Virtual Board: A Digital Writing Platform for Effective Teaching-Learning

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***Abstract*—With the advent of a global pandemic, the world changed drastically with a wave of new technologies. The teaching learning process also saw an overwhelming change, where both teachers and students communicated via online. To facilitate such interactions, several tools were developed. Many online video conferencing platforms were vividly used starting from Google Meet to Microsoft Teams, etc. A new approach demands usage of new techniques, software, hardware and often platforms. The specific task of writing in a teaching learning scenario is of eminent importance and it often requires using hardware extensions such as digital writing pads, stylus, etc. Such external hardware devices can be categorised based on how easy and effective they are for communication. Adopting the basic feature of air tapping in head-mounted displays such as Microsoft Hololens for augmented reality applications, here we devised a platform which enables a person to write on a virtual board. To be specific, we proposed a system called virtual board, that enables a person to write "in-the-air" using a pointing device and which automatically translates into text. This enhances the task of writing in a teaching learning scenario. To justify its usability, we performed a subjective test. Participants were asked to perform a similar task both on our proposed virtual board and also on a commonly used digital writing pad. A post-session questionnaire was provided to the participants based on the experiment. Results obtained after analysing the feedback in form of responses clearly showcase that the developed system is truly accepted in terms of the ease of learning and writing, and its effectiveness in a virtual teaching learning environment.**

***Index Terms*—Digital Writing, Subjective Test, User Experience, Virtual Board**

I. INTRODUCTION

With the advent of a global pandemic, the world changed drastically with a wave of new technologies. For teachers and students, online tools for education have become a significant part of their lives. To carry out the teaching process remotely teachers all around the globe started using various online tools as well as technological gadgets. One of the popular methods used is to streaming lectures live to the students from classrooms. To implement this methodology a teacher is required to have a webcam in working condition along with a good quality internet connection. An internet connection is also required on the students' end. While the setup is easy, this methodology failed to provide the healthy classroom environment and interaction it aimed at facilitating. Many teachers found it difficult to handle the online meeting environments running on a laptop/PC and the writing board simultaneously.

Integration of technology in the teaching process took place many years ago with the introduction of smartboards [1]. As a result, teachers began to get accustomed to these digital gadgets. Although smartboards were being used in classrooms for many years before the pandemic struck, multiple problems were faced by teachers when classes needed to be conducted in online mode. This was so because the real problem was to create the offline teaching-learning environment in online mode. Also, the said smartboards were a common scene only in the urban areas. The rest of the world was still not comfortable with digital tools for teaching. However, as per requirement the teaching and learning activities adopted the virtual mode. One other method widely used in the current teaching learning activities is writing pad.A digital writing pad is a device that allows users to create digitally rendered data by writing and drawing on it using a stylus(or digital pen). Such digital writing pads are available in the market and manufactured by various trusted brands. However, these digital writing pads come with a set of disadvantages in terms of the infrastructural and maintenance requirements, ease of use, and affordability. During virtual learning, students felt a significant learning gap from classroom studies. The problem was mainly in the visualization of the concept. To address the problem, in this work a virtual board tool may is developed. The mentioned tool acts as a whiteboard and can be used by teachers for taking classes in online mode. The aim of this work is to create a multipurpose teaching aid for teachers teaching in the virtual model. To test the usability of the virtual board tool we perform subjective tests comparing the virtual board with a digital writing pad.

II. LITERATURE SURVEY

As a result of the Covid-19 pandemic, all educational institutions shifted to the online mode of working. The online mode posed many challenges for the students and teachers/professors. More than 60% of the students are unhappy with the online mode of education, despite the fact that they are more accustomed to new technologies. This survey of 874 respondents showed that nearly 70% of participants felt completely dissatisfied, while 25% of participants were moderately satisfied with online classes. Some of the reasons given by the participants for their unhappiness with online teaching/learning are, lack of technical and infrastructural support, as well as lack of technical knowledge in the use of tools and gadgets for the virtual teaching learning process [1]. One of the challenges was teaching without a white/Black Board and chalk/marker pen respectively. There are many alternatives that can be used to write on a digital screen but most of them require additional infrastructural support like a writing pad, pen, keypad, etc. Also, a lot of teachers faced problems in using such devices. On exploring to find a solution to this problem, we came across the idea of a digital air canvas, which allows the user to write/draw on digital screens using hand gestures. In other words, the user can draw in the air. There has been many efforts in literature to address this problem, authors have described methods to develop a virtual board that can detect and track the movements of a coloured pointer or a LED pointer [2]. Apart from being useful in online education, a virtual board can also be useful for specially-abled people and senior citizens who struggle with touchscreen devices [3]. It can be utilized to create digital art. It can also be integrated with other technologies like augmented reality, as an extension in other video conferencing solutions like Google Meet, Microsoft Teams, etc.

