UNIVERSITY OF GOTHENBURG

Development of a Mobile Test Suite to Determine the Sobriety of Motorists

Bachelor of Science Thesis in Software Engineering and Management

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an explanatory caption for the (possible) cover picture
with page reference to detailed information in this essay.]

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***Abstract*—The project presented in this paper describes some aspects relating to the implementation and feasibility of a mobile phone based test suite that has the goal of helping police officers to determine whether someone is sober or under the influence of alcohol or drugs and, if influenced, may be unfit to drive. The three currently implemented tests that are described in this thesis evaluate medical as well as psychological aspects. Medical and technical background information for the tests as well as the research process and implementation methods used during the course of the project are also listed. Preliminary results based on a small number of volunteers so far show promising results, although an in-depth evaluation remains to be done.**

***Index Terms*—mobile eye tracking, psychophysical testing, mobile computing, traffic safety, driving under the influence**

I. Introduction

The abuse of alcohol and drugs is an ever growing problem in modern societies and its effects are especially noticeable when looking at statistics related to traffic accidents that occur under the influence of such substances. While the effects of alcohol are widely known and accepted, it is often not acknowledged that illicit or pharmaceutical drugs can also have a significant influence on driving, but dangerous driving such as drifting between lanes, speed violations are observable in the driving style of drivers under the influence of both alcohol as well as medical or illicit drugs [1]. For example, in Germany, 1.6% out of 2.4 million accidents that had been registered by the police in 2010 were related to alcohol and drugs and with 5.6%, this percentage is even higher when looking only at accidents where one of the participants was injured. 9.4% of traffic accidents with a deadly outcome were also due to alcohol or drugs [2]. Laws dealing with impaired driving are available in most countries and already account for quite a number of sanctions such as temporary or permanent license revocation for drivers who are caught while driving inebriated.

As a control instance, the police often set up checkpoints or flag down suspicious drivers to perform roadside testing for determining whether someone is impaired by a prohibited substance (including alcohol). There are a number test methods that can be used to determine the level of impairment, ranging from more or less simple reaction, balance or dexterity tests as well as drug wipes to breathalyzer tests that can be used during such roadside tests to more complicated laboratory tests. Due to the rapid "evolution" of modern (designer) drugs as well as growing use of prescription or over-the-counter drugs that may also have a negative influence, even with these methods, detecting drug impairment is not an easy task and in comparison to alcohol level calculation, specific standards for measuring the level of drug impairment are often unavailable. What one should remember is that while it is certainly important to be able to exactly determine the level of a substance in a suspect's body using some laboratory analysis methods, it is also interesting to be able quantify the individual effects. Depending on many factors, these may differ between individuals and while someone with a high level of some substance may appear sober, another person with considerably lower levels of the same substance may be severely impaired. Nevertheless, both individuals should not be allowed to continue driving.

As mentioned before, many test methods have been established for testing and rating effects that contribute to an individual's ability to safely participate in traffic situations. But especially tests that have been established for use during roadside testing [3], [4], e.g. the "Standardized Field Sobriety Test" (SFST) often have disadvantages such as being highly dependent on the experience of the police officer or police surgeon who conducts the test and they lead to more or less subjective results [3]. On the other hand, methods that might be used to obtain more objective ratings are often not usable outside of a laboratory setting. There are currently no methods or tools that integrate all necessary features, can easily be used in a mobile setting, have proven their validity and can stand up to the legal requirements for a trial if necessary. It would therefore be highly desirable to design a tool that could cover all these aspects and make it possible to provide the police with a mobile, reliable and easy-to-use tool in the form of a mobile test suite that could be used to obtain objective data about someone's impairment.

With the advent and widespread use of modern smartphones and tablet PCs, this goal might finally have become achievable. Such devices offer many different sensors such as integrated high resolution cameras, accelerometers, touch screens etc. that could probably be put to use for implementing tests for the purpose of sobriety testing. Already, some apps available in the application stores of various mobile platforms claim to be able to determine the level of (alcohol) intoxication of their users, but these apps usually do not have a scientifically proven background and are in fact often quite inaccurate. Often, they only ask their users about the number of drinks they had as well as their body weight for calculating the approximate level of alcohol in the bloodstream. They also do not cover other aspects such as individual differences, combination with other substances, health issues and so on and as such, are not reliable.

A. Research Question

Based on what is known about the medical and physiological background related to sobriety testing as well as the capabilities of today's mobile devices, is it really feasible to implement a mobile test suite that

1) covers the necessary aspects,
2) is of short duration,
3) is easy to use,
4) leads to robust and objective results,

and can for example aid police officers in their daily work during roadside testing?

B. Overview

The remainder of this report is structured as follows: Section II will provide introductory information about the medical and physiological background upon which sobriety testing – no matter if dealing with established methods or those that are still under development – is based. In addition, a short overview of those parts of current mobile phone technology that are relevant to find a solution for the research question. Section III describes the research methods, including the strategies, settings and data collection processes that were employed during the course of the described project. The design and implementation part for the prototypical mobile application that was constructed based on this research is described in Section IV. This includes a basic description the development setup and software libraries used as well as the algorithms that were employed for the most important parts of the designed app. A short description of test methods used during the development cycle is also given. Since the project is still at an early stage and real evaluation data is currently not yet available, Section VI discusses some positive points as well as problems that were already noticeable. Finally, Section VII concludes and gives an outlook on future work, including the basic setup of a sound, scientific evaluation that is planned for the near future.

II. Background

A. Medical and Physiological Background

In order to better understand established test methods as well as to get an idea about developing or enhancing tests for alcohol and drugs that can be implemented on mobile devices, it is important to comprehend the basic medical and physiological background, e.g. the effects these substances have on the human body.

The physical and psychological effects of alcohol and other drugs depend on many factors. For one thing, these substances can influence the central nervous system as well as the brain, and may thus affect autonomous functions of the body such as heart rate, blood pressure or pupillary dilation (e.g. widening of the pupils). Judgement, movement and balance, perception and emotions may also be impaired. For example, alcohol depresses the central nervous system and its effects are partly similar to those of opiates or tranquilizers. Depending on the amount of ingestion, drinking alcohol may lead to memory lapses, poor judgement [5], slowed reaction times as well as distorted vision [6], including tunnel-like vision, and problems with balance [7], which may for example also lead to the occurrence of nystagmus (a jittery movement of the eyeball) in certain situations [8]. Many substances, no matter if they are ingredients of illegal, or prescription, or even over the counter drugs, may have similar effects. Additional factors influencing the impact of drugs and alcohol on an individual include the general health status, gender and weight or whether someone has already developed a certain level of tolerance to a substance and is showing signs of dependence. Thus, even if two individuals have consumed the exact same amount of a substance or have an equal level of that substance in their bloodstream, they may still present with different grades of impairment and essentially, their ability to safely participate in traffic may suffer even if they are below the legal limit (if there is one) for the substance(s) in question. Nevertheless, whether someone is below or above a specific, predefined limit for a laboratory test value is often taken as an important measure, especially for legal proceedings. There are two problems with this dependence on such fixed limits. For one thing, when considering illegal drugs, especially new, so-called "designer" drugs may not even show up on conventional laboratory screening tests. The second point is that although alcohol and drugs are the main problems to be considered in the context of safe participation in traffic situations, there are also some medical conditions (including fatigue) that may have a negative influence on an individual in this context. Therefore, ideal tests that have the purpose of rating the level of impairment must be able to test for potential effects on an individual's ability to drive without depending on laboratory values.

