Towards Smart Classroom: Affordable and Simple Approach to Dynamic Projection Mapping for Education

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***Abstract*—In order to transform the traditional classroom into an interactive space, we developed a projection mapping toolbox: an affordable, simple alternative to complex systems. Our system uses Python and Microsoft Kinect V2 for dynamic projection mapping (PM). We demonstrated three ways PM can be used to make Augmented Reality (AR) applications for classroom use. We projected free body diagrams onto boxes, made AR quiz tacking for teachers, and made an AR game. The goal of the projection mapping toolbox is to help students learn more efficiently and raise academic achievement.**

Index Terms*—*education, smart classroom, dynamic projection mapping, augmented reality, marker tracking

I. INTRODUCTION

Recently, Augmented Reality (AR) and Virtual Reality (VR) platforms have been developed for various applications. AR is an interactive source that allows users to manipulate virtual objects without losing their presence in the real world. Users are less immersed in the virtual world when using AR compared to VR; AR provides a balance between human interaction and virtual elements. Mobile applications or specialized headsets are broadly used to provide AR experiences. Another way of experiencing AR is through projection mapping (PM). Projection mapping is a technique used to transform 3D objects into interactive displays. Users can superimpose graphics on top of dynamic objects, changing its appearance and making them more versatile. Projection mapping creates room scale AR experiences, where users do not need to worry about obstruction from cables or heavy headsets [1]. Room scale AR experiences combined with non-specialized hardware make projection mapping a compelling tool for education.

AR experiences using projection mapping offer great potential for improving education. In the traditional classroom,

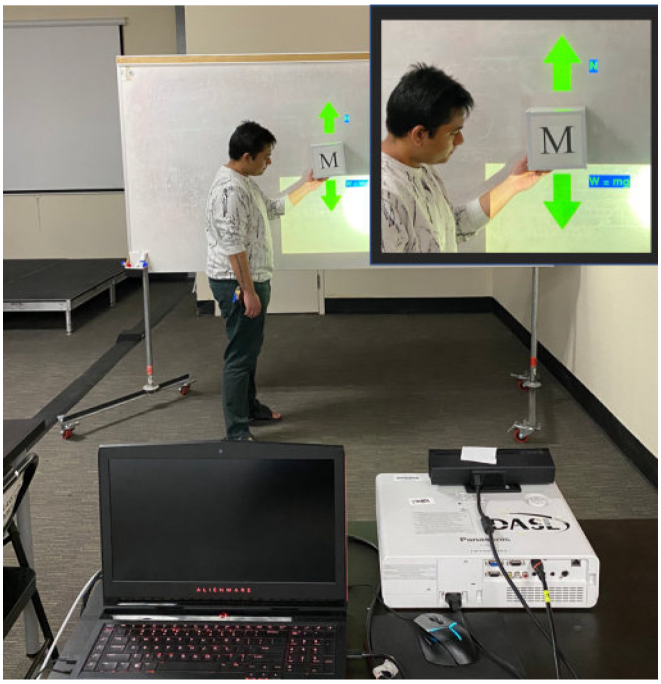

Figure 1: Animating 3D objects using Projection mapping toolbox

students have difficulty visualizing graphics in textbook pages and on computer screens. Giving students a hands-on experience through AR will enhance academic achievement and motivation. Students that are kinesthetic learners will benefit from interacting with physical displays instead of simply viewing diagrams. Studies have shown that having interactive tools in classroom engage students in learning [2]. Currently, the most interactive learning tool in classrooms are SMART

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boards [3]. The SMART board is a combination of projector and computer which is used to display media onto a white board. While it provides great tools for teachers, it does not provide any AR experiences. This paper presents the Projection Mapping toolbox, which aims to make classrooms smart and engaging. This paper is divided into the following Sections, Section II shows related works, Section III shows the experimental setup, Section IV shows the methodology, Section V shows the results and Section VI concludes the work and addresses future work.

