ISSN 1870-4069

Augmented Reality System for Passing Ishihara's Colorblindness Test

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Abstract. Sight is the most important sense for humans, it perceives information that allows identifying other people, risks, objects, and their location. Two types of cells are involved in the sight sense: rods, which perceive the light length; and cones, which perceive the light frequency. Unfortunately, some people have a condition associated with a decreased or absent perception of color, called colorblindness. Colorblindness is considered a disability that affects almost 10% of the world's population. Several diagnoses allow detecting colorblindness with different levels of effectivity, but the most used is the Ishihara's test. Despite the variety of colorblindness diagnoses, there are not effective treatments for this condition. Alternatively, different researchers have created Augmented Reality (AR) systems for assisting the colorblind. Those assistants transform the environment changing colors or labeling objects in real-time by establishing color levels for highlighting specific regions. A colorblind assistant must include tools for passing diagnoses like the Ishihara's test, but if they are based on color levels, then other objects that are not part of the test but have similar colors could be highlighted, creating a confusing streaming environment. In this work, we propose to identify the Ishihara's plate test with feature extraction and develop an AR system for adding 3D objects that allow to colorblind people passing the Ishihara's test.

Keywords: Augmented reality, colorblindness, Ishihara's test.

1 Introduction

Sight is the most important sense for humans because it senses information that allows identifying other people, risks, objects, and their location. In addition, human modern

Table 1. Colorblindness occurrence in the world [5].

Severity Variant	Color Variant	Prevalence Men/Women	
Monochromacy	Acromatopsia	0.00003%	
Dichromacy	Deuteranopia	1.27 %	0.01%
	Protanopia	1.01%	0.02%
	Tritanopia	0.0001%	
Anomalous Trichromacy	Deuteranomalia	4.63%	0.36%
	Protanomalia	1.08%	0.03%
	Tritanomalia	0.0002%	

life includes activities related to the sight sense like working, learning, driving, watching media content, among others [1–4].

The retina in the eye contains two types of cells associated with vision sensing: rods, which perceive the light length; and cones, which perceive the light frequency. After that, the information travels from the optic nerve to the brain, which interprets it.

Unfortunately, some people have a decreased perception of color compared to the mean, this Color Vision Deficiency (CVD) is called colorblindness, initially described in 1793 by John Dalton’s scientific work, who also suffered from this condition [5].

People with CVD often struggle with their environment, because they find difficult interacting with elements designed for trichromats — people with a normal perception of colors [5, 6].

Colorblindness is considered a disability because it causes conflicts in the life of the colorblind, it affects their careers, job’s, and responsibilities [7].

The classifications for colorblindness consider severity and affected cones. Anomalous trichromacy is the softest condition with diminished perception, and is subdivided in Protanomaly (red cones), Deuteranomaly (green cones), and Tritanomaly (blue cones). Dichromacy is present when there is an absent cone and is subdivided in Protanopia (red cones), Deuteranopia (blue cones) and Tritanopia (green cones). The most critical condition called Achromatopsia causes the absence of color perception [5, 8]. Table 1 shows the world’s occurrence of men and women with colorblindness variants.

There are several diagnoses for colorblindness, some of them are so simple that its application can be supervised by any person with a normal view, and its results can ensure the detection of color blindness, but a medical consultation should verify its results [5, 9].

Colorblindness tests are divided into four diagnostic areas: anomaloscopy, accommodation tests, pseudoachromatic plates, and electronic tests [5, 10].

The most used diagnostic instrument for colorblindness detection are pseudoachromatic plates, this type of tests are the most simple, but its results are inconclusive and it is advisable after having a positive result, to verify the variant of colorblindness with a test of greater accuracy [5, 9].

Fig. 1. 42 Ishihara's plate [11].

Table 2. Checklist for evaluation with Ishihara test of 17 plates, where the X mark that cannot be read [11].