1) Established Tests for Roadside Testing: In many jurisdictions, test suites such as the Standardized Field Sobriety Tests (SFSTs [3], [9]) or similar tests are being administered by police officers or police surgeons in order to determine some of the aforementioned effects. The SFST test suite, as it was for example specified by the National Highway Transportation Safety Administration (NHTSA) in the United States of America, includes the horizontal gaze nystagmus (HGN) test, the walk-and-turn test, and the one-leg-stand test [8], [10]:

a) Walk-and-turn test: For the walk-and-turn test, the officer first instructs the suspect to place the left foot on a line on the ground and to place the right foot directly in front of the left one. The task is then specified as "take nine heel-to-toe steps" while keeping the eyes on the ground and loudly counting each step, then turn and use the same heel-to-toe maneuver for returning to the starting point. While the test is performed, the officer looks for eight different criteria relating to balance, attention (did the individual listen to the instructions?) and concentration. If two or more of those criteria are matched, the walk-and-turn test is considered as failed.

b) One-leg-stand test: The test subject is instructed to raise one foot about 15 cm above the ground level and to count out loud for 30 seconds. The test is considered failed if two of four criteria are matched: using the arms for balance, hopping, swaying or putting the raised foot on the ground.

c) Horizontal gaze nystagmus (HGN): For the HGN test, the officer must move a visual stimulus (often a finger or a pencil) in front of the subjects eyes from side to side. This movement is repeated several times and should take about two seconds from the center to the respective side. The visual stimulus should have a distance of 30 to 40 cm to the eyes. As with the other tests, there are several criteria that are considered for success or failure of this test: equal tracking of the stimulus with both eyes, smooth pursuit of the stimulus and whether there is a distinct nystagmus [8] (rapid and jittery movement of the eyeball from side to side) at the maximum deviation from the center. If nystagmus is observed, it is also noted how early it starts, i.e. at what angle from the center.

Although such tests are widely used and – if performed correctly – give good results, studies have shown a number of problems that may occur. For example, for the walk-and-turn test, a straight line on level ground is required in order not to let the tested subject stumble and many individuals, for example older persons or those with inner-ear or orthopedic problems may have balance problems even when sober [10]. For the HGN test, the results may be problematic if the stimulus is moved too fast or if an officer wrongly judges the angle of onset of the nystagmus. Altogether, if the limitations of these or similar tests that are used for roadside testing are not sufficiently accounted for, officers may wrongly judge someone to be not sober. For many of the criteria that are employed, it may be questionable whether they are matched correctly or not. The results are therefore of a highly subjective nature [11] and dependant on an officer's experience and how well he has been educated with respect to performing such tests.

B. Laboratory Test Methods for Attention and Distractibility

To assess attentional performance, something that is important for many areas of application, the German company "Psytest" developed the TAP (Test of Attentional Performance) test suite which is currently available for the Windows platform only. In its initial form, it was used to examine patients with cerebral lesions for attentional deficits [12]. Similar to such patients, as mentioned before, drivers who are potentially under the influence of alcohol or some drug may also present with deficits with respect to attention, the ability to concentrate on a task and reacting to various stimuli. An additional, "mobility" adapted version, specifically TAP-M ("TAP mobility") that is based on the TAP test suite, was therefore designed this area of application [13]. Basically, during the testing process, the TAP suite as well as the adapted version TAP-M present test subjects with very simple but nevertheless distinguishable stimuli that require a reaction using a simple motor response [12]. Everything that can distract the tested person from the task should be avoided and the tests are kept as simple as possible to be able to exclude factors such as motor problems, educational or language deficits that might otherwise have an influence on the outcome of the test.

TAP-M can be used to assess a number of abilities that are important for testing whether some is fit to drive. This includes, for example, tests covering spatial vision, but also factors relating to alertness, attention or distractibility.

Due to covering very important aspects of fitness to drive as well as the expected simplicity of implementing them on a mobile platform, two sub-tests of the TAP-M test suite, namely those dealing with "sustained attention" and "distractibility/alertness", were selected for integration in the prototypical mobile application that was developed over the course of this project. This will be described in more detail later on.

C. Technical Background: Mobile Devices and Their Capabilities

Nowadays, mobile devices are being carried around by almost everyone and offer a wide range of functionalities. They include front and back cameras, high-resolution touch screens, they have the ability to record and play video and audio, and also make it possible to connect to various Internet services "on-the-go" by using WiFi or mobile broadband connections. Other attractive features available in current mobile devices are GPS navigation, but also short range wireless technologies like Bluetooth and NFC. Altogether, these features offer many possibilities for aiding users in their everyday lives as well as for more professional functions. Apps that make use of such features can be found on almost all mobile platforms such as Android, iOS, Windows Phone and others and cover many application areas [14]. Nevertheless, there are some aspects that must be kept in mind for a project such as the one outlined in this paper. Especially for Android devices, which were selected due to their widespread use as well as the ease of developing apps for this platform, the technical capabilities of available devices vary greatly. Not all devices integrate sufficient hardware capabilities. For example, the device should offer a high-quality camera chip with a resolution of at least two megapixels as well as good image quality even in low-light conditions. In addition, in order to detect rapid movements (e.g. the aforementioned nystagmus), it should be capable of capturing videos with a minimum frame rate of 30 frames per second. The touch screen should quickly respond to touch events, should have sufficient and uniform illumination, a high resolution and a minimum screen diagonal of 4.5 inches. Especially the last point must be respected since many test methods that are based on presenting users with a visual stimulus – some of which will be described later on – require a minimum view angle which can only be met if the size of the screen is sufficient.

For the project described in this paper, it was expected that current high-end devices would offer sufficient capabilities for successfully implementing a prototype application containing the desired tests.

