with augmented integrator is stabilized and the output $y(t)$ tracks the constant reference signal $r(t)$ while minimizing the H_2 norm of the closed-loop transfer function with controlled plant from $L[\dot{w}(t)]$ to $L[\dot{z}(t)]$ of $\hat{P}(s)$.

3 SOLUTION OF STATMENT

The solution to the derivative state constrained H_2 optimal control defined above is given by the following procedure:

(i) Variable Linear transformation for the prescribed degree of stability [7].

(ii) Singular value decomposition and variable transformation to obtain the standard H_2 structure.

(iii) Hamilton matrix for obtaining the stabilizing solution of the H_2 optimal control problem.

3.1 Variable transformations

In order to consider the effect of the prescribed degree of stability α to a controller, each vector variable is exponentially weighted as follows.

$$\begin{bmatrix}\tilde{\dot{x}}(t)\\ \tilde{\dot{x}}_I(t)\end{bmatrix}=e^{\alpha t}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}, \tag{6}$$

$$\begin{aligned}\tilde{\dot{w}}(t)&=e^{\alpha t}\dot{w}(t),\\ \tilde{\dot{z}}(t)&=e^{\alpha t}\dot{z}(t),\\ \tilde{\dot{u}}(t)&=e^{\alpha t}\dot{u}(t),\end{aligned} \tag{7}$$

$$\begin{bmatrix}\tilde{\dot{y}}(t)\\ \tilde{\dot{y}}_I(t)\end{bmatrix}=e^{\alpha t}\begin{bmatrix}\dot{y}(t)\\ \dot{y}_I(t)\end{bmatrix}. \tag{8}$$

Hence, the generalized plant $P_\alpha(s)$: shown in Eq. (9) after applying the transformed vector variables Eq. (6)-Eq. (8) is given by

$$P_\alpha(s):\begin{cases}\dfrac{d}{dt}\begin{bmatrix}\tilde{\dot{x}}(t)\\ \tilde{\dot{x}}_I(t)\end{bmatrix}=\left[\begin{bmatrix}A & 0\\ -C_2 & 0\end{bmatrix}+\alpha I\right]\begin{bmatrix}\tilde{\dot{x}}(t)\\ \tilde{\dot{x}}_I(t)\end{bmatrix}+\breve{B}_1\tilde{\dot{w}}(t)+\begin{bmatrix}B_2\\ 0\end{bmatrix}\tilde{\dot{u}}(t)\\ \tilde{\dot{z}}(t)=\breve{C}_1\begin{bmatrix}\tilde{\dot{x}}(t)\\ \tilde{\dot{x}}_I(t)\end{bmatrix}+\breve{D}_{12}\tilde{\dot{u}}(t))\\ \begin{bmatrix}\tilde{\dot{y}}(t)\\ \tilde{\dot{y}}_I(t)\end{bmatrix}=\begin{bmatrix}C_2 & 0\\ 0 & I\end{bmatrix}\begin{bmatrix}\tilde{\dot{x}}(t)\\ \tilde{\dot{x}}_I(t)\end{bmatrix}+\breve{D}_{21}\tilde{\dot{w}}(t),\end{cases} \tag{9}$$

The solution to the derivative state constrained H_2 optimal control defined above is given by procedure (ii) and (iii).

3.2 Singular value decomposition

There always exist unitary matrices V_j, U_j, $j = 1,2$ for the singular value decomposition of $\breve{D}_{12}$ and $\breve{D}_{21}$;

$$\breve{D}_{12} = U_1 \begin{bmatrix} 0 \\ \Sigma_1 \end{bmatrix} V_1,\ \Sigma_1 = \begin{bmatrix} \sigma_{11} & & \\ & \ddots & \\ & & \sigma_{1m_2} \end{bmatrix},\ m_2 = \dim\left[\breve{\tilde{u}}(t)\right],$$

$$\breve{D}_{21} = U_2 \begin{bmatrix} 0 & \Sigma_2 \end{bmatrix} V_{12},\ \Sigma_2 = \begin{bmatrix} \sigma_{11} & & \\ & \ddots & \\ & & \sigma_{1p_2+p_2} \end{bmatrix},\ p_2 + p_2 = \dim\begin{bmatrix} \breve{\tilde{y}}(t) \\ \breve{\tilde{y}}_I(t) \end{bmatrix},$$

where Σ_1, Σ_2 are the diagonal singular value matrices. Using the results obtained above, the input and output vectors as well as the generalized plant are accordingly transformed as shown in the following.

