Augmented Reality Go: Extending Traditional Game Play with Interactive Self-Learning Support

Takahiro Iwata Tetsuo Yamabe Tatsuo Nakajima
Department of Computer Science and Engineering, Waseda University
{takahiroiwata, yamabe, tatsuo}@dcl.info.waseda.ac.jp

Abstract—**The augmented reality (AR)-based learning support has several advantages over virtual reality or PC applications. AR enables to maintain the physical interaction that an activity originally offers, thus the skills and knowledge acquired in an augmented learning process can be intuitively applied to practice use. Whereas lots of AR-based self-learning support systems have been developed in previous studies, it has not been sufficiently evaluated how it influences a learner's mindset and the efficiency of training. In this paper, we investigate the user experience brought by AR technologies in a self-learning process. We chose the game of Go as a study program, and developed the Augmented Reality Go (ARGo) system to compare the AR and conventional PC-based learning assistance. We found that the physical interaction with the original game apparatus enhanced the subjects' intrinsic motivation towards self-learning. Moreover, the original look-and-feel induced deeper concentration and higher elaboration on problem solving. Design issues are also discussed to generalize the concept of AR self-learning support towards broader application domains.**

I. Introduction

Augmented reality (AR) technology has been developed to support complicated tasks, such as driving, machine assembly, and medical operation [1]. AR technology enables the reduction of cognitive load by superimposing auxiliary information onto the actual workplace in real time. Several types of information assist in *situation awareness* development, for example an annotation aids to understand the status and attributes of an object [4]. Visualization allows the user to recognize invisible information, such as the density of odorless chemical gas. The scenery beyond obstacles can be visualized as well so that the sense of sight is extended with a see-through capability. It is expected that the user can acquire skills and learn knowledge more efficiently with the reinforced situation awareness. The augmentation manner and architecture vary from application to application, but they more or less augment the real world with digital services.

In [14], Milgram *et al.* proposed the Reality-Virtuality continuum to illustrate the relationship between AR and virtual reality (VR) applications. As the proportion of virtual objects increases, the augmented workspace gets closer to the virtual environment. For example, driving simulators aim at training beginner drivers in a virtual environment that is constructed inside a monitor. They still can keep and allow physical interaction with a real steering wheel, an accelerator pedal, and a gear. However, most information, events, and stimuli that appear or happen in the real environment would be lost in the simulator that virtualizes the world. If the system is designed from the AR perspective, feedback will be shown on the windshield of a real vehicle running on the street. Thus the reality of a surrounding environment can be maintained, even though the real objects cannot be easily manipulated or controlled as virtual ones.

Most previous mixed reality (MR) studies discussed brand-new system development as a main issue of the work. Thus, they usually developed either AR or VR application, instead of comparing those different approaches illustrated on the Reality-Virtuality continuum. As the proportion of reality and virtuality changes, the interaction design alters correspondingly and it provides different user experience. In terms of learning support, it is expected that each reality-based augmentation and virtuality-based approach involves pros and cons that affect the efficiency of training. However, it has not been sufficiently evaluated which aspect of AR-based learning support surpasses VR-based approach. Particularly, the advantage of physical interaction needs to be clearly identified to adopt AR technology, as sophisticated virtual environments have already been developed and used for training support.

In this paper, we investigate the user experience brought by AR technology in a self-learning process. We chose the board game of Go as a learning task, which is one of the most popular strategic games particularly in Asian countries. We developed the Augmented Reality Go (ARGo) system to support interactive self-learning for Go skill acquisition. In contrast to the conventional learning style with PC applications, ARGo allows beginners to play with the traditional game apparatus such as Go board and stones. Feedback is directly projected onto the Go board so that original look-and-feel can be maintained in an interaction process. Any additional devices, such as head mounted displays (HMD) or mobile phones, are excluded from the system on purpose. We also developed a PC-based Go learning system that provides same contents with ARGo. Then, we conducted a user study to identify the differences between these AR and PC-based self-learning styles. We particularly focused on the learning performance and the level of intrinsic motivation in the experiment.

In the next section, we introduce the game of Go and the concept of augmented traditional game play. Then in Section III, we explain the concept and architecture of the ARGo system. As mentioned above, we evaluate both AR and PC-based Go learning system in Section IV. Lastly, we discuss design issues of the augmented traditional game systems based on the user study, and identify future work in Section V.

1533-2306/11 $26.00 © 2011 IEEE
DOI 10.1109/RTCSA.2011.43

II. Augmented Game Play for Self-Learning Support

A. The Game of Go

Go is a traditional board game for two players, where the objective is to occupy a larger portion of the board than the opponent. Go originated in China and is nowadays played all over the world particularly in East Asian countries such as China, Korea and Japan. The game of Go offers a good mental exercise and trains logical thinking skills. Black and white stones are used to control the territory and a wooden board with a grid of 19 x 19 lines is used as the game field. The rules of Go are relatively simple to other board games, but the underlying strategies are extremely complex and rich. As in chess and reversi, numerous set sequences and strategies have been invented to reduce the complexity, but studying them requires the player to deeply understand the strategic concepts. Thus, it often takes a long time for beginners to do well against experienced opponents. For example, *Joseki* is typical set sequences and strategic patterns that often appear in advanced-level matches. Beginners can effectively improve their offense, by studying the Joseki and following experts' strategic thinking process. Moreover, defense can be also improved as the player can expect possible strategic patterns that the opponent will use (i.e., projection level enhancement in the situation awareness model [4]).

In Japan, few young people play Go while the generation advanced in age enjoys the game a lot. Usually, to acquire new skills and knowledge, expert players guide a novice and teach the know-how in hands-on work. However, the opportunity to meet Go experts is pretty limited as learners need to find and visit Go salons. Moreover, the concept and traditional terms of Go is rather unique and unfamiliar than other games, such as poker and darts. Thus, particularly novice players need to learn a lot of things before starting to enjoy the essential point of the game. Even though training with digital contents (e.g., video games) is available today, most beginners give up self-learning due to the practical hurdle. Indeed, PC games are a useful tool to practice Go without any human help and time restriction. The user can quickly access large knowledge stored in a database. Dynamic and fancy animation allows the user to intuitively understand the game flow and sequence. However, the process easily gets monotonous and boring as the completely digitalized contents lose a flavor of real game play. Then, we focused on the advantages of traditional physical interaction.

