ManDown - Diagnostics Sensing of Ataxic Gait and Nystagmus

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***Abstract*—Sensing multiple alcohol-related symptoms through the use of everyday wearable devices is integral in managing drinking habits. In order to provide a safer drinking environment for social drinkers, our ManDown app would manage the alcohol intake of the user by providing a non-invasive measure of their blood alcohol content(BAC) levels. The focus for this report would be on the detection of ataxic gait and nystagmus. An insight into prior medical research on the effects of these alcohol-induced symptoms would be given. Related work based on the detection of these symptoms through the use of mobile devices would also follow. The findings from these two research areas would then be used to propose designs for the detection of these two symptoms. These designs would be used for the diagnostics sensing portion of ManDown.**

I. Introduction

Social drinking has important sociocultural functions in modern day society. However, risks arise when people drink over the limit. Alcohol-related deaths in the UK have risen by 13% over the past decade, while hospital admissions due to alcohol-linked injuries have increased by 33%[7]. This report aims to address these tragic statistics with the development of ManDown, a social app with an emphasis on managing the alcohol intake of a user.

In order to evaluate the current state of a user, sensors are required to diagnose specific alcohol-related symptoms. This is done through the **Diagnostics Sensing Module**, for which the focus for this report would be based on the detection of associated motions due to ataxic gait and nystagmus.

The **Diagnostics Sensing Module** would operate with the **Gamification Module** in order to send user information to a local storage in the phone. This data would then be utilised by the **Data Management Module** and **Machine Learning Module** modules to diagnose the aforementioned symptoms with a formalized binary classification problem of drunk or sober.

Hence, the **Diagnostics Sensing Module** is the organ devoted to diagnosing symptoms for ManDown, and be used to test the hypothesis that through the use of a smartphone and wearables, it is possible to accurately detecting intoxication.

II. Module Requirements and Challenges

This module would focus on the design of a system for detection of motions associated with ataxic gait and nystagmus. This involves an in-depth understanding of the symptoms and their respective mechanisms. Next, the optimal sensing method used for these symptoms would be evaluated and determined, before signal processing is applied to send only required data to the **Machine Learning Module**.

The challenges for this module are the following:

1) Identify the body mechanisms associated with these symptoms
2) Identify the features and factors of these symptoms that would change with alcohol ingestion
3) Identify possible methods of detecting these alcohol-induced feature variations
4) Identify optimal solutions for passing this data through to the machine learning module for diagnostics

In order to overcome these challenges, this paper will look into publications on these symptoms, as well as methods of detecting these symptoms. The findings from these two research areas will then be used to provide an initial electronic sensor diagnosis system.

III. Ataxic Gait Research

As mentioned previously in the design report[12], blood alcohol concentration(BAC) levels at 0.06% and higher causes a complex multifaceted deterioration in body control[7]. This can materialize in *ataxia, nystagmus, scanning dysarthia, slowed reaction times* as well as a *loss of motor control*. Intoxication would hence be defined as a BAC level of 0.06% for the purpose of this report. In this section, the symptoms of ataxic gait would be explained, before prior research on ataxic gait, gait analysis through the use of smartphones and related work on detecting intoxication through ataxic gait would be shown.

A. Symptoms and Signs: Ataxic Gait

Ataxia is an involuntary loss of coordination of the muscles[14]. This causes ataxic gait[2], which is the inability of an afflicted to stand on one leg or perform tandem gait(a walking motion where the toes of the back foot touches heel of the front foot with each step). This tends to result in a staggering movement, with lurching from side to side.

B. Medical Research: Alcohol-Induced Ataxic Gait

Prior research for alcohol-induced ataxic gait after intoxication showed that gait is affected quite prominently, with details on the response time and ataxic gait motion. In a paper by *Demura et al.*[3], the gait and one-leg stance of 15 adults with an average age of 21.9 years was monitored. Their readings were taken 10, 20 and 30 minutes before and after ingesting alcohol. Their results showed that **after 20 minutes, most adults display a decline in their balance, as well as their gait stride.** Another paper from *Stoll et al.*[1] monitored the postural sway of 30 subjects with a BAC of between 0.02% and 0.15%. The subjects were required to perform a static stance, from which their sway area and average sway path was monitored. Their findings found that the **sway area was the most sensitive parameter for differentiating those subjects with a BAC less than or more than 0.08%.**