II. Related Work

Within the classroom, research has proven the benefits of projection mapping to education; overall, the use of AR leads to better communication, collaboration, and engagement compared to traditional teaching [4]. AR has been used to teach physiotherapy students, as they struggle to apply textbook anatomical knowledge to real life [4]. In this case, the projection mapping, which mainly focused around augmentation and annotation, was carried out using Augmented Studio. Augmented Studio, an AR system, has body tracking in order to project anatomical information onto a volunteer in real time. Because of the projected images, referencing certain anatomical structures was easy and students reported a better understanding of the content. Also, the effects of AR in the classroom have been proven through experimental testing, where students used simulations then proceeded to test on content in chemistry and anatomy. The results from tests and surveys reported academic improvement and more motivation to learn [5]. In a computer science classroom, RoomAlive was utilized to create a virtual space where students could easily collaborate [6]. By projecting a student's screen onto the wall, the class is not restricted to viewing work through a single computer screen. The system, called RoomAlive, uses depth-cameras and projectors; by projecting images onto physical surfaces, rooms are able to transform into virtually immersive spaces. Another research study similar to ours showed the benefits of projection mapping for robot mechanics. With their proposed system, they proved projection mapping to be a beneficial teaching material as it is compact, user friendly, light weight, and cheap. The study proved an increase in student understanding and motivation after the use of AR in the classroom [7]. Unfortunately, their system was only restricted to robot mechanics. Spacial augmented reality has also been used for visual arts, like in theaters, galleries, and museums. Projection mapping also has practical applications outside of the classroom. As shown through RoomAlive, systems can project images based on their physical surroundings and the user's actions. RoomAlive has been used to create engaging gaming experiences, as users are able to be present in the "virtual world".

Another research done on dynamic projection mapping used a high-speed optical axis controller and a reflective sheet. The high-speed optical axis controller consists of a 1000 fps camera, projector, mirrors, lenses, beam splitter, and light absorber. This system provided high-speed tracking in low light conditions [8]. Even though there are already examples of projection mapping in education, most of them require expensive hardware. Expensive and specialized hardware makes it difficult to implement those systems in the classroom.

With the Projection Mapping toolbox, we aim to bring an AR experience to classroom. Unlike other complex expensive systems, our system was created using Python and Pygame. The coding in Python makes the system easier for high school students and teachers to use, even those with minimal coding skills. High school students will be able to interact and visualize study materials, while instructors can easily teach complicated materials. Whether it is to play an AR quiz game or display a student's presentation, we aim to turn the traditional classroom into a social environment where students can have an interactive learning experience.

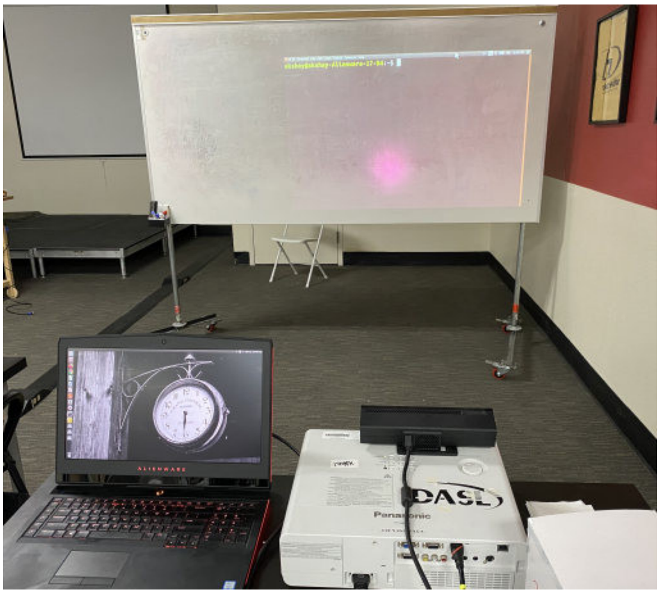


Figure 2: Room Setup: On the right, Kinect is placed onto the projector, and the white board is 2.6 m apart

III. EXPERIMENTAL SETUP

This section provides information on the hardware and software required for the Projection Mapping toolkit.

A. Hardware Setup

To cover more features in the experiment room, a large field of view (FOV) equipped camera is required. The Microsoft Kinect V2 was selected for testing because it has a large FOV and higher resolution.Table I depicts the comparison between three common RGB-D sensors. For our current research, only raw data from the Kinect's IR camera was used. No on-board depth generation was used to track marker.

