Building an Interactive 3D Hologram by SVM: Revolutionizing Educational Systems

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Abstract: This paper describes designing an interactive 3D hologram and putting it into application. The hologram is a globe reflection that can be used effectively as an educational tool, replacing traditional educational tools and causing a revolution in the human computer interaction field. The designing process is done in several steps. First is training a support vector machine to be able to detect human hands. After the hand detection system, the reflection of a 3D globe similar to holography is built by Pepper's Ghost. Thirdly, the hologram is designed to interact with the human hand. Thus the final work is an interacting hologram. While this interactive hologram can be applied in numerous areas, the target in this paper is the educational field. This project aims to open new doors in the world of human computer interaction.

Keywords: Hand Detection, Macshine Learning, Support Vector Machine, 3D, Interactive, Hologram, Educational Tool, Human Computer Interaction.

1. INTRODUCTION

Perfection is mandatory rather than an option in order to excel in a world full of competition. Many inventions have proved efficacious and useful to humankind. Others with seemingly equal promises, like the Hologram, have not been yet applied on a full scale. This is unfortunate and is due to many reasons such as hardware and software limitations, as discussed before in [1]. But what if those technologies with seemingly a lot of potential were built and introduced into our lives? This will definitely revolutionise our traditional routine systems like education, health, transportation, communication and so on.

This paper discusses the building process of an interactive 3D globe hologram, in an attempt to put the hologram technology into application. The next section of this paper discusses the concepts applied in this work, namely hologram and machine learning. Then, the building process of the interactive hologram is discussed, and the following section discusses the proposed application of the invention. Lastly, future implications of this project are discussed along with the discussion of how this interactive hologram can be further enhanced and updated.

2. THEORY & CONCEPT

A. Hologram and 3D Projection

Holography is the technique of using light waves to record an image of a 3D object on a 2D photosensitive plate [4]. A laser beam is split into two, an interference pattern is caused, and finally an image is reconstructed that can be viewed by laser light or white/candle/sun light. In all, a hologram can be viewed by the naked eye without the need for glass or mirror. Holography is a promising technology, but is hard to build outside labs and without the required equipment. However, hologram illusions are easier to create using simple methods. Such a method is the Pepper's Ghost.

Pepper's Ghost is an illusion technique [7], introduced by John Henry Pepper in 1862, which produces 3D illusions of objects. It is widely used in theatres, television and similar areas. In this technique, a piece of glass is usually placed at a certain angle so that it reflects the 3D object in front of the human eye, thus an illusion holography is created.

B. Machine Learning

Machine learning, which involves training a machine so that it learns to do a specific task, is broadly divided into many topics such as training Support Vector Machines (SVM) and Artificial Neural Networks (ANN). Support Vector Machines (SVM), are trained to be able to classify samples into two different classes. SVM have been used by many researchers in areas like face detection.

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Support Vector Machines (SVM), are trained to be able to classify between two different classes (images). This separation is done by placing the best hyperplane (figure 1) that can separate the two different classes, with the help of points called support vectors [5]. A hyperplane means searching for the largest margin (that of maximum width) that separates all data points of one class from all data points of the other class. For instance, the '+' points belong to one class, and the '-' points belong to the other class respectively.
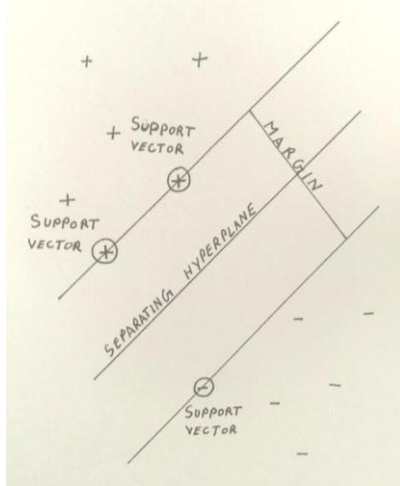

Figure 1. Separating hyperplane of a SVM

Mathematically, SVMs are implemented by a set of sequential equations. The separating hyperplane is given by the following equation:

$$<w,x> + b = 0, \qquad (1)$$

where $<w,x>$ is a dot product of weights and data points, b is bias.

