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Mobile Services Supporting Color Vision Deficiency

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Abstract- **This paper presents an application for smartphones, which supports people with color vision deficiency (CVD). Following a general introduction we discuss briefly relevant aspects explaining the causes and types of this disease. A variety of test procedures have been developed, allowing to diagnose different categories and levels of CVD. As we propose a new mobile solution to support people with and without CVD, we first summarize related work with special attention to mobile applications. People suffering from color vision deficiency are restricted in observing or acting correctly in many daily life situations, of which some are described. Next we propose our superior and more advanced Android smartphone solution which fulfills three purposes: (a) it allows to easily diagnose red/green and blue/yellow color deficiency (b) it supports people suffering from CVD by listing colors, which normally would not be recognizable as soon as the smartphone camera is directed towards any object (c) it provides a simulation mode, which presents any object to people without CVD the way people suffering from CVD would see them. The paper shows results of ongoing research, following the design research paradigm. Therefore only preliminary design considerations will be discussed. The paper concludes with some ideas on future work, which will be considered for the next research cycle.**

I. INTRODUCTION

A. *Medical problem*

Color Perception

The human eye has a nearly spherical form with a diameter of about 25 mm. Human color vision is entirely based on the input the retina detects. The light of the scene falls through the pupil onto the retina on the inner back of the eye ball. The retina has a size of about 1100 mm and consists of multiple layers of different cells. First the uppermost layer detects light and distinguishes between colors. This layer consists of cells that are able to detect electromagnetic waves at a wavelength between 380 nm and 780 nm: about 6.8 * 10^6 cones and 110 * 10^6 to 125 * 10^6 rods are distributed on the retina [1].

Rods are responsible for vision in low light conditions and for detection of brightness. They react to low light but are unable to distinguish different light spectra. Since healthy humans are trichromats the retina features three kinds of cones used for color vision. They cover different not disjunctive spectra and are called L, M and S for the short, medium and long wavelength that they react to. The L type reacts to the most reddish light, with the highest absorption values at 577 nm [2]. M reacts to a more greenish light of

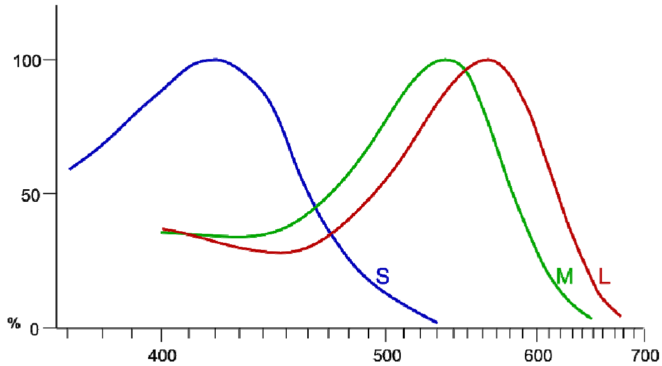

Fig. 1. Relative response of S, M and L cones to light of different wavelength (according to [3])

comparatively medium wavelength. M cones are very similar to L cones and react to a spectrum not too different from the L cones. The maximum sensitivity is at 540 nm [2]. The S cones spectrum differs significantly from that of the other cones'. Its perceived wavelength is much shorter. The S types maximum sensitivity is at 477 nm [2] (see Figure 1). The cones and rods create signals dependent on the absorbed light, which is passed to the deeper layers of the retina. These layers form a neural net of about 200m cells performing a first processing of the signals [1]. According to the opponent process the three color signals from the cones are converted into two signals on almost orthogonal color axis. A red-green axis created from the L and M cones signal and a blue-yellow axis created from the S cones signal plus a combined one of the others [4].