III. Methods

A. Research Strategy

The research strategy throughout the thesis work follows the design research approach, since for the study, an appropriate solution has to be designed after identifying all factors contributing to the problem. With design research, it is possible to design, implement, evaluate and – if necessary – adapt the solution which can serve to increase the quality of the design and research. Moreover, design research focuses on the necessity of approaches that allow to learn about phenomena in the real world rather than in a purely laboratory setting and on the need to derive research findings from formative evaluation. This makes it fundamentally suitable as a strategy to be applied for this project [15].

B. Research Process

This section will explain the various stages of design research shown in Figure 1 and their relevancy to each stage of the research as it was undertaken during the study.

1) Awareness of Problem: The research process starts with become aware of an interesting problem. This may for example be triggered while following research and new developments in similar areas [15]. There were various such "triggering" points in the context of this study. Currently, besides the aforementioned conventional testing methods with all their limitations, there are currently no test suites that cover all aspects necessary for an appropriate solution for roadside testing. This includes that all tests integrated into such a test suite must be easy to use, short in duration and also suitable for people who are not familiar with modern technology. Additional emphasis must be placed

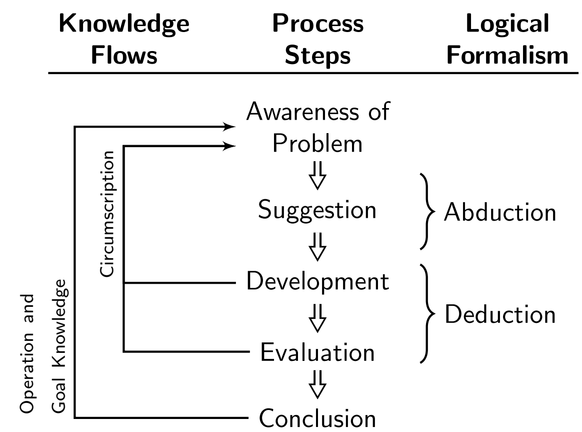

Fig. 1. Reasoning during the design cycle, adapted from [16]

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on the reliability, reproducibility and meaningfulness of the results such an application gives. Based on all this, we finally ended up with the research question as specified above:

> Based on what is known about the medical and physiological background related to sobriety testing as well as the capabilities of today's mobile devices, is it really feasible to implement a mobile test suite that
>
> 1) covers the necessary aspects,
> 2) is easy to use,
> 3) leads to robust and objective results,
>
> and can for example aid police officers in their daily work during roadside testing?

2) Suggestion: The suggestion phase is the second step of design research and is closely associated with the previous step [15]. It is the creative phase: new functionality or combinations of already existing methods or technology are envisioned in the context of the identified problem. Applied to the presented project, the suggestion phase built upon studying relevant literature and other sources, interviewing experts and discussing the problem with colleagues. Thus, it was possible to identify potential solutions for the identified problem, namely by identifying and envisioning mobile adaptations of pre-existing tests methods that were deemed appropriate for inclusion into a novel, mobile device based test suite.

3) Development: During the development phase, previously accumulated ideas are brought to life. For the presented work, this was done by implementing the selected tests on Android based devices using tools and methods that will be described in more detail later on.

Special care must be taken regarding design and implementation at this stage in order to avoid problems later on.

4) Evaluation: Following development, the product – in the presented case, the prototype of the mobile test suite –

needs to be evaluated with respect to the criteria that were identified in the “Awareness of Problem” phase. Deviations from the expected results, e.g. due to problems that one was previously not aware of, must be noted and tentatively explained [15]. In contrast to other approaches such as positivist research, where one tries to confirm or disprove a hypothesis, in design research, the initial hypothesis is rarely the one that is kept; rather, information gathered during evaluation, such as collected data, findings and personal reflections, as well as information obtained during other parts of the design research cycle are used to start a new cycle (Figure 1).

During the course of the project, this specifically applied to some ideas initially thought to be useful for the eye tracking task, i.e. the selection of appropriate image processing methods, while the preliminary evaluation of the mobile versions of the sustained attention and distractibility tests quickly led to satisfying results. Although altogether, based on the evaluation phase, several iterations of the cycle were thus started for parts of the application, only the resulting (current) implementation of the test methods is described in the sections below.

5) Conclusion: Once all previous phases have been successfully completed, the conclusion represents the termination of the specific design research approach [16]. Regarding the presented project, this remains for the future.

C. Research setting

The research and development phase took place at the Peter L. Reichertz Institute for Medical Informatics (PLRI) at the Hannover Medical School in Hannover, Germany in order to simplify integration into the development team at the PLRI. Thus, it was also possible to profit from direct access to the staff and their knowledge, and especially, to participate in official meetings with external project partners from nearby institutions such as the University of Hildesheim that were held at the institute with the purpose of evaluating the progress of the project. In addition to the on-site research at the PLRI, online meetings with experts at the Gothenburg University were also held in order to gain a better understanding of general research principles.

D. Data Collection

A literature review as well as interviews of fellow team members were performed in order to prepare the basic design of the mobile test suite and to subsequently construct the prototype application. Using this prototype, the data collection process took place using data acquired with two different, Android based smartphones (Android 4.1.2), i.e. a Samsung Galaxy S3 as well as a Samsung Galaxy Note 2. At the start of the project, both devices were relatively high end; both, especially the Galaxy Note 2 also have a comparatively large screen which makes them ideal for the project. Several features of the devices are put to use for the data collection process: Currently, the application can make use of both internal cameras of the devices for the eye tracking part of the test suite – although the front camera is only used for testing purposes during development – as well as the touch screen.

1) Eye Tracking: For the purpose of performing the eye-tracking test, the video data from the test subject’s face is acquired using the camera of the mobile device. Already during development, it became important to be able to test on realistic videos acquired in varying environmental conditions that would allow a decision whether nystagmus had been recorded or not. For this purpose, an additional, small and very simple application (Figure 2) was constructed and used that made it possible to evoke nystagmus on purpose while recording the video data, without resorting to the use of any substances. This second application is based on the principle of an optokinetic drum [17]. Using the device’s screen, it presents the user with a stripe pattern that can move from left to right or right to left at a previously defined speed in order to evoke nystagmus while recording the data using the front camera of the device, which fortunately has a sufficient resolution on the two aforementioned devices. While recording, the device should ideally be placed on a tripod.

For use in more realistic situations, the test subject is presented with an external stimulus similar to conventional nystagmus testing and the data is recorded from within the test suite using the back camera of the device.