To achieve the best separating hyperplane, the following equation needs to be satisfied:

$$y_i(<w,x_i> + b) \geq 1, \qquad (2)$$

where y is +/- one depending on the class

To simplify quadratic equations, Lagrange multipliers α_i are applied with the constraint and subtracted from the condition for maximal margin, which is $\frac{1}{2}\langle W, W \rangle$. Thus, after applying primal Lagrange multipliers,

$$L_P = \frac{1}{2}\langle W, W \rangle - \sum_i \alpha_i \left(y_i(\langle w, x_i \rangle + b) - 1 \right) \quad (3)$$

After equating L_P to zero, and solving we get:

$$w = \sum_i \alpha_i y_i x_i \quad \text{and} \quad 0 = \sum_i \alpha_i y_i \quad (4)(5)$$

Thus the dual Lagrange multipliers become:

$$L_D = \sum_i \alpha_i - \frac{1}{2}\sum_i \sum_j \alpha_i \alpha_j y_i y_j \langle x_i, x_j \rangle \qquad (6)$$

Values of α_i lies in the range $0 \leq \alpha_i \leq C$, where C is a constraint which keeps values of α_i within a limited range.

On the other hand, for nonlinear transformations, Kernels are often applied since a simple hyperplane cannot separate the two classes of data points apart. The concept of the Kernel method is that there exists a function *φ* that maps *x to a* linear space S, such that

$$K(x,y) = <\varphi(x),\varphi(y)> \qquad (7)$$

This dot product takes place in the linear space S. Different types of SVM kernels can be trained (such as linear, Gaussian, RBF or Radial Basis Function, and order one, two, three and four polynomial) in order to analyse the detection performance of each kernel type and select the one with best training results. As mentioned before, machine learning of SVM has been performed by many researchers for detection purposes. In a previously designed project [2], SVM has been trained for designing a face detection and eye tracking keyboard system.

3. BUILDING & DESIGN

The designing of the interactive hologram can be divided into three stages:

A. Hand Detection by SVM

In this research, hand detection was performed by SVM. The SVM has been trained in exactly the same way as explained in the previous section. In [3], the focus was on face detection, whereas this SVM is trained for hand detection. Mathematically, the separating hyperplane is given by equation (1). 80 hand samples were used (40 positive, 40 negative) for training [Appendix]. These hand samples were images captured by ordinary webcam. The training images were preprocessed (to make them more visibly clear) and used for training SVM of different kernels and values of constant C (C, cost of classification, is a parameter that tells the SVM what hyperplane is needed in order to classify hand and non-hand samples correctly) [2][3]. This was done to find out which kernel and C are best for hand detection. Kernel options trained were Linear, Polynomial degree 2 & 3, Quadratic, Gaussian, Homogenous polynomial, and Radial Basic Function. When plotting the weight and average weight, best results (where graphs appeared similar to a hand) were found with the Linear, Gaussian, Homo Poly and RBF (Radial Basis Function). As such, these four functions were again plotted and compared, as illustrated in Table 1.

TABLE I.   COMPARING DIFFERENT KERNELS

Kernel	C = 0.001	
	Weight	*Average Weight*
Linear		
Gaussian		
Homogenous polynomial degree 1		
RBF [a=1, b=1]		
RBF [a=2, b=2]		
RBF [a=4, b=5]		

As can be seen from Table 1, the linear kernel produced best weight plot. The next step was to find out the best value for C, so SVM with different C values from 5000 to 0.00000001 were trained, as illustrated in Table 2.

From the plotted weight, it was inferred that the best C value is 0.00001. Thus, the final decision was training SVM of linear kernel with C value of 0.00001, for the purpose of hand detection.

TABLE II.   COMPARING C VALUES

C value	Linear Kernel	
	Weight	*Average Weight*
5000		
1000		
100		
10		

C value	Linear Kernel	
	Weight	*Average Weight*
1		
0.1		
0.01		
0.001		
0.0001		
0.00001		
0.00000001		

B. Hologram 3D Reflection

As discussed before, there are many alternatives to produce holography which are easier to build and produce the same visual 3D effect. As such, in this project 3D hologram projection was alternatively achieved through Pepper's Ghost technique. As such, an inverted prism of four sides was built using transparent paper, with the following measurements as shown in figure 2 [8].
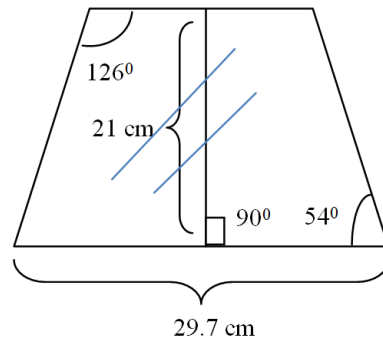

Figure 2. Prism each side measurements

A video of four of the same 3D objects was prepared. The video was designed in such a way that the built prism will be placed in the centre of the video at the 'X' as shown in figure 3, while it is playing on a screen. Any display screen can be used. Here, a laptop was used as display screen.