Color blindness

True color blindness, monochromatism or achromatism,

		Male	Female
Protan	Dicromatie	1,01 %	0,02 %
	Anomale Trichromasie	1,08 %	0,03 %
Deutan	Dicromatie	1,27 %	0,01 %
	Anomale Trichromasie	4,63 %	0,36 %
Tritan	Dicromatie	0,005 %	0,005 %
	Anomale Trichromasie	~0,0 %	~0,0 %
Monochromasie		0,003%	0,002%

Fig. 2. Relative Abundance of Visual Chromatic Defects [2]

which allows no color perception at all, occurs very rarely (see Figure 2). Dominantly only one of the three cones is affected. If one of the cones is defect, it will be harder to distinguish colors on the corresponding color axis and CVD is the result (see Figure 3). This condition is called anomalous trichromacy. If one type of cones is completely absent or not working at all, the person is a dichromat and will not be completely unable to distinguish colors on one color-axis. Both anomalous trichromacy and dichromasy do not affect other abilities of the vision than color perception. Abilities like visual acuity and night vision are unaffected. Depending on the defunct cell the conditions are called protan, deutan and tritan defects which are named after the Greek prefix in the order they were discovered [2]. The well-known red/green-CVD, which is the most common type, divides into the two types protan and deutan for defective L or M cones. Both defects are passed on by the X-chromosome, thus men are much more affected than women. About 8 % of men suffer from either a protan or deutan defect. Since L and M cones are similar to each other and add to the same color axis, both cause similar undistinguishable colors. In general, the red-green axis cannot be distinguished [4]. The tritan defect is caused by a dysfunctional or malfunctioning S cone, resulting in a blue-yellow CVD. Less than 0,01 % of the population are affected by a tritan defect [4].

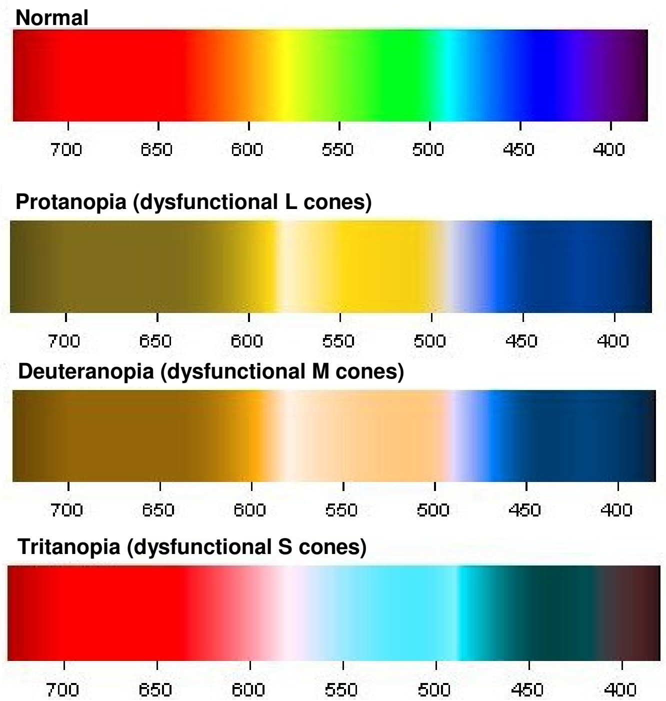

Fig. 3. Color perception in comparison as spectrum diagram [5]

B. *CVD Test Procedures*

Anomaloscope:

An anomaloscope is a device, which provides the most precise and reliable qualitative and quantitative measurement for anomaly in color perception. Typically it is used for red/green CVD, but modifications to rate blue/yellow CVD have been developed. The patient has to look through the device onto two colored areas. One area shows yellow as a reference. The mix of red and the green components of the other colored area are adjustable, so increasing the red component decreases the greenish level [6]. The task for the patient consists of adjusting the red/green mix ratio to appear as the yellow reference area shown underneath. The level of red/green CVD may now be expressed as the so-called Anomaly Quotient which describes the ratio of green to red component proportion [7,8].

Full color vision results in an Anomaly Quotient of 1.0, values significantly below indicate a protanomaly, and values above 1 a deuteranomaly [6]. This ratio is used frequently in specific recruitment processes as criterion for exclusion based on a predefined threshold value.