The generalized plant can be obtained by using the following variable transformations defined by

$$\breve{\tilde{w}}(t) = V_2 \hat{\tilde{w}}(t), \tag{10}$$

$$\hat{\tilde{z}}(t) = U_1^T \breve{\tilde{z}}(t), \tag{11}$$

$$\breve{\tilde{u}}(t) = V_1 \Sigma_1^{-1} \hat{\tilde{u}}(t), \tag{12}$$

$$\begin{bmatrix} \hat{\tilde{y}}(t) \\ \hat{\tilde{y}}_I(t) \end{bmatrix} = \Sigma_2^{-1} U_2^T \begin{bmatrix} \dot{y}(t) \\ y_I(t)(t) \end{bmatrix}. \tag{13}$$

Substituting Eq. (10)-Eq. (13) into Eq. (9), then the transformed generalized plant $P_\alpha(s)$: which is reduced to the standard form of the H_2 control problem is then obtained as

$$\hat{P}_\alpha(s): \begin{cases} \dfrac{d}{dt}\begin{bmatrix} \hat{\tilde{x}}(t) \\ \hat{\tilde{x}}_I(t) \end{bmatrix} = \left(\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I\right)\begin{bmatrix} \hat{\tilde{x}}(t) \\ \hat{\tilde{x}}_I(t) \end{bmatrix} + \hat{B}_1 \hat{\tilde{w}}(t) + \hat{B}_2 \hat{\tilde{u}}(t) \\ \hat{\tilde{z}}(t) = \hat{C}_1 \begin{bmatrix} \hat{\tilde{x}}(t) \\ \hat{\tilde{x}}_I(t) \end{bmatrix} + \hat{D}_{12} \hat{u}(t) \\ \begin{bmatrix} \hat{\tilde{y}}(t) \\ \hat{\tilde{y}}_I(t) \end{bmatrix} = \hat{C}_2 \begin{bmatrix} \hat{\tilde{x}}(t) \\ \hat{\tilde{x}}_I(t) \end{bmatrix} + \hat{D}_{21} \hat{\tilde{w}}(t), \end{cases} \tag{14}$$

where

$$\hat{B}_1 = \breve{B}_1 V_2,$$

$$\hat{B}_2 = \begin{bmatrix} B_2 \\ 0 \end{bmatrix} V_1 \Sigma_1^{-1},$$

$$\hat{C}_1 = U_1^T \breve{C}_1,$$

$$\hat{C}_2 = \Sigma_2^{-1} U_2^T \begin{bmatrix} C_2 & 0 \\ 0 & I \end{bmatrix},$$

$$\hat{D}_{12} = U_1^T \breve{D}_{12} V_1 \Sigma_1^{-1} = \begin{bmatrix} 0 \\ I \end{bmatrix},$$

$$\hat{D}_{21} = \Sigma_2^{-1} U_2^T \breve{D}_{21} V_2 = \begin{bmatrix} 0 & I \end{bmatrix}.$$

Suppose that the transformed generalized plant $\hat{P}_\alpha(s)$ of Eq. (14) satisfy the following relations:

(A1) $\left(\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I,\ \hat{B}_2,\ \hat{C}_2\right)$ is stabilizable and detectable.

(A2) $\hat{D}_{12}$ and $\hat{D}_{21}$ have full rank.

(A3) $\begin{pmatrix} \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I - j\omega I & \hat{B}_2 \\ \hat{C}_1 & \hat{D}_{12} \end{pmatrix}$ has full column rank for all ω.

(A4) $\begin{pmatrix} \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I - j\omega I & \hat{B}_1 \\ \hat{C}_2 & \hat{D}_{21} \end{pmatrix}$ has full row rank for all ω.

The first assumption (A1) is for the stabilizability of the transformed generalized plant (14). The assumption (A2) is sufficient to ensure the controller is proper. The assumption (A3) and (A4) guarantee two Hamiltonian matrices belong to dom(Ric).

