Device-Free Personal Response System based on Fiducial Markers

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Abstract—Conventional student response systems require electronic devices for collecting personal responses, such as, wireless RF remote keypads, portable handholds, PDAs, tablets, and cell phones. Although these devices are becoming inexpensive and popular, their management causes additional burdens for teachers and students. We propose a method of collecting student responses by means of printed fiducial markers and tracking technology based on computer vision. Students can submit a response by holding up their marker sheets. Teachers can continuously track and record the responses using personal IDs in real time. Multiple choice question and 2D positioning implementations are presented. We confirmed the tracking capacity of our system through an experiment with 19 participants.

Keywords—student response system; clicker; visual tag; 2D matrix code

I. INTRODUCTION

To realize interactive learning that facilitates communication between teachers and students during classroom lectures, several systems have been investigated and implemented. Liu et al. [11] proposed a wireless technology enhanced classroom that supports everyday activities in a classroom context. Roschelle and Pea [19] described the potential of wireless Internet learning devices. These approaches are promoted by progress in wireless networking technology and the widespread use of mobile or handheld devices that can connect to the Internet. Student response systems, for example, clickers such as those from EduClick [12], are popular in classroom settings as tools for facilitating interactivity between a teacher and learners. The advantages of a clicker system even in large classrooms containing approximately 200 students have been investigated [13], and the benefits and effects of interactivity have been established.

Most student response systems require the use of electronic devices for collecting personal responses, such as, wireless RF remote keypads, portable handholds, PDAs, tablets, and cell phones. Although these devices are becoming inexpensive and popular, they must be managed for practical lectures in educational settings. The resulting diminished benefit of such a system in larger classes is a disadvantage. If we could collect student personal responses without the use of such devices, the benefits of an interactive lecture system would be enhanced.

In this paper, we propose a method that realizes a device-free student response system by introducing fiducial marker recognition technology.

II. PROPOSED METHOD

To reduce the burden of student device management, we propose a method and architecture for a device-free response system based on fiducial markers, which are also called two-dimensional matrix codes or visual tags. Fiducial markers are commonly used to embed URLs or specific identification data on paper and realize augmented reality (AR), for example, to overlay three-dimensional CGs on a real-world view [1, 2].

Fiducial markers are also widely used in learning contexts. Asai et al. presented a tangible navigation system for learning the lunar surface [4] and a haptic AR environment that transmits vibrations to a learner’s hand [5]. Juan et al. used a similar technology to implement a tangible cube interface for edutainment [6]. Martín-Gutiérrez et al. applied this technology for learning by mechanical engineering students and provided an educational toolkit [7]. However, the technology has not been applied in student response systems that require tracking of large numbers of markers. We employ fiducial markers to collect personal responses from students in a conventional classroom.

Fig. 1 shows the typical usage of the proposed architecture. At the beginning of the lecture, a teacher distributes an AR fiducial marker sheet (Fig. 2) to each student. Since the marker IDs differ, they can be used to identify students. When the teacher poses a multiple choice question, students respond by holding their visual marker sheets up to the teacher’s camera. The camera continuously captures an image of the markers. Using marker tracking technology, the position, orientation, and ID of each marker sheet can be obtained. The system can identify the orientations as student responses. For instance, the four orientations of the fiducial marker sheet (upside-top, upside-left, upside-right, and upside-bottom) can be clearly distinguished by the AR tracker. Thus, the system can automatically analyze and identify the students’ responses.
A. Interaction Techniques

Two methods of associating data with responses are typically used. One is a discrete response, such as associating the answers to multiple choice questions with each of the four directions named above. The other is a continuous response that uses the value of position and orientation data as completely as possible. Considering these methods, we propose two types of interaction techniques that use the position and orientation data.

1) Response for Multiple Choice Questions: As described above, the rotation of the marker can be used to identify discrete responses to multiple choice questions. We consider four responses to be sufficient for typical multiple choice questions. However, when more choices are available, such as all one-digit numbers (0–9), the system must support multiple marker sheets belonging to a student. Alternatively, we should separate the rotation into more than four possible responses or use “response by pointing” as described below.

