Autonomous system for track athletics guidance for the visual impaired

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Abstract

Currently, visually impaired people still suffer from the lack of adequate pedestrian guidance systems suited to their needs and without which they are not able to have a good quality of life, something that must be addressed urgently. Visually impaired athletes, more specifically, are not able to train and practise their runs due to increasing costs regarding guide athletes, infrastructures and needed equipment. In this work, available positioning/navigation techniques and guidance systems were evaluated regarding a set of requirements demanded for the specified target audience. Although the solutions mentioned have some key aspects developed, there is no system that gathers all the required functionalities. It is with that motive that it is proposed the ***TSAG*** *system, a navigation guidance system for visually impaired athletes, that provides vibratory and audio feedback to an athlete during his competition, while using Pedestrian Dead Reckoning (PDR) techniques to track its position and correct it if it deviates from the course.*

Keywords— accelerometer, Android, Dead Reckoning (DR), gait, Global Positioning System (GPS), gyroscope, kinetic

1 Introduction

It is estimated that, in 2013, over 4%[1] of the world's population (285 million) had visual impairments and one of the main consequences of such disability is the loss of autonomy in terms of navigation, something that these people have to deal with every day. However, nowadays current solutions have their limitations since, for instance, the walking sticks/canes give a vary narrow range (navigation wise) for the visually impaired person, which also has to learn how to correctly collect, process and react accordingly regarding the information that is provided from the equipment. The same goes for the *seeing eye dogs*, since they require a lot of time and money to be trained for these specific guidance tasks and added responsibilities.

The lack of a suitable solution is also verified when it comes to physical activity, since they do not have the same opportunities to participate in regular sports and do not attain the social and physical benefits since their main barriers are time, the lack of adapted facilities and equipment, human resources, and monetary cost. This is very noticeable when we consider visually impaired running athletes, that on top of all the mentioned above barriers, they also need a runner guide, which will lead to more costs and the athlete is limited to the guide's performance and stamina.

Nevertheless, the increasing evolution of technology (specially regarding the **navigation**, **mobility** and **accessibility** areas) has come to a point where it can be possible to consider the development of a portable navigation system that can address this shortcoming.

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[1] Source: World Health Organisation (WHO): `http://www.who.int/mediglsentre/fglstsheets/fs282/en/`

1.1 Motivation

Current navigation systems and sensor technologies allow us to overcome some of these difficulties. With this motivation, the purpose and goal of this work is to address and develop a portable, autonomous and precise guidance system for visually impaired athletes to allow them to autonomously practice and compete in various physical activities, mainly running sports.

Nowadays, only a small minority of developed systems that were addressing this issue are still being used, mainly due to the lack of precision, inadequate interaction with the user, the (high) cost of the available systems and the deficiency of usage, since some of the available technologies are old and do not present some important features that are needed in order to tackle this situation. Although there are some promising techniques (mostly positioning algorithms),and with the increasing evolution of technology, we are able to develop a new system that can take advantage of all the available Precise Point Positioning (PPP) techniques (but also refurbish them a bit to best suit the user's needs) and ally them to a low-cost but efficient device.

1.2 Requirements

An automated guidance system will allow visually impaired athletes to train in an autonomous fashion whenever they need or whenever the guide runner cannot be present, allowing a significant increase in the availability of this so common sport. In order to do so, it is of key importance to adequately define the specifications of the system, namely: i) develop a **low-cost** all-in-one solution, ii) develop a solution for a **portable** device, iii) develop a solution with adequate **positioning precision** algorithms iv) develop an all-in-one solution which brings an overall **ease of usability** and v) a device where it is possible to **develop** applications for its software/firmware. Nowadays, smartphones already include a GPS receiver, sensors such as **accelerometers** and **gyroscopes**, wireless connections and also audio/vibratory interfaces.

Due to the conditions of the running track, the competition and the athlete themselves, it is important to assure the following while developing the system:

- the **improvement** of the **precision** in the positioning estimates of low-cost GPS receivers with the usage of techniques such as Real Time Kinematic (RTK) or PPP;
- the **improvement** of the **guidance position** in devices with simple GPS data by developing DR techniques that explore specific motion characteristics of the athletes and the racing track geometry;
- the **development** of a system that will be engage and able to interact with several devices, such as beacon station to transmit data to use in RTK and PPP techniques, but also with several mobile nodes (the athletes);
- the **definition** and **implementation** of adequate interfaces with the system;

1.3 Goals

The main goal of this work is to develop an autonomous guidance system for visually impaired athletes with low-cost and portable embedded sensors, such as *smartphones*, allowing visually impaired athletes to run without the guide runner. The system must be autonomous, and with enough precision to guide the athlete within the track limits. At the same time, it must be portable, economically viable and accessible, and with an appealing interface that is also easy to use, comprehend and interact with.