3.3 Hamiltonian matrices

Under the above assumptions (A1)-(A4), the optimal H_2 solution to the transformed generalized plant (14) is given as follows;

A couple of Hamiltonian matrices are constituted as

$$H_2 = \begin{bmatrix} \left(\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I\right) - \hat{B}_2 \hat{D}_{12}{}^T \hat{C}_1 & -\hat{B}_2 \hat{B}_2{}^T \\ -\hat{C}_1{}^T \hat{C}_1 + \hat{C}_1{}^T \hat{D}_{12} \hat{D}_{12}{}^T \hat{C}_1 & -\left(\left(\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I\right) - \hat{B}_2 \hat{D}_{12}{}^T \hat{C}\right)^T \end{bmatrix}, \tag{15}$$

$$J_2 = \begin{bmatrix} \left(\left(\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix}^T + \alpha I\right) - \hat{B}_1 \hat{D}_{21}^T \hat{C}_2\right)^T & -\hat{C}_2{}^T \hat{C}_2 \\ -\hat{B}_1 \hat{B}_1{}^T + \hat{B}_1 \hat{D}_{21}^T \hat{D}_{21} \hat{B}_1{}^T & -\left(\left(\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix}^T + \alpha I\right) - \hat{B}_1 \hat{D}_{21}^T \hat{C}_2\right) \end{bmatrix}. \tag{16}$$

Then, it is guaranteed that the solutions exist, which make

$\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I + \hat{B}_2 \hat{F}_2$ and $\begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \alpha I + \hat{L}_2 \hat{C}_2$ stable.

From the couple of Riccati solutions,

$$X_2 = Ric(H_2) > 0,\ Y_2 = Ric(J_2) > 0, \tag{17}$$

it is able to construct the following optimal solution

$$\hat{K}_{H_{2\alpha}}(s) = \left[\begin{array}{c|c} \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} + \hat{B}_2 \hat{F}_2 + \hat{L}_2 \hat{C}_2 & -\hat{L}_2 \\ \hline \hat{F}_2 & 0 \end{array}\right] \tag{18}$$

to the transformed generalized plant (14), where

$$\hat{F}_2 = -(\hat{B}^T{}_2 X_2 + \hat{D}_{12}\hat{C}_1),$$
$$\hat{L}_2 = -(Y_2\hat{C}_2^T + \hat{B}_1\hat{D}_{21}.$$

The optimal control is then

$$\dot{\hat{u}}(t) = \hat{F}_2\begin{bmatrix}\dot{\hat{x}}(t)\\ \dot{\hat{x}}_I(t)\end{bmatrix}, \hat{F}_2 = \begin{bmatrix}\hat{F}_{2x} & \hat{F}_{2x_I}\end{bmatrix}. \quad (19)$$

A general control formulation with the derivative state constrained optimal H_2 integral servo controller $\hat{K}_{H_{2\alpha}}$ is given by the general configuration shown in Fig. 1. Consequently, the assumptions supposed above (A1), (A2), (A3) and (A4) can be reduced to the following expressions.

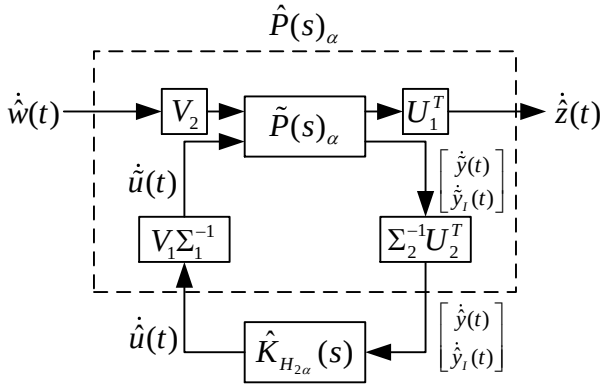

Figure 1: Block diagram of the structure for closed-loop system with equation (18).

Lemma: Suppose the system parameter matrix in equation (14) satisfy the assumptions (A1), (A2), (A3) and (A4), then following assumptions hold;

(A1)' $\left(\begin{bmatrix}A & 0\\ -C_2 & 0\end{bmatrix}, \begin{bmatrix}B_2\\ 0\end{bmatrix}, \begin{bmatrix}C_2 & 0\\ 0 & I\end{bmatrix}\right)$ is stabilizable and detectable.

