SENSES - WHAT U SEE?
Vision Screening System Dedicated for iOS Based Devices Development and Screening Results

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Abstract: This paper describes a design and implementation of the vision screening system dedicated for iOS (iPhone/iPad/iPod Operating System) based devices. The aim of the system is to promote and popularize the vision tests, especially among children and youth. The examination consists of color vision and contrast differentiation tests. After the examination the system automatically evaluates users' answers and generates the results. Test data are anonymously sent to the server allowing for a detailed analysis. The paper contains analysis of the results on the population of about 3800 people. Presented data show that vision problems concern about half of users. The analysis was divided into two age groups (pre-school children and older) and two types of eye disorders - vision acuity and perceptions of colors including Dalton testing. Test for the first age group has been adapted to examine people with special educational needs.

1 INTRODUCTION

The visual system in humans allows individuals for assimilating information from the environment. The vision loss may rob a person of the possibility of being for example a dentist, driver or a pilot and may dramatically decrease quality of life. Frequently occurring defects of vision is color blindness. There are many types of color blindness. The most common are red–green hereditary photoreceptor disorders. Most clinical color tests are designed to be fast, simple, and effective at identifying broad categories of color blindness. In the application the Ishihara color test was implemented. This test contains not only numerals but also the color paths extend it.

The second very important parameter describing the eyesight defects is the visual acuity that is a measure of the spatial resolving power of the visual system. This parameter indicates the angular size of the smallest detail that can be resolved. Visual acuity has traditionally been used as the primary indicator of the magnitude of functional impairment due to vision loss.

2 SYSTEM DESCRIPTION

The aim of the work was to design and to develop a system for vision screening. The main advantages of the application are its simplicity, friendly user interface and the ability to perform a screening test without any assistance of an ophthalmologist. Thus the system objectives, such as promoting access to health services and equal opportunities for children with vision impairments, are met. This system is widely available for all users of the iPhone, iPod and iPad devices around the world. Currently, the test may be conducted in two languages: English and Polish.

Testing method and evaluation algorithms have been selected on the basis of studies conducted in Poland on a large group of several hundred thousands of patients. The study has been carried out since 2000.

The choice of the iOS platform was dictated by its increasing popularity and the fact that there are a few devices using this operating system and having similar and reproducible parameters. The implementation of the system described on other mobile platforms, that use operating systems, such as Android or Symbian would be more difficult. A variety of devices using these operating systems are

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very large and this would force an external calibrator usage.

2.1 Target Platform Capabilities

iPhone and iPod devices are equipped with 3.5-inch (diagonal) screen, while the iPad device is equipped with 9.7 inches screen. Displays of those devices have very good quality.

The examined group of hardware was characterized by similar parameters, which allowed for significantly reducing the problem of preparing the test data to the particular device screen characteristic. Quality and repeatability of the devices enabled to prepare application that ensures a sufficient level of test result reproducibility, especially sufficient for vision screening. This application does not require external calibrators, which would discriminate so wide application usage.

The use of this platform guarantees also access to good application distribution channel (the Apple App Store), and ensures narrow collection of target devices. These factors have allowed the development of a universal and effective application, useful for the end user.

2.1.1 Calibration Procedure

More than twelve devices were tested using the color calibrator, which enables to specify the conditions under which the person should take the test.

Based on the results of each device the entire graphics, which is presented to users during the testing was adjusted.

A wavelength characteristic in orthogonal direction with OceanOtics USB2000+ spectrometer was measured. Brightness of the screen must be set for each device above the average value. This accuracy is sufficient to perform the screening test and obtain reliable results, even for the contrast discrimination test.

2.2 Application Design

There are two types of test available for the users. Either test for school children or test for youth and adults. Furthermore, the first type of test may serve as a tool for the diagnosis of vision problems for people with special educational needs.

Two different versions of the application have been developed (version for iPad devices and version for iPhone/iPod devices) to enable taking advantage of different features of those devices.

2.2.1 Color Vision Test

The test for adults bases on the Ishihara plates and allows also for detection of color blindness.
The user's task during the test is to recognize and to choose the correct number presented in an image or to select the 'continue' option if he/she is not able to recognize the number.