The system will be designed considering outdoor running tracks and the path to be followed by the athlete must be predefined, well known and free of obstacles, but it must provide a fast response since the athlete will be at a fast pace (up to 10 m/s). With such guidance system, it is possible to facilitate physical activities, in particular running sports, available to more people with visual impairments. The system must also provide feedback at all times due to the athlete's disability, so it can inform of its current position in the track (during the race) and it must provide useful alerts if it happens to deviate for its course.

2. Related Work

In order to be able to develop a solution that will be suitable for our purpose, it is important to pinpoint the criteria needed while taking in consideration the requirements established in 1.2. It is necessary to consider such a **device** that is reliable, resistant to constant motion while practising sports (e.g. running) and it must also be able to provide such accurate and precise positioning information for the targeted audience. In such device, a **set of built-in sensors** will be needed in order to provide the most precise and accurate positioning results due to their output data allied with the existing PDR techniques/algorithms.

Hence it is necessary to consider and evaluate the solutions (academic and commercial) available as well as other relevant related work and/or technology in order to understand the strengths and weaknesses of each available solution, but knowing *a priori* that most of them are not prepared for the fast pace motion that running sports require. This will lead to the development and implementation of a solution that matches the desired criteria.

2.1 Supporting Platforms/Devices and Existing Sensors

Smartphones have become very popular and indispensable carry-on devices for people in recent years, and they are embedded with various sensors which could be used for many interesting applications. Sensors in smartphones can provide unlimited possibilities for applications to help and change the life of people. With that, developing an application that interacts with various types of sensors is easier to be accepted instead of creating and developing for specific equipments [14], given the improvement of Micro-Electro-Mechanical-Systems (MEMS) and the fact that the presence of sensors (with an improved component integration to increase performance with reduced costs) in mobile phones has risen exponentially in order to provide new features/services to end-users. [4]

2.1.1 Accelerometer

An accelerometer is a sensor that is able to detect the forces the sensor is subjected to. It is also able to determine the orientation of a device towards the ground by measuring the gravitational force. Given this, accelerometers have become the preferred choice for continuous, unobtrusive and reliable method in human movement detection and monitoring, and with that, the use of accelerometry as a quantitative measure to completely define the movement of a body in space has many advantages over other the existing techniques. [11]

In order to obtain the best results while measuring a person's attitude and gait, it is recommended that the accelerometer, and in the case of this work, the smartphone should be placed next or as closely as possible to the center of mass of the body, such as the sternum, hip or waist, although it is important to achieve such an algorithm that can determine a person's steps without considering a fixed position for the equipment. [1]

2.1.2 Gyroscope

The gyroscope is a sensor used for measuring or maintaining orientation, based on the principles of angular momentum. Gyroscopic sensors are used in navigation systems and for finding the position and orientation of devices. Combining a gyroscope with an accelerometer allows the device to sense motion on three axes - the roll (rotation around the YY axis), pitch (rotation around the XX axis) and yaw/azimuth (rotation around the ZZ axis) rotations allowing for more accurate motion sensing abilities.

The coordinate system is the same as the one used in the accelerometer. Rotation is positive in the counter-clockwise direction (right-hand rule). That is, an observer looking from some positive location on the x, y or z axis at a device positioned on the origin will report positive rotation if the device appeared to be rotating counter clockwise. The range will be at least 17.45 rad/s (i.e.: $\sim$ 1000 deg/s).

2.1.3 GPS

A Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on Earth as long as there is an unobstructed line of sight to at least four or more GPS satellites. The system provides critical capabilities to military, civil and commercial users around the world. It is maintained by the United States government and is freely accessible to anyone with a GPS receiver [5].

The majority of GPS receivers are built into mobile phones nowadays, with varying degrees of coverage and user accessibility. Some phones use an assisted GPS (A-GPS) function when they are out of range of their carrier's cell towers (although it gives a poor precision). Others can navigate worldwide with satellite GPS signals as well as a dedicated portable GPS receiver, upgrading their operation to A-GPS mode when in range.