C. Gait Analysis using Smartphones

Research was done on using smartphones for gait analysis, from which 2 papers stood out. These papers were useful in confirming the possibility of using everyday wearables to detect gait-based symptoms. *Nishiguchi et al.*[5] performed a study into the accuracy of utilising the accelerometers in smartphones for gait analysis. Their paper compared the results from a gait analysis software to the signal-processed data from a smartphone accelerometer. Their findings showed that **using a smartphone accelerometer has a high correlation with gait analysis, and established that a smartphone alone could be used for analysing gait characteristics.** *Cho et al.*[8] provided a method for recognising a person's activities from a Google Android smartphone through the use of sensors in the phone. This was done from the use of a mixture-of-experts(ME) model and was trained with a global local co-training(GLCT) algorithm. Their paper provided **machine learning methods for the training model required for gait analysis on a smartphone.**

D. Related Work: Intoxication Detection with Gait Analysis

Related works on intoxication detection using Gait Analysis yielded 4 sources. These sources were useful in proving the reliability and accuracy of using gait analysis for intoxication detection, and was key in the design of the ataxic gait diagnostics sensor. The first source was the field sobriety tests[16], as mentioned in the design report[12]. The Walk-and-Turn Test and the One-Leg Stand Test mentioned in [12] detects ataxic gait specifically. A report submitted to the US Department of Transport[18] for evaluating the accuracy of these tests showed that these tests were able to **discriminate BAC levels above and below 0.08% with an accuracy of up to 94%.**

Arnold et al.[6] displayed an app developed for identifying and displaying a user's level of alcohol intoxication based on their gait. The accelerometer in a smartphone was used for sensing the movements of a user, before machine learning is applied on the data obtained in order to produce an accurate prediction of the gait analysis. Their results displayed that there is **an average of 56% accuracy for classification**, which was impressive considering that a large number of factors influence gait. A limitation of their experiment was the lack of use of additional sensors in the phone.

Nassi et al.[9] investigated the use of several wearable devices such as a Google Glass, LG G-watch, Microsoft Band and a Samsung Galaxy S4 to detect intoxication levels. The motion data for each sensor is used in tandem with machine learning to provide a binary classification(drunk or sober). The BAC levels are also used to provide an indicator of the intoxication levels. Their results showed that combining various wearable devices for gait analysis can improve the detection of intoxication. However, the results obtained from just the use of a smartwatch and a smartphone was almost as reliable. This provided **a rationale for the wearables for intoxication detection to be a smartphone-smartwatch combination.**

Kao et al.[6] designed a smartphone app to monitor the gait of a person after ingesting alcohol. Their experiments involved monitoring the accelerometer data of a smartphone in the pocket of participants before and after alcohol is ingested. By comparing the step times and gait stretch of sober and drunk gaits, a characterisation into the intoxication level is provided. Their paper **provided an example into the factors that could be measured for gait analysis.**

The following guidelines are devised from the research completed on ataxic gait:

1) Ataxic gait diagnosis should take into account the 20 mins response time
2) Ataxic gait diagnosis can make use of body sway area, step time and gait stretches to detect intoxication
3) Ataxic gait diagnosis can be performed with the sensors in a smartphone, but for higher accuracy, multiple wearables could be used

These guidelines will be followed in the high level design of the ataxic gait diagnosis.

IV. Nystagmus Research

In this section, nystagmus symptoms would be explained, before medical research done on how alcohol affects nystagmus. Finally, related work on intoxication detection through nystagmus would be shown.

A. Symptoms and Signs: Nystagmus

Nystagmus is a rapid involuntary movement of the eyes. This results in twitching eyes and jerking at angles of 45 degrees while the afflicted's head is pointing forward, and makes steady observation difficult.[13]

B. Medical Research: Alcohol-Induced Nystagmus

A study was done on nystagmus invoked by alcohol ingestion by *Romano et al.*[10]. In this experiment, 15 participants were given alcohol until a BAC of 0.6% was reached. The effects of alcohol on gaze stability was then analysed using the overall effects on the gaze holding system, specific eye effects and the difference between gaze angles in the temporal and nasal hemifields. Their findings showed that **all subjects were afflicted with an increase in gaze instability, with a median of a two-fold increase of eye drift velocity.** *DJ et al.*[4] published a paper looking into the effects of different doses of alcohol on eye motion. They conducted a study in which participants were given differing alcohol amounts, from 0.4g/kg to 0.8g/kg doses of alcohol. Their findings found that **alcohol caused a systematic impairment of smooth pursuit eye movements and accuracy**.