Figure 3. 3D video

In this way, when the prism is placed on top of the display screen and at the centre position of the video in figure 3, Pepper's Ghost effect will be achieved and a hologram will appear at the centre of the prism, as shown in figure 4. As can be noticed, the hologram is noticeable in both darkness and under light conditions.
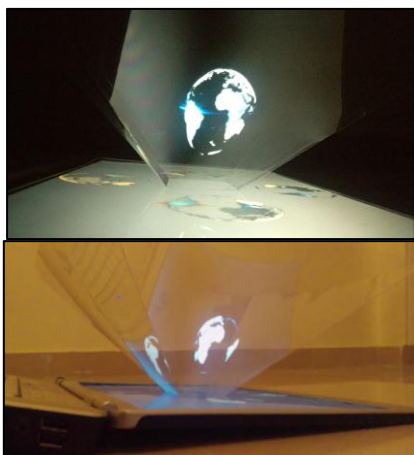

Figure 4. Holographic projection (top: dark room,

bottom: light room)

C. Interactive 3D Hologram

The previous sections discussed building a hand detection system by SVM and a hologram reflection. Building the latter is easy, but the challenge is to be able to communicate with this hologram. This is the aim of this section. The last step is to make this hologram 'interactive' by responding to human hands. The following layout describes how hand detection and the holographic reflection are combined.
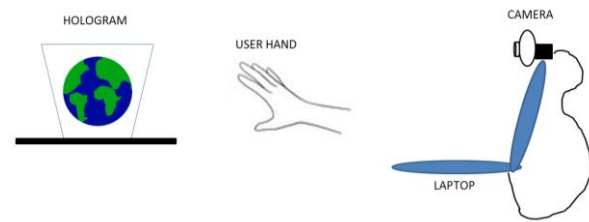

Figure 5. Interactive Hologram Setup

In figure 5, the user's hand is placed between the hologram and a camera, such that any movement of the user's hand is captured and interpreted by the camera. For instance, if the user points towards a certain location on the globe, the camera will capture that movement through hand detection and interpret accordingly (output result).

4. APPLICATION

With the proposed setup in section 3, any application can be built. The use of this interactive 3D Hologram is infinite. For example, there can be interactive books with hologram pictures, interactive maps with 3D visualisation of landscapes and mountains, and even interactive wearable holographic hand watches. However, this research targets the educational field and thus, the idea was to design an interactive and educational globe. Three different applications with few variations were built:

A. Application 1: Planet Names

The first application is the simplest of the three. This application is a 3D globe that is intended to inform the user that the planet the user points to is called 'earth'. How does it work? It depends entirely on the detection of hand. Once the user places any hand in front of the 3D reflection of the globe, the camera will detect the presence of the hand in front of the globe, as in figure 6. Once the hand is pointing to the globe, the system will output the sound file 'earth'. Thus, it can be used as an educational tool in schools. When users point to the planet, the name of the planet will be heard.
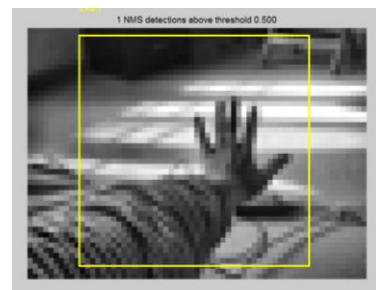

Figure 6. Hand detected by designed system

B. Application 2: Land and Sea Areas

This application is an interactive 3D globe that informs the user of two areas on the globe: land and sea, according to what area the user points to. Its working first involves detecting the user's hand, as in figure 6. After processing, the exact position of the hand is calculated with the help of the bounding box in figure 6. Figure 7 is the detected hand after processing, specifically applying edge detection techniques. The black and white image of the detected hand helps in finding the exact position of the user's hand. When this exact position is calculated, the system outputs sound files accordingly.

Figure 7. Detected hand in black and white

If the user was pointing to a white area (according to pixel values), that is the land. If the user was pointing to a black area (according to pixel values), that is the sea. A threshold value is set to decide whether it is a white or dark area. Thus, this 3D hologram globe is an educational tool that can be used effectively to point out land and sea areas on the earth. As can be seen in the 3D globe of figure 4, the land is white while the sea is black.

C. Application 3: Names of Continents

In this application, the 3D globe is interactive in such a way that a user points to any continent on the 3D and the name of that continent will be outputted as audio by the system. For simplicity, each continent was given a different colour. First, similar steps to application 2 are applied here, starting from hand detection with SVM followed by image processing to get a black and white hand image as in figure 7. Finally, to find out what continent the user is pointing to, the pixel values the user is pointing to are compared to the previously calculated pixel values of the different continents, as illustrated in Table 3.