2.2 Academic Development - State of the Art

Since 1980, several designs have been proposed to achieve a reliable navigation system for the visually impaired people in a way that it is possible to provide the best possible guidance while navigation in a certain region with the usage of various feedback signals (e.g. speech and/or vibration motors).

2.2.1 Positioning Techniques

As referred in section 2, navigation guidance systems based on simple GPS devices suffer from some positioning precision issues. To solve this, solutions have been proposed using Differential Global Positioning System (DGPS) and Real Time Kinematic (RTK) techniques [3, 18]. The use of Differential Global Positioning System (DGPS) implies the use of significantly more expensive equipment and more importantly the existence of a reference point, which is a huge obstacle to this work. Because of that, newer solutions were proposed where GPS was only used as part of the guidance system by exploring another positioning technique for the context of our target audience.

For the purpose of this work, it is important to establish the concept of velocity-based navigation that is usually referred to as **Dead Reckoning (DR)**. This technique relies on signals that indicate if a person is moving, through a velocity vector, in order to determine its new position based upon known or estimated speeds over elapsed time and course. [19]. Also, and as an extension of the DR technique, it is important to also establish the concept of **Pedestrian Dead Reckoning (PDR)** [17], which allows to collect the distance travelled since a person's starting point. That distance can be obtained with the usage of an accelerometer, but it is necessary to comprehend which region of the human body is best to place the device in order to obtain the best results as well as comprehend the various motion activities a person can achieve. All that must be considered with what was stated in 1.3, which is to develop such a system that is able to apply data fusion between GPS and inertial sensors (that apply the DR techniques), leading to a improvement of navigation and precise positioning using low-cost GPS receivers.

2.2.2 Activity Classification

In order to apply in a reasonable way the positioning techniques stated above, it is important to understand classify and understand the possible movements/motion activities a person is able to do.

As described in [9], during walking and/or running stages, a person's body goes through several motion phases or states described as *gait* - the way locomotion is achieved using human limbs. With the usage of an accelerometer, it is possible to identify when a person takes a step, more precisely, the simplest feature to identify is when a foot first hits the ground as this creates peaks in the acceleration record. However, the characteristics of a person's gait can change with the speed of motion, injury, age, disease or the surface where the motion takes place. These factors have also to be taken into account.

Regarding the speed of motion or *step frequency*, it is also important to be able to detect a person's running stage, not disregarding the fact that this stage can generate *false steps*, since the accelerometer can register peaks (equivalent as a step) during running motions (for instance, body swing). Hence, as suggested in [12] and as referenced in 2.1.1 , the smartphone will obtain the best results, i.e, the lowest erroneous results, if is placed closely to the waist or hip.

2.2.3 Activity Detection Algorithms

In [7], various step and walk detection algorithms smartphone oriented are evaluated. Due to the phone's specifications and its built-in sensors limitations, it was determined that the ***Windowed Peak Detection - (WPD)*** is the optimal option for step counting regardless of the smartphone placement allied with a straightforward thresholding of the accelerometer standard deviation that will robustly and cheaply detect periods of walk.

The WPD algorithm establishes a threshold regarding the data collected from the calibration phase (due to the athlete's physical characteristics). Once that threshold is defined, a step will be considered and accounted if a peak that is detected surpasses that threshold. However, it needs to be further explored in order to develop an extension to this algorithm so it can adapt for any motion stage the person is in (whether it is a walking or a running stage).

2.2.4 Available Systems

There are also various systems developed (in an academic environment) with the goal of providing a reliable navigation solution suited for the visually impaired people, mostly focusing on the PDR techniques. In [20], a comparison of the available systems is made pointing out the strengths and weaknesses of each one, however and for the purpose of this work, there are two systems that are relevant. Both of them are described as follows:

Padati In [16], the Padati solution is presented as an indoor navigation system relying on PDR techniques in order to detect the user's steps and respective length, not by relying on the device's location and orientation features but by using map matching and signal/particle filtering. Though the system has shown very promising results, the fact that it demands a manual and long calibration phase per each user and the usage of map matching features makes this system not suited to be considered for our solution.