B. Physical Interaction in Learning

Physical interaction with tangible game apparatus is an important aspect to keep a learner's motivation during a self-learning process. Traditional Go play requires to manually place and remove Go stones to/from a Go board. For example, some previous studies claimed that physical interaction enhances user experience with pleasure and achieves emotional engagement [15], [18]. Good user experience derives intrinsic motivation towards sustainable effort whereas self-learning tends to become boring quickly. As the rule of Go is difficult for novices, the training program should be designed to keep intrinsic motivation over a long-term period. The term intrinsic motivation was defined by Deci, and it is driven by the interest or enjoyment evoked during achieving a task [2]. Thus, we attempted to enhance traditional game environments with AR technologies, in order to keep its original physical interaction as much as possible.

For example, tangible user interface (TUI) is a good example of the technologies that extend the physical interaction of conventional systems. The concept of TUI was originally introduced by Ishii and Ulmer in 1997 [8]. They coined the term as real world augmentation with digital information. Everyday physical objects and environments are coupled with digital information; and a user can fetch, control and manipulate them through the interaction with either graspable or ambient media. Beyond conventional graphical user interfaces, the TUI concept is expected to break the literacy barrier between a service and users. The metaphor of everyday objects implies possible interaction to the coupled digital service, then the user can intuitively manipulate it without learning new commands for interaction. For example, valves' metaphor would remind the user to adjust the amount or speed of a streaming object by turning a controller.

TUI changes conventional mice and keyboards-based interaction and hides the presence of PC from the user's focal area, thus TUI has been also studied in the domain of education [3], [5], [10], [17], [19]. Even though the learner cannot use PC well, TUI allows to perform interaction with familiar everyday objects. Moreover, physical interaction involves other advantages that conventional devices cannot reproduce, such as tactile sense. According to [11], tactile stimuli would activate the prefrontal cortex in a human brain and facilitate memory consolidation. This finding implies an important factor in learning system design. Hands-on work would bring better performance rather than conventional PC-based e-learning, and moreover it would maintain higher intrinsic motivation to achieve continuous learning. Thus, in this paper, we applied the AR technology to seamlessly integrate digital information and services into the original Go playing style.

C. Traditional Game Augmentation

While digitalization causes the loss of the aforementioned advantages, pervasive computing technologies support various aspects of traditional games [13]. There are roughly two styles to apply the technologies to game play: creation of novel forms, and augmenting existing forms. In [6], Hinske *et al.* mainly focused on supporting the players by providing services in digitally augmented traditional game environments, instead of surrounding them with virtual game elements. They also proposed two important aspects of the augmentation: *the game flow virtualization of the game* and *the physical augmentation of the game*. The game flow virtualization enables an augmentation system to deal with a game rule so that it can check the rule consistencies and violations. Moreover, the system can provide information that is relevant to the game at appropriate timing. The physical augmentation also identifies two main objectives: unobtrusive technology integration and non-negative influence on the original game's rich social interactions.

As their guideline indicates, ideally technologies support a gaming process with minimum interference. Moreover, technologies are supposed to be cognitively disappeared into background. As Hinske *et al.* pointed out, however, game objects are often small and will influence the choice of technologies. For example, RFID (radio frequency identification) tags are convenient to identify the objects. However, in order to detect the location of such small objects on a small tabletop, readers also need to be small or other positioning techniques are required. Flexibility is also a problem. If the tags are attached to cards, they should be enough thin and bendable so that players can shuffle the cards without breaking them. Regarding to RFID tags, anti-collision mechanisms are another issue. If a reader does not support it, the objects cannot be piled up and thus possible use cases will be limited. However, currently such anti-collision readers are still expensive. Thus physical augmentation could change game objects' appearance, but players still should be able to play the game in the traditional way (when the augmentation support is switched off).

Based on the augmented traditional games concept, we developed Augmented Reality Go (ARGo) to support a beginner player's self-learning process. In the next section, we explain the detail of system and its architecture.

III. Augmented Reality Go System

A. Concept and Design

The ARGo system was designed based on the design guideline proposed by Hinske *et al.* [6]. Firstly, players interact with the system with traditional Go game apparatus: Go board and stones. According to the guideline #5, *"the game should still be playable (in the "traditional" way) even if technology is switched off or not working"*. As we attach importance to its original and traditional play style, we did not replace any game apparatus with digital devices. Instead we added a mobile projector to provide visual feedback and a web camera to detect game events in real time. As the guideline #3 states, *"the focus should remain on the game and the interaction itself, not on the technology"*. Therefore we did not either add any extra devices or modify the equipment. For example, visual markers or RFID tags would be useful to accurately recognize the situation on the board. However, it would lose the original look-and-feel, and moreover draw the player's attention to the device. Guideline #4 also supports this approach, as *"technology integration should be done in a way that is unobtrusive, if not completely invisible"*. Figure 1 shows the overview of the ARGo system user interface.

As shown in the figure, guidance information is superimposed on the real Go board and changes corresponding to the situation. The guideline #8 identified the requirement of feedback design on augmented traditional games, as *"players should receive simple and efficient access to information.*

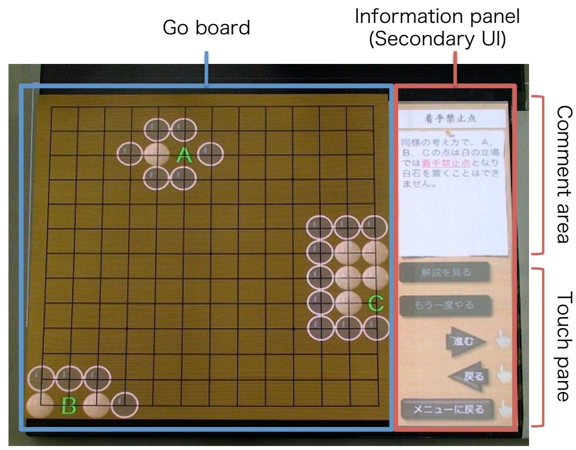

Fig. 1. Overview of ARGo system user interface.