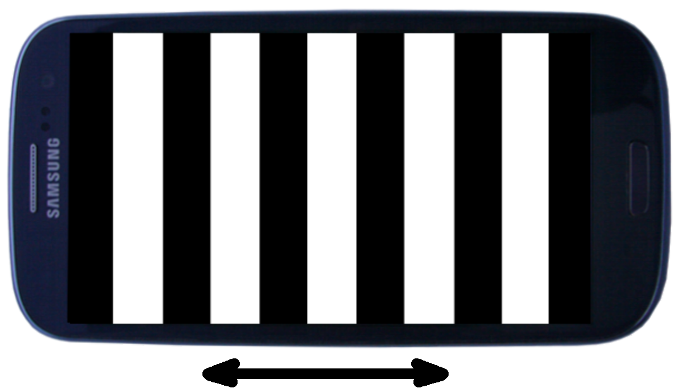

Fig. 2. Optokinetic drum app used during acquisition of test data for eye tracking. The app can be parametrized with respect to speed, direction of movement and size of the presented stripes.

The evaluation and calculation of parameters that can be used to determine whether, and if so, to what degree, nystagmus occurred is done via the eye tracking methods integrated into the test suite. Currently, along with a reference to the video under consideration and additional information about the acquisition situation that is available, the calculated parameters, in this case, center coordinates and radius of the detected iris for each frame, are stored in an internal SQLite based database within the application for later reference and evaluation. Currently, the app itself only presents very basic results in the form of raw data; for evaluation purposes, the data can be exported and evaluated using external tools.

2) Sustained Attention and Distractibility Testing: When performing sustained attention or distractibility/alertness testing, touch screen events evoked by the user are recorded to gauge a user's reaction while the test runs and presents the appropriate stimuli. Parameters that are recorded are based on the time span between presentation of the stimulus and whether the reaction of the user was appropriate; thus, it is also possible to calculate the number of correct or false answers along with the reaction time of the users. Again, all parameters are saved to the internal SQLite database integrated into the app. This includes the coordinates of the touch screen event, the elapsed time between presentation of the visual stimulus and the touch event, whether the answer was correct or wrong as well as additional information about the current test. Just as for the eye tracking part of the application, currently, the app itself only allows a limited evaluation and presents the user with a table of the raw data, but the data can be exported for further evaluation. A more comprehensive in-app evaluation will be integrated at a later stage of the project.

E. Limitations

While working on the presented work, some limitations had to be faced. The main limitation was the short duration; the real research project of the working group at Hannover Medical School is only just starting, with the work presented in this thesis only being a small part of the overall project; due to the deadline for the thesis, it was not possible to go into more depth which would have been desirable.

IV. Implementation of the Prototypical Test Suite

This section explains the reasons behind the methods chosen for implementing the application and also mentions the libraries and algorithms that were used for the current version of the mobile test suite.

A. Basic Design of the Mobile Smart Tracking Application

Nowadays, smartphones are carried out by many people and usually people know how to work with them. If they are to be used for roadside testing, an app that has the goal of aiding police officers in their decision about someone's sobriety must take a number of aspects into account:

1) *Robustness*: Test method integrated in a mobile test suite must be usable in various conditions found outdoors. They should not be too sensitive to adverse conditions or at least, it should be possible for officers to easily construct the necessary settings, e.g. by using a sunshade or setting up appropriate lighting, which is often done by the police when setting up official traffic control points.
2) *Repeatability of results*: When used on the same test subject in the same setting, it should ideally always lead to the same results
3) *Good usability*: The app must be easy to use, even for test subjects that have physical impairments that, although they do not make that person unable to drive, may have an influence on the ability to interact with a mobile device. All elements that are presented on the screen should have a sufficient size and there should be as little textual content as possible. Any texts should be kept as simple as possible and be available in multiple languages. Of course, this also implies that the mobile devices used for testing have a sufficient size and appropriate technical capabilities.

The tests that were implemented in the prototype for the mobile test suite were chosen for a number of reasons. Most importantly, they cover a number of aspects relevant to driving and thus, when used in combination, may lead to better overall results, i.e. a more secure decision. While the distractibility/alertness and sustained attention tests cover psychophysical aspects that may partly be compensated if the tested individual makes an effort, the eye tracking test used for detecting nystagmus can be used to test reactions that are not under conscious control. Also, all test are already established methods, although not all of them are currently applied for roadside testing and, as mentioned before, at least the nystagmus testing can have serious limitations if applied incorrectly.

B. Tools and Software Libraries

The main programming language used for developing Android applications that can extend the functionality of such devices is a customized version of Java [18] that is available as a software development kit (SDK) from Google. This SDK was also used for developing the current version of the test suite. Unfortunately, especially for the computationally demanding image segmentation for the eye tracking part of the test suite, this Java based implementation is not fast enough to allow for real time evaluation of the acquired data. Although using the Android Native Development Kit (NDK) that is also available from Google would allow a more efficient implementation [19], for simplicity reasons it was decided to refrain from using it and to instead resort to a work around. In addition to the aforementioned development environment, for implementing the eye tracking part of the application which necessitates image and video processing functionality, the FFmpeg library as well as the JavaCV library (in turn based on the Open Source Computer Vision (OpenCV) package) were used.

1) JavaCV: The Open Source Computer Vision (OpenCV) is a library of programming functions for real time computer vision [20]. It has been released under the BSD License and is free for both commercial and academic use [21]. In its original implementation, OpenCV mainly focuses on real-time image processing. It is written in C++ and nowadays there are interfaces for Python, Java and MATLAB. The JavaCV package is a wrapper that allows the Java Virtual Machine (JVM) to access the OpenCV library directly and can also be used for Android. JavaCV wraps functionality that is normally available using the C and C++ API of OpenCV [22].

2) FFmpeg: FFmpeg is free software licensed under the LGPL or GPL licenses. It provides libraries and programs that allow handling multimedia data [23]. In case of the eye tracking test, FFmpeg is used to grab the frames from the recorded video and to pipe them into the eye-tracking algorithms. It is also used to record the results in MPEG-4 format.

C. Implementation of Eye-tracking test

For closely approximating the position of the iris of each eye, the application uses the basic structure that is specified in the flowchart in Figure 3. It integrates algorithms that were identified as useful during the research phase. These will be explained in more detail in the following paragraphs.

1) Region of Interest for Face and Eyes:

a) Face detection: Face tracking in live or recorded video is not an easy problem, since the color of the skin, the lighting of the scene as well as the orientation the face may change subtly between frames. Fortunately, OpenCV already includes algorithms for continuous detection of faces that are essentially based on methods that were published by various authors [24], [25]. Basically, the algorithms are making use of Haar-like classifiers. These algorithms can also be used with JavaCV and are employed to track the position of the face. This so-called "region of interest" (ROI) can be used for sanity checks to narrow down on the positions of the eyes. Otherwise, especially when the video of the test subject is recorded against an inhomogeneous background, "eyes" might be found in places where there are none in reality.

b) Eye detection: Using the ROI determined for the face, similar algorithms for detecting the eye positions that are available in OpenCV/JavaCV are then employed for locating both eyes. They also use classifiers that were specifically trained for detecting the right or left eye. Once ROIs for the eyes have been found and sanity checking against the ROI of the face has proven them valid (i.e., upper half of the "face", correct side for "left eye" and "right eye"), all further calculations are performed on the region of interests calculated for the eyes.