AutoGait AutoGait, as presented in [8], is a mobile platform that determines a user's walking profile and estimates the distance walked using the GPS built-in receiver of the device. This platform was designed taking in account both indoor and outdoor scenarios and is able to calibrate to best suit the user's physical characteristics as a background process. Due to their GPS filtering and activity profiling algorithms, AutoGait achieved very good results, however, it lacks an orientation module (something crucial to our target audience) and it works on a separate device from the mobile phone, so it is not suited to be considered for our solution.

3 System Architecture

After analysing all of the state of the art technologies regarding our established requirements, herein is presented a solution that gathers the most suited positioning techniques out of the ones described in 2.2 into a device with built-in sensors that are able to track the position of an individual. Furthermore, guidance features are also added in order to make sure that the visually impaired athlete stays on course. In order to achieve such a system, in this chapter, the architecture of the presented solution is described, explaining each component's role to achieve the defined goals. Also in this chapter, some additional considerations are specified in order to explain certain approaches while developing the system, namely the athlete's biomechanics and the scenario where the system will be used, the running track.

3.1 System Design & Features

The athlete will place the smartphone with the **TSAG** application running near its waist, since it provides the best motion readings/values [12]. The TSAG system will be composed by the **Tracking** component (the main one), which will allow the system to guide the athlete during its trial by evaluating its gait and its direction due to the usage of the gyroscope, which will evaluate the athlete's body rotations (through taking them into account) in order to detect possible deviations from the original course. Alongside, a **Calibration** component will measure the user's features (by the data obtained from the built-in sensors) and will create a user's profile or threshold in order to provide more accurate readings, especially when counting the athlete's steps and distance travelled. Meanwhile, a **Positioning** component, mainly featured by the device's GPS receiver, will provide the athlete's current position (in geodetic coordinates) as a reinforcement of the main component.

TSAG would also provide feedback to the athlete (vibratory or auditory aid) in several cases: **i)** the start and completion of a trial (considering the distances determined in the trials and by calculating the distance tracked), **ii)** mispositioning - the system will generate guidance information to allow the athlete to get back on the correct track. Additionally, the obtained information can be logged to monitor the athlete's performance in order to be able to improve it.

3.2 Other Considerations

The system presented is mainly focused on the three components described above, however, there are some additional considerations that are necessary to take into account so it can fully function for its purpose. These considerations are focused towards the user - the visually impaired athlete and also the scenario where the race takes place, the running track. Although it will not affect the general design of the system, these considerations will allow to better comprehend the necessities involved for this work, allowing it to best suit the user's needs and performance.

3.2.1 Biomechanics

Athlete's Running Speed It is important to characterise the subject of our work, the athlete. Even being visually impaired, the athlete has a high physical endurance and stamina, being able to perform harsh or demanding physical activities. In [15], a study is made to the biomechanics of a physical activity, such as running, and the impact it has on the athlete.

It is established that, in average, an athlete will achieve running speeds between 3.2 m/s (11.52 km/h) and 3.9 m/s (14.04 km/h).

Step Length As stated in **??**, in order to develop a proper PDR algorithm, it is necessary to know the height, weight and gender of the user, since they are factors that can alter the output results. In [17], it is proposed a kinetic formula (static approach) to best obtain the stride (or step length):

$$step\_size = height.k \text{ [17]}$$

where k is the kinetic factor and the height is measured in meters. The static approach can be considered for this system because although it is an intense physical activity, when the athlete is running, its stride does not vary during the race. In fact, is important to maintain the same pace during a race. **On average, an athlete's step length is between 1.00m to 1.20m**.

Step Period If we consider the results obtained above, it is possible to obtain the athlete's average step period:

Minimum Step Period (s): $\frac{1m}{3.9m/s} = 0.2564$
and Maximum Step Period (s): $\frac{1.2m}{3.2m/s} = 0.3750$

This data allows to obtain the rate of each step occurrence, since $F(Hz) = \frac{1}{T(s)}$:

Minimum Rate (Hz): $\frac{1}{0.3750s} = 2,666$
and Maximum Rate (Hz): $\frac{1}{0.2564s} = 3,900$

3.2.2 Scenario Specifications

Another important consideration to take in account is the scenario in which the system will be used - the running track. A key aspect to focus on is the semi-circle (right after the 84.39m of a straight section) due to the fact that it is necessary to know the angle/deviation that an athlete needs to create to stay in course. It is known that:

Inner_Circle Radius = $36.5m$
and Outer_Circle Radius = $45,04m$

and:

Minimum Deviation (degrees): $\theta \approx 1.4$
and Maximum Deviation (degrees): $\theta \approx 1.7$

meaning that it is necessary to consider the **minimum deviation value of 1.4 degrees** so the athlete stays on course. If the athlete starts to form a wider deviation, the system has to alert of such event and has to help the athlete to get back on track. However, it is necessary to take into account the hip rotation that the body makes while in motion and when it's about to perform a turn. In [2], several hip rotations were measured while the subjects were performing physical activities such as walking and running. As an average result, it was established that the hip rotation angle is $\approx$ 15 to 20 degrees. So the minimum deviation that the **TSAG** system must perceive is the combination of the hip rotation angle with the minimum track deviation.