Feedback should be immediate and continuous". Digital information appears on the board includes *territory visualization* and *virtual stones*. The territory visualization aims at supporting the player to recognize invisible links between stones. Go players need to form own territory with stones, thus it is important to be aware of their distance and position. However, a beginner player tends to miss the area developed by the opponent, as they often pay attention to a specific part of the board. It is difficult for novices to keep staying on the outlook particularly when they are excited to attack their opponent's territory. The ARGo system visualizes the links as bright lines so that the beginner player can grasp the situation easily. The virtual stones are used in self-learning modes, as the system allows single user play with a virtual opponent (Figure 1).

We explain the detail of supported modes in Section III-B, and the services provided for the learner implement the guideline #1 *"the technological enhancement should have an added value"*. Lastly, the system also provides a secondary user interface to accept complementary interaction. The information panel in the figure is prepared next to the Go board where main information appears. The information panel consists of the comment area and touch pane. The comment area shows text messages such as instructions or tips of strategic patterns to proceed with learning. The user dialogues with the comments by touching virtual buttons on the touch pane. The surface of the information panel is made of paper and all information on the secondary user interface is projected from the mobile projector. The touch pane equips infrared reflective sensors next to the paper as shown in Figure 2-B. Figure 2-A shows the virtual buttons projected onto the paper. The virtual menu indicates the interactive area with iconic representation (Figure 2-B).

The secondary user interface was designed based on the guideline #12, *"secondary user interfaces should be minimized"*. People often concentrate on game playing and experience the deep involvement that removes awareness of everyday life. According to [9], *"during play, distractions from major*

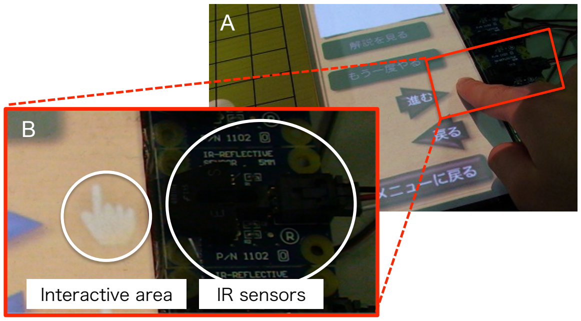

Fig. 2. Touch pane and virtual buttons. The Phidgets IR sensor attached next to the interactive area detects the finger placed on line (Figure 2-B) by periodically measuring the proximity to an obstacle.

game tasks should be minimized by reducing nongame-related interactions and reducing the game interface to maximize the amount of screen taken up with game action". Interaction with an augmented game should follow this principle, in order to let a player experiences flow. However, it is difficult to automatically and perfectly recognize game relevant information. Thus players should be able to explicitly interact with the system to switch modes or correct detection errors for example. This user interface should be designed to naturally fit to an original interaction process, rather than forcing a conventional PC interaction on a user. As a side effect of the system design, the ARGo system can be set up with small cost, and moreover it becomes portable. The system consists of conventional consumer products and the original Go apparatus rather than newly invented devices that are not available in the market. Thus consumers can easily purchase the parts and set up the system with a downloadable application. We believe that this approach contributes to spread the game of Go and also the AR technology to consumers.

B. Use Cases

The ARGo system supports several modes for both self-learning and conventional two players match. As previously mentioned, the self-learning modes allow the user to acquire fundamental knowledge and skills without extra human support. The match mode aims at visualization of invisible know-how that experts can recognize whereas novices tend to miss or simply cannot perceive.

1) Self-Learning Modes: The self-learning modes aim at providing a beginner player with fundamental knowledge of Go rules and the technical strategies often used in a match. There are three modes in total, and each mode emulates a traditional (analog) self-learning approach. For example, a *Kifu mode* is a digitally supported Kifu study that usually uses a textbook to replay professional matches. The AR technology reduces required effort by automating a part of learning process. The self-learning modes are explained below.

Kifu mode: *Kifu* is the record of stone move that is usually manually made only in professional matches. An efficient approach to learn Go fundamentals is to repeat stone move to trace professional players thought on the strategy. In the conventional way, users have to hold a Kifu book to check the position of stones, and it sometimes makes difficult to concentrate on comprehension. Moreover, the Kifu is usually written in the compressed format with special symbols. Thus it is difficult particularly for beginner players to understand them at a glance. In this mode, the application visually indicates the position of stone move along with comments on the strategy. Then, users can follow the sequence without fragmenting attention to other materials.

Joseki mode: As mentioned above, *Joseki* means a set sequence or a typical strategic pattern that is frequently used in a match. A good knowledge of Joseki helps the player to adopt the set sequence to own tactics and improvise a counter strategy to their opponent's hand. In this mode, the ARGo system offers interactive courses to study the flow and the point of strategy. This mode aims at enabling the player to utilize the strategic patterns without system support. Therefore, at first the application shows virtual stones on the board. However, it gradually decreases the number of visible stones as the learner proceeds to advanced phases. This iterative learning helps the player to remember and use the patterns in actual matches.

Tsumego mode: *Tsumego* is one of typical exercises to find out the best sequence of move in a given situation. In this mode, a specific situation is given with virtual stones. The learner can freely place a real stone to a free space. Then, the system takes turn and makes a counterattack by placing a new virtual stone in a different color. The process continues as if the learner plays against a real opponent in an actual match. If the player can successfully resolve the problem, a red circle appears in the comment area as a sign of the right answer (Figure 3). Then, the player can proceed to another problem or challenge more difficult levels.

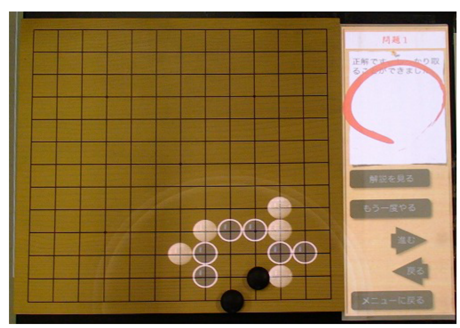

Fig. 3. Human player's real stones and the system's virtual stones in the Tsumego mode. The red circle in the comment area indicates that the player successfully resolved the problem.