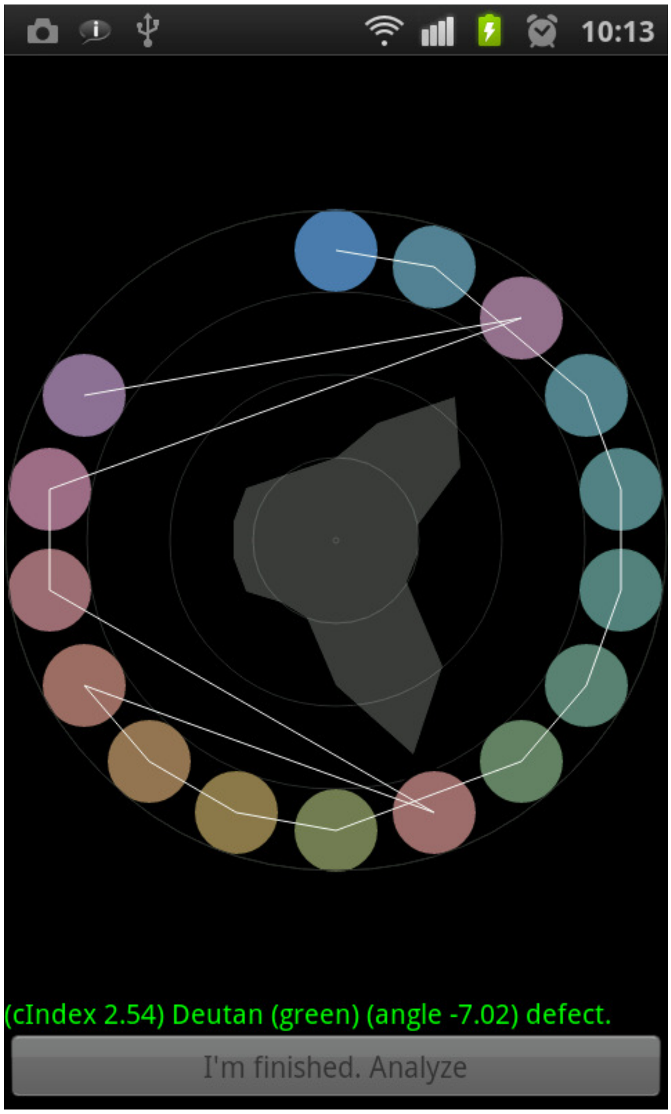

Fig. 4. Screenshot of Color Arangement Test (Farnsworth-Test) with result, showing the correct order (white line), areas of confusion (grey area) and the type of defect (green text).

As the display of smartphones builds on the primary colors red, green and blue, an implementation of such test procedure is not feasible. The spectra of colors perceived as identical are physically indistinguishable as well. So the reference color yellow will be produced by the display based on the same red and green pixels as the mixed color.

Pseudoisochromatic Plates:

This test procedure employs a series of plates on which numbers or letters are printed in dots of primary colors surrounded by dots of other colors, well known under the name Ishihara test. The figures are discernible by individuals with normal color vision but not so by people with CVD. Depending on the colors used on each of the plates, people with CVD may identify different numbers than given. The test procedure does only allow for dichotomic results (presence/absence of CVD). [9]

This type of test procedure may be easily implemented on mobile devices with common types of color displays, although the results may vary due to different color representations. Altering the view angle onto the screen which might lead to a change in the perceived color or forged color representation on the phones display in general may even result in wrong test decisions.

Color Arrangement Test:

Color arrangement tests use pads of different color, which have to be ordered by the tested person. This type of test can be used to detect red/green CVD as well as blue/yellow CVD and to determine their degree. The Farnsworth-Munsell 100-Hue Test has been the first of that kind. The colors of the pads (aka disks or plates) are based on the color system developed by Albert Henry Munsell [2]. These pads differ only in hue and have to be arranged according to a color circle [9,10]. The test allows exact identification of those color ranges, which are recognized insufficiently. Thus a simple score will be calculated expressing the level of CVD. Furthermore a graphical evaluation allows the exact representation of different hues perceived insufficiently [11]. Beside the complex Hue-100 version with 85 pads an abridged version, called the D-15 test has been introduced. 15 numbered pads with all different hues have to be put in sequence. An automated evaluation procedure by Vingrys and King-Smith [12] allows an easy implementation and much faster enforcement, still leading to detailed test results. Small changes to the displayed color values lead to less drastic changes in the test result that with simple yes-or-no results from a color arrangement test. The abridged D-15 version with only 15 plates does fit the screen dimensions of a smartphone much better than the Hue-100 version. (see Figure 4)

We regard the D-15 test therefore as appropriate for the proposed mobile application; it will be initiated right after starting the application. [13].