2) Noise Reduction: Filtering is an important task in signal and image processing. Eliminating noise in images, allowing image resampling and extracting interesting visual features are some of the functionalities of image filtering [26], [27]. Depending on the camera capabilities of the device used for performing the eye-tracking test, the acquired image might contain noise that can be significantly reduced by median image filtering. Computationally, this is a relatively inexpensive, non-linear image filter and exclusively beneficial against salt-and-pepper noise [26]. The principal purpose of median filtering is to omit noise without blurring sharp edges that contain important information [28].

3) Edge/Contour detection: Various methods can be used to determine specific features of the eye such as the iris. For finding similar objects, color information is often used and, for example by using classifiers or other methods, it is also possible to base a decision on whether something matches the desired object on other properties. Such properties can also include information about the shape, size or texture of the objects one wants to find. Since the color of the eyes varies greatly and the classifiers already available in JavaCV/OpenCV only work for situations where the iris is almost centered, i.e. the individual looks straight ahead, it was decided to employ a different strategy. Independent of the color of the eyes, the iris can always be clearly differentiated from to the eyeball's white parts and is of circular form. To find the border of this circular form, an efficient and robust edge detector in form of the so called Canny filter was employed [29]–[31] after the images had been converted into single-channel grayscale images.

a: *Convert to grayscale image:* The images grabbed from the device's camera consist of three channels, representing the primary colors red, green and blue values of the corresponding pixels, mimicking what the human eye is able to see [32]. The Canny edge detector can only make use of single channel images. To reduce this three-channel image to a single channel, it must be converted to a single channel gray level image [33], for example by using the average values of all three channels or by using the lightness information of the pixel. For our purpose, using the average values for reducing the acquired images to grayscale has proven sufficient to be able to detect the edges.

b: *Determine the gradient magnitude:* The next step after eliminating the noise is to find the intensity gradient. This is done by using the so-called Sobel operator [34] on each pixel of the region of interest in horizontal and vertical direction (H_x and H_y, shown in Figure 4) that essentially calculates the first derivatives in both directions (G_x and G_y) by applying the filter kernels H_x and H_y to the original image data A using a convolution operator (denoted by $*$):

$$\begin{aligned} G_x &= H_x * A \\ G_y &= H_y * A \end{aligned} \tag{1}$$

Using these two values, the gradient magnitude, i.e. the "strength" of the edge for each pixel can be calculated as

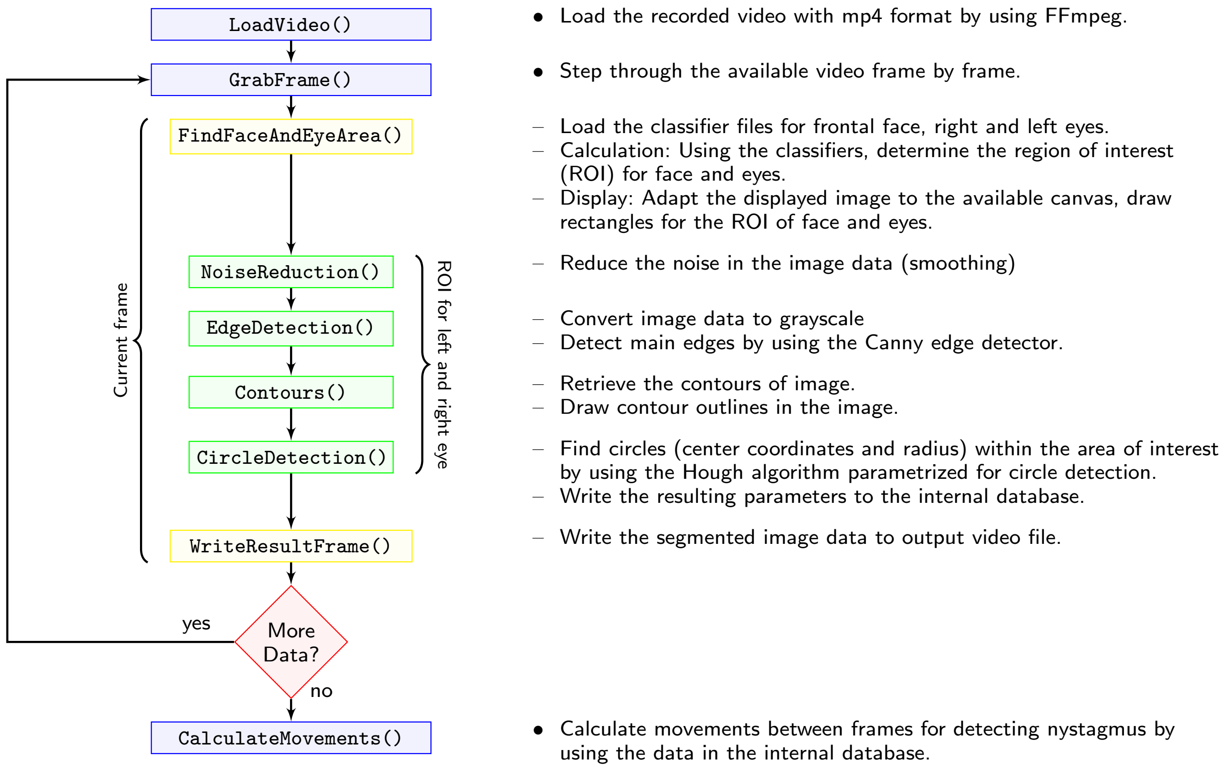

Fig. 3. Flow chart describing the eye detection process integrated in the prototype.

-1	0	1
-2	0	2
-1	0	1

H_x

1	2	1
0	0	0
-1	-2	-1

H_y

Fig. 4. Filter kernels for the Sobel operator in horizontal and vertical direction

$$|G| = |G_x| + |G_y| . \qquad (2)$$

c: *Edge direction:* Once the gradient and gradient magnitude values have been calculated, it is important to determine the direction of potential edges by calculating the gradient angle θ (Figure 5):

$$\theta = \tan^{-1} \frac{G_y}{G_x} \qquad (3)$$

Depending on the rounded value of θ (which is a value of either 0, 45, 90 or 135 degrees) and the gradient magnitude of the pixel and its selected neighbors, it is then determined if a pixel can really belong to an edge or not. For example, if the direction of a pixel has been calculated as 0 degree, it is considered as possibly belonging to the desired edge if its gradient magnitude is larger that of its neighbors in north and south direction. Similar calculations are performed for the other three directions, i.e. horizontally as well as for both diagonal directions.