If the player gets stuck and gives up the problem, they can check a model stone move in animation (Figure 4). The point of answer and advice are offered in the comment area so that the learner can notice wrong points and improve their strategy. Each mode provides a variety of problems with different levels so that the learner can choose an appropriate difficulty level based on their current skill. Moreover, the player can retry any number of times with different stone move.

As shown in these modes, the advantage of our approach is to allow players to get information through the original interaction offered by the Go board and the stones. By superimposing information onto the board, players can concentrate on the match at hand or self-training without fragmenting their attention towards an instructional book and etc. This is important to enable the players to allocate enough cognitive resources for recognizing the situations in the game. Using original game apparatus as the basis of system preserves traditional look-and-feel, such as distance between players, touch of a wooden board and sound of stones.

2) Match Mode: In this mode, two players play the game of Go as usual, but feedback information appears on the board to help beginners recognize the current situation and make better decisions. As mentioned above, it is difficult to recognize invaded areas, since the invasion process gradually progresses as new stones are put on the board. Moreover, on a large board, beginners tend to concentrate on localized fighting and overlook the big picture in the process.

To take a good strategy on both offense and defense, it is important to be aware of the relationship among stones. However, it often requires a great deal of experience and attention, thus beginner players tend to miss the information. Thus, in order to prevent losing a territory, the system shows a warning message to draw the player's attention if an undesirable situation occurs somewhere on the board. In addition, this mode supports stone position recording, thus the players can review the game process after the match to improve their strategy. Figure 5 shows an example of the territory visualization.

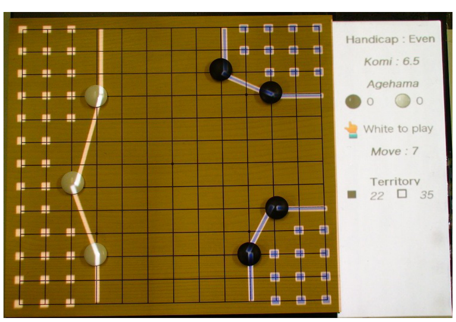

Fig. 5. Territory visualization by coupling stones with blinking lines. The dots represent storable areas and the system automatically counts them in the right pane (e.g., in the figure, the black stone's territory scores 22 points whereas white's one is 35).

The ARGo system couples neighbor stones with blinking lines and indicates the areas where the player possibly can keep. The visual information is shared among the players so that they also can notice the dangerous areas where can be easily attacked. If the opponent's stone is placed between own stones, the line disappears since the link is broken. The dots in the figure assist in recognizing the size of own territory, and corresponding points are automatically calculated and shown in a numerical format on the secondary user interface. The tentative score is useful to understand the situation, particularly for beginner players.

C. System Architecture

As mentioned above, the ARGo system was designed based on the original Go game apparatus and minimum additional devices. A mobile projector on a tripod stands beside the Go board and projects visual feedback to support game play. A web camera is also attached to the tripod so that the game situation can be recognized through image processing. We also prepared the secondary user interface to allow a player to explicitly interact with the service with fingers. Thus a Phidget IR sensor[1] is integrated to the information panel. A conventional laptop PC is used to process the sensor data and captured images in order to recognize game events. Therefore, the system is quite mobile over all and can be set up easily. Figure 6 shows the overview of the ARGo system architecture.

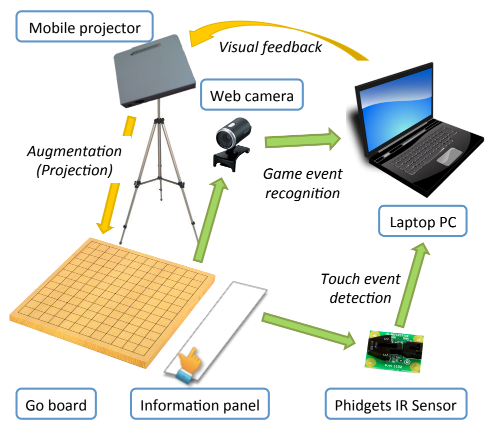

Fig. 6. ARGo system architecture overview.

The ARGo system handles two types of input: game events and touch events. The web camera periodically captures images of the Go board from above. Then, the image is processed with the OpenCV library[2] to analyze the stones' position. Firstly, all intersections of the grid on the board are recognized from color difference from the background. Secondary, Go stones are detected as their color component value exceeds preliminary configured threshold. Usually Go stones' diameter is about 22 mili meter, even though the size slightly differs between white and black ones. Thus, the size and color are enough distinguishable by the web camera-based vision analysis. Since the images are captured from above, the player's hand or fingers could hide a part of the board during game play. Thus the system compares multiple images over a certain time period and eliminates the undesirable obstacles.

Regarding touch events, five IR sensors monitor the surface of the touch pane. The IR sensors are attached just next to the information panel, and detect the objects that appear above the

[1]Phidgets Inc. http://www.phidgets.com/
[2]Open Computer Vision Library http://sourceforge.net/projects/opencvlibrary/

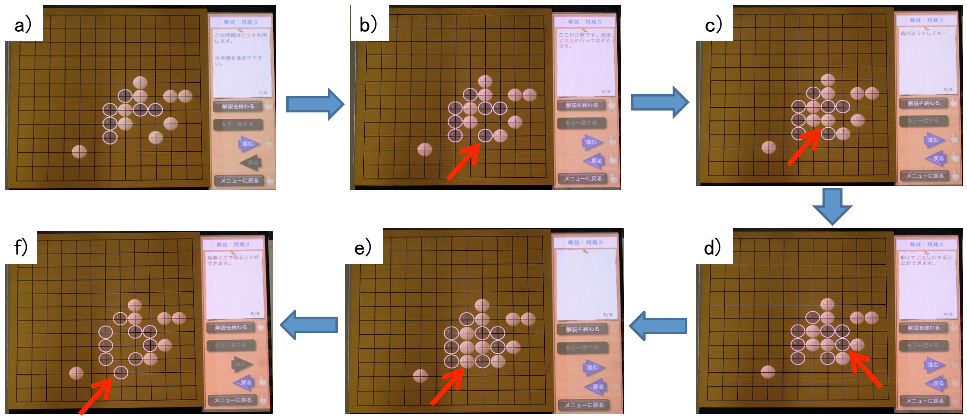

Fig. 4. Demonstration of a correct sequence in the Tsumego mode. White and black stones are placed in turn, and the player can remove the opponent's stones by surrounding them with own stones. The red arrow indicates the stone newly placed in the scene. For example, in phase (f), black stones completely formed the territory and white stones inside are removed. The sequence instructs how to form the area without allowing the opponent to notice and escape from the approach.