III. Proposed Methodology

Algorithm 1 Developing the Virtual Board

V $\leftarrow$ capture video in real-time using device camera
f $\leftarrow$ extract frames from videos at 30fps
f_{hsv} $\leftarrow$ convert RGB frames to HSV color space
C $\leftarrow$ canvas preparation using f_{hsv} with Ink buttons for user interaction
M $\leftarrow$ identify the mask of the handheld marked over the canvas C
M_T $\leftarrow$ trajectory of M is displayed over C using white pixels
Cnt $\leftarrow$ contours are detected using M_T over C
Cnt_H $\leftarrow$ largest contour is identified
D $\leftarrow$ a deque is used to store the co-ordinates of Cnt_H
The co-ordinates in D are plotted over C. =0

In this work, a virtual board wherein the users can draw using their fingers or a pen/marker is presented. The virtual board is a hands-free digital drawing canvas that utilizes computer vision techniques to recognize and map hand gestures and create illustrations on a computer screen. The proposed methodology for developing the virtual board involves making use of the cross-platform library, namely OpenCV because of its human-friendly syntax and exhaustive set of libraries. The user's laptop/PC webcam is used to capture the fingertip movement. The virtual board then tracks this movement and draws it on the camera screen as well as a plain white screen. Users can choose one text colour from the four available colour options. An option for clearing the screen as and when required is also available. The programming setup required for this work includes Jupyter Notebook, OpenCV and Numpy libraries, and the programming language Pyhton. The algorithm for creating the virtual board mainly consists of six steps as mentioned in Algorithm 1. These six steps are detailed as below.

A. HSV colour space

Initially, the incoming image from the webcam (frame) is converted into the HSV colour space. HSV is a cylindrical color model that remaps the RGB primary colors into dimensions that are easier for humans to understand [4]. These dimensions are hue, saturation, and value. The image in HSV colour space is highly suitable for colour tracking done using computer vision techniques. Therefore, the HSV colour space is used in this work.

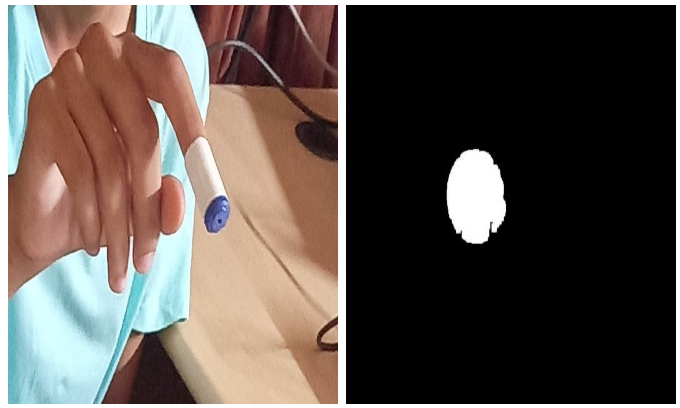


Fig. 1: During subjective test, participants used a cap to virtually interact with the system (left), which is masked by our model using white pixels for further processing (right).

B. Track bars and canvas frame

In the next step, track bars are set up for the HSV frames obtained in the first step. A track bar is like a tool used to adjust the values of one or more variables. Here the trackbars are used to adjust HSV colour space frame properties such as lower hue, upper hue, lower saturation, upper saturation, lower value, and upper value. Adjusting the trackbar values help increase the precision of mask generation. Once the trackbar values are set, a NumPy structure called range is created, which is used to obtain the mask for the marker. The mask is a black-and-white image of the webcam captured frame, where the marker trajectory is depicted using white colour while the surrounding pixels are in black. The mask makes the contour detection process more accurate [5]. In this step, the canvas frame is also prepared. The preferred canvas space consists of hundreds of pixels. Four buttons allowing the user to choose different ink colours are created at the top of the canvas. This is implemented by reserving a few pixel areas for these buttons. When the marker is in the area of any of these buttons, their corresponding functions are triggered to change the ink colour or clear the board. This proposed canvas is depicted in Figure 2.