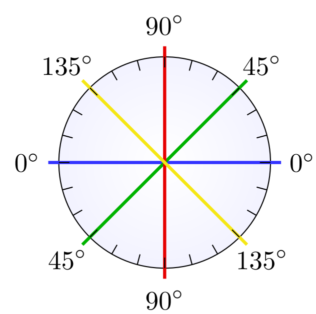

Fig. 5. Gradient angles

d: *Hysteresis:* The final thresholder employed by the Canny filter uses a method called "hysteresis". Similar operators often only use a fixed threshold and this can cause a line to appear broken in some areas of the image (similar to a dash line, also called "streaking"). The Canny filter uses two threshold values to avoid this problem. If the value of the pixel under consideration is smaller than the lower threshold, it is rejected and if it is above the upper threshold, it is accepted. For values that lie between both thresholds, it is only accepted if the values of its direct neighbors are high enough. The two threshold values used for hysteresis should be chosen such that they can serve to work with the expected signal-to-noise ratio. In the application, two fixed thresholds are used (50 and 100 for 8 bit grayscale image data) that have proven sufficient for segmenting the irises of the eyes independent of eye color.

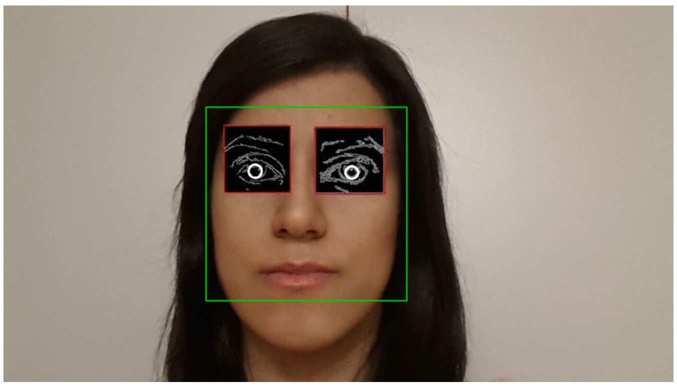

Fig. 6. Circles approximating the iris based on the calculated edges.

4) Circle detection: Detecting circular and other objects is an important task in image processing that can for example be carried out by applying a Hough transform to the image data. It is an established and efficient algorithm [35], [36] for locating objects that can be described by an equation or a set of equations and corresponding parameters, e.g. lines, circles or ellipses. This makes it ideal for determining the position of the iris based on the edges detected in the previous step.

A point with the coordinates (a, b) lying on a circle with radius R can be calculated by using

$$\begin{aligned} a &= x - R\cos(\theta) \\ b &= y - R\sin(\theta) \end{aligned} \quad (4)$$

with x and y representing the center point. Equation 4 is then applied for each point (a, b) of the previously determined edges using loops for θ ($0°$ to $360°$, e.g. in steps of 1 degree to describe a whole circle), R (range approximating the expected radius) as well x and y (range: expected area for center coordinates, equal to the current ROI). For each of the parameter combinations, a multidimensional array (here: 3-D for x, y, and R), the so called Hough accumulator, is increased at the point described by the current combination of parameters. After looping through all edge pixels in this way, it is possible to determine the parameters for the circle that best represents the edge pixels by locating the local maximum (Figure 7) in the Hough accumulator.

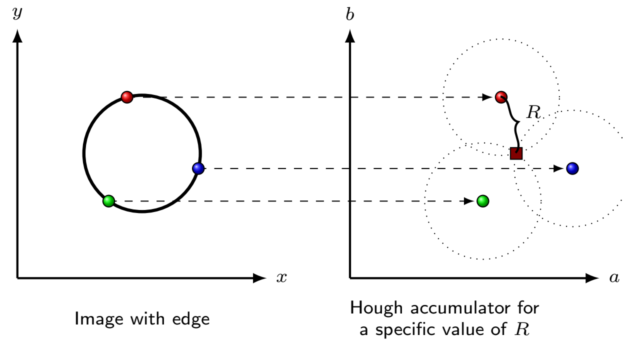

Fig. 7. Looping through an "edge image" represented by a circle (left) to build the Hough accumulator (right). Parameter combinations for three exemplary points from the "edge image" are drawn on the right side.

5) Evaluation of movement: While performing the eye tracking test, the test subject is asked to follow a visual stimulus (usually a pen-like object or a finger of the person performing the test) with his eyes without moving the head. The visual stimulus should be presented in a side-to-side movement as described above. If the test subject is under the influence of alcohol and/or drugs, nystagmus will occur when the visual stimulus is at the maximum deviation from the straight-ahead position. Using the center coordinates determined for the irises of both eyes in the previous steps, it is easily possible to track the movement of both eyes and to determine subtle movements and even nystagmus, which is represented by rapid changes of direction in the region of maximum deviation.

D. Implementation of the Distractibility / Alertness test

The test for distractibility/alertness as it is currently implemented in the prototypical mobile testing app follows the corresponding test of the previously mentioned TAP-M test suite [12]. The test consists of three rounds and the duration of each round can be set to a time span between one and five minutes. In each round, a sequence of differently colored, smiley-like face icons (happy or sad) appears on the center of the device's screen. Each icon is shown for at least 1 second. Between two face icons, a dot (sufficiently sized to be clearly visible, but considerably smaller than the face icons) is shown for half a second on the center of the screen in order to keep the focus of the test subject on that area. The test subject is asked to press a button shown on the touch screen as soon as a white colored sad face appears. If the test subject reacts to any other face/color combination, the answers is rated as incorrect. The same happens if a white colored sad face is shown and the test subject does not press the button (Figure 8). The time span between the presentation of the "white sad face" icon and the test subject's reaction is also recorded. All values are stored in the internal database of the application, and, once all rounds have been finished, are used to calculate a score representing the user's distractibility value that represents the ability to

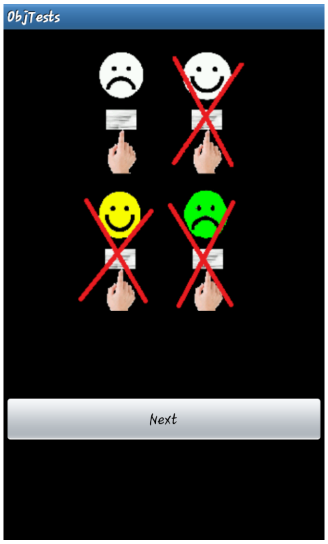

Fig. 8. Instruction screen for distractibility/alertness testing.