4 Implementation

With the system presented in the earlier chapter, mainly the components that are part of, it is necessary to understand how the techniques described in 2 get together and work along with the smartphone's built-in sensors and the GPS receiver. So, in this chapter, the implementation of the **TSAG** system will be described in a away that it makes it able to comprehend how everything gets together by making it suitable for visually impaired athletes. The description of the system (and its implementation) will be usage/user oriented, which means that each component will be described on how it functions for a certain feature.

4.1 Development Process

4.1.1 Tracking & Calibration Components

In order to either detect or track the athlete's movement, the use of the built-in sensors such as the accelerometer and the gyroscope is needed. In order to access them, both the ***Sensor*** and ***SensorManager*** Android libraries or Application Programming Interface (API) are necessary.

4.1.2 Peak Detection

Focusing on the ***Windowed Peak Detection - (WPD)*** algorithm mentioned in 2.2.3, which checks the peaks generated from the accelerometer output data, it has to be adapted to the running activity, which means the ”window” used to detect those peaks has to be flexible, or in some cases, non-existent. So, the approach presented in [6] is used but adapted to the system's needs.

Calibration: This is where the calibration component will take place. After collecting a reasonable amount of data a threshold will be found, meaning that the peaks detected in the algorithm are more reliable and feasible to be considered as a step.

4.1.3 Step Amount and Distance Travelled

With the threshold established, all the peaks that the algorithm detects will be considered as steps. This means that we can collect and consider as valid all the steps that were detected by this algorithm during the race. With this amount, we can obtain the distance the athlete has travelled since the starting point. In order to do so, we use the following formula:

$$\textbf{num\_stride} = numSteps$$
$$\textbf{distTravelled(m)} = \frac{num\_stride * stride\_length}{100}$$

Filtering: Also as stated in [17], the output acceleration data must be filtered in order to be gravity-free and noise-free (to measure the real acceleration of the device) so it can be less prone for detecting false steps.

4.1.4 Body Rotation & Orientation (Data Fusion Procedure)

The **TSAG** system must be able to detect the athlete's body rotation so it can predict possible track deviations, i.e., prevent the possibility of the athlete to get out of the track. This will be accomplished by using a data fusion procedure/algorithm that gathers both the accelerometer and gyroscope sensors and a software-based sensor that measures the magnetic field. The data fusion algorithm developed [13] is the "foundation" that makes the system able to tell the athlete's orientation. In order for this data fusion algorithm to work, the sensors mentioned above have to be ready to provide data at the same time. To ensure that, the *synchronized* function is used, however, each sensor has its own handler. This handler (for the gyroscope) will need some accelerometer and magnetic field values prior to function.

Although this is the best way to determine the rotations made by the athlete, when the gyroscope is used continuously (during a large period), it tends to provide faulty values due to integration issues. To correct that, a timer task was developed to be triggered with a fixed period to apply correction filters to the values obtained. The values that are the outcome of this task are the ones that matter for our work. Afterwards, we need to consider which values can tell us if the athlete is deviating from its original track. If we consider the frame of reference in 4.1.1, mainly the ZZ and XX axis, we can determine if a deviation occurs by normalising the current pair of values (azimuth, pitch) and creating a new pair with the current pitch only. From here, we use the Pythagorean theorem by forming a right triangle, and with that, it is possible to find the deviation angle by using the following formula:

$$\sin(\theta) = \frac{module\_current\_pitch}{module\_current\_pair}$$

4.1.5 Positioning Component

The **TSAG** system also has a positioning component, which allows us to obtain the coordinates of the athlete on the racing track. In order for this to be possible it is necessary to create an Android Service, which is able to work alongside the previous mentioned components (in the background). Every time the athlete achieves a new position on the racing track, the GPS receiver will capture a new coordinate set (more focused on the latitude and longitude), and each set is stored in a coordinate log. The implemented service was based on Rahul Wingnity's approach [22].