Number	Normal View	Protanopes or Deuteranopes		Monochromats	
1	12	12		12	
2	8	3		X	
3	29	70		X	
4	5	2		X	
5	3	5		X	
6	15	17		X	
7	74	21		X	
8	6	X		X	
9	45	X		X	
10	5	X		X	
11	7	X		X	
12	16	X		X	
13	73	X		X	
14	X	5		X	
15	X	45		X	
		Protanope		**Deuteranope**	
		Strong	**Mild**	**Strong**	**Mild**
16	26	6	(2)6	2	2(6)
17	42	2	(4)2	4	2(4)

The Ishihara's pseudoachromatic plates popularity is such that they have become a reference icon for colorblindness [5].

Ishihara's test contains several plates with numbers designed in colors that colorblind people often confuse with the background. The misidentification serves as a reference to diagnose the variant of colorblindness, but the severity of the condition cannot be detected [11].

The Ishihara's plates diagnose protanopia, protanomaly, deuteranopia, and deuteranomaly. Alternatively, other pseudoachromatic tests have been designed to detect tritanopia and tritanomaly, which are undetectable by the original Ishihara's test. Fig. 1 shows the Ishihara's plate 42, which is seen by people with strong protanopia or protanomaly, such as 2 and by deuteranopia and strong deuteranomaly, such as 4 [12].

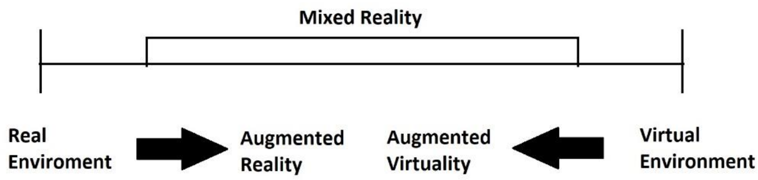

Fig. 2. Mixed reality diagram including the AR technique [18].

The Ishihara's test analyzes depending on the incorrect identification of plates. Table 2 shows the possible wrong identifications and its corresponding diagnoses.

Despite the variety and effectivity of colorblindness diagnoses, there are not effective treatments for this condition [3, 5].

Alternatively, different researchers have created Augmented Reality (AR) systems for assisting colorblind people. Those assistants transform the environment changing the colors or labeling objects in real-time by establishing color levels to highlight regions, but they are not a suitable alternative for passing diagnoses like the Ishihara's test, because other objects with colors like the ones in the test could be highlighted creating a confusing streaming environment. Some of this assistants are shown in [1, 2, 13–16].

In this work, we propose to identify the Ishihara's plate test with feature extraction instead of color levels, after that we develop an AR system for adding 3D objects that allow to the colorblind passing the Ishihara's test.

2 Theoretical Framework: Augmented Reality

Augmented Reality (AR) is a mixed reality technique that enhances reality by adding digital information like computer-generated images or 3D objects in real-time [17, 18]. Fig. 2 shows the techniques of mixed reality including AR.

The main goal of AR is simplifying the life of a person by bringing digital information to its perception, or in other words, increasing the available information for a specific application where its initially undetectable in the real world [18].

AR is a tool for assisting individuals with special needs associated with limitations on their perception, like it occurs with colorblindness [8, 19].

There are several computer vision techniques used in AR for perceiving a 3D viewpoint for rendering virtual objects. These methods are used in two stages: tracking and reconstructing [18].

The tracking stage correlates the information between the 3D world frame and a point perceived by the camera, it is divided into two areas: feature-based techniques, which find the correlation with 2D images; and model-based techniques, which uses a 3D model for correlation [18].

Tracking with marker-based AR systems uses features in 2D real images for projecting virtual elements. These systems capture an image from the environment and

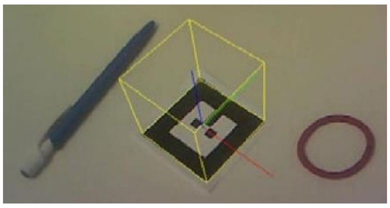

Fig. 3. Example of a tracking marker for rendering virtual elements [20].