II. EFFECTS OF CVD ON DAILY LIFE

Vision is an important sense for orientation in everyday life. Since distinction between certain colors is the only restriction people with CVD have, they can easily cope with most everyday situations. But all situations with different color-coded information or multiple objects with similar lightness but different hue might cause significant problems. These might occur on different levels either in private or work life.

Artificial Signals and Safety

It is obvious that people with limited color vision are unable to understand color-coded signals created by humans that bear no other distinguishing features. That might be traffic lights, which are easy to be recognized in daylight situations when the position of the light can be seen. But at night or from great distance when the relative position can not be seen, they are hard to be deciphered correctly and not as fast as with full color vision. Other light sources, like stoplights, street lights or advertisements might make it even more difficult or impossible to distinguish the current state of a traffic light. Some professions, like pilot or locomotive engineer, have therefore high requirements on vision. For both professions the full ability to identify color-coded signals quickly and clearly is mandatory. An incorrect identification of an aircraft's navigation light or a delayed recognition of a stop signal may have catastrophic consequences. Maneuvering a ship has similar requirements, since many signs are color-coded. The police sets high demands for applicants, too. Even some professions with less safety critical task patterns formulate equally high requirements on color vision. Electricians need to distinguish individual cores of cables, which are usually marked with different colored jackets. This makes it difficult or impossible for them to solder on plugs or replace cables precisely. Other electronic components, such as resistors are also color-coded and can hardly be distinguished by people with CVD.

Aesthetic impressions

For people with CVD aesthetic impressions are fundamentally different when many different colors come together. The overall impression of a painting or image can differ substantially compared with people without CVD or the artist's intention. In addition, people with CVD might face huge problems regarding the color of their clothing. This is often perceived as one of the biggest limitations in everyday life. Clothing that seems grey to people with CVD, can actually have a flashy bright color and might cause undesired color combinations. Also non-matching or repugnant patterns are not perceived as such. Although the fashion changes every year and tastes are individually different, some combinations never lead to a satisfying result. In extreme cases this can lead to oddities like different colored socks. In short, people suffering from CVD might never feel to have a safe sense of fashion.

Orientation and Maps

The task of orientation in everyday life is more difficult with limited color vision, because location information is often color-coded. Some of these color appear to people with CVD as grey-levels. Road maps and transit maps are usually filled with color-coded information. Different colors represent different lines (e.g. London tube), types of roads or landmarks. In addition the recognition of the matching colors in the real environment is required when routes are only coded by color and not an additional name or number. Using public transport is therefore especially demanding in stations where multiple lines meet and must be distinguished by color only. Other charts and graphs tend to use colors to distinguish or emphasize things, too. It can be difficult for people with CVD to distinguish those or even recognize them as highlighted.

Further areas

While pharmaceutical products are usually clearly labeled on the packaging, individual pills are often only distinguishable by color. Mistaking those might pose serious risks. Many natural processes are accompanied by color changes, which may not be identified correctly. Sunburn might be told apart from a tanned skin too late. The degree of ripeness of fruits might not be recognized correctly. Also similar fruits might be hard to distinguish when color information is not reliably identified (see Figure 5). Many other fields, such as playing board games or even distinguishing the flavor of colorful sweets pose problems to people with CVD, too. Besides identifying colors, the problem is how to even become aware of ambiguous colors.

Fig. 5. Color perception with total Deutranopia (dysfunctional M cones) when judging the ripeness of fruits [14]

C. Color Detectors for blind people

Color Detectors are especially designed for use by blind people and therefore their requirements differ essentially form those of people with CVD. For blind people the user interface has to be kept much simpler than for people with CVD, who are able to control relatively more complex and dynamic interaction patterns. Color names are typically provided by speech output of color names. These type of devices are typically priced between 100,- and 500,- Euro and for blind people they can be covered by health insurance companies but not for people with CVD. They are dedicated hardware devices, which work only in close distance to the object under study. For many common situations they are therefore less easy to use or even useless.