Although the rotation dimension (roll) is used, the pitch and yaw dimensions are available for transmitting information. Pitch represents the elevation angle, and yaw represents the heading angle (Fig. 3). They can be mapped to responses indicating students’ attitudes such as self-confidence and motivation. However, the use of additional positional data should be carefully designed by using feedback because the data may reduce the stability of the responses.

2) Response by Pointing: Using pitch and yaw position data, students can specify a 2D position on a single projected display. If proper visual feedback is given, students can control their pointers by changing the yaw and pitch, which are related to the X- and Y-axes, respectively (Fig. 4). Because the position is determined by the relative coordinates, no previous calibration is needed.

An interaction technique similar to “multiple mice” is effective; earlier studies revealed the benefits of social pointing/positioning tasks [9, 10]. Chang and Chen [8] compared competitive/cooperative and individual/group conditions in social single display tasks with multiple mice. In contrast, our system lacks mouse buttons. Hence, we must consider a clicking/selecting method within our architecture. In addition to the above two interaction techniques, the system can use the position data to extract additional information. For example, the seat location can be estimated and used to assess motivation and attendance [20].

B. Benefits

The primary benefit is the reduction in the burden and time required for managing electronic devices. Previous response systems require special electronic devices for each student. The distribution, collection, and management of these devices and the need to consider battery consumption during every lecture session cause a burden for teachers and lecture organizers. The system in our proposed method requires only fiducial marker paper sheets for collecting personalized responses. Once a teacher distributes marker sheets associated with each student, the teacher can let the students manage their sheets during the course term. Paper is light, stable, flexible, inexpensive, and easier to reproduce than electronic devices. Although the marker is printed on a cardboard sheet, the sheet weighs less than a celluloid sheet. If a marker sheet is stained or lost, a student can easily reproduce it because it can be printed by an ordinary printer. Thus, the burden introduced a student response system is minimized for both teachers and students.

The secondary benefit is the system’s simplicity. Teachers are required to use only a PC and at least one camera. Of course, the camera’s resolution is important for proper tracking of multiple fiducial markers. However, high-resolution cameras are becoming inexpensive. When many markers must be recognized, teachers can introduce additional cameras and PCs. Thus, the system is scalable and flexible.

As [13] discussed, one of the benefits of conventional clickers is that they maintain anonymity. Students can respond freely even if they are unsure of their answers. Our approach can also provide anonymity because the fiducial markers are difficult for humans to identify. Moreover, we
provided markers are fixed; the maximum number of fiducial markers with relatively few computations. The AR ToolkitPlus [3] as the tracking engine. AR ToolkitPlus is C.

Anonymity is sacrificed. A colored marker sheet can be easily implemented, although the teacher wants to view the status of student responses directly, the camouflage mechanism that prevents explicit disclosure of student responses (section III). When the teacher wants to view the status of student responses directly, the colored marker sheet can be easily implemented, although anonymity is sacrificed.

C. Disadvantages

One of the major disadvantages of this system is recognition failure caused by occlusions and insufficient lighting. To prevent occlusions, the camera should be mounted at an appropriate height. In some lectures with a projection screen, teachers tend to dim the classroom. Dim conditions increase the recognition failure rate. To prevent this problem, additional light sources should be introduced. If limited lighting is inevitable, it is necessary to bring a source of invisible light, such as an infrared lamp.

In the proposed architecture, the camera’s resolution is important, and the recognition of high-resolution camera images increases the load on the teacher’s PC. The load for processing the image may decrease the tracking refresh rate. However, the system does not require an extremely high refresh rate because the final responses are confirmed only at the end of the quiz period. In comparison with popular clicker systems, the system architecture provides a limited number of responses. Because there is no feedback mechanism, students cannot confirm whether their responses are accepted properly. Therefore, teachers should prepare a projection screen to show the status of responses during the period. However, PCs and projector configurations are popular, and they are also commonly required in conventional clicker systems.

III. IMPLEMENTATION

We implemented our response system by adopting AR ToolkitPlus [3] as the tracking engine. AR ToolkitPlus is an AR tracking library that can recognize a large number of fiducial markers with relatively few computations. The provided markers are fixed; the maximum number of identical markers is 4096. However, no registration is necessary. QP Toolkit [18] is an alternative for a limited number of tags.