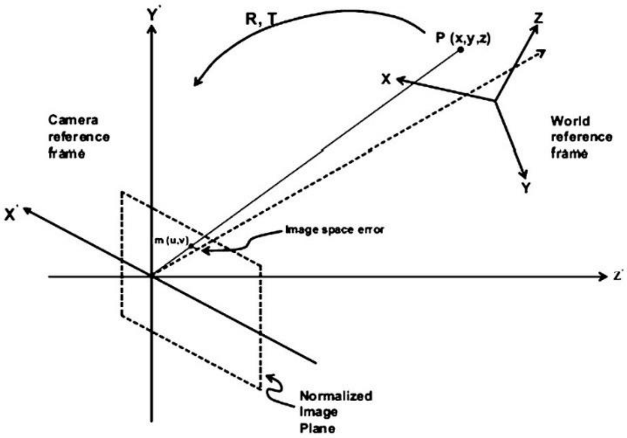

Fig. 4. Transformation from W to C [18].

detect the marker's location and orientation. Fig. 4 shows an image marker used in the tracking stage for extracting the place information [20].

Marker identification implies feature extraction techniques, like HOG (Histogram of Gradients) or SIFT (Scale-Invariant Feature Transform), detailed in [20].

Reconstruction stage generates the 3D word coordinate system using the information obtained from the tracking stage [18].

AR reconstruction stage uses two main planes to correlate features and objects. Let $(x, y, z)^T$ be a point feature with its projection on its image plane $\left(\frac{x}{z}, \frac{y}{z}, 1\right)^T$. These two points are in two different coordinate systems, the World Reference System (W) and the Camera Reference System (C)[18].

AR reconstruction involves using several point features perceived by the camera in C and interpreting them in W with the transformation in equation (1).

$$q_i = Rp_i + T \,, \tag{1}$$

where $p_i(x_i y_i, z_i)^T$ with $i = 1, ..., n$ is a set of non-collinear reference points in W, $q_i(x_i', y_i', z_i')^T$ are the corresponding set of points in C, R is a rotation matrix and T is a translation vector. The schema of this transformation is shown in Fig. 4, where m is a feature point in the detected marker.

Fig. 5. Top view of Ishihara's plate with number 74.

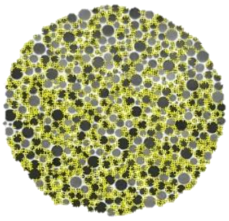

Fig. 6. Features extracted from Ishihara's plate with number 74.

3 Methodology

The development in this work is based on the section 2 definitions applied using Vuforia™ library, which includes the required functions and scripts in C# and Unity™ for implementing the proposed AR assistant.

The first think to do is define the markers for extracting its features, required for later detection in the tracking stage. In this work, we select the Ishihara's plates as markers for feature extraction. Therefore, we must upload the 24 plates to Vuforia's engine by taking photographs of the plates in a top view and obtain its features, like its shown in Fig. 5 and Fig. 6 showing the 74 plate and the features extracted, respectively.

After extracting features from the patterns, we define the 3D objects for the reconstruction stage based on two situations: when the plate is a number or when is just a line.

When the plate is a number, we built a 3D object with a 3D text that adds the number of the plate with a bright yellow color and its corresponding coordinate system, the programmed scene used in Unity™ is shown in Fig. 7.

The plates without number are associated together to a 3D object that contains the 3D text "line", like is shown in the Unity™ scene in Fig. 8.

