A Simple Sheet Bending Recognition for Augmenting a Two-dimensional Marker-based Response Analyzer

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***Abstract*—**
Conventional response analyzers use various student devices such as clickers and mobile devices, which require the additional burdens of charging and managing. Fiducial marker-based response analyzers have been proposed to relieve these burdens. The IDs and rotations of the fiducial markers are used to identify students and their respective answers. The marker-based approach is straightforward, but transferrable data are limited to the ID and the rotations. To enhance the transferrable data, we introduce a method of extracting curves of the marker sheet. Since a paper sheet is flexible, students can control the shape of the sheet intuitively. We have implemented our method by modifying a conventional fiducial marker recognizer and confirmed its effectiveness.

I. Introduction

Research and development of response analyzers have been conducted to achieve interactive learning that enhances communication between teachers and students [1], [2]. EduClick [3] is a popular clicker tool for facilitating interactivity between teachers and students. The advantages of a clicker system, even in large classrooms containing approximately 200 students, have been investigated [4], and the benefits and effects of interactivity have been established.

A clicker tool uses wireless radio frequency (RF) remote keypads for student devices. Other studies that achieve enhanced communication between teachers and students also use portable handhelds, personal digital assistants, tablets, and cell phones. Although these devices are becoming inexpensive and popular, they must be managed for practical lectures in educational settings.

Device-free response systems based on fiducial markers have been proposed to reduce the burden of student device management [5], [6]. A device-free response system based on fiducial markers uses multiple student-response-marker sheets and teacher cameras to capture the markers. Each student response marker has a unique identifier (ID). Basically, such a system can recognize the rotation (Roll in Figure 2) of a marker image, as well as the marker ID. If the marker sheets were distributed previously to the students, the rotation (orientation) of the marker can represent answers to multiple-choice questions. Moreover, the pitch and yaw (see Figure 2) points to the screen, like a mouse (see Figure 3). Thus, the system is an alternative to a response analyzer, which tracks and records students' responses.

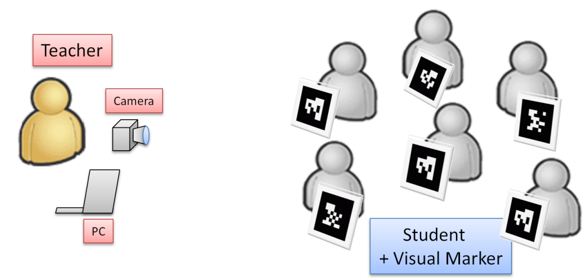

Fig. 1. Overview of a device-free response analyzer system based on fiducial markers [5]

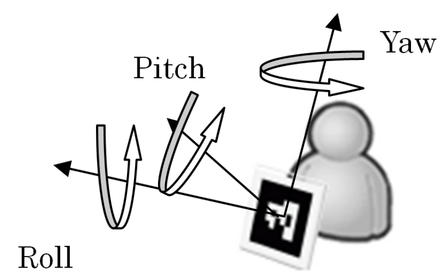

Fig. 2. Posture of a student marker sheet in [5]

AwareResponse (Figure 1) uses a two-dimensional matrix code technique for achieving augmented reality (AR) [7], [8]. Cross et. al. [6] developed a specialized fiducial marker system recognizer called qCard. They reported that the accuracy and speed of the proposed recognizer, as well as the cost, compared with a clicker system. We believe that the device-free response systems based on fiducial markers become important because of their simplicity, low-cost, and low management requirements.

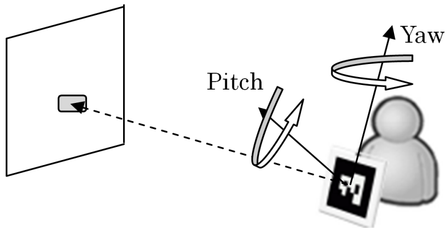

Fig. 3. Screen pointing method proposed by [5]

II. Problems of the device-free response analyzer method

As described above, the device-free response analyzer method is simple and inexpensive. However, the method has disadvantages with increased numbers of responses. Typical student devices such as RF remote keypads provide many keys. Combination of the keys can enhance the number of responses without raising special concerns. For a device-free response analyzer, the possible responses are posture (roll, pitch, and yaw) and position (x, y, and z) relative to the camera. The number of responses to multiple-choice questions can be increased by assigning smaller rotation angles for each choice. For example, responses to eight choices are achieved by assigning 45 degrees of rotation per choice. However, smaller angles cause higher recognition error rates. We can also overcome this limitation by introducing multiple marker sheets for each student. However, as the number of marker sheets increases, students need to manage more sheets. This management task can disturb their learning process. Therefore, we consider enhancing responses using a single marker sheet.