For the research, a Panasonic PT-VW431D projector connected to a Dell Alienware gaming laptop was used. Any "off-the-shelf" projector can be used. The code was tested on a laptop consisting of intel i7 cpu, 32GB ram and NVIDIA GTX 1080 graphics card. The following components provided

TableI:ComparisonbetweenKinectV2,AsusxtionPro,Intel realsenseD435

Specifications	Kinect V2	Asus xtion pro	Realsense D435
RGB Image	1920x1080	1280x1024	1920x1080
Depth Image	512x424	640x480	1280x720
IR Image	512x242	640x480	1280 x 720
Max Distance	4.5m	3.5m	10m
Min Distance	0.5m	0.8	0.1
RGB Field of View	84.1x53.8	58x45	69.4x42.5
Depth Field of View	58.5x46.6	58x45	87x58

more than sufficient power to run the Projection Mapping toolbox. To set up the room, the Kinect was mounted on top of the projector and the screen was 2.6 meters away from the projector, as shown in figure 2.

One of the biggest obstacles in projection mapping is the change in lighting [8]. Common marker tracking systems rely on a RGB camera [9]. RGB based markers cannot be used for projection mapping because interference from the projector makes it difficult for the RGB camera to detect markers. To overcome this problem, marker detection was done through an Infrared (IR) camera. Since Infrared and RGB light have different wavelengths, they do not interfere with each other. Thus, there is more accurate tracking, as shown in figure 6. In order to identify markers in the room, markers were created using retro reflective tape. Retro reflective tape is a specialized material which reflects light back to the original source [10]. It is most commonly used on streets and traffic signs. At night, light coming from a car's headlight illuminates the signs for better legibility. For the current setup, IR light coming from the Kinect was used to illuminate the marker and the Kinect's IR camera was used to detect them.

B. Software setup

Python and Robot Operating System(ROS) were used to develop the Projection Mapping toolbox. Currently, the Projection Mapping toolbox runs on Ubuntu 16.04, but in the future it will also run on Windows for easy use.

The Projection Mapping toolbox relies heavily on sensor calibration. A properly calibrated system provides an accurate relationship between different cameras inside the Kinect and between the Kinect and projector. Both the Kinect and projector were modeled as pin-hole cameras and simple triangles were used in order to find the necessary components. The calibration process helped determine the sensor's intrinsic and extrinsic matrices. An intrinsic matrix contains useful information such as focal length, scaling factor, and optical center. Intrinsic values were later used to transform 3D points to pixel values. Moreover, an extrinsic matrix defines transformation between lenses which will be later used for coordinate transformation between Kinect and the projector. The combination of an intrinsic and extrinsic matrix is called a Camera Matrix. For a robust calibration, a ROS iai-Kinect2 package was implemented to calibrate the Kinect sensor [11]. The ProcamCalibration from the RoomAlive Toolkit was implemented to calibrate the projector [1]. Both packages use modified versions of OpenCV's camera calibration functions [12]. After the calibration process is finished, two Camera Matrices will be generated: one for the Kinect and another for the projector, as shown in the equation 1.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f_x/s & 0 & c_x \\ 0 & f_y/s & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{10} & r_{11} & r_{12} & t_1 \\ r_{13} & r_{14} & r_{15} & t_2 \\ r_{16} & r_{17} & r_{18} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad (1)$$