area. When a player puts their finger in its recognition range, the system immediately detects the touch event. This design allows to decouple sensing hardware and software interface. Thus the virtual buttons can be dynamically arranged and configured whereas hardware buttons cannot. Figure 7 shows the real appearance of ARGo system. In the figure, a game menu is projected and the user can choose the mode by putting a Go stone into one of the circles.

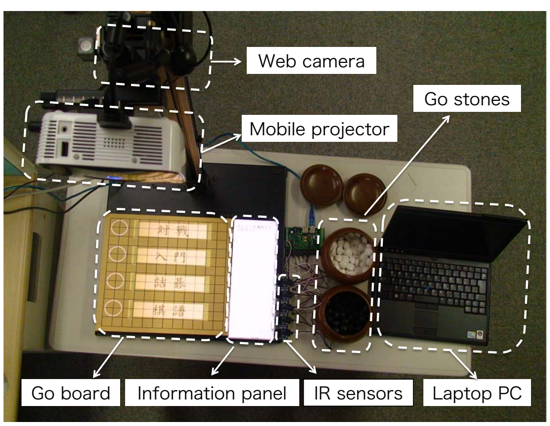

Fig. 7. ARGo hardware setup.

The main software part of the ARGo system was implemented as an Adobe AIR (Adobe Integrated Runtime) application[3]. Adobe AIR offers a runtime library to deploy rich desktop applications on multiple platforms. The ActionScript 3.0 language is used to describe the code, and thus powerful Flash user interface can easily be designed in an application. As the ARGo system provides visual feedback, we applied the Adobe AIR technology to implement both the main game logic and a feedback generator. Moreover, the AIR framework makes it easy to install the application and manage the version of the system. Figure 8 illustrates ARGo system components.

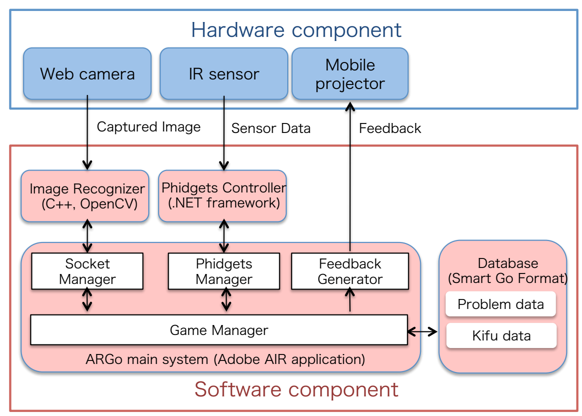

Fig. 8. ARGo system components.

As shown in the figure, the ARGo main system includes Game Manager, Socket Manager, Phidgets Manager, and Feedback Generator. Game Manager is the heart of entire system and controls other components based on the game logic. All services, such as the Joseki mode and the Kifu mode, are implemented in the component and change modes according to the current player's choice. Socket Manager handles a connection from/to Image Recognizer. As we implemented the vision recognition function as a separate module from the main system, communication needs to be mediated by Socket Manager. Image Recognizer initializes the web camera and fetches images of the Go board. Then, it invokes the OpenCV library to process the image and analyze the current game situation. Afterwards, the data of the Go stone position is transmitted to Game Manager through Socket Manager.

Phidget Manager communicates with Phidgets Controller that sends commands to the IR sensors to detect touch events.

[3]Adobe AIR http://www.adobe.com/products/air/

Phidgets Controller runs independently and periodically notifies raw sensor data to Game Manager. If the sensor value exceeds the preliminary configured threshold, a touch event is triggered and Game Manager recognizes it as an explicit input from the player. Based on the game mode and situation, Feedback Generator changes the visual appearance of Flash GUI of the main system. In order to prevent from reflection of the projected light, the GUI window is designed based on black background. Lastly, game data, such as Go problems data and game events data are stored into the database. We applied smart game format (SGF)[4] to represent the game data. SGF is a text-based file format and designed to record a game event sequence of two players board games in a unified manner. For example, SGF is the most popular format to save game records in web-based Go services. SGF allows to maintain complex game flows easily, and we also can reuse Go problems that are offered by other services.

IV. Evaluation

In this paper, we conducted a user study to evaluate the effect of the AR-based self-learning by comparing from the conventional PC-based e-learning. As we mentioned in Section II, the traditional playing style would involve advantages in its physical interaction. Physical interaction with the game apparatus enhances user experience and emotional engagement. Therefore, intrinsic motivation towards self-learning would increase more than completely digital interaction. Moreover, tactile stimuli would support knowledge acquisition and skill development by activating brain functions.

A. Method

In order to compare the ARGo system with the conventional e-learning, we developed an extra PC game mode in the system. The ARGo system was developed as an Adobe AIR application, and thus it can also run on a PC with offering exactly same contents with the AR mode. In the PC mode, we replaced the physical interaction with the conventional mice and keyboards-based interaction. Figure 9 shows screenshots of the PC mode.

Fig. 9. Screenshots of the PC mode used in the user study (left side: Tsumego mode, right side: game menu).

We gathered 18 volunteer subjects in the study (male: 17, female:1, age:21-32). All subjects were novices who did not have preliminary knowledge about the game of Go. They knew the term Go, but did not know the rules and basic strategies.