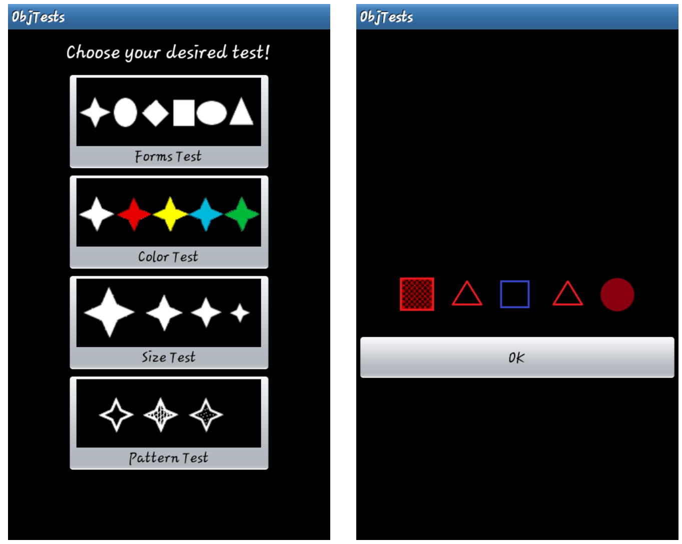

Fig. 9. Choice of test type, i.e. which patterns/colors are to be used for performing the test (left); screen presentation during the test (right).

react to a specific stimulus while also being presented with distracting, irrelevant information. This is an essential ability for driving.

E. Implementation of the Sustained Attention Test

The second test from the established TAP-M test suite [12] selected for integration into the mobile testing app is the “sustained attention” test.

As shown in Figure 9 (left), first, the type of optical stimuli to be used while the test is running must be chosen (e.g. by the police officer). It is possible to choose between four different sets of icons that consist of differently shaped, colored or sized symbols that may also have different fill patterns.

During the test, a specific number of icons selected from the previously chosen icon set is shown on the screen (Figure 9, right). Each set of icons is shown for 1 second and just as for the distractibility/alertness test, in between, a dot is shown on the center of the screen in order to keep the test subject’s focus there. The test can be carried out in two levels of difficulty and again, runs for a predefined period of time. Depending on the level and on which set of optical stimuli was chosen, while the test is running, the test subject is asked to react if either one or more two feature dimensions (level one: shape only, level two: shape as well as color/fill pattern) match in two directly neighbored symbols.

Similar to the distractibility/alertness test, the results are again saved in the application’s internal database, this time along with the chosen level and type of icon sets, and can be used to determine a score for the test subject’s ability to concentrate for a specific period of time. The score represents how well someone can maintain attention for a (longer) period of time while also being under a certain pressure.

V. Results

Since, as mentioned before, current roadside tests do not cover all desired aspects and for various reasons, their results are often quite subjective, an application or device that would aid officers in their decision about someone’s sobriety would be highly desirable. The prototypical application presented in this work was implemented in order to find out whether mobile devices are appropriate for this purpose. The integrated tests were selected for a number of reasons. Since the use of alcohol and drugs may lead to memory lapses, poor judgement [5], slowed reaction times as well as distorted vision and the test suite can be used to evaluate the sobriety of the test subject by examining factors related to medical/physiological as well as psychological issues that were identified as being important. In their already existing, previously described “police officer based” or “computer based” implementations, the tests either suffer from being unavailable in a mobile setting (distractibility or sustained attention testing) or not giving clear and objective results if not performed correctly (HGN testing = eye tracking). The two exemplary tests selected from the TAP-M suite were easily implemented and did not challenge the hardware of the mobile devices that were available. The main focus was on the more complicated implementation and basic testing of the eye tracking part of the mobile application, which uses the automatically determined position of the irises of the eyes for calculating the movement of the eyes while a visual stimulus is presented and therefore is much more demanding with regarding hardware requirements.

Due to the shortness of available time, so far, the only tests that were done were performed on a small sample of staff members of the PLRI at the Hannover Medical School as well as a small number of volunteers from family and friends and an in-depth evaluation is still lacking. Thus, current results regarding the app are solely based on comments from these users as well as own experiences gained during the implementation. When evaluating the comments, the users did not voice problems with respect to usability, although one older person commented about having had problems with using the touch screen for the sustained attention and distractibility/alertness tests. One color blind test subject also commented on the use of colors (specifically red and green); while using one of the colorized icon sets of the sustained attention test, he simply was not sure about when to press the button. He did not have any trouble with icon sets where the decision about when to press the button could be based on shape, size or pattern. Other comments given by users regarding the two tests making use of the device's screen dealt with usability in adverse conditions such as sunlight leading to reflections or low contrast on the screen. Whether this will be a serious problem for using the test suite in roadside settings remains to be seen.

For the eye tracking test, segmentation of videos acquired from the test subjects was easily done if the scene was evenly lit and there was sufficient light. Since an edge based approach was used for segmenting the iris of the eyes, segmentation results used as a basis for determining the circles approximating the irises of both eyes were easily obtained and (manually) rated as correct even for different eye colors: The available test subjects had eye colors ranging from light blue to dark gray, greenish hues as well as dark shades of brown. While during the "awareness of problem" phase described above, it had been considered to use the position of the pupils as a basis for determining the movements, this idea was quickly discarded since it became apparent early on that with current mobile camera capabilities, it would not be possible to obtain robust results for test subjects with dark eyes. On the other hand, the edge based detection of the irises gave good results regardless of eye color. Also, test subjects were not overly taxed when this test was performed since they only had to follow a visual stimulus with their eyes without having to interact with the devices themselves.

VI. Discussion

Already, during the implementation of the prototype, several limitations became apparent. The most obvious one are the mobile devices themselves. While there were no major problems with respect to the hardware configuration for the sustained attention and distractibility/alertness tests, the same was not true for the eye tracking (nystagmus) test. So far, at least for the Java based implementation path that was chosen, the mobile devices available during development did not provide sufficient computing power for real-time segmentation of the iris if the video was captured at the necessary frame rate of 30 frames per second. Thus, a workaround – capturing the necessary data in the form of video files and segmenting them in a second step – had to be used. It can be expected that as soon as the segmentation process has been optimized, e.g. by using a native implementation based on the NDK [19] instead of the Java SDK based approach, the segmentation process will run considerably faster. Also, both devices used during the development process, i.e. the aforementioned Samsung Galaxy S3 as well as the Samsung Galaxy Note 2, had problems with detecting the desired structures if the scene was unevenly lit or in low light conditions. Both aspects might change with newer devices that contain better hardware. For example, in first test runs on a brand-new Samsung Galaxy S4 (Snapdragon 600), the segmentation process already ran approximately twice as fast as on its predecessor and, although – again due to a lack of time – there was no extensive comparison of the results obtained for the two devices (i.e. with videos acquired in the exact same conditions), the camera of the S4 model appears to have fewer problems with low light conditions than that of the Galaxy S3.