To capture images, we used two IEEE 1394 high-resolution cameras (PGR Scorpion SCOR-20SOC-KT, 1600 × 1200 pixels). To obtain the best image quality, two IEEE 1394-PCI interface cards were installed in a PC (Pentium 4, 3.8 GHz, 2-GB memory).

Our system consists of a recognition module and a user interface module. The recognition module, which processes captured images from the IEEE 1394 camera, was written in Visual C++ with libraries provided by Point Gray Research Inc. The recognition module implements the Java Native Interface (JNI). The user interface module is written in Java SE with the Piccolo2D graphic library, and it accesses the recognition module via the JNI. When the user interface module requests scanning, the recognition module calls a method with a set of IDs and a translation matrix. Then, the user interface module displays the responses on the screen.

Figs. 5(a) and (b) show the response feedback views for students and a teacher, respectively. This view includes student labels that display student IDs and names as fundamental notification data. When the view is in the multiple choice question (MCQ) mode, a response character is shown at the upper right of each label. The original response characters for MCQ mode are “A,” “B,” “C,” and “D.” However, explicit visual feedback includes student names and reveals the responses of all students. It may thus increase students’ anxiety during a quiz. Therefore, we introduced a camouflage feedback mechanism. When the view is in the camouflage feedback mode, one of the characters aligned with the top edge of the fiducial marker (we call these camouflage response characters) is randomly selected and displayed instead of the original response character. The camouflage response characters are also randomly assigned from E to Z for each student and marker orientation. Thus, a student cannot easily recognize identify others’ responses at a given time. The camouflage response characters are set in advance when the marker sheets are printed. The students can find their own camouflage response characters on their marker sheets (Fig. 2).

A teacher can view the colored response feedback view (Fig. 5(b)) which corresponds to the student view (Fig. 5(a)). Therefore, the teacher can recognize the student responses intuitively. In addition, the teacher can sort the student label order in both student and teacher views by either submission time or student ID under the response grouping condition (Fig. 6) or the nongrouping condition (Fig. 5(b)). The ID-sorted view helps students to locate their responses, and the time-sorted view allows teachers to determine the fastest submitted response among a group of students.

In the response by pointing mode, the student label appears similar to a mouse cursor (Fig. 7). Students control the pitch and yaw of their sheets to specify the 2D positions on the screen. After specifying the position, a student can stop holding up the sheet.

IV. PRELIMINARY EXPERIMENT
To verify the marker tracking scalability of the system, we tested the recognition module with a marker visualizing system. We asked 19 participants to hold up a marker sheet and tested the MCQ and pointing modes in a small lecture room. We set two cameras in the room, one in front of the screen and the other in the middle of the lecture room. Fig. 8 shows the experimental setting. The system could successfully track the direction of 18 of 19 markers in the MCQ mode, but the pointing mode did not work well owing to the low stability of the position data caused by distance from the camera. We need to reconsider the calculation method of position-to-pointer mapping in light of pointer stability.

V. RELATED WORK

Cinematrix Interactive Entertainment System [14, 15] captures audiences holding small green and red reflective paddles and recognizes the number of paddles of each color to realize interactive mass feedback. Maynes-Aminzade et al. [16], inspired by this approach, presented several methods of implementing a large audience entertainment system based on computer vision. Domingo et al. [17] proposed a similar solution to capture audience emotions with blue and white shakers for the 2004 Olympic games. These techniques are effective for mass responses from large audiences such as those in stadiums or theaters. However, they do not allow the identification of individual responses. We propose a method of identifying both the audience and the response under classroom conditions.

VI. CONCLUSION AND FUTURE WORK

Since Japan’s 3/11 disaster, teachers and lecturers in Japan are required to improve learning methods by introducing good practices and ideas under a tight budget. We proposed a method of facilitating interactive lectures by introducing student responses without costly devices. We presented fiducial marker sheets, which can be used to collect student responses and student IDs. The inexpensive sheets and fiducial marker tracking technology enable teachers to introduce interactive lectures without managing student devices.

The device-free method reduces the burden on both teachers and students in terms of device management and
daily operation. In particular, teachers can use the time saved to develop a teaching method, including the learning content and materials. We believe that this is the essence of improving learning and education.

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