D. Software Applications (apps)

Some applications can be found in Google's Android market, which provide a certain level of support for people with CVD. iOS and other mobile operating systems offer similar Applications. Common to all is the usage of the camera of the mobile handset and some information output regarding the displayed colors. For the following we exemplify our discussion by referencing and comparing ColorFind, Color Detector und Color Blindness Correction.

ColorFind

ColorFind from GoldenShores Technologies, LLC[1] has a rather simple interface consisting of only the camera view, a quit-button and a single line for the color name output. The camera view is squeezed on half of the screen in landscape mode and therefore it is barely usable in landscape mode. The only functionality of this app it to continuously list the color name of any object at the center of the camera picture. The color names list consists of black, grey, white, red, green, blue, yellow, purple, brown, pink and orange only. No further discrimination is given, hue or brightness are ignored completely. As this list of color names corresponds with the capabilities of common smartphone cameras, intensive colors will be properly recognized. Less saturated colors will be represented poorly. Light-colored wooden surfaces on the for example image might be named by the system as either yellow, brown, pink or grey - darker areas even as orange. ColorFind does not keep the screen active, thus the screen will turn off and lock after the time interval predefined in the Android settings. We conclude that this application provides only limited support for people with CVD because of its limited range of colors and inaccuracy in many situations.

Color Detector:

Color Detector from mobiala.com[2] is available for free and allows different ways to present the color shown at the center of the camera picture after clicking anywhere on the screen to start. In the top line the color names are listed as plain text, differentiating brown, blue, purple, red, green, grey, white, yellow or orange. On option the color name will be output audible to the user. The complex color names belong to a set of over 80 elements, which are far from self-explanatory and are far beyond the resolution capabilities of today's

[1] https://market.android.com/details?id=goldenshorestechnologies.ColorFind.standard

[2] http://www.mobialia.com/color-detector

smartphone cameras. To give an example: a green apple might be labeled as Costa Del Sol, Horses Neck, Deco, Cola, Onion, Green Mist, Pale Leaf or Maire. Changing the view angle of the camera or modifying the light conditions (sometimes even under constant conditions) leads to inconsistent results. The color white will be only recognized in case of overexposure leading to the RGB values (255,255,255).

The 2nd and 3rd types for presenting colors are HTML and RGB based. The numbers for red, green and blue are listed either in hexadecimal format (HTML) or as decimals (RGB), making it difficult for the average user to interpret them. The 4th presentation follows the HSV color system notation, providing hue, saturation and value as text only. Again, the average user is most likely not able to understand this notation, as the hue is given as an angle in degrees, a graphical presentation would be needed but is missing.

Color Blindness Correction:

Color Blindness Correction from NGHS.fr [3] is offered currently at the Android Market for 1,49 Euro. The interface offers a variety of elements, most of them we consider as non-intuitive or at least difficult to understand. Most of the screen is covered with the current camera picture overlaid by a variety of information details. To cut it short, most of the criticism formulated above does apply the same way. The Diagnose-Wizard pops up at application start, it is purely text based and lists the following questions: "*1.) Which colors do you confuse? 2.) What is the color you don't see? 3.) What color do you see best?*" To each question one may answer with one of two options or "I don't know!" Now, in case all these answers would have been "I don't know!" the wizard sets protanopia as CVD type, although the more frequent CVD is deuteranopia. With this type of textual profiling based on these few questions only, the type of CVD must be known to the user beforehand, thus providing no support by diagnosing any specific CVD.

Further program components are Color Blindness Correction, Alter Colors, Simulate Only. Compared with the before mentioned apps it is more feature rich, but it still lacks the capability of storing any user specific profiles containing individually specified color labels of references to colored objects.

General Software Support

Some software packages provide optional support for CVD by increasing or changing certain color mode parameters. As an example we refer to the computer games "Left 4 Dead" and „Left 4 Dead 2" which provide a "Color Blind Mode" for the adjustment of hue and color schemes especially for red/green CVD players. Windows offers support for people with impaired vision, too. Speech output is very common, but increasing the contrast or support by a magnifying mode as well. None of these options are dedicated specifically to people with CVD.