Individuals with normal color vision perceive one number. Those with red/green color deficiency see a different number (Durant and Zanker, 2009), (Linhares and Nascimento, 2010), (Miyahara and Hwang, 2006), (Nolan et al., 2008). Figure 1 shows an example test board used in the color discrimination test. In this case the user should select the number 45. If the user selects the number 15, the system will classify the answer to the red-green type daltonism group.

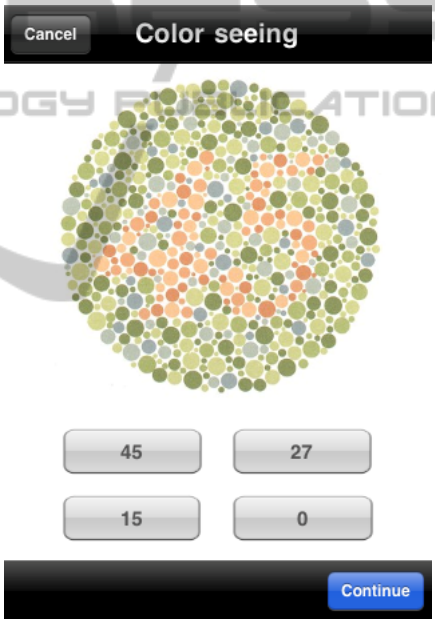

Figure 1: Color discrimination test – adults' version. Application screenshot.

In the test for children and people with special educational needs the person examined has to indicate the correct path between two points on the displayed board – maze. Because the destination devices are equipped with high quality touch screens, application can automatically assess whether the correct path was pointed out.

Location and shape of the path drawn on the screen (Figure 2) by the user are automatically compared with the reference path parameters assigned to the particular test case. As a criterion for assessing the correctness of paths, the following

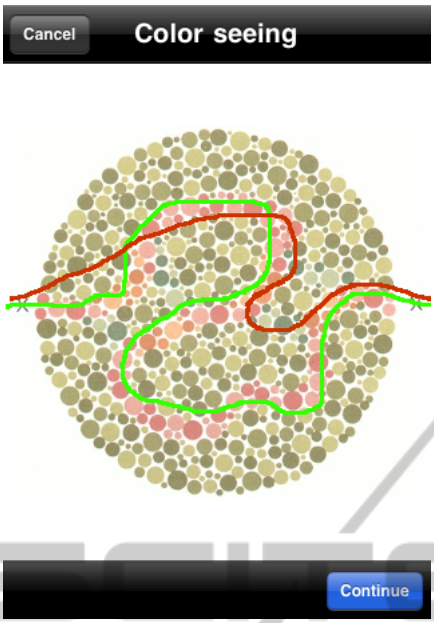

Figure 2: Color discrimination test – children version, with additionally drawn two examples paths. Correct path has been marked in green, while the incorrect path was marked in red.

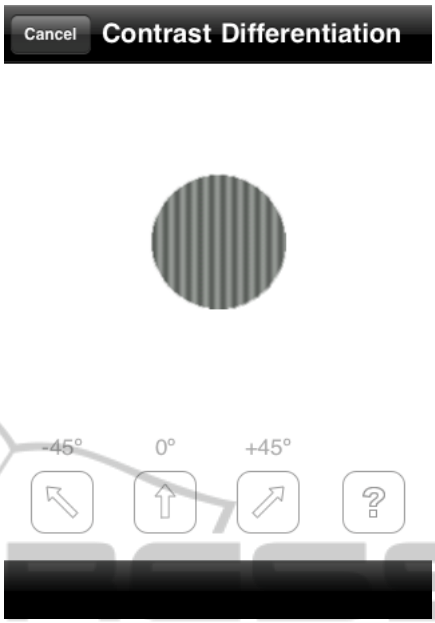

Figure 3: Contrast differentiation test. Application screenshot.

parameters are taken into account: its length and the distance of points. In addition, margins of error were determined depending on the size of the screen and the size of the presented pattern.