(A2)' D_{12} and $\begin{bmatrix}D_{21} & 0\\ 0 & D_{21I}\end{bmatrix}$ have full rank.

(A3)' $\begin{pmatrix}\begin{bmatrix}A & 0\\ -C_2 & 0\end{bmatrix} - j\omega I & \begin{bmatrix}B_2\\ 0\end{bmatrix}\\ \begin{bmatrix}C_1 & 0\\ 0 & C_{1I}\end{bmatrix} & D_{12}\end{pmatrix}$ has full column rank for all ω.

(A4)' $\begin{pmatrix}\begin{bmatrix}A & 0\\ -C_2 & 0\end{bmatrix} - j\omega I & \begin{bmatrix}B_1 & 0\\ 0 & B_{1I}\end{bmatrix}\\ \begin{bmatrix}C_2 & 0\\ 0 & I\end{bmatrix} & \begin{bmatrix}D_{21} & 0\\ 0 & D_{21I}\end{bmatrix}\end{pmatrix}$ has full row rank for all ω.

Proof of Lemma: It is clearly shown that the optimal solution for the transformed generalized plant (14) can be obtained under the assumptions (A1)'-(A4)'by applying the facts of the rank properties (A1)-(A4) [13].

4 MAIN RESULT

By integrating the transformed generalized plant (14) with respect to time t with all initial values equal to zero, the optimal servo controller is obtained by following theorem. Thus, the optimal H_2 servo control solution for the system (14) is given by Eq. (18) of the theorem under the assumptions (A1)', (A2)', (A3)' and (A4)'. We have the following main result.

Theorem (Derivative State Constrained Optimal H_2 Integral Servo controller)

The derivative state constrained H_2 integral servo controller for the controlled plant (5) is given as

$$K_{H_{2\alpha}}(s) = \left[\begin{array}{cc|c}\begin{bmatrix}A & 0\\ -C_2 & 0\end{bmatrix} + \begin{bmatrix}B_2\\ 0\end{bmatrix}F_{2\alpha} + L_{2\alpha}\begin{bmatrix}C_2 & 0\\ 0 & I\end{bmatrix} & & -L_{2\alpha}\\ \hline F_{2\alpha} & & 0\end{array}\right] \quad (20)$$

under the assumptions (A1)', (A2)', (A3)' and (A4)', where

$$F_{2\alpha} = V_1\Sigma_1{}^{-1}F_2 = -V_1\Sigma_1{}^{-1}V_1{}^T\left\{\begin{bmatrix}B_2^T & 0\end{bmatrix}X_2 + D_{12}{}^T\breve{C}_1\right\},$$

$$L_{2\alpha} = L_2\Sigma_2{}^{-1}U_2{}^T = -\left\{Y_2\begin{bmatrix}C_2^T & 0\\ 0 & I\end{bmatrix} + \breve{B}_1\breve{D}_{21}{}^T\right\}U_2\Sigma_2{}^{-1}U_{.2}^T.$$

The optimal control is then

$$\dot{u}(t) = F_{2\alpha}\begin{bmatrix}\dot{x}(t)\\ \dot{x}_I(t)\end{bmatrix}, F_{2\alpha} = \begin{bmatrix}-F_{2\alpha x} & F_{2\alpha x_I}\end{bmatrix}. \quad (21)$$

Using Eq. (21), the optimal control law with integral feedback is written by

$$u(t) = -F_{2\alpha x}x(t) + F_{2\alpha x_I}\int_0^t e(t)dt\,. \quad (22)$$

This theorem can be proved as follow.