[3] http://www.nghs.fr

III. Concept and Realization of a Mobile Service For People with CVD

Prior to describing the details of the development, a short remark on the underlying research approach helps to understand the cyclical structure of the overall process as well as the steps within each cycle. The Design Research Approach has been broadly discussed in the Information Systems Community and is well accepted there and in the field of engineering research. For a detailed discussion we refer to [15] and the literature provided there [16, 17]. In figure 6 the essential steps and outputs are shown, allowing us to refer to these terms in the following.

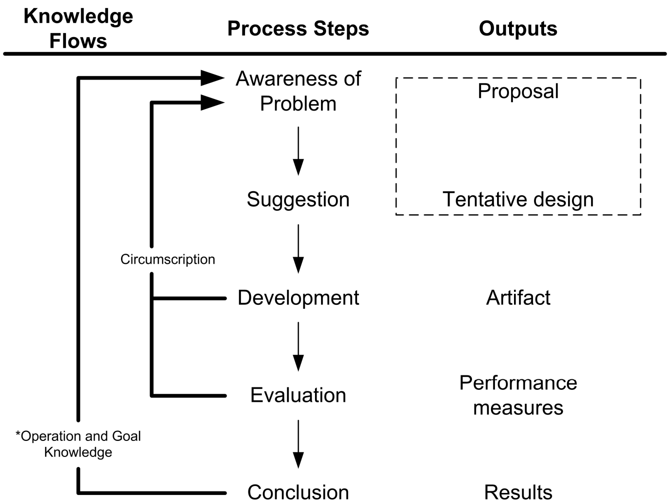

Fig. 6. Design Research Approach [15]

As the penetration rate of smartphones increases rapidly, the development of mobile services to support people with CVD is an obvious opportunity, as they will not need any dedicated device. The current and future smartphones have all necessary hardware components to fulfill the requirements of these types of mobile applications forming a service suite (apps). Smartphones with mobile operating systems like iOS or Android are predominantly found in the hands of users who are willing and sufficiently experienced to add new offerings to their application portfolio. Furthermore it is easily possible to expand the functionality of an application over the time and distribute it widely. This option is not given with most dedicated devices. Like with other apps such as product or price scanners, the usage of our CVD app may be integrated into many normal activities without the problem that other people will immediately discover that its user has a CVD problem. Thus the suffering from CVD and the need for support represents basically "the awareness of the problem".

But our focus is broader, as we aim to design a mobile service (an application suite) for different user groups. In addition to CVD support we want to generate broader awareness and substantial understanding of this disability, so that other people may find them useful, too. We therefore consider a segmentation of application components ("suggestion and tentative design"), as described next.

A. *Use cases in general*

As we would like to generate broader awareness, the proposed mobile service should start with a self-assessment in order to either detect an existing CVD or full color vision ability. It should report on the type and level of CVD and advice to consult an ophthalmologist. Furthermore, these data will be used for generating a user profile, which allows in a separate mode to generate an augmented reality. Considering such an app as a pre-test available for free and widely available might even be cost efficient as only critical cases an ophthalmologist is needed for an assessment.

Based on the considerations in section II we decided to implement the abridged color arrangement test (D-15 test), which does not take longer than two minutes to detect the CVD because the test results allow us precise assessment in one test step within 2 minutes on the small screen.

For people without CVD it is sometimes difficult to imagine or foresee potential problems of people with CVD, thus they might work with inappropriate colors (e.g. architects or construction managers are often using colors for signs, signals or icons to indicate floor levels, public transport lines etc.). The proposed app provides a simulation mode, showing the world through the smartphone camera as seen by people with CVD. Thus specific awareness might lead to use an unproblematic color combination and/or the usage of additional elements (i.e. text, symbols, etc.). An example of the simulator mode is shown in figure 7. Finally the mobile application could be useful for educational purpose. Students in computer science can see the conditioned sensor data and the working steps of the algorithms in real time. So it is possible to build an understanding of these methods. This argument may apply to some degree for students in other fields as well (e.g. general medical practitioner, ophthalmology, optician trainees etc.)