TABLE III.   CONTINENTS PIXEL VALUES

Continents	Colour	Mean	Standard Deviation
Asia (ORANGE)		R:250.7803 G: 96.4224 B: 47.7791	R: 1.2613 G: 10.9592 B: 10.7988

Continents	Colour	Mean	Standard Deviation
Europe (RED)		R: 244.5951 G: 56.9986 B: 62.2018	R: 5.3621 G: 5.5386 B: 5.6865
Africa (YELLOW)		R: 241.9594 B: 202.6743 G: 49.8409	R: 8.3881 G: 14.2753 B: 17.3441
N America (LIGHT GREEN)		R: 70.5633 G: 243.4621 B: 72.7107	R: 8.8173 G: 2.3627 B: 8.8662
S America (DARK GREEN)		R: 43.7652 G:154.5000 B: 44.2417	R: 5.3119 G: 6.7355 B: 5.7276
Australia (PURPLE)		R: 229.7079 G: 111.7573 B: 174.4297	R: 3.0063 G: 1.8131 B: 3.2045
Sea (BLUE)		R: 57.5682 G: 168.1791 B: 251.1683	R: 18.8199 G: 14.8257 B: 3.0720

The pixel values of the position pointed to by the user are extracted, and their standard deviation (SD) is calculated. Then this calculated SD is compared to that of the different continents in Table 3. If the SD falls under the SD of purple, then the continent the user is pointing to is Australia. Standard Deviation has proved to be a better measure for comparison to mean. SD makes room for a little variation in the three channels of a colour. Thus, even if the colours on the 3D globe change slightly due to lighting, categorising colours can still produce correct results due to SD comparison.
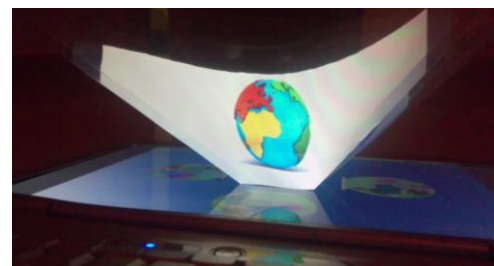

Figure 8. Interactive 3D Globe: Continents

Thus, an interactive 3D globe, in Figure 8, was finally designed that informs the user of the different continents on the globe. This informative 3D globe can be used to educate children in schools about the different continents on the planet.

5. RESEARCH & FUTURE IMPLICATIONS

A number of conclusions are inferred from this research work, as follows:

1) This project builds an interactive 3D globe using concepts of holography, hand detection through SVM, and image processing.

2) The aim of this research is to put hologram technology into useful implementation. This was achieved by making the hologram 'interactive'. While a couple of holograms were built (like those developed by musion.com in [6]), most are just visual and not interactive until today.

3) In order to keep this project simple and convenient, holography was achieved using simple means through Pepper's Ghost technique.

4) The designed 3D hologram works under dark surrounding and under light.

5) The project works correctly under the assumption that users place their hands upright straight in front of the hologram.

This project introduces new ways in the educational field. Interactive 3D globes can be used by students in schools to explore the plant, by using their hand movements. It definitely makes education more interesting and engaging. It can be further enhanced and developed on a larger scale to include many 3D interactive objects that help in teaching and thus introduce smart classes. For instance, a 3D alphabet can be designed that reads out the letter aloud when students point to a letter. Human parts can be studied through this interactive 3D technology. As such, there are infinite uses of this research project once introduced into the educational sector.

Not just the educational sector, but the 3D interactive holography can be applied in all aspects of our lives. It cuts down hardware expenses in building products by creating a 3D image of any product. It can save money, energy and time. In fact, it has the possibility to create a revolution in the human interaction world, by introducing new ways to interact with our surroundings. With the same techniques used to build the project discussed in this paper, interactive 3D mobile phones can be built that simply respond to human hands by hand detection techniques like SVM. Thus, this project, though built on a small scale in this paper, could be expanded to many applications. It could introduce a new era in the HCI world, just like other technologies like smart eye glasses, augmented reality headsets, and more.

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APPENDIX

Few hand samples used in training SVM:
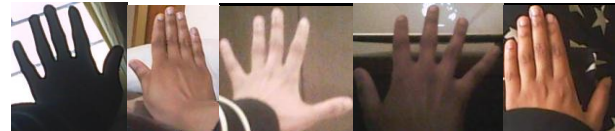
Zeenat AlKassim obtained her MSc. in Electrical Engineering from United Arab Emirates University, UAE, and her BSc in Computer Engineering from Prince Mohammad bin Fahd University, KSA. Her research interests are in areas of HCI, Computer Vision and Image Processing. Some of her major projects were building a laser keyboard, and eye tracking keyboard. She has also conducted projects in the fields of web development and app design. She has experience in academic and fieldwork. Ms. AlKassim intends to conduct more research in innovation and artificial intelligence for a better and smarter future.