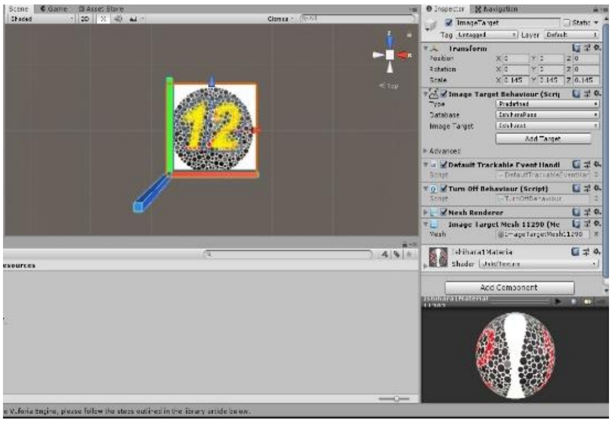

Fig. 7. Scene created in Unity^{TM} for the 3D object associated with a numbered plate.

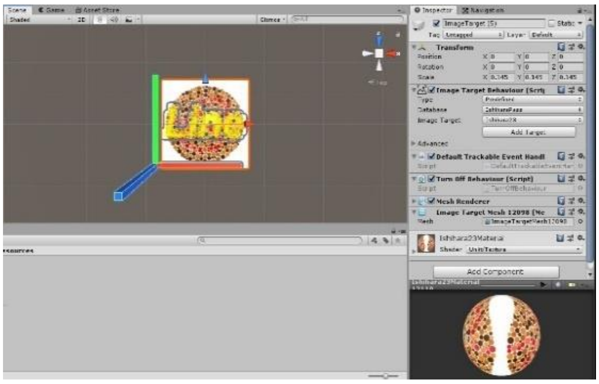

Fig. 8. Scene created in Unity^{TM} for the 3D object associated to a plate without number.

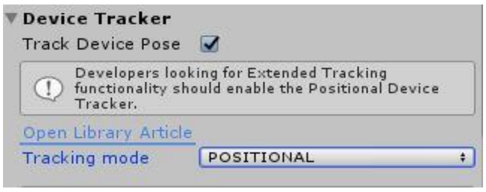

Fig. 9. Device tracking option in Vuforia's engine.

After obtaining the Ishihara's plates features and the output 3D objects, the Vuforia's engine adds and infinite loop where the cellphone camera takes pictures continually and they are processed for matching every instance of the extracted features, if there is a feature detected, then the reconstruction stage allows identifying W and rendering a the corresponding 3D object for the plate.

Finally, we configure the tracking device option in Vuforia's engine, which allows to maintain the position and orientation of W with the cellphone accelerometer, like its shown in Fig. 9.

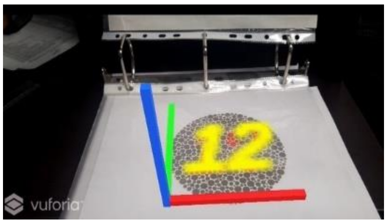

Fig. 10. Ishihara's plate 12 perceived by the AR system.

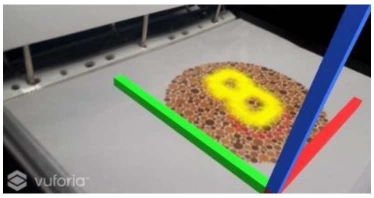

Fig. 11. Ishihara's plate 8 perceived by the AR system.

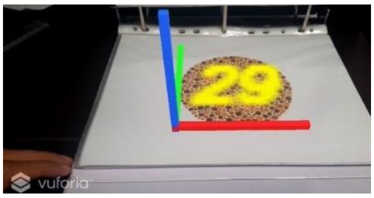

Fig. 12. Ishihara's plate 29 perceived by the AR system.

4 Results

In this section, we run the results obtained with the AR system for helping people to pass the Ishihara's colorblind test.

4.1 Design of Experiment

The feature generation and programming in Unity^{TM} was made in a desktop PC with Microsoft Windows 10 Pro x64, with a Core(TM) i7-6700 @ 3.40GHz processor, 16.0 GB RAM memory. The compiled version was run in a Samsung Galaxy Note 8 cellphone running Android^{TM} 9.0.