IV. METHODOLOGY

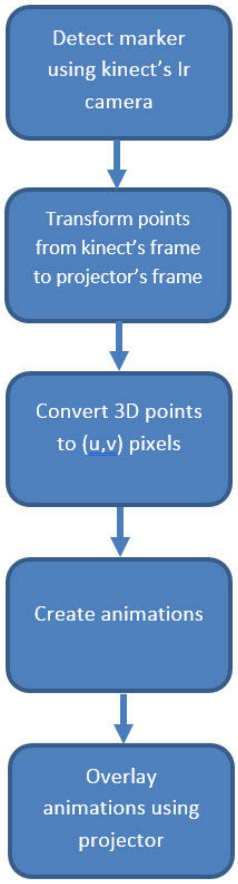
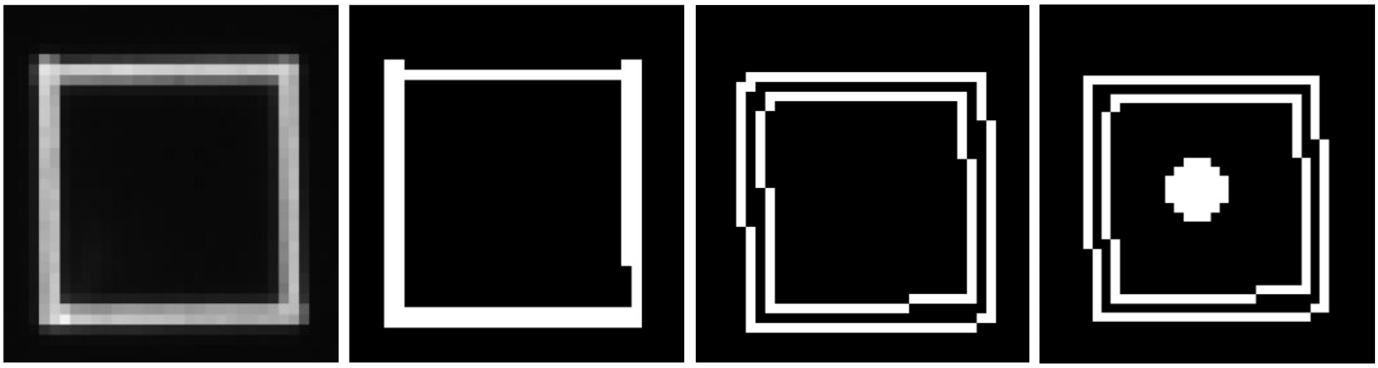


Figure 3: Projection Mapping toolbox pipeline

The Projection Mapping toolbox will follow the pipeline shown in Figure 3. The Projection Mapping toolbox will constantly receive image data published by the Kinect2-bridge. The Kinect2-bridge is a part of iai-Kinect2 ROS package and acts as a driver for the Kinect sensors [11]. Once an image is successfully received from the sensor, the Projection Mapping toolbox will execute the marker detection node.

A. Marker Detection:

The marker detection node will read the image and will start segmenting the marker. An IR image pixel corresponding with



(a) Raw Ir Image from Kinect (b) Binary Image (c) Apply canny edge detector (d) Find moment of image

Figure 4: Method for finding center of marker

the marker will have a high intensity because most of the IR light is reflected back from the retro reflective material. Simple thresholding was done to give every high intensity pixel a white colour and the rest of the room a black colour. A binary image created using thresholding makes it easier to locate a marker in the image. Afterwards, a Canny edge detector was used in order to find the contours of the marker. After finding the contours of the marker, the marker's width and the marker center point in pixel value can be easily calculated by finding the moment of the image. Figure 4 shows the result of different filtering done on the original image. To find the position of the marker, a similar triangle method was used. Equation 2 was used to determine Z_{marker} (the distance between the marker and the Kinect).

$$Z_{marker} = (W_{marker} * F_{IR})/P_{marker} \tag{2}$$

Where, W_{marker} is Marker's width in millimeters, F_{IR} is focal length of IR camera, which was acquired from Kinect's camera matrix and P_{marker} is marker's width in pixel value. it is assumed that marker is parallel to camera. Once Z_{marker} is calculated, equation 3 and 4 were used to find X_{marker} and Y_{marker} of the marker's center point.

$$X_{marker} = ((u_{IR} - ox) * Z_{marker})/F_{IR} \tag{3}$$

$$Y_{marker} = ((v_{IR} - oy) * Z_{marker})/F_{IR} \tag{4}$$

(u, v) are the pixel coordinates of the marker's center point in the IR image, and $(ox, oy)$are the coordinates of the principle centers of the image plane. (ox, oy)were acquired from Kinect's camera matrix and was used to move the origin from the center to the top right. Figure 5 shows conversion from (X, Y, Z) point to (u, v) values.

B. Point Transformations:

Once a marker's position is calculated, the transformation script will transform the marker's center point from the Kinect's image frame to the projector's image frame. To achieve this, previously calculated extrinsic values were used.