Firstly, we asked questions to preliminary investigate the subjects' knowledge and interest in the game of Go. Then, a human instructor explained the basic concept and Go rules to the subject. This process was conducted interactively so that the subject could ask questions as the need arises. After the preliminary instruction, the subjects proceeded to a self-learning phase. The self-learning phase aimed at evaluating the learning effect on the AR and PC modes, and the subjects were randomly assigned to either one of two groups. For example, group A tried out the AR mode, while group B used the PC mode first. We prepared several topics related to basic rules and strategies, and the subject could learn them at their own pace. After completing the teaching material, we examined the level of understanding and acquired knowledge. Then, the subjects proceeded to the system comparison phase. We prepared the phase in order to compare user experience between the AR and PC modes. For example, the group A was asked to use the PC mode after the AR mode, even though we only used the first test results to assess the efficiency of learning support. The amount of problems and instructions were exactly same in these modes. We asked some questions after every test to record the subjects' impression and comments on the ARGo system.

We designed a part of the questionnaire based on the Intrinsic Motivation Inventory (IMI)[5] to assess the subjects' motivation towards self-learning. The IMI consists of multidimensional scales that aim at measuring participants' subjective experience related to an activity performed in laboratory experiments. The IMI is used in the context of sport and exercise, such as a basketball shooting task and participation in aerobic dance, for example. We focused on four subscales in the IMI: *interest/enjoyment*, *pressure/tension*, *perceived competence*, and *value/usefulness*. Every question belongs to one of the subscales, and the level is represented by 7-point Likert scale. For example, the question #1 is *"I thought playing Go was quite enjoyable"*, which was originally *"I thought this activity was quite enjoyable"* in the IMI. This question belongs to the interest/enjoyment subscale. The answer *"not at all true"* was mapped to 1 point, and 5 points represent *"somewhat true"* whereas *"very true"* was scored by 7 points. We prepared 19 questions based on the IMI and show the results in the next section. In order to prevent the framing effect, some questions are stated in negative styles (e.g., *"I thought this was a boring activity"*). In this case, the answered score is reversed to calculate the average of the questions in a subscale.

B. Results

We summarized the user study results from three aspects: intrinsic motivation for self-learning measured by the modified IMI subscales, user experience brought by the ARGo system, and learning performance analysis based on system logs.

[4]SGF File Format http://www.red-bean.com/sgf/

[5]Intrinsic Motivation Inventory http://www.psych.rochester.edu/SDT/measures/IMIdescription.php

1) Intrinsic Motivation for Self-Learning: Figure 10 shows the averaged scores and its standard deviation (SD) acquired from the results of modified IMI questionnaire.

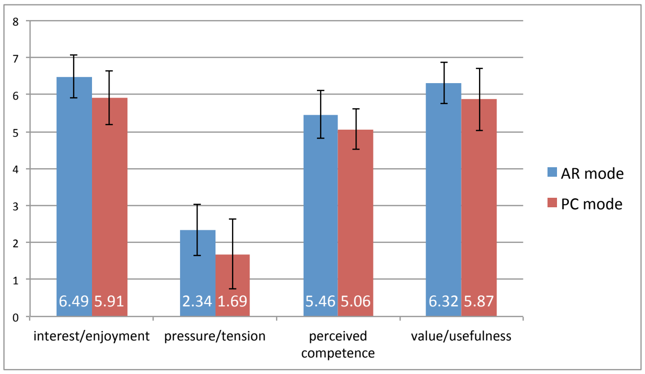

Fig. 10. IMI subscale scores.

Regarding positive subscales, such as *interest/enjoyment*, *perceived competence*, and *value/usefulness*, the AR mode scores were superior to the PC mode. The *interest/enjoyment* subscale is mainly considered the self-report measure of intrinsic motivation, thus the result indicates that AR-based self-learning derived more intrinsic motivation than PC-based e-learning in the study. Other subscales also supported this result, for example the subjects found greater *value/usefulness* in the AR mode. However, the AR mode also scored higher *pressure/tension* in the study. Handy interaction in the PC mode might cause this result, we discuss the reason in Section V.

2) User Experience: In order to investigate the user experience brought by both learning modes, we asked several questions to the subjects. Table I summarizes the questions and averaged scores. We also asked reasons and comments in the free-writing style to survey the detailed reasons.

TABLE I. USER EXPERIENCE COMPARISON BETWEEN AR MODE AND PC MODE (5-POINT LIKERT SCALE, 5: STRONG AGREE, 1: STRONGLY DISAGREE).

	Question	Average score
Q1	I deeply considered to solve a problem in the AR mode, rather than the PC mode that offers mouse click-based interaction	4.28
Q2	I enjoyed self-learning tasks in the AR mode better than the PC mode.	4.39
Q3	I had higher concentration in the AR mode than the PC mode.	4.11
Q4	I felt frustration in physical stone manipulation by hand.	3.72
Q5	Go stone recognition error prevented from learning process.	3.94
Q6	Time lag in stone recognition prevented from learning process.	3.44
Q7	I could intuitively recognize the information and virtual Go stones projected onto the Go board.	4.89
Q8	I could intuitively use ARGo system in the AR mode.	4.72

The Q1 aimed at studying the thinking process difference between the two modes. The AR mode induced to think deeply to the solve problems given in the experiment. Some subjects commented *"I felt as if playing a real game in the AR mode, and the sense of reality promoted consideration"* and *"I felt as if playing with a real human player, so I could concentrate on the learning"*. An interesting comment was that *"As handling (i.e., grasp and replace) real stones in the AR mode is somehow boring, I started elaboration not to make a mistake"*. The PC mode offers mouse-based instant interaction, thus the subject could easily undo/redo the process. However, as the AR mode uses real Go stones, the subject needed to remove and place them manually once they made a mistake. The cost of motions induced higher elaboration, whereas at the same time frustrated the subject (Q4). A subject also commented that *"I could have longer time to think the answer as each physical interaction was performed slower than mice-based one"*.