4.2 Results of the AR system

The images detected are retransmitted adding the 3D corresponding objects. The entire processing is carried out on the Android^{TM} cellphone. The Ishihara's plates detected with numbers are shown from Fig. 10 to Fig. 14 with different orientations and distances.

Fig. 13. Ishihara's plate 73 perceived by the AR system.

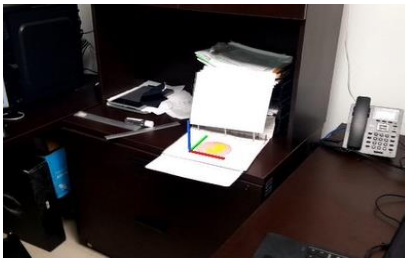

Fig. 14. Ishihara's plate 3 perceived by the AR system.

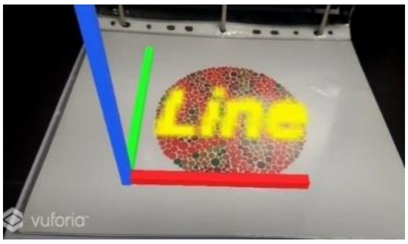

Fig. 15. Ishihara's plate without number perceived by the AR system.

The Ishihara's plates detected without a number are perceived like in the example detected in Fig. 15.

4.3 Results Obtained by Colorblind People with the AR Assistant

The AR assistant results were verified by presenting twice the Ishihara's test to four people with colorblindness. The first one without help from the proposed AR assistant and the second one assisted with it. The obtained results are shown in Table 3.

5 Conclusions

In this work, we proposed an augmented reality assistant for allowing the colorblind people to pass the Ishihara's test using its plates as markers for superimposing 3D objects and identifying the plates.

Table 3. Comparative of Ishihara's test results on colorblind people with and without using the proposed AR assistant.

Correct plate	Plate seen without AR assistant				Plate Seen with AR assistant			
	P1	P2	P3	P4	P1	P2	P3	P4
12	12	12	12	12	12	12	12	12
8	3	N	3	N	8	8	8	8
29	29	N	N	N	29	29	29	29
5	N	N	N	N	5	5	5	5
3	N	8	N	N	3	3	3	3
15	N	15	15	N	15	15	15	15
74	N	21	84	N	74	74	74	74
6	N	N	N	N	6	6	6	6
45	N	N	N	N	45	45	45	45
5	N	8	11	N	5	5	5	5
7	N	7	7	N	7	7	7	7
16	N	N	16	N	16	16	16	16
73	N	N	N	N	73	73	73	73
LP	N	N	N	LP	LP	LP	LP	LP
LP	N	N	N	LP	LP	LP	LP	LP
26	N	26	26	2	26	26	26	26
42	N	42	42	4	42	42	42	42
LP	N	LP	LP	LP	LP	LP	LP	LP
LP	N	N	N	LP	LP	LP	LP	LP
LP	N	N	N	N	LP	LP	LP	LP
LP	N	N	N	N	LP	LP	LP	LP
LP	N	N	N	N	LP	LP	LP	LP
LP	N	N	N	N	LP	LP	LP	LP
LP	LP	LP	N	LP	LP	LP	LP	LP
Score obtained	8.33%	29.16%	29.16%	25%	100%	100%	100%	100%

Our proposed assistant identifies the 24 Ishihara's plates and uses the cellphone sensors for perceiving changes in the world's frame after detecting the image features, even if the camera has been moved a long distance apart from the object.

The four colorblind people tested in this work with the proposed assistant, improve their results and pass the test with a 100% score, even when the worst case only perceived 8.39% of the Ishihara's plates.

5.1 Future Work

The proposed assistant only allows to pass the Ishihara's test, but a full assistant for colorblindness must include a color identification tool. This tool must be added to the proposed assistant following a methodology related with color identification.

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