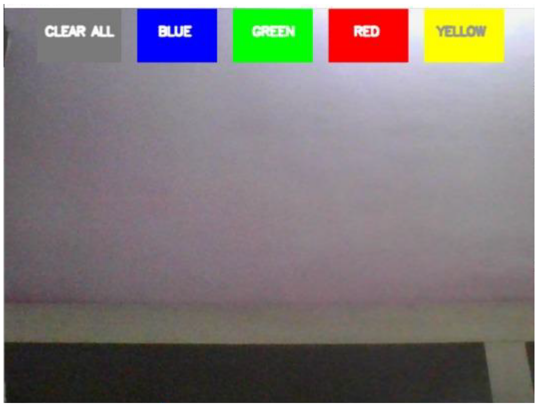


Fig. 2: Tracking Window : canvas with buttons for selecting ink colours and clearing the screen.

C. Mask Preprocessing

OpenCV morphological image processing is a procedure for modifying the geometric structure in the image. These operations are used to remove noise from the image and identify intensity bumps or holes in the picture. In this work, two processes have been used for this purpose - erosion and dilation. Erosion is used to diminish the features of the object. It erodes the boundary of the image in the foreground. Dilation increases the area of the image. It dilates and accentuates the features in an image. These steps are found to be helpful in the isolation of individual elements for contour detection [6].

D. Contour Detection

Contours can be explained as a curve joining all the continuous points (along the boundary), having the same color or intensity. The contours are useful for shape analysis, object detection, and recognition. Using contour detection, the borders of the pen/marker are detected and easily localized in the image. Once the contours are detected, the circumference of the circle enclosing the largest contour(the marker) is obtained. Using this circumference, the largest contour's center is found and its coordinates are stored in a deque data structure. This deque stores the position of the contour on each successive frame and these stored points will be used further to make a line using the OpenCV drawing functions.

E. Drawing on the Canvas

The primary objective of this work is to track the movement of a marker and draw it on the user's laptop/PC screen. Once the largest contour is detected, its coordinates in every successive frame are stored in a deque. Four different deques are created for the four available ink colours. The contour position is checked against an if-else statement to determine whether the user is drawing, clearing the screen, or changing the ink colour. If the user is drawing/writing, the contour positions are appended in the deque of the ink colour being used. On the other hand, if the user is pointing at any of the buttons, their corresponding functions are called to do the desired task. If nothing is detected on the screen, a section in the code ensures that all deques remain empty until a contour gets detected. Finally, points are plotted on the canvas at the coordinates stored in all deques by following an approach mentioned in [7]. The resulting text/drawing is visible in the webcam window, also called the tracking window (Figure 2). Apart from the webcam window, the shape/text drawn by the user is also visible on a white paint window for more clarity. The user does not need to touch the laptop/PC screen in order to carry out any of the operations on the virtual board; the pointer(finger/marker etc.) is properly detected from an appropriate distance.

The link to a demonstration video for the virtual board is publicly available at [1].

IV. Experimental Results and Analysis

Subjective testing has been a very interesting tool for evaluating performance of tools and platforms for specific use-case [8]. In a similar direction, we performed subjective test to compare our proposed virtual platform for teaching learning process with the teaching aids available in the market. A digital writing pad is widely been accepted as an important tool for the teaching learning process. Therefore, for comparison purpose we chose a digital writing. The performed subjective test is mostly directed towards understanding the accessibility of a digital writing pad and performing the similar task using our proposed virtual board. Here we used the XP-Pen Deco Pro Medium which is a popular writing pad and is considered to be very accurate. We used a total of 36 naive subjects drawn from a pool of engineering students at Indian Institute of Information Technology Vadodara, India. They were requested to wear any vision correcting devices that they regularly wore like glasses or contact lenses.

A. Test Environment

The testing of the application was conducted in a classroom setting. The virtual board sometimes detects elements of the user's background as its contour. To solve this problem, users were seated in front of a plain background. The lighting of the room was kept normal.

B. Test Execution

Each participant was given verbal instructions at the beginning of each test to clearly explain the purpose of the virtual board application, how to use it. Similar set of instructions were also given on how to operate the digital writing pad. For each participant, the subjective test was conducted in two parts. In the first part, the participant experiments with the virtual board tool, as depicted in Figure 3, and in the second part, they perform the same task using the digital writing pad.