III. Using "Bend" to enhance response

Conventional device-free response analyzer methods [5], [6] assume that the marker sheet is a solid, plane surface. However, most markers are printed on paper or cardboard. The paper or cardboard sheets are easy to bend or warp, if twisted by students. The physical characteristics of the paper sheets (bending and warping) can be utilized for enhancing responses on a device-free response analyzer. The present study aims to develop a method for detecting bending/warping of paper sheets to augment device-free response analyzers. When the amount of sheet bending/warping becomes available, the system can provide further response feedback from students. Such further response feedback can be used, for example, to convey the students' self-confidence explicitly to the teacher and enrich the communication between teacher and students. Moreover, once the feedback is accumulated, the system can analyze a student's characteristics on the basis of tendency of the log.

A. Design Criteria

We have considered the following four design criteria for developing a method of detecting bending/warping of a marker sheet.

1) A standard web camera has been used for simplicity.
2) The algorithm for estimating the amount of bending/warping must be as simple as possible to reduce additional computational costs.
3) The shapes of the marker sheet need not be captured precisely. However, the method must capture only the amount of bending/warping that is caused by students' actions.
4) There must be no extra devices or sensors embedded in the marker sheets.

For the first design criterion, we could choose elaborate methods such as stereo or depth cameras. Stereo cameras calculate distance to the object using multiple camera images. Depth cameras such as Microsoft KINECT can also detect the distance to an object precisely. Using these techniques, a system can capture the three-dimensional (3D) shapes of a marker sheet and images simultaneously. However, such stereo and depth cameras are still more expensive than conventional webcams. Moreover, these configuration configurations complicate a system. Since the advantages of a device-free response analyzer are its simplicity and low cost, these configurations may reduce the method's utility. Hence, we have used a standard web camera. One of the merits of the single webcam approach is to enable system implementation on smartphones and tablets.

For the second design criterion, we value having less computation. A device-free response analyzer must capture many marker sheets at once and keep track of state changes. Even though computational power continues to grow, the calculation method must be as simple as possible. This criterion is also important for implementation on smartphones and tablets.

The third design criterion is related to the objective of the research. The objective is to develop a method for detecting bending/warping of paper sheets for augmenting device-free response analyzers. Thus, the method need not capture the 3D shapes of a marker sheet. A device-free response analyzer depends on the marker recognition method. Conventional marker recognition methods use the dot patterns printed inside markers to detect IDs. Therefore, the method does not support drastic bending/warping that hides the dot patterns. We focus on partial bending/warping of the marker sheet caused intentionally by students.

The fourth design criterion considers the possibility of sheet enhancement. Bend sensors can detect the amount of bending/warping. Although such sensors are becoming inexpensive, the additional cost of manufacturing special paper sheets must be avoided.

IV. Proposed method

We begin this section with an overview of the conventional ARToolkit recognition method [7]. Then, we describe our proposed method for estimating the bending/warping of marker sheets.

A. Conventional recognition method

An ARToolkit fiducial marker comprises black quadrilateral borders and interior patterns. The ARToolkit recognition process is as follows.

1) ARToolkit finds connected components of pixels with a gray level lower than the threshold parameter.
2) External border contours are extracted from connected pixel components.
3) The four quadrilateral border corners are extracted from the external border contours.
4) The four quadrilateral border corners are used to remove perspective distortion. Then, the interior patterns are recognized by sampling patterns.

B. Extracting the amount of bending/warping

Figure 4 shows typical images of marker sheets captured by a camera. Images (a) through (d) represent planar marker sheets (i.e., no distortion), and images (e) through (h) show marker sheets with distortion.

In an early prototype, we tried to estimate distortion using the standard deviation of the four edge lengths. Edge length can be computed simply from the corner coordinates. The standard deviation works well if a marker ' s and the camera ' s normal vectors are parallel. However, in conditions such as those in Figure 4 (a), (b), (c), and (d), the standard deviation does not represent the distortion of the marker sheets well.

From Figure 4, we see that the distortions of the marker sheets are observed in the curving of the external border contours. Therefore, the system calculates those contours through the following steps.

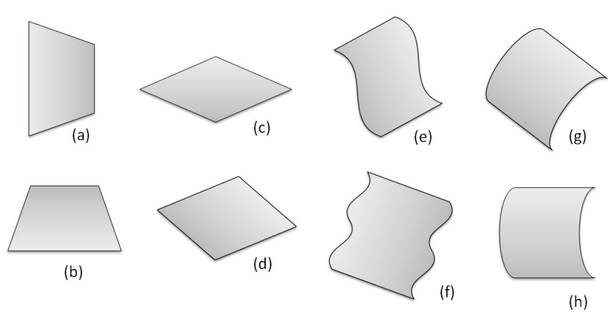

Fig. 4. Typical images of marker sheets captured by a camera

1) Prepare two-dimensional (2D) coordinates for the four corners (C_0, C_1, C_2, C_3) and the external border contours. Note that the 2D coordinates of the external border contours do not include the coordinates of the four corners. As shown in Figure 5, the pixels of the external border contours are adjacent.
2) Compute a line segment from C_0 to C_1.
3) For each pixel of external border contours between C_0 and C_1, calculate the distance from the line segment. (see point P in Figure 5)
4) Sum the distances, and then compute the sum of the distances from the other three edges similarly.
5) For normalization, divide the sum of the distances by the area of the marker images (i.e., pixels of a marker)
6) Take that value to be the amount of bending/warping of the marker sheet, with the amount of bending/warping of the marker sheet becoming zero, when all external border contours are linear.