C. Related Work: Intoxication Detection with Nystagmus

The Horizontal Gaze Nystagmus(HGN) Test is a method used in field sobriety tests to determine whether a person is intoxicated. The tests involve observing whether a suspect's eye are capable of smooth pursuit, ability for the eyes to track an object together, as well as looking for sustained nystagmus for 4 seconds. A study done by the National Highway Traffic

Safety Association states that by itself, **the HGN test is 77% accurate in detecting intoxication**[15].

Wilson et al. looked into types of image processing methods for smartphone based HGN tests[19]. Their method made use of an Android device to perform pupil location techniques on two still images, followed by geometric estimation to perform facial feature estimation. Their method was designed for minimal computation on video frames, which was ideal for mobile devices. Their methodology worked reliably for tracking an eye gaze with a mean error of 11%. However, their findings showed that their **experimental analysis was insufficient to accurately and reliably assess alcoholic inebriation, due to different lighting conditions as well as different faces.**

An app called *BreathalEyes* used a smartphone camera to record the HGN of a person[17]. First, a person is asked to face the camera, where their eyes are to be positioned in a green rectangle on a smartphone screen. The person is then asked to open their eyes as wide as possible and look as far to the side as possible for 10 seconds. This app then gives an approximate BAC level of the user depending on the detection obtained. However, limited details of its accuracy and methodology were provided. However, the usage details **provided an idea for which smartphone HGN tests could be conducted.**

Thien et al. made use of an LED device that provided visual cues for a user to follow with their eyes[11]. The front facing camera of an Android smartphone is then used to monitor the user's gaze. This involved the use of face detection, as well as a tracker for the pupil. In order to classify the pupil movements for intoxication detection, **the frequency of the pupil oscillation was used to characterise the BAC level.**

From these papers, we obtained the following guidelines for nystagmus:

1) Nystagmus diagnosis can be implemented with a smartphone camera
2) Nystagmus diagnosis can be done through the detection of smooth pursuit and eye jerkiness to detect intoxication
3) Nystagmus diagnosis can be done through an analysis of the oscillation frequency of an afflicted's pupils while following a visual cue
4) Nystagmus diagnosis implemented with a smartphone has to be performed in constant lighting conditions, and facial expressions of user must be consistent(no blinking during analysis)

V. High-Level Design

The high level design for both diagnoses would involve the choice of sensors, the hardware or software interfaces and any signal processing required before machine learning is done.

1) Ataxic Gait: As mentioned in [9], it is possible to use multiple sensors to detect the motion of a afflicted person. [5] also showed the possibility of simply using a smartphone's tri-axial accelerometer alone for gait analysis. The method chosen for motion sensing would be through the use of the accelerometers of a Motorola Moto 360 first-gen smartwatch, as well as an Android smartphone device. This is due to the realistic possibility of a person always having a smartphone on their person at all times, while having an additional wearable with the smartwatch allows the possibility for providing more accurate information. The method touched upon in [5] would be improved upon through the use of the gyroscope to monitor rotationary motion.

Given that both devices run on an Android OS, the code development would be done through the use of Android Studio, with the Software Development Kit(SDK) version being Android 5.0. This ensures that the app will run on approximately 40.5% of all Android devices. The software would then be used to obtain accelerometer and gyroscope data from the smartphone.

Signal processing done would involve normalisation of the sensor data such that smartphone orientation does not affect the output values, as well as noise filtering.

2) Nystagmus: The motion sensor for nystagmus would involve the use of an Android device with a camera. This has been done in previous projects as seen in [11][17][19], and is ideal nowadays given that a smartphone is readily available. Android studio and OpenCV 2.4.3 would be utilised in order to determine the pupil location and perform eye motion tracking.

In order to facilitate progress in the 8-week long project, a single diagnosis would be implemented first. This is due to the time constraints on implementing a diagnostic system for both ataxic gait and nystagmus. Ataxic gait diagnosis is chosen as the higher priority due to the higher number of sources for implementing a working gait analysis app, as well as its reliability in relation to nystagmus diagnosis as seen from the research sources. However, if time permits, both diagnoses would be performed for an overall higher accuracy for the detection of intoxication.