B. *Development*

Based on the suggestion and tentative design considerations we now move on to the construction of an artifact as the next step of the design research cycle (see figure 6). Earlier on we have determined that most of the existing applications are mainly technical driven developments. Developers have their focus primarily on the capabilities of current types of smartphones, but less on the requirements of the users. Most apps are not build for every day usage and rarely feature complete. Most apps even lack the option to detect any existing CVD. Building on this insight we followed a user centric approach by aiming for a tool with ease of use in daily life, avoiding any possible unintended disclosure or stigmata. Thinking through the different challenges and habits of the users was a key task, which due to the author's different areas of expertise in research (from soft Information Systems to Computer Science Research) was very stimulating. Facing the needs of different user groups we choose to present the data in different presentation formats,

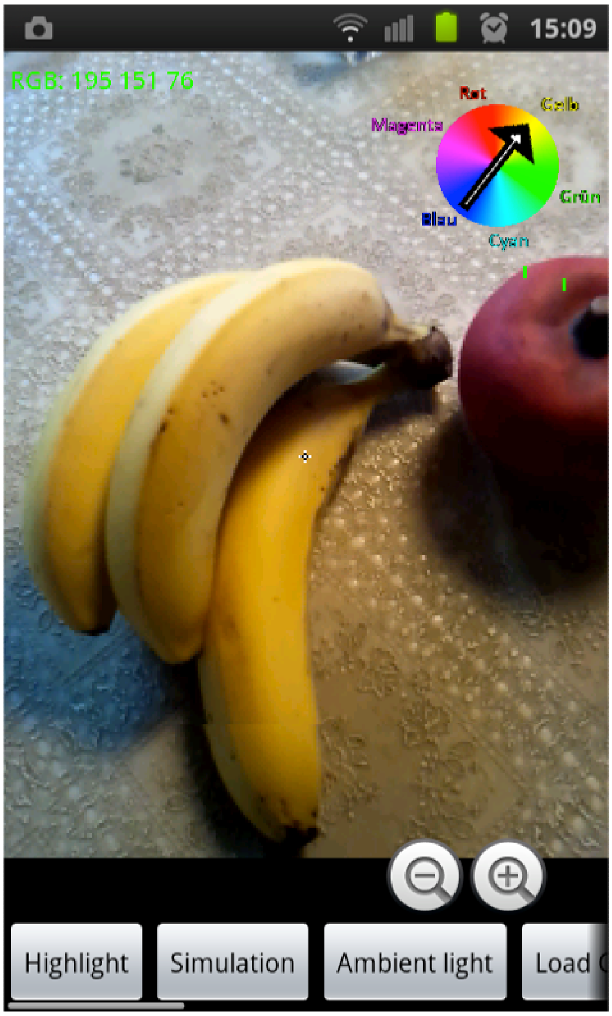

Fig. 7. Screenshot of the app, clarifying the color of fruit via the color wheel.

varying from simple textual content, symbols, scales, complementary colors, accentuation of edges as far as raw color data in RGB, HSV or hex data. Depending on the user group the context appropriate information will be displayed. Some of these formats and data will only be used for development or the usage in the course of studies, so that students can see live sensor data. In addition to textual or graphical information the user may choose to get speech output. The user might choose to wear a Bluetooth headset so that he can use the app even without reading the display for long (holding it close). The above-mentioned problem of textual content presentation remains unsolved, as some well understandable vocabulary of names or labels for colors has to be chosen.

At application start the user chooses the usage role (regular user, medical staff, architects, students). In case the of the roles regular user or medical staff the app jumps top the CVD test, generating a profile for any regular user. For medical users the test procedure may be repeated.

Fig. 8. Simulating a deutan defect and identifying the color via color wheel

Another main function of the application is the augmented reality view. Based on the profile support is provided to detect the color of any object the center of the camera is directed on. See figures 7-9 for example, showing real screenshots taken with our application.

C. *Preliminary Evaluation*

In step 4 of the design research cycle, (see figure 6) a sound and broad evaluation is required. As we present research in progress, large field trials are not available, yet. But based on preliminary results from usability studies with smaller groups of students, we gain input for improvements, which drives our next development iteration. Key criteria are acceptance of such a mobile service suite, different usability considerations, preferences regarding the textual information presentation and varying usage scenarios (on the bus, in the shopping mall etc.). Specific attention will be paid to user groups without a strong technical background and of different ages. Difficult to test but important from our point of view is the criterion of non-intrusiveness.