2.2.2 Contrast Discrimination Test

The contrast patterns were prepared by using Gabor 2D function theorem. The Gabor functions are often used in vision abnormalities detection and stimulation, because these patterns can be manipulated in spatial frequency and spatial domains independently (Foley et al., 2005), (Graham et al., 2010), (Hardy and Valois, 2002). The size perception of the Gabor pattern depends on contrast.

The aim of the contrast discrimination test is to determine the direction of slope of the line in a presented picture by pressing the appropriate button (Figure 3). The user performs the test for each eye separately covering the second eye with a hand. Depending on the correctness of answers images with different contrast are presented, and the contrast threshold for the user examined is determined.

The results of the contrast differentiation test can be presented graphically in the form of visogram, which corresponds to audiogram for hearing tests. An example of visogram has been presented and discussed in Section containing the results for the two examined age groups.

2.3 Examination Results

After completion of the test, the application generates the result in form of one of the following sentences:
- you probably have vision problems;
- probably you do not have vision problems.

In the case of the negative test result, the user is informed about the necessity of result verification with a specialist. In such a situation, additionally partial results are displayed, to inform the user, which test was failed - whether she or he has problems with color seeing, contrast dedifferentiation, or may be both. In case of failing result of the contrast differentiation test, detailed result for separate eyes are displayed.

After completing the examination, system sends detailed results of tests and additional data to the server to enable to perform an accurate analysis. In addition to the test outcome, information about testing device and language, the user can agree to share its localization data from GPS chip.

3 SCREENING RESULTS

The following Section contains a detailed analysis of the data that have been sent from the users' devices at the end of the examination and stored in the local database. In four weeks after publication of the application in the Apple AppStore (the application

engineered is available as a free dwonload), the complete vision test has been performed 3781 times. The analysis of the tests results including additional information transmitted from the user's devices has been presented.

3.1 General Discussion

In Figure 4 the total number of tests grouped by the device type is presented. Vision tests have been performed 215 times on iPod device, 297 times on iPhone and 3269 times on iPad device, respectively.

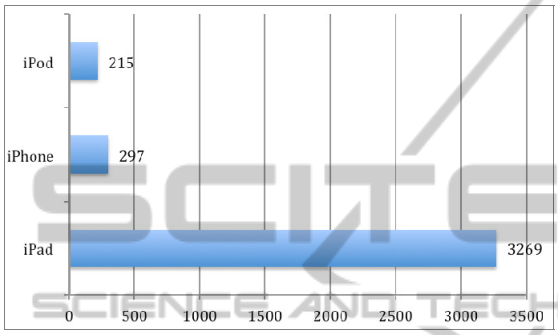

Figure 4: Total number of tests, grouped by the device type.

Probably the largest number of test was performed on iPads, because the App Store contains the lowest number of medical applications dedicated especially for those devices.

Table 1: Total test results, grouped by device.

	All	Probably healthy	Possible problems
iPad	3269	1828	1441
iPhone	297	169	128
iPod	215	104	111
	3781	2101	1680

According to Table 1, 55.92% iPad users passed the requirements for a positive screening test result. Combining all types of devices the test was passed in 55.57% of cases.

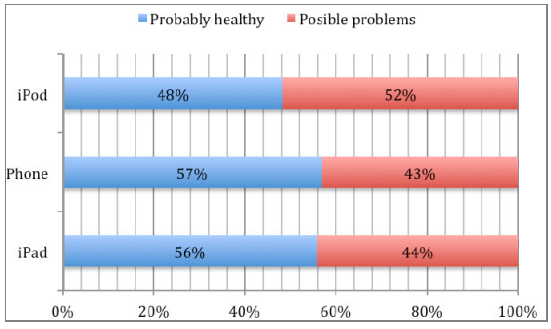

Figure 5: Percentage of positive and negative results, grouped by the device type.

The mean percentage value of positive tests results for particular groups of devices is around 53.73%. The percentage values grouped by the device type are presented in Figure 5.

Some additional parameters together with the tests results that allow for a more complete analysis of the collected data are stored on the server. One of the important parameters is the geographic position.

63% of users have agreed to reveal their geographic localization at the time of the test. Figure 6 shows on the map where all those tests were performed.