VI. Implementation

A. Ataxic Gait

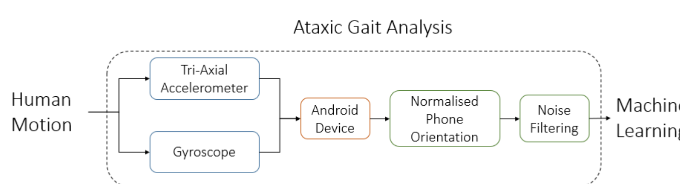

Figure 1. Implementation of Ataxic Gait Diagnosis

Figure 1 illustrates the flow diagram for a proposed ataxic gait diagnosis. The accelerometer sensors detect motion in the x, y and z domain, and these output signals from the accelerometer would provide an idea into the motion of the user. The gyroscope sensors would track the rotation or twist, and would be useful for normalizing the accelerometer data readings such that the gait features could be characterised regardless of the orientation or placement of the smartphone.

Initial tests on the data revealed that the signal from the accelerometer contained a noise that required filtering. This would be done through the use of a simple moving average filter to smooth the input data for the machine learning classification.

The machine learning classification would involve training the model to recognise a normal walking gait and differentiating it from ataxic gait. A normal walking gait would be expected to be periodic in nature, as walking is a repetitive motion. This fundamental frequency would be expected to be around 1-5Hz[6], which is verified from the experimental data.

As stated in [6][1], the average step length, step time as well as body sway area would change as the amount of alcohol ingested increases. In order to determine this, time-series windows of around 50s in length will be used for monitoring a number of characteristics: The number of steps taken, average step length, average time between the steps, average velocity, cadence and skewness of these signals. These are chosen based on contributions from the projects cited above in **III**. Our project would then analyse these factors to note whether a correlation with BAC levels exist. This would allow us to evaluate the hypothesis that the sensors on a smartphone and a wearable would be sufficient for intoxication detection.

B. Nystagmus

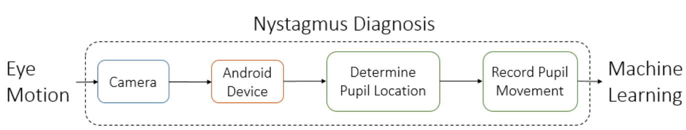

Figure 2. Implementation of Nystagmus Diagnosis

Figure 2 illustrates the flow diagram for nystagmus diagnosis. In order to determine the location of the user's pupil, a method adapted from [10] is used. First, the inner eye corner, as well as the dimensions and paths of the pupil have to be captured. This is done through the use of two still images, with one of the eye being centred, and the other with the eye pointed towards the outside corner. Next, in order to estimate the pupil path estimation, an object on the screen of the Android device is used as a visual cue for the eye. This object would move along the screen in a linear path at either a constant or sinusoidal speed. These two systems would allow for the position of the user's pupil to be established.

For eye motion tracking, the frame of reference has to be stabilised with respect to a location on the user's eye. This can be done through the use of the inner eye corner as a reference point, from which all eye movements would be relative to. The eye detection can be done using a Viola-Jones Haar Cascade, implemented in OpenCV. These eye movements would translate to positions from which Nystagmus can be detected. By determining how well an eye is able to follow a visual cue, the smooth pursuit property could be investigated, in addition to the jerkiness motion of an eye.

However, this method contained several limitations. With different lighting conditions, the camera on the Android device would fail to detect the pupil. Thus, this would only work in stable light conditions. Movement of the Android camera would affect the readings on Nystagmus effects, and lastly, the user is assumed to not blink entirely throughout the data capturing.

VII. Conclusion

This report provides a background into previous work implemented on detecting alcohol-induced ataxic gait as well as nystagmus. These findings are then used to provide an example implementation of mobile device-based detection systems for intoxication detection. In the event that non-invasive detection systems on a simple smartphone app prove successful with an acceptable degree of accuracy, this could help alleviate modern day problems with overdrinking and the dangers associated with it. Furthermore, the studies done in these fields could be applied to other symptoms involving optical motion and body motion, thus paving the way for groundbreaking progress in the mobile healthcare industry.

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