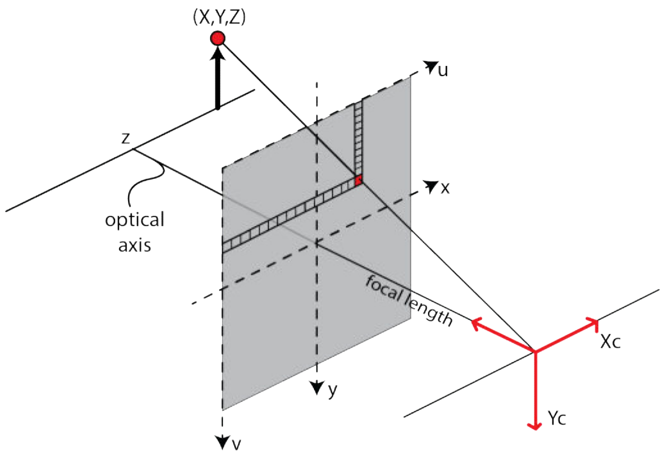


Figure 5: Camera modeled as Pin-hole camera.

For the current setup of the room, the Kinect was placed four inches above the projector. Therefore, the only transformation required was in the vertical axis. This transformation allows users to locate the marker's position relative to the projector. This method can be used to convert points from the Kinect's image frame to the projector's image frame.

$$\begin{bmatrix} X_p \\ Y_p \\ Z_p \end{bmatrix} = \begin{bmatrix} X_{marker} \\ Y_{marker} \\ Z_{marker} \end{bmatrix} \begin{bmatrix} r_{10} & r_{11} & r_{12} & t_1 \\ r_{13} & r_{14} & r_{15} & t_2 \\ r_{16} & r_{17} & r_{18} & t_3 \end{bmatrix} \tag{5}$$

Afterwards, Marker's X, Y, and Z values were converted to $(u, v)_p$ pixel values in the projector's image plane. This can be achieved by manipulating equations 3 and 4 and creating equations 6 and 7.

$$u_p = (X_p * F_p)/Z_p + ox_p \tag{6}$$

$$v_p = (Y_p * F_p)/Z_p + oy_p \tag{7}$$

$(X, Y, Z)_p$ are coordinates for the marker's position, F_p is the focal length of projector, and $(ox, oy)_p$ are the coordinates of the principle center in the projector's image plane. By keeping the projector's and computer's resolution same, we can assume $(u, v)_p = (u, v)_{computer}$. Markers pixel values will be used to overlay animations.

C. Animation:

All of the previous steps are done in the background and users do not have to worry about transformations unless they are trying move the Kinect or projector to a different location. Most of the demonstrations were made using Pygame. Pygame is a game development package for Python, which makes it easier for beginners to make an interactive demonstration or game. A marker's position will be directly updated in Pygame and users can use the marker as reference to make animations.

D. Projection:

In order to project content from a computer screen to the room, a projector was connected to the computer, with both set to the same resolution and "Mirror Display" turned on. Lastly, when the Pygame script was executed, all the elements in the Pygame window were automatically superimposed onto the marker/object.

V. RESULT

The following section describes three examples that were created using the Projection Mapping toolbox. The following examples were developed by high school students with beginner-level coding skills. This section will also describe the performance and accuracy of the system.

Figure 6: Ir marker seen through IR camera and RGB camera

A. Physics Demo

In classes such as physics, students need to draw diagrams in order to visualize concepts. Viewing images on a screen or a textbook page allows for a straightforward understanding of concepts, but makes it difficult for students, especially kinesthetic learners, to fully grasp the material. In order to solve this issue, we plan to use AR for students to visualize free-body diagrams, as shown in figure 7. In our demonstration, labeled arrows were projected around the perimeter of a physical box to resemble a free body diagram. As the user moves the box around, the arrows will follow it. Teachers can easily reference certain components of the diagram and students can physically interact with the display.

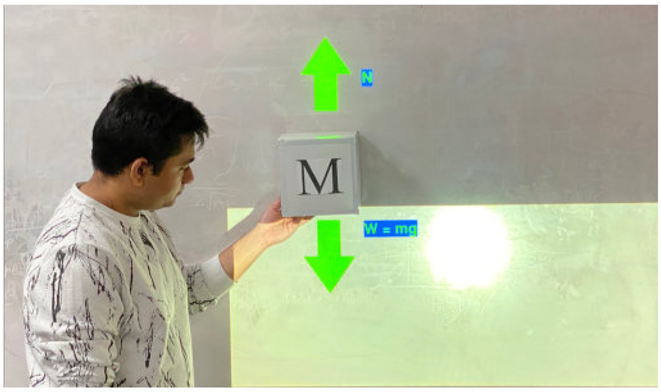


Figure 7: Interactive Free Body Diagram

B. AR quiz tacking

AR can be used to engage the class in multiple-choice quiz games, as shown in figure 8. Teachers can write questions on the board and add AR elements to make it engaging. In the demonstration, the projector displayed a happy or sad face depending on the answer. Rather than giving students a quiz using pencil and paper, the AR quiz game provides an interactive experience to test their knowledge. This demonstrates how preexisting course materials can be merged with AR elements.