The Q2 indicates the AR mode made the self-learning process playful. We found that physical interaction with the original game apparatus enhanced emotional engagement. 16 subjects mentioned that putting stones by hand increased the pleasure of the learning process. They also commented that the original game apparatus produced the real atmosphere of the Go game. In Q3, the subjects also agreed that the AR mode induced higher concentration. Physical interaction was the main reason, as hands-on stone manipulation was supported by 15 subjects. As the Q5 and Q6 scores indicate, we could not find significant negative influence in the augmented interaction. For example, the error rate and delay in the stone position recognition were still acceptable to most subjects. The Q7 and Q8 scores also implicate that the ARGo system design was proper enough to study the game of Go. Superimposed information was nicely integrated and did not interfere with the learning process.

C. Self-Learning Efficiency Analysis

Regarding the efficiency of learning support, we only used the first test results as we wanted to equalize the baseline of knowledge level among all subjects. We could expect that a subject would acquire certain amount of knowledge after the first trial, thus ignored the second test results on purpose (it was only used to compare the usability of two modes). The subjects who studied with the AR mode correctly answered 12.1 out of 14 questions on average (*SD=1.76*), whereas the group who studied with the PC mode scored 12.67 points (*SD=1*). The result shows that the PC mode support was slightly superior to the AR mode, but we did not find significant difference in terms of the efficiency difference between two modes. Probably the user study period was too short to assess self-learning performance, thus we will plan long-term evaluation in the future work.

We also investigated system logs to analyze the detailed interaction in the self-learning process. The subjects spent 37 minutes on average, whereas the AR mode took 1 hour and 2 minutes (about 1.7 times time period of the PC mode). In the learning process, we prepared 10 intermediate tests to periodically check the subject's level of understanding. The subject could repeatedly try the same test until they could manage to provide correct answers to the system. Even if they failed the test, the system allows them to check the correct answer with detailed explanation. We recorded the time period during the subjects remained on the test pages and the number of explanation check. Table II summarizes the statistics of the self-learning processes in the user study.

TABLE II. STATISTICS OF SELF-LEARNING PROCESSES

Game mode	Learning time period on the test pages (sec)	Number of retrials	Number of explanation check
AR	1105	12.6	1.1
PC	524	7.4	2.6

The AR mode took about twice as long to complete all the intermediate tests in the PC mode. Physical interaction and response time corresponding to stone recognition would be one of the main reasons. Moreover, as the *number of retrials* and *number of explanation check* indicate, the AR mode encouraged to retry the test without checking correct answers and explanation. As previously mentioned, physical interaction induced deeper concentration and higher elaboration. The AR mode affected the subject's attitude, and it resulted in behavior change.

V. DISCUSSION AND FUTURE WORK

In this paper, we have attempted to keep the original look-and-feel of traditional games as much as possible. Our approach maintains physical interaction with the game apparatus while other research work often replace them with digital devices. We expected that the augmented physical interaction brings pleasurable user experience and directs more attention towards a learning activity, whereas the self-learning process easily gets boring. Tactile stimuli that the player perceives during the game play would facilitate memory consolidation, and moreover it offers the sense of immersion. The augmented feature can be instantly removed as we used the original game apparatus. It allows the user to easily adapt acquired knowledge and skills to practice without any extra efforts.

The user study was not long enough to demonstrate the learning efficiency improvement, but the AR-style game play successfully enhanced intrinsic motivation towards the self-learning process. We expect that higher intrinsic motivation would bring sustainable attention and effort in long-term self-learning. Moreover, according to the subjects' comments, real game apparatus also induced deeper concentration and higher elaboration on problem solving. Visual feedback was seamlessly integrated to the Go board and the subjects could easily understand the situation. We also offered a secondary user interface with touch interaction, and it helped to explicitly control the learning progress by hand.

In the future work, we will improve the system design based on the below discussions. We aim at generalizing the concept of augmented traditional games to cover a wide range of learning activities, including non-gaming application domains. As a limitation of user study, the results should be carefully generalized as it would depend on the Go game's unique form factor and playing style. Moreover, a long-term study is required to evaluate the effect on efficiency improvement. We will also work on more robust, miniaturized, and easy-to-configure setup to complement the shortcomings of current ubiquitous computing services.

A. Interaction Cost Design for Attitude Change towards Higher Elaboration

Digital user interface is useful to manipulate information by eliminating physical restriction, such as time and space. Mice-based interaction allows to instantly create, copy, replace, change, and dispose information with small move. Thus the user is expected to improve the efficiency in learning by allocating more cognitive resources and attention towards essential tasks. As we found in the user study, however, smaller interaction cost does not necessarily induce higher elaboration. People tend not to carefully consider a problem if they can instantly redo and undo their actions with small cost. Even though an incorrect decision is taken, the user can check the correct answer and immediately retry the problem. In fact, we could see the behavior trend in the PC mode study mentioned in Table II.

The user study results indicated that the *interaction costs* originated in the physical interaction influenced the learner's attitude and behavior. In [12], Heidi proposed the concept of interaction costs as a framework in information visualization. The framework distinguishes seven types of costs based on the user's action stages in an interaction. For example, the *cost of view changes* emerges as a main issue at the *interpret perception* stage, since the user needs to re-interpret perceived information each time the view changes. In general, mice-based interaction involves less *cost of motions* at the *execute physical sequences* stage than the physical interaction. The user directs less attention towards a motion as the involved costs decrease, however, it could prevent from allocating enough time for elaboration. Particularly in the case that the learner acquires skills in a complicated problem domain, such as the Go strategy, they should carefully consider the place to put the next stone with foreseeing possible counterattack. This requires highly intelligent elaboration, and the user cannot easily advance to the automated skill-based response level [16].

In augmented traditional games, tangible objects are not simply treated as a controller or user interface, but as the information to be controlled. Whereas digital information can be controlled by single mouse click, the learner needs to place and remove Go stones by hand. It could frustrate them as implicated in the *pressure/tension* subscale in Figure 10. However, proper burden on a motion contributes to perform a careful action. The system designer can choose which part of the traditional interaction is replaced with digital devices. As the digital part increases, the system's stance on the Milgram's Reality-Virtuality continuum gets closer to the VR end [14]. It depends on the type and characteristics of the game, but the designer should consider attention and elaboration level required by the learning process. Physical objects would realize dynamic manipulation and assist in intuitive information acquisition. Moreover, the physical interaction would induce higher elaboration whereas the interaction cost of motions increases.