Proof: As the facts of the rank properties of the Lemma, this immediately shows that the optimal solution (20) for the generalized plant (5) implies the theorem under the assumptions of (A1)', (A2)', (A3)' and (A4)'. This concludes the proof of the theorem. □

5 OPIMAL FEEDBACK CONTROL AND TRACKING ERROR

For using the feedback control (21), the optimal control allows tracking of constant reference input in the infinity of time.

$$\begin{aligned}\dot{u}(t) &= -F_{2\alpha x}\dot{x}(t) + F_{2\alpha x_I}\dot{x}_I(t) \\ &= \begin{bmatrix} -F_{2\alpha x} & F_{2\alpha x_I} \end{bmatrix} \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} \begin{bmatrix} x(t) \\ x(t) \end{bmatrix} + F_{2\alpha x_I} r(t)\end{aligned} \tag{23}$$

Then from Eq. (1) and Eq. (23), we have

$$\begin{bmatrix} \dot{x}(t) \\ \dot{u}(t) \end{bmatrix} = \begin{bmatrix} I & 0 \\ -F_{2\alpha x} & F_{2\alpha x_I} \end{bmatrix} \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix} \begin{bmatrix} \dot{x}(t) \\ \dot{x}_I(t) \end{bmatrix} + \begin{bmatrix} 0 \\ F_{2\alpha x_I} \end{bmatrix} r(t) + \begin{bmatrix} d_0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ -F_{2\alpha x} d_0 \end{bmatrix}. \tag{24}$$

This of Eq. (24) approach zero as $t \to \infty$, then the all steady-state variables are constant which is given by

$$\begin{bmatrix} x(\infty) \\ u(\infty) \end{bmatrix} = \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix}^{-1} \begin{bmatrix} I & 0 \\ -F_{2\alpha x_I}^{-1} F_{2\alpha x} & F_{2\alpha x_I}^{-1} \end{bmatrix} \cdot \left(\begin{bmatrix} 0 \\ F_{2\alpha x_I} \end{bmatrix} r(t) + \begin{bmatrix} d_0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ -F_{2\alpha x} d_0 \end{bmatrix} \right). \tag{25}$$

This of Eq. (25) approach zero as $t \to \infty$, then the output is tracked the reference input r(t) and does not effective the disturbance as follow:

$$\begin{aligned} y(t) &= \begin{bmatrix} C_2 & 0 \end{bmatrix} \begin{bmatrix} x(\infty) \\ u(\infty) \end{bmatrix} \\ &= \begin{bmatrix} C_2 & 0 \end{bmatrix} \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix}^{-1} \begin{bmatrix} I & 0 \\ -F_{2\alpha x_I}^{-1} F_{2\alpha x} & F_{2\alpha x_I}^{-1} \end{bmatrix} \cdot \left(\begin{bmatrix} 0 \\ F_{2\alpha x_I} \end{bmatrix} r(t) + \begin{bmatrix} d_0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ -F_{2\alpha x} d_0 \end{bmatrix} \right) \\ &= \begin{bmatrix} C_2 & 0 \end{bmatrix} \begin{bmatrix} A & 0 \\ -C_2 & 0 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ I \end{bmatrix} r(t) = r(t). \end{aligned} \tag{26}$$

Then, the optimal control allows that the output is tracking of constant reference input in the infinity of time while rejecting the constant disturbance of Eq. (1).

6 EXPERIMENTAL RESULTS

A torsional vibration is occurred to the speed of motor by connecting flexible shaft. The vibration is an impediment to improve the characteristics of the two-inertia system. The experimental results of the speed control of the two-inertia system using the proposed controller will be shown to be effective to suppressing the vibration in this section. A structure of two-inertia system is shown in Fig. 2.

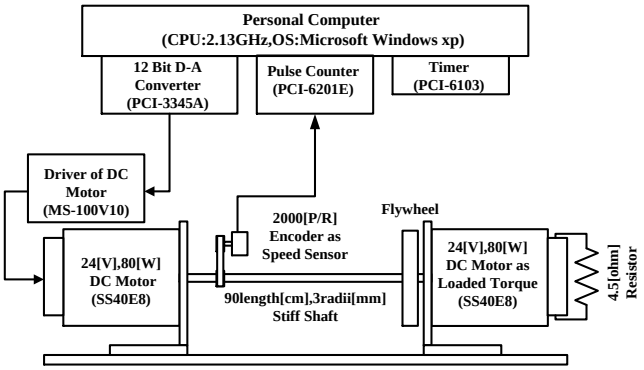

Figure 2: Structure of the two-inertia system.