For sustained attention testing, even during development, it already became apparent that while it was okay to integrate the currently available choices for the different icon sets for testing purposes, for the final application that will be used in the roadside setting it is meant for, a single, specific symbol set should be chosen in order not to overtax users (police officers as well as suspects). This will probably come down to a symbol set and test level that simply uses differently shaped and sized symbols of white color on black background to provide users with a high contrast. Other feature dimensions such as different colors or fill patterns should probably be put aside. This will also avoid problems with this test in low light conditions or if someone has deficiencies in color vision (e.g. red-green color blindness). Unfortunately, avoiding the use of colors does not work for the distractibility/alertness test since in this case, color is essential. Nevertheless, special care should be taken to choose colors that can also be clearly differentiated by someone with color blindness. Since there are various types of color perception problems, the colors chosen for the symbols should at least have different levels of lightness.

Physical deficiencies of the test subjects might also lead to problems; these are aspects that will need careful evaluation at a later stage of the project. For example, since the sustained attention as well as the distractibility/alertness tests both require users to interact with the device's touch screen, someone with sensory problem in his fingertips, e.g. due to carpal tunnel syndrome, might not be able to "feel" whether the button was really touched as desired. Auditory feedback, e.g. in the form of a "beep" once the touch event is noted, might be helpful in this context, Nevertheless, this requires a careful evaluation of whether such a sound is audible even in a roadside setting (e.g. due to unavoidable background noise) and whether this beep can falsify the test results in any way by providing additional distraction. Physical deficiencies leading to problems during the eye tracking based test for nystagmus may include strabismus (being cross eyed). Usually, someone having this condition has one dominant eye that is used for perception; therefore, in this case, only the dominant eye should be evaluated. Future versions of the application should for example provide settings to make this possible.

Another point to note with respect to the current implementation of the eye tracking test is that the movement of the eyes is currently determined solely based on the movement of the irises. This may be sufficient at this early stage, with test subjects that try to hold their head as still as possible during the test if they are told to do so. With non-compliant test subjects, especially those that are nervous or are afraid of having been caught, one should not rely on this. One solution for this problem could be to use some anatomical landmarks that remain fixed in relation to the position of the eyes, e.g. the corners of the eyes or the nasolabial folds and this should be considered for the next iteration of the development cycle as it was described in the section describing the research process.

Finally, another limitation that may influence a decision of whether someone is sober or not is that test subjects do not always behave in the same way. This is true for all tests involving the police, not only for the presented mobile solution: Even innocent people often become very nervous when a police officers wants to check on them. This might lead to them not being able to focus on the tests and might therefore have a negative influence on the test results. This is also where the "human factor" has to come in again. Usually, a police officer will notice this nervousness and consider it for his overall decision. The aim of the mobile app was never to replace this human factor, but to give police officers a tool that can aid them in their work.

VII. Conclusion

This study set out to investigate the feasibility of developing an android application which determines the sobriety of motorists on mobile devices which covers all the necessary aspects. Although, for the prototype, only three basic tests were implemented, due to the modular design of the application, additional tests can easily be added. If the test suite is to be of use, all tests integrated into it have to be easy to use, short in duration, applicable even in adverse conditions found in roadside testing and their results must be reliable and meaningful. Unfortunately, due to lack of time, it was not yet possible to perform an in-depth evaluation to obtain a definite answer for the research question as it was stated in at the beginning, although the three tests presented in this thesis have been implemented successfully.

The evaluation of the test suite with respect to reliability and validity as well as usability will take place in several steps. For a planned quantitative evaluation of the mobile test suite, the first step will be a feasibility study on a group of healthy test subjects who are not influenced by any substance and who have not been previously acquainted with the existing prototype in order to confirm the overall concept. The subjects will be asked to perform each test several times under different environmental conditions. Time measurements for each sub-test will be taken (including the time needed for standardized explanation of the tests as they would be given by an officer in a roadside setting). Means and standard deviations for each test (including various test rounds where applicable) and for each test subject will be recorded for later descriptive analysis. These values will be used to detect intra- and inter-individual differences. While variations of the results for single individual for various runs of a test (i.e. intra-individual differences) are expected to be small, the inter-individual variations will probably be larger. Variance analysis testing will be applied.

Since the tests for distractibility/alertness and sustained attention are well established tests that already exist as part of a standardized test suite for PCs, the test subjects will also be asked to perform the same number of test runs for both tests on this system in order to to gain reference values (baseline). A similar approach should be taken for the eye tracking test, although in this case, the comparison has to be done against tests being performed by experienced police officers. At a later stage, a normalization of the test suite with a larger sample size of a defined study population will have to follow and subsequently, a comparative study including influenced as well as sober test subjects will be performed. Basic usability testing, for example based on methods found in [37] will also be carried out.

Acknowledgement

The author would especially like to thank Dr. med. Urs-Vito Albrecht, MPH and Dr. rer. biol. hum. Ute von Jan at PLRI MedAppLab, P.L. Reichertz Institute for Medical Informatics of the Technical University Braunschweig and Hannover Medical School, Hannover, Germany for providing me with the subject and for their valuable guidances and contributions. Partial funding for the overall project of "Mobile Smart-Tracking", of which the work presented here is a small part, was provided by the "Bund gegen Alkohol und Drogen im Straßenverkehr e.V. (B.A.D.S.)", a German association aiming at the prevention of alcohol and drug abuse while driving. Special thanks also go to Lars Pareto and Morgan Ericsson for their thoughtful guiding of this thesis work at University of Gothenburg in Gothenburg, Sweden.

Presentations

Parts of the work presented in this thesis have already been accepted for presentation or are under review for the following national and international conferences:

- *Under review:* Albrecht UV, Khosravianarab K, Folta-Schoofs K, Teske J, Kanngießer J, von Jan U. Mobile Smartracking – Finding Objective Parameters for Determining Fitness to Drive. BMT 2013, Graz, Austria.

- *Accepted:* Teske J, Khosravianarab K, von Jan U, Kanngießer J, Folta-Schoofs K, Albrecht UV. Mobiles Smarttracking – Mobile und objektivierbare Untersuchung der Fahrtüchtigkeit. 9. Gemeinsames Symposium der Dt. Ges. für Verkehrspsychologie e.V. und der Dt. Ges. für Verkehrsmedizin e.V., 27.09.2013, Heringsdorf.

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