After all instructions were provided, the participants begin the subjective test with the virtual board using a marker's cap as their pointer for the application. The participants write the words "Virtual Board" in the air using their fingers, and the same gets written down in the application's webcam and corresponding paint window. Subsequently, the participant performs the same task of writing "Virtual Board" using the

[1]https://drive.google.com/file/d/1lMLGnNJIpVe377Y0a87MXmGJRPEuMEGq/view

digital writing pad. To perform the given task, they use a digital pen and a glove, provided along with the writing pad. The text drawn on the writing pad gets displayed on a laptop screen in the paint window. The software driver necessary for operating the writing pad was installed before starting the subjective test. Further, we also evaluate the virtual board's usability and compare user preferences between the virtual board and the digital writing pad. In this regard, we created a questionnaire for the subjective test participants. The questionnaire consisted of 10 questions and are listed as below:

- Q1 Rate how user friendly the application is on a scale of 1 to 5 (where 1 = not at all, 5 = extremely user friendly).
- Q2 Rate the ease of writing on the virtual board in comparison to writing pad. (1-5; 1 = extreme discomfort, 5 = extremely comfortable)
- Q3 How clear the written text/drawing on the virtual board is in comparison to writing pad. (1-5; 1 = Not at all clear, 5 = extremely clear)
- Q4 How would you rate the Virtual Board application on the basis of system requirements? (1-5; 1 = High end system requirements, 5 = Minimal System Requirements)
- Q5 How would you rate the virtual board based on the system storage ? (1-5; 1 = A lot of space is needed, 5 = Requires no space)
- Q6 How was your overall experience with virtual board? (1-5; 1 = very poor, 5 = excellent)
- Q7 Which one would you prefer in terms of minimal infrastructure requirement? (Virtual Board or Writing pad)
- Q8 Which application according to you is more affordable? (Virtual Board or Writing pad)
- Q9 Which one according to you will require more maintenance cost? (Virtual Board or Writing pad)
- Q10 Which one according to you is more accessible? (Virtual Board or Writing pad)

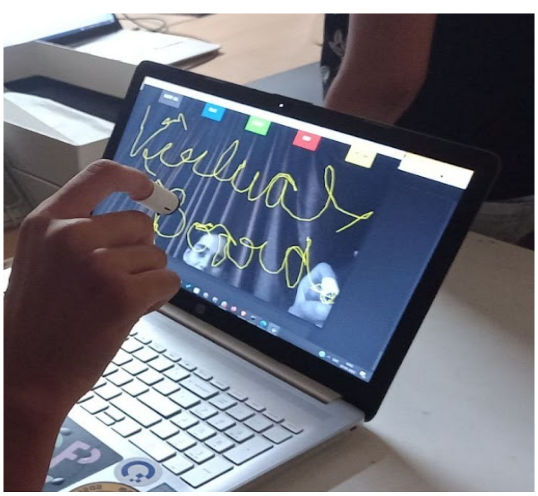


Fig. 3: Subjective test execution for Virtual Board.

V. Results and Discussion

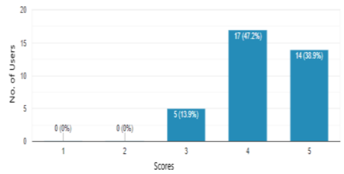
After conducting the subjective test we assess the opinions gathered through it to validate the proposed virtual board's usability. The ratings for questions from 1 to 6 are shown in Figure 4 using a bar plot.

It can be seen from the plot of Q1 that the participants found the virtual board to be quite user friendly. This would be the case given any user can easily explore through the features of the application using their fingers as screen pointers. In Q2 and Q3, the users had to rate the ease of writing and clarity of text of the virtual board in comparison to the digital writing pad. The bar plots of the above questions indicate that the virtual board performed average in these areas, with no clear preference shown for any of the two tools. In this case, one of the factors affecting the results would be the imperfect contour detection in the virtual board application. Also, at present it is difficult to put spaces between two words/shapes on the virtual board. At the same time, Q4 and Q5 give positive results for the virtual board. As indicated by the bar plots and mean values, the users were satisfied with the virtual board's dependency on system requirements and system storage. This is due to the fact that the virtual board does not require any additional software drivers or storage space. Q6 asked the users to rate their overall experience after using the virtual board. As per the results, around 88% of users gave a score greater than 3. It indicates that a large part of the users was satisfied with the virtual board. The mean and standard deviation of the ratings given for Q1 to Q6 are provided in Table I.