In this system, two motors are connected by long shift (90cm) with the spring constant of the shift. The left side of motor is driving the right side of the load motor with the shift. By using Newton's second law, the linear dynamic equation of the two-inertia system with constant disturbance T_L is represented by

$$\begin{aligned} J_m \frac{d\omega_m}{dt} + F_m \omega_m &= u(t) + \tau_d, \\ J_L \frac{d\omega_L}{dt} + F_L \omega_L &= \tau_d - T_L, \\ \frac{d\tau_d}{dt} &= K_s(\omega_m - \omega_L), \end{aligned} \tag{27}$$

where J_m, J_L, F_m, F_L and K_s are the inertia of motor, the inertia of load, the friction of motor, friction of load and spring constant of the shaft, respectively. For tracking reference input, the integral $x_I(t)$ of the error vector $e(t)$ between the reference input $r(t)$ and controlled output $\omega_m(t)$ is defined as

$$x_I(t) = \int_0^t e(\tau) d\tau, \; e(t) = r(t) - \omega_m(t). \tag{28}$$

The parameters of the augmented controlled plant (3) is given by

$$A = \begin{bmatrix} F_m / J_m & 0 & 1/J_m & 0 \\ 0 & -F_L / J_L & 1/J_L & 0 \\ K_s & -K_s & 0 & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix}, B_2 = \begin{bmatrix} 1/J_m \\ 0 \\ 0 \\ 0 \end{bmatrix},$$
$$d_{0=} = -T_L, \; C_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}.$$

The state variables of Eq. (3) is given by, $x(t) = \begin{bmatrix} \omega_m(t) & \omega_L(t) & \tau_d(t) & x_I(t) \end{bmatrix}^T$, where $\omega_m(t)$ denotes the speed of motor at time t, $\omega_L(t)$ denotes the speed of load at time t, $\tau_d(t)$ represents the torque of shaft and $\omega_m(t)$ denotes the disturbance torque. The numerical values of J_m, J_L, K_s are shown in Table 1. In the case of the numerical values, the friction of motor, friction of load and spring constant of the shaft are neglected, respectively.

Table 1: Numerical values of two-inertia system.

$J_m[Kg\cdot m^2]$	$J_L[Kg\cdot m^2]$	$K_s[N/m]$
0.0866	0.0866	400

The designing parameters $B_1, B_{1I}, C_1, C_{1I}, D_{11}, D_{11I}, D_{12}, D_{21}$ and D_{21I} in the generalized plant of Eq. (4) are chosen as:

$$\left.\begin{aligned} C_1 = B_1^T &= diag[\sqrt{10^{qi}} \quad \sqrt{10^{qi}} \quad \sqrt{10^{qi}}] \\ C_{1I} = B_{1I}^T &= [\sqrt{20000}] \\ D_{11} &= diag[\sqrt{e^{ni}} \quad \sqrt{e^{ni}} \quad \sqrt{e^{ni}}] \\ D_{11I} &= \left[\sqrt{100}\right] \\ D_{12} &= [1] \\ \begin{bmatrix} D_{21} & \\ & D_{21I} \end{bmatrix} &= diag[\sqrt{0.01} \quad \sqrt{0.01}] \end{aligned}\right\}, \qquad (29)$$

where *qi* is the standard weighting parameter of C_1 and B_1 and *ni* is the weighting parameter of D_{11} for reducing the vibration.

By using the theorem of the main result, the feedback control laws for *ni*= -12 and *ni*= -5.5 are given by Eq. (30) and Eq. (31), respectively.

For *ni*= -12, the control law is obtained as:

$$\dot{u}(t) = -\left[5.321 \quad 1.903 \quad 0.014 \;\vdots\; -141.366\right]\begin{bmatrix} \dot{x}(t) \\ \dot{x}_I(t) \end{bmatrix}. \qquad (30)$$

For *ni*= -5.5, the control law is obtained as:

$$\dot{u}(t) = -\left[20.805 \quad -12.299 \quad 1.305 \;\vdots\; -123.289\right]\begin{bmatrix} \dot{x}(t) \\ \dot{x}_I(t) \end{bmatrix}. \qquad (31)$$

Regarding $\alpha = 20$ as the prescribed degree of stability, the variation of closed-loop poles when the parameter *ni* vary from -9 to -2 is shown in Fig. 3. It is seen that the original poles of the open-loop system locate on the imaginary axis. It verifies that the pair of poles with imaginary part approach to the real axis when the parameter *ni* becomes large. It seems that the vibration of speed is reduced by design parameter *ni*.