In summary of all these steps in the design research cycle we may stop at some point with a conclusion. This may either lead to state that a satisfied level of problem solution had been reached or more likely, that based on new technology

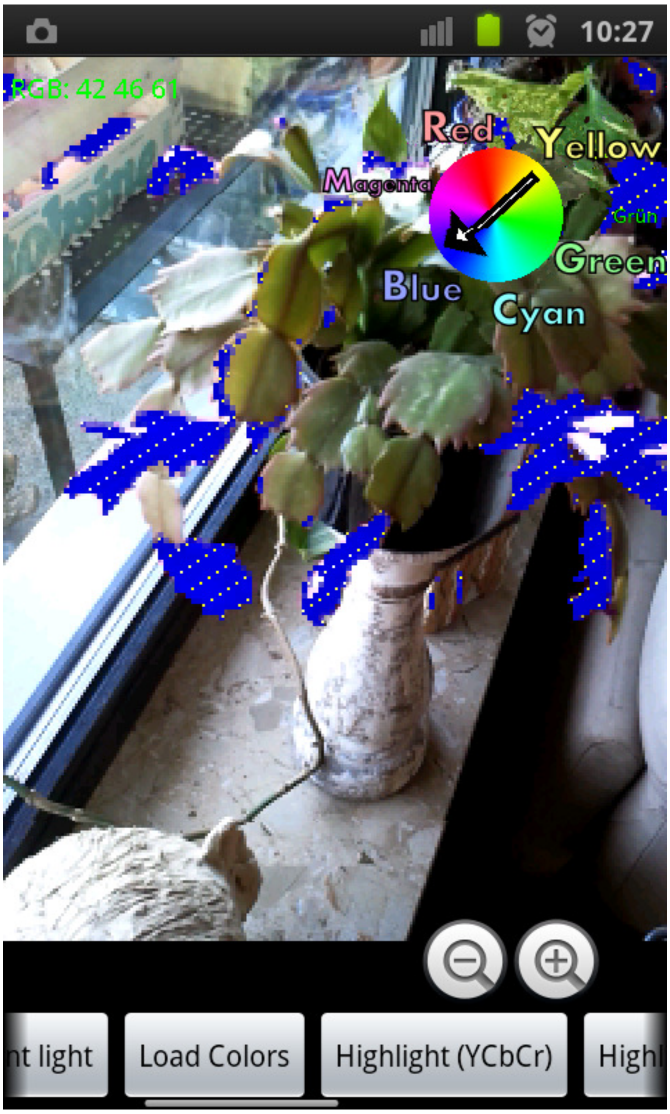

Fig. 9. A user selected color is highlighted in high contrast color

much more sophisticated, advanced and even simpler procedures are available to start a project from scratch. The overall circumscription of the problem space and earlier evaluation results will still be highly valuable input.
Cameras of smartphones are mostly controlled automatically by hardware loops which will provide the best visual

impression on the display. Technically, this requires color correction mechanisms that are not easily accessible to the application programmer. Calibration of such a camera is possible in principle, but not easy to accomplish. Although these circumstances imply that a color camera cannot be used as a color measuring device, it has been shown in the experiments that even then the color naming methods are quite reliable. In addition it has to be noted that users are cooperative, in general, and can modify the aspect of an object such that the camera will get the best possible image.

IV. CONCLUSION AND FUTURE WORK

In this paper we explained our mobile application which can assist people suffering from color vision deficiency problems (CVD). The camera of a regular smartphone is used to capture an image and the display can be used to simulate color deficiency to people with normal vision.

Several tests are implemented to give users insight in their color vision capabilities. In contrast to other existing application our system provides only rough color names but also supports user selected colors and an interface with a graphical representation that is suited to assist CVD.

Preliminary tests showed that the system is highly accepted this user group and also interesting to the normal control group to understand CVD. We will provide more elaborate evaluations in the final contribution and we will continue our research in this field.

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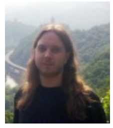

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