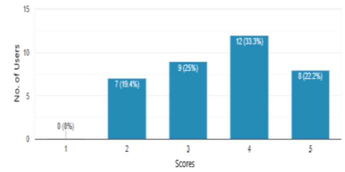
Question	Mean	Standard Deviation
Q1	4.25	0.69
Q2	3.58	1.05
Q3	3.56	0.94
Q4	4.25	0.97
Q5	4.00	0.93
Q6	4.31	0.75

TABLE I: Mean and Standard Deviation of the collected scores

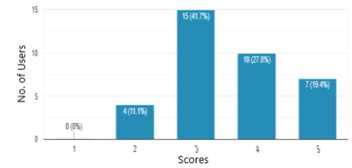
Questions 7 to 10 draw a direct comparison between the virtual board and the digital writing pad. The results for these questions are provided in Table II. As indicated by these results, more than half of the users feel that the virtual board is more suitable in terms of the minimal infrastructure required for using and the ease of accessibility. It is so because only running a piece of code is required to use the virtual board, while in the case of a writing pad, the user has to arrange an entire digital writing pad set (writing pad, digital pen, gloves). Q8 and Q9 indicate that more than 85% of the users found the virtual board a more affordable choice because it does not incur high costs, unlike the digital writing pad, which is expensive and requires regular maintenance.



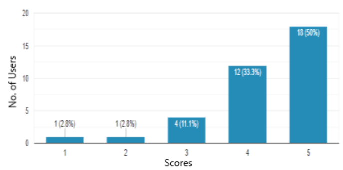
(a) Response for Q1.



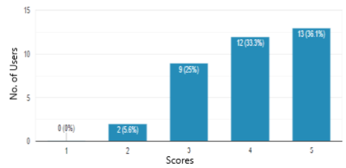
(b) Response for Q2.



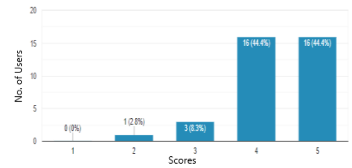
(c) Response for Q3.



(d) Response for Q4.



(e) Response for Q5.



(f) Response for Q6.

Fig. 4: Bar plots of the number of users and their corresponding scores for questions 1 to 6.

Question	Virtual Board	Digital Writing Pad
Q7	88.9%	11.1%
Q8	86.1%	13.9%
Q9	88.9%	11.1%
Q10	86.1%	13.9%

TABLE II: Results in Percentage for Q7-Q10

From the above analysis, we may conclude that users prefer the virtual board over a digital writing pad because of its user-friendly quotient and accessibility. The virtual board essentially provides all the features given by a digital writing pad without having to implement any setup procedures or needing additional hardware accessories. On the other hand, the users agreed that writing on a digital writing pad is easier and gives clearer results. A possible explanation for this may be that the users are accustomed to writing with pen and paper, while it was a relatively new experience writing/drawing in the air. Also, at present, the virtual board does not perform well when the user needs to create a space between two or more words/shapes. One other observation obtained during the subjective test was that the virtual board delivers its best performance when the surroundings have a reduced illumination. The above-mentioned limitations can be eliminated with deeper knowledge and application of computer vision techniques. With the elimination of such shortcomings, a hands-free writing/drawing tool such as the virtual board might have higher acceptance among users.

VI. Conclusions and Future Work

The primary target of this work is to develop a system that can help in visualization and writing of content during an online teaching learning activity. The proposed virtual board allows a hands-free drawing program which uses OpenCV libraries to detect the user's pointer finger. It utilizes computer vision techniques to recognize and map hand gestures and create illustrations on a computer screen. Furthermore, to evaluate performance of the virtual board in real scenario, we performed subjective test. A widely used digital writing pad was selected for the test. Participants were asked to perform similar task on both the digital pad and the proposed virtual board. Post-session questionnaire was provided and the inputs were analysed. It was observed that the participants felt the proposed virtual board to be more easy and effective in a teaching learning scenario. Thus this solution can be considered as a pointer towards a presentation requiring less accuracy in comparison to a writing pad. However, we believe the contouring and detection of markers have scope to be more accurate and precise. In future we plan to test the proposed system on live class teaching platforms (by trained professionals) for feedback. Other than learning activities, this tool can be used for several other purposes. It can be utilized to create digital art. It can also be integrated with other technologies such as augmented reality applications and as an extension with the video conferencing platforms like Google Meet, Microsoft Teams, Zoom, etc.

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