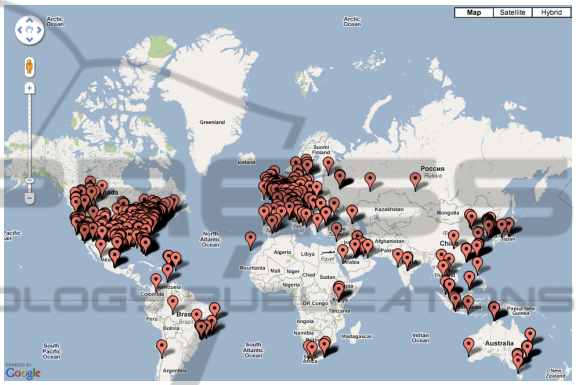

Figure 6: Places of testing in the world.

Table 2: Total test results, grouped by the country.

	All	Probably healthy	Possible problems
United States	1669	947	722
United Kingdom	391	227	164
Italy	136	75	61
Germany	134	69	65
Republic of Korea	125	57	68
Netherlands	122	68	54
Canada	117	66	51
Australia	105	57	48
France	101	58	43
Brazil	95	51	44
Spain	85	52	33
Russian Federation	73	42	31
Mexico	50	28	22
Poland	47	24	23
China	37	20	17
Taiwan (Province of China)	31	12	19
Norway	28	10	18
India	25	10	15
Singapore	23	10	13
Sweden	20	11	9
	3414	1894	1520

Reading language and the region code by the application is possible for all devices on which the

test is performed. The region code is stored in a format defined by ISO 3166-1 alpha-2 standard, so it allowes for assigning users to particular countries. It was assumed that the user maintains the same region code even if he/she is temporarily in a different place with another region code (this means that the default region settings are not changed due to the temporary change of the residence). The results for 20 countries in the function of the number of test performed are presented in Table 2. The results in Table 2 represent 90% of the total results. 10% of the results spread across 58 other countries.

Results presented in Table 2 are ordered by the decreasing number of test conducted in various countries. The first two entries in the table are the USA and GB, due to the fact that the application is available in English language, which is the official language in those countries.

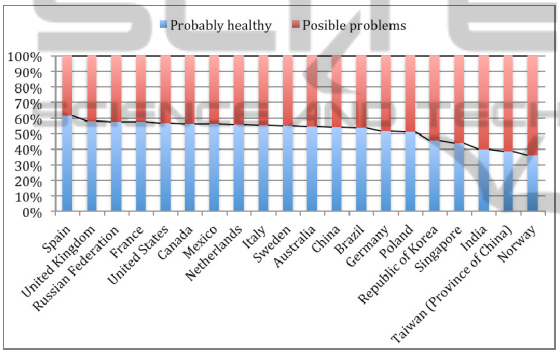

Figure 7: Percentage of positive and negative results, grouped by the country, ordered by descending positive results.

Figure 7 shows the percentage distribution of results in 20 countries listed by the decreasing number of correct results of test conducted. The average of the properly performed tests in these countries equals 51.87%. The biggest percentage of properly performed tests was recorded in Spain and the least number of properly performed tests in Norway - in both countries tests were performed in English language.

3.2 Adults

The largest trial group were youth and who performed 3096 tests.

For the additional analysis three countries with the largest number of test results and also Poland were chosen. This is equal to 1885 test cases.

Table 3 shows the overall results of tests for selected countries. Further individual test results are analyzed. From the 1398 analyzed results in the USA, 67% were correct, and 33% were negative and required further vision examination and verification of a specialist. Similarly, in the UK for the 340 tests, 66% cases obtained a positive result and 34% negative.

Table 3: Total test results, for selected countries.

	All	Probably healthy	Possible problems
United States	1398	934	464
United Kingdom	340	224	116
Italy	114	75	39
Poland	33	23	10

Figure 8 shows the percentage distribution of positive and negative test results. Ordered by highest percentage of positive results in Poland to the lowest percentage of positive results in the USA.