B. Spatial Interaction Design for Augmented Realities

One of the most important factors of the traditional game playing style can be explained by the term *ma*; it is a Japanese word that represents distances among objects in a space [7]. The term *ma* is originally used in art and design, but it also can be used in a wider range of activity domains, such as martial arts and theatrical performances. In martial arts, players adjust the distance to an opponent in order to keep their own territory to take good offense and defense. In theatrical performances, actors and actresses coordinate the timing of actions in order to make a great impression to audiences. The *ma* includes concepts of spatial distance, gap and pause, so both physical and mental distances among game objects including human players can be represented in this single word. At the same time, it is hard to reproduce the *ma* in digitalized games, since the *ma* is total information that players perceive in physical interactions.

In the user study, the subjects perceived information from the flat Go board. We originally focused on the differences between physical interaction and mice-based interaction. However, after the user study, we started to consider that the AR mode also offered spatial stimuli even though the board with Go stones looks almost flat. The size of the real board is different from the digitally illustrated one in the PC mode. Moreover, the angle and distance from the user's viewpoint also differ. Both a Go board and a PC display direct a user's attention to the certain size of square area, but these spatial design factors would influence the sense of reality perceived from the entire system. Moreover, the thickness and the shadow of real stones would contribute to recognize spatial information, such as visualized territory shown in Figure 5. As we conducted the user study only on fundamental strategy learning, further comparative study is required to investigate the legibility of spatial information.

According to the questionnaire (Q7), the subjects could intuitively recognize two-dimensional virtual stones, thus the both real and virtual stones could successfully coexist in the ARGo system. The system applied a mobile projector to provide visual feedback, and did not force additional devices such as HMDs on the user. As a drawback, only two-dimensional feedback can appear on the board, whereas see-through displays allow to perceive three-dimensional information. As Go is almost two-dimensional board game, our approach suitably fit and worked enough to implement the concept. However, other games or non-gaming activities except board games use a spatial field. For example, darts require to throw a dart from the line distanced from a dartboard. Darts support system would show an ideal trajectory of a flying dart in a space so that the user can bodily adjust throwing form. However, three-dimensional projection is still not commercialized yet and requires large-scale setup in the room. In this case, the system should deploy a HMD as it is a realistic approach to superimpose the guide information onto the space.

ACKNOWLEDGEMENT

This research was supported by Waseda University Global COE Program International Research and Education Center for Ambient SoC sponsored by MEXT, Japan.

REFERENCES

[1] R. T. Azuma. A survey of augmented reality. In *Presence: Teleoperators and Virtual Environments*, pages 355–385, 1997.
[2] E. L. Deci and R. M. Ryan. Intrinsic motivation and self-determination in human behavior. Plenum Publishing Corporation, 1985.
[3] T. Döring and S. Beckhaus. The card box at hand: exploring the potentials of a paper-based tangible interface for education and research in art history. In *TEI '07: Proceedings of the 1st international conference on Tangible and embedded interaction*, pages 87–90, 2007.
[4] M. R. Endsley. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 37(1):32–64, 1995.
[5] M. Fjeld, J. Fredriksson, M. Ejdestig, F. Duca, K. Bötschi, B. Voegtli, and P. Juchli. Tangible user interface for chemistry education: comparative evaluation and re-design. In *CHI '07: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 805–808, 2007.
[6] S. Hinske and M. Langheinrich. W41K: digitally augmenting traditional game environments. In *TEI '09: Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*, pages 99–106, 2009.
[7] T. Iimura. A Note for MA: Space/Time in the Garden of Ryoan-Ji. *MILLENNIUM FILM JOURNAL*, 38, 2002.
[8] H. Ishii and B. Ullmer. Tangible bits: towards seamless interfaces between people, bits and atoms. In *CHI '97: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 234–241, 1997.
[9] D. Johnson and J. Wiles. Effective Affective User Interface Design in Games. *Ergonomics*, 46(13 & 14):1332–1345, 2003.
[10] H. Kaufmann and B. Meyer. Simulating educational physical experiments in augmented reality. In *ACM SIGGRAPH ASIA 2008 educators programme*, 2008.
[11] K. Kubota. *Hand and Brain (Te to nou - nou no hataraki wo takameru te).* Kinokuniya book store, 1982.
[12] H. Lam. A framework of interaction costs in information visualization. *IEEE Transactions on Visualization and Computer Graphics*, 14(6):1149–1156, 2008.
[13] C. Magerkurth, A. Cheok, R. Mandryk, and T. Nilsen. Pervasive games: bringing computer entertainment back to the real world. *Computers in Entertainment*, 3(3), 2005.
[14] P. Milgram, H. Takemura, A. Utsumi, and F. Kishino. Augmented reality: A class of displays on the reality-virtuality continuum. In *Proceedings of the SPIE Conference on Telemanipulator and Telepresence Technologies*, pages 282–292, 1995.
[15] S. Price, Y. Rogers, M. Scaife, D. Stanton, and H. Neale. Interacting with Computers : Using 'tangibles' to promote novel forms of playful learning. *Interacting with Computers*, pages 169–185, 2003.
[16] J. Rasmussen. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics*, 13(3):257–266, 1983.
[17] L. Terrenghi, M. Kranz, P. Holleis, and A. Schmidt. A cube to learn: a tangible user interface for the design of a learning appliance. *Personal and Ubiquitous Computing*, 10(2-3):153–158, 2006.
[18] L. Xie, A. N. Antle, and N. Motamedi. Are tangibles more fun?: comparing children's enjoyment and engagement using physical, graphical and tangible user interfaces. In *TEI '08: Proceedings of the 2nd international conference on Tangible and embedded interaction*, pages 191–198, 2008.
[19] J. Yamashita, H. Kuzuoka, C. Fujimon, and M. Hirose. Tangible avatar and tangible earth: a novel interface for astronomy education. In *CHI '07 extended abstracts on Human factors in computing systems*, pages 2777–2782, 2007.