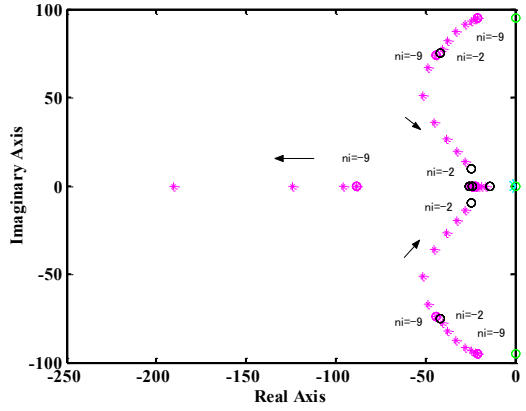

Figure 3: Closed-loop poles location for varying from *ni*= -9 to *ni*= -2 and $\alpha = 20$.

In experimental results, it is shown that the effectiveness of the controller can be reduced the vibration by the parameter *ni*. The experimental results in shown in Fig. 4-Fig. 6. In Figure 4, the oscillatory response occurred for selecting the weak design parameter *ni*= -12 of Eq. (32). However, the oscillatory response can be reduced for selecting the design parameter *ni*= -5.5.

$$D_{11} = diag\left[\sqrt{e^{ni}} \quad \sqrt{e^{ni}} \quad \sqrt{e^{ni}} \quad \sqrt{20000}\right] \qquad (32)$$

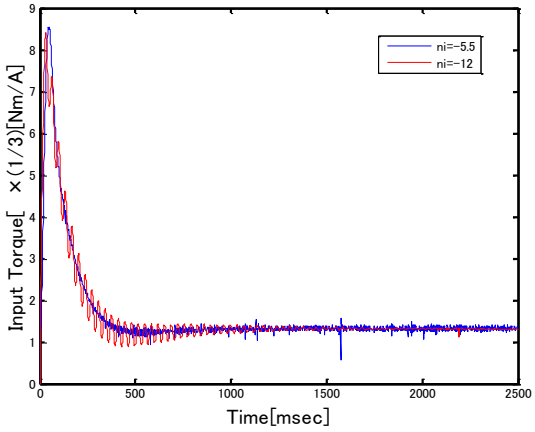

Figure 4: Responses of input torque of motor for *ni*= -12 and *ni*= -5.5.

Figure 5 shows the close loop responses of this plant with the feedback control gain of Eq. (30) and Eq. (31) for setting the reference speed 2500[RPM], respectively. Significantly, the output speed of motor is tracking the reference speed with removed the torsional resonance by the designing parameter *ni*= -5.5.

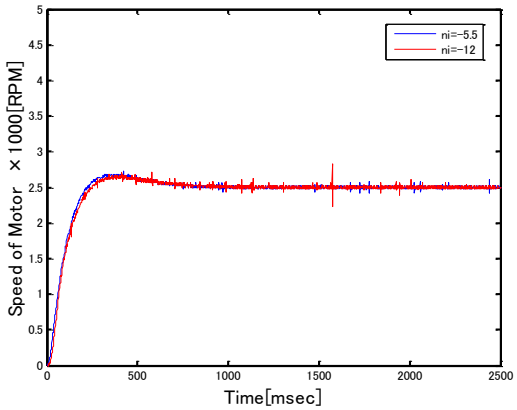

Figure 5: Responses of speed of motor for setting reference speed 2500[RPM] when *ni*= -12 and *ni*= -5.5.

In order to confirm the rejection of disturbance, Figure. 6 show that the response of speed is recovered the steady state when the load disturbance torque $T_L[N\cdot m]$ is applied to the motor after driving steady state speed of motor.