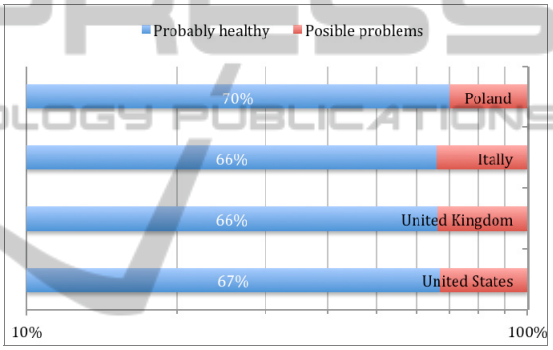

Figure 8: Percentage of positive and negative results, for four selected countries.

Among 1013 negative results of test for adults, 729 people have not passed color differentiation test (Table 4) and in 209 cases at least one answer indicating color discrimination problems has been given (in 89 cases at least two such answers have been given, and the evaluation algorithm classified those answers as characteristic for color blindness). The contrast test was not passed in 439 cases. 334 people did not pass contrast differentiation test for the left eye, and 255 for the right eye. It means that 150 people at the same time have provided incorrect answers for the left and the right eye.

Table 4: Negative results of color discrimination test and contrast differentiation test for adults.

Color discrimination test (total)		729
	Daltonism	209
Contrast differentiation test (total)		439
	Left Eye	334
	Right Eye	255

Table 5 shows the negative results of the color test in selected countries. For each number of negative results, the number of Dalton diagnoses has been given.

Table 5: Negative results of color discrimination test for adults in selected countries.

	Color discrimination test	
	All	Daltonism
United States	313	90
United Kingdom	81	21
Italy	32	8
Poland	7	2

It shows that red-green blindness appears in average of 27% of people with vision problems (from 25% in Italy to 29% in the USA).

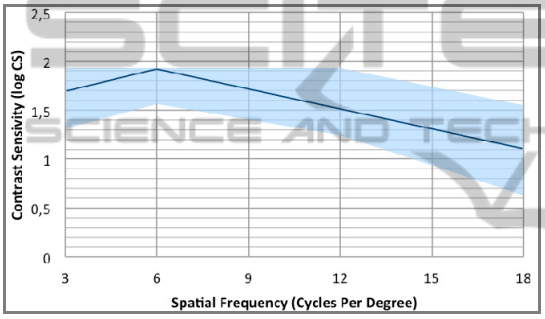

Figure 9: The result indicates lack of problems with contrast differentiation (adult).

The results from the contrast differentiation test for one eye are presented in Figure 9. If the results represented as a dark blue line are contained in the threshold range marked with light blue color, the test result is counted as passed.

Table 6: Negative results of contrast differentiation test for adults in selected countries.

		Contrast discrimination test	
	All	Left Eye	Right Eye
United States	222	169	119
United Kingdom	58	48	32
Italy	10	5	5
Poland	3	2	3

Table 6 presents the results of contrast differentiation test for the left and the right eye separately. It may be noted that in the case of a test for adults, problem for both eyes simultaneously had 30% of people from the USA, 38% of respondents from the UK and 67% of people from Poland. People from Italy did not provide erroneous answers for both eyes simultaneously.

3.3 School Children

Sight tests for children have been completed 712 times. These results have been subjected to similar analysis as test results for adults. The consideration to the same four have been considered.

Table 7: Total children examination results, in four selected country regions.

	All	Probably healthy	Possible problems
United States	271	13	258
United Kingdom	51	3	48
Italy	22	0	22
Poland	14	1	13

According to Table 7, in the United States 271 tests for children were conducted. 13 of them were positive and 258 negative. For 51 results in the UK 48 were negative, and 3 positive.

So large number of failed tests may indicate that the tests were performed with an inadequate attention, or the instruction was misunderstood. Problems with touch screen usage are also possible for the inexperienced users.

In Figure 10 the percentage distribution of positive and negative test results were presented. The largest percentage value of negative test results was obtained in Italy (100%), while the lowest percentage value of negative test results was obtained in the USA (95%).