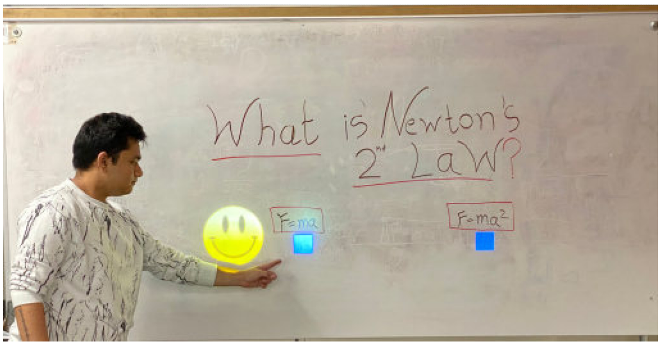


Figure 8: Interactive Quiz tacking

C. AR game

The Projection Mapping toolbox can be used to make AR games, as shown in Figure 9. In this demonstration, the character is controlled by a game pad which is projected onto the wall. A small piece of reflective tape was applied to the user's hand as a marker. In classes for coding or game development, this can be used as a tool to test a student's code. It can also be used in any extracurricular activity at school.

D. Accuracy

The projection mapping pipeline heavily relies on an accurate value for the Z_{marker}. The following section will compare the Z_{marker} calculated by the projection mapping pipeline, Kinect's depth image, and real world measurements. Values acquired by all three methods are shown in table II. The projection mapping pipeline was able to compute Z_{maker} with

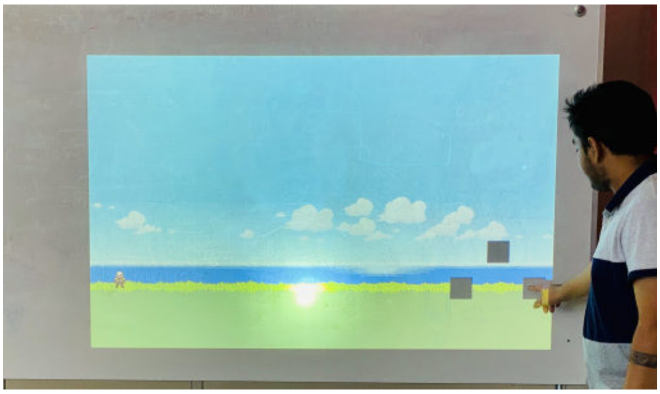


Figure 9: Interactive Game

Z_{marker} calculation			
Method	Average Accuracy	Min	Max
Proposed Method	96.85	95.41	99.90
Kinect's Depth image	99.99	99.89	99.99
Real World measurement	N/A	N/A	N/A

Table II: Accuracy of Z_{marker} was calculated using the proposed method, Kinect point cloud, and real world measurements

an accuracy of 96.85%. As shown in II, it was important to note that Kinect had a higher accuracy (99%) than the proposed methods. While Kinect's higher accuracy can be beneficial for certain tasks, it was not compelling for our current research. There were two major downsides of using Kinect: increased latency and less working area.

Kinect can only compute a maximum depth of 4.5m as shown in table I. On the other hand, the proposed method can detect a marker at a maximum distance of 8.0m. When Kinect was used, the projection mapping pipeline had a latency of 0.5 seconds, while the proposed method had a latency of 0.14 seconds.

VI. Conclusion and Future Work

The proposed method had sufficient accuracy and minimal latency for developing augmented reality applications. By proposing this toolbox, researchers envision a smart classroom where students are taught using modern methods. AR enabled course work will engage students and make learning more effective.

In order to achieve the goal of a smarter classroom, more development is required. Our method has limitations, as this paper only presented a preliminary toolbox. More development is required to make the Projection Mapping toolbox more accurate and efficient. In order to make the toolbox more user friendly, Windows support is also required. Beginners would have difficulty working in the Linux operating system.

VII. ACKNOWLEDGMENT

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