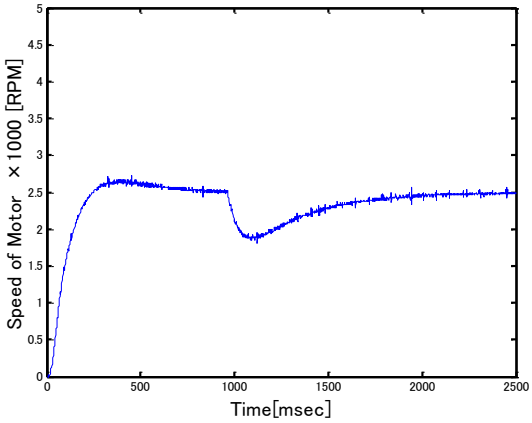

Figure 6: Response of speed of motor for applying the disturbance $T_L = 0.142[N \cdot m]$.

7 CONCLUSION

The optimal H_2 controller using derivative state constrained optimal H_2 integral servo controller has been proposed. The proposed controller is effective to reduce the vibration responses of the controlled system by H_2 control framework. It is recognized that the design parameter ni of matrix D_{11} can applied to the oscillation system with the reference inputs as well as constant disturbance. The experimental results have verified that the proposed schemes can be effective to reduce the oscillation and to mitigate the effect of the constant disturbance for the two-inertia system. The optimal H_2 controller with derivative state constraint will provide a method for improving vibration by comparing with other optimal control methods for future research.

REFERENCES

[1] J. J. Hench, C. He, V. Kucera and Meheman, "Damping Controllers via Riccati Equation Approach," IEEE Tran. On AC, Vol. 43, No. 9, pp. 1280-1284 (1998).

[2] H. W. Smith and E. J. Davison, "Design of Industrial Regulators," Proc. IEE, Vol. 119, No. 8, pp. 1210-1216 (1972).

[3] R. E. Kalman, "When Is a Linear Control System Optimal?" ASMEJ. Basic Engineering, ser. D, Vol. 86, pp. 51-60 (1964).

[4] T. Takeda and T. Kitamori, "A Design Method of Linear Multi-Input-Output Optimal Tracking Systems," Trans. SICE, Vol. 14, No. 4, pp. 359-364 (1978).

[5] M. Ikeda and N. Suda, "Synthesis of Optimal Servosystems," Trans. SICE, Vol. 24, No. 1, pp. 40-46 (1988).

[6] I. Masubuchi, A. Ohara and N. Suda, "A Design of Robust Servo Systems for Structured Uncertain Plants," Proc. SICE, Vol. 30, No. 9, pp. 1051-1059 (1994).

[7] B. D. O Anderson and J. B. Moore, "Linear System Optimization with Prescribed Degree of Stability," Proc. IEE, Vol. 116, No. 12, pp. 2083-2089 (1969).

[8] J.C.Doyle, K.Glover, P.P.Khargonrkar and B.A. Fran cis, "State-space solution to standard H_2 and H contr ol problem," IEEE Trans. Automatic Control, Vol. A C-34, pp. 831-847 (1988).

[9] T. Trisuwannawat, K. Tirasesth, M. Iida, N. Komine and Y. Ochiai, "Derivative State Constrained Optimal H_2 Control for Oscillatory Systems and Its Application," Trans. IEEJ (Industry Applications Society; IAS), Vol. 120-D, No. 6, pp. 775-781 (2000).

[10] N. Komine and K. Yamada, "Optimal H_2 Integral Co ntroller Design with Derivative State Constraints for Torsional Vibration Model," Proc. KES2010, pp. 545 -554 (2010).

[11] W. Ichiyama, N.Komine, T. Benjanarasuth and M. Y oshida, "Optimal H_2 Integral Servo Controller with Derivative State Constraints for Suppressing under Damping of Oscillatory System," Proc. JSST2011, pp.436-440 (2011).

[12] N. Komine, M. Nishigaki, T. Mizuno and K. Yamada, "A Design Method of Derivative State Constrained H_2 Integral Servo Controller for Suppressing under Damping of Oscillatory System," Proc. AsiaSim201 2, Part I, pp. 515-162 (2012).

[13] N. Komine, M. Nishigaki, K. Yamada and T. Mizuno, "A Design Method of Optimal H_2 Integral Servo Pro blem," Proc. IWIN2013, pp.141-148 (2013).

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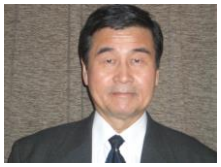

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