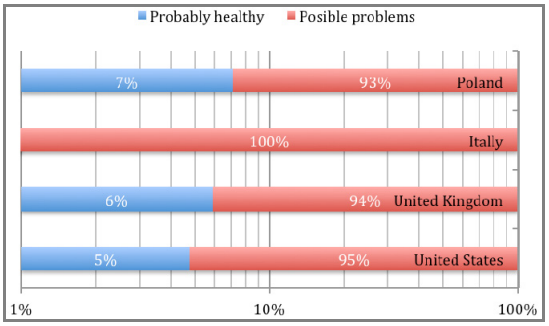

Figure 10: Percentage distribution of positive and negative test results for selected countries.

Table 8: Negative results of color discrimination tests and contrast differentiation tests for children.

Color discrimination test (total)		660
	Daltonism	--
Contrast differentiation test (total)		211
	Left Eye	140
	Right Eye	163

660 persons engaged in a test designed for children obtained a negative color vision test result (Table 8). In the case of children's examination, the daltonism test is not executed.

The contrast test was not passed by 211 people of which 140 people failed a contrast test for the left eye and 163 for the right eye. Hence the conclusion that 92 people got incorrect answers for the left eye and right at the same time.

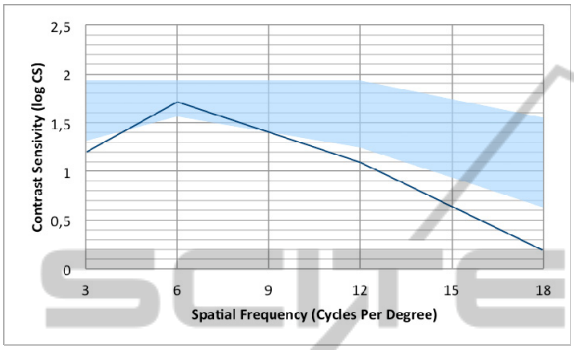

Figure 11: An example of a visogram for children. The result indicates problems with contrast differentiation (children)

The results of the contrast differentiation test for one eye are presented in Figure 11. Because the results represented as dark blue line are not contained in the threshold range marked with light blue color, the test is not evaluated as passed.

Table 9: Negative results of color discrimination test for children in selected countries.

	Color vision test
United States	254
United Kingdom	47
Italy	22
Poland	13

Table 9 shows the negative results of the color seeing test in selected countries. According to Table 7 and Table 9, 98% of all negative results in USA were caused at least by the problem with color vision. Similar conclusions can be derived for other countries, where percentage values are equal to or greater than 98%.

Table 10 presents the contrast differentiation test results for children. The data are presented for the left and right eye separately.

It may be noted that in the case of a test for children, problem for both eyes simultaneously had 49% of people from the USA, 44% of respondents from the UK and 40% of people from Italy. People from Poland did not provide erroneous answers for both eyes simultaneously.

Table 10: Negative results of contrast differentiation test for children.

	Contrast differentiation test results		
	All	Left Eye	Right Eye
United States	92	73	64
United Kingdom	16	13	10
Italy	5	3	4
Poland	3	2	1

4 CONCLUSIONS

Performed analysis was made according to results from the group of unique users. Additionally 893 persons performed the test at least 2 times and maximum 12 times.

There may be doubts whether a particular test was made just for trying, or to obtain a conclusive result. Since the results of examination are sent to the data storage at the end of the test, this may lead to the conclusion that the users' intention was to finish the test and to obtain reliable results. It should be noted that the test results strongly depend on how precisely the person performing the test respects the instructions displayed on the device's screen (lighting conditions, recommended distance of eyes from the screen).

The latest versions of iOS based devices allow for the preparation of a system capable of producing more reliable results. Built in cameras would allow not only control the lighting conditions during the test, but also to check the distance from the device screen. Considering the great popularity of the application it will be made supported by other languages, which should increase the number of conducted examinations and eliminate errors caused by the language barrier.

Results of color differentiation test for children suggest that there is a need to add the feature indicating the path in a multi-step manner through repeatative taking the finger off the device screen. The results presented in the paper confirm the need to perform vision screening tests. It should be noted that the examination sessions were not conducted in the laboratory, and during the test the user was able to manipulate the distance of the device from the eyes, which facilitated the correct answer identification.

Procedures of the detection of vision defects have been chosen on the basis of research carried out by using computer vision test system. The internet version of the system is available at the address: www.telewelfare.com.

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