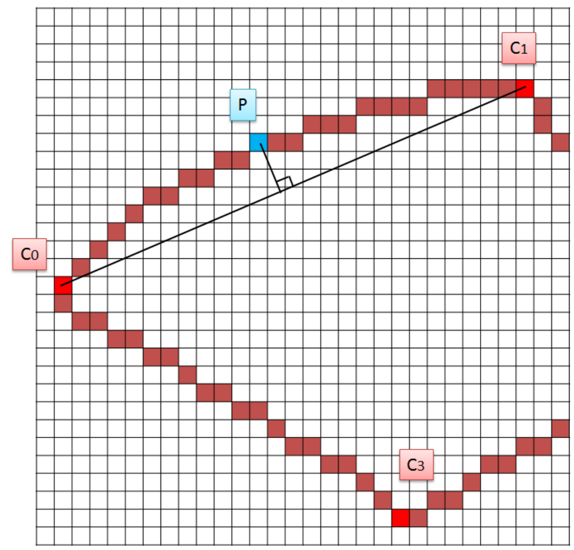

Fig. 5. Distance between a pixel of the external border contour and a line segment

V. Implementation

To verify the method, we have developed a recognition system based on a Java version of NyARToolkit [1]. NyARToolkit is an implementation of ARToolkit. Since all APIs are implemented using classes, the NyARToolkit is superior for extension and modification. In addition, NyARToolkit provides automatic threshold detection and its own serial ID marker system (called NyARIdMarker[2]). The serial ID marker system is especially beneficial for preparing multiple marker sheets for students. Without serial ID markers, registration of each marker image is necessary. Even though NyARToolkit is implemented in Java, its optimized algorithm and sophisticated design contributes to faster recognition of multiple markers, similar to that of the original ARToolkit. Thus, NyARToolkit is suitable for implementation of the device-free response analyzer.

NyARToolkit provides six types of serial ID marker systems, Model2 through Model7. Model2 is the simplest ID system with interior patterns divided into 25 (5 × 5) cells. Model7 provides 225 (15 × 15) cells as interior patterns. In this research, we use the Model2 ID system for the experiment. Model2 provides 512 (0-511) unique IDs, a sufficient number of IDs for assigning marker sheets to students. In addition, Model2 is robust for ID recognition, even if the marker is located far from the camera.

[1] http://nyatla.jp/nyartoolkit/wp/

[2] http://sourceforge.jp/projects/nyartoolkit/docs/standards_document0001/ja/2/standards_document0001.pdf

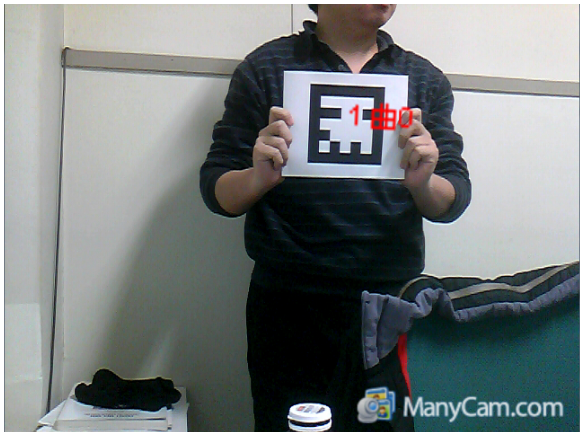

Fig. 6. Planer state (value zero)

Fig. 7. Slight warping (value six)

Figure 6, 7, and 8 show snapshots of our experiments. We used ID 1 of the serial ID marker and bent the marker sheet manually. The first digit represents the marker ID (1) and the last digit represents the amount of marker sheet bending/warping. In Figure 6, the value was zero because the marker sheet was planar. In Figure 7 and 8, the values were six and ten, respectively. We confirmed through the experiments that the proposed method works properly in most cases. However, when the camera did not observe marker distortion, the bending value becomes zero. One possible solution is to introduce a secondary camera to capture the same marker sheet from a different angle.

Fig. 8. Warping (value ten)

VI. Conclusion and Future works

In this paper, we propose a simple method for detecting bending/warping of fiducial marker sheets for augmenting device-free response analyzers. The method calculates the linearity of the external border contours of markers. When the linearity was high, the marker sheet was in a planar state. The method can naturally enhance the number of responses as compared to the conventional method without changing the marker sheets or cameras. Students can control the level of bending/warping intuitively using their hands. Since the algorithm is simple, the additional computational cost is low. Thus, the recognition system can be implemented on smartphones and tablets that have cameras. We confirmed experimentally the method's effectiveness. We intend to evaluate the method by applying it to real learning environments with many students.

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