Usage Restriction: In order to take full advantage of the **TSAG** system, it is important to obtain a first valid position from the GPS signal (through the receiver). It will take a few minutes for the GPS receiver to obtain a constellation set and be able to provide new coordinate sets. When the receiver has finally obtained a new position, it will alert the system so it can provide a Text-To-Speech (TTS) aid informing the athlete of such event. Only after that first position, both the GPS and PDR components of **TSAG** can obtain or track the following athlete's positions.

PDR algorithm: As stated in 4.1.1, with the tracking component (that uses the accelerometer and gyroscope), we are able to collect the distance the athlete has travelled considering a first valid coordinate set, but in case of loss of PDR signal and the device's receiver cannot provide a position, the PDR algorithm is used to provide an estimate of the athlete's current position. This is possible to achieve by using Thaddeus Vincenty's [21] direct geodetic solution algorithm. The algorithm makes it possible to obtain a new coordinate set if a starting point coordinate set is provided and the distance that (in this case, the athlete has travelled) was made. In order to implement this algorithm in the Android environment, the solution provided by Mike Gavaghan [10] was used.

Combining the data that is obtained from the GPS receiver, with the usage of the Android's *LocationManager* library, when a coordinate set is obtained, the system will utilise the latitude, longitude and bearing (in case of loss of signal from the GPS) in the PDR algorithm. Since the coordinate set was obtained by the

WGS84 reference ellipsoid, it is necessary to pass this information also as an argument so that the new coordinate set will be also in that reference. The last component, the distance, is provided by the tracking component. The combination of this five elements used in the formula is the key of the **TSAG**'s PDR approach.

4.1.6 Feedback Provider

Due to the athlete's visual impairment, it is necessary to implement a resourceful and efficient feedback provider component that will be able to guide the athlete in a way that it won't be needed any auxiliary aid during the race. This component will have a vibratory service and a TTS module.

The vibratory service (provided as an Android library) allows us to make the device vibrate accordingly with certain events that are considered important and relevant for the whole user experience. For this work, two vibratory patterns will be used, each one to be triggered when a deviation occurs (either to the left or to the right). Due to the high consumption of CPU resources (that have to be allocated in order for this service to work properly without disrupting **TSAG**'s main component), an auxiliary thread will be created for each vibratory pattern and can only be triggered when a deviation occurs. A vibratory pattern is simply a time sequence chosen to make the device vibrate when a certain event is detected.

The TTS module will provide speech aids to the athlete whether they have an informative character (e.g distance travelled) or an imperative character (e.g. deviation detected - must correct position). This module is also provided as an Android library. The configuration is based on four factors: pitch, rate, language and sentence to be spoken.

5 Evaluation

5.1 Methodology and Scenarios

The evaluation (or better yet, the methodology) prepared to test the **TSAG** system will be focused on each system's components in separate but also the system will be evaluated as a whole, which means, it will be tested as the visual impaired athletes should experience the system. The tests will also focus on the activity that is being performed by the user who's testing the application.

Separate Test 1: The first separate component test will verify the **accuracy** of the tracking component, mainly the step counting (and amount) and also the distance estimation. To compare the amount of steps, the test user will be asked to control as best as possible the amount of steps that it has walked during the chosen test course (while walking or running). The result obtained by the system will be compared to the amount the user has counted by itself. The distance calculated by the system will be compared to the distance provided between two known points (using *Google Maps*™).

Separate Test 2: The second separate component test will verify the **precision** of the **TSAG**'s positioning component. All the GPS data (obtained from the receiver) will be evaluated by tracing a route (with the coordinates log) on an online tool named *GPS Visualizer*[2] to verify the proximity to the real target and chosen course. The same will be done with the coordinate log obtained from the PDR algorithm. The logs will be obtained while walking and also running, as the first test mentioned above.

System Test: This test will evaluate the **TSAG** as a whole, but it will have special focus on the orientation and feedback components. Since that, in this test, the objective is to replicate the conditions that the athlete has, it is important to verify one of the main rules that the athletes have to follow while competing: This means that the test user, if not visually impaired, will be asked to be blindfolded or at the very least, to close its eyes while walking or racing through the test course. Since it will be tested in an outside area, the user will also have to user a headphone set in order to listen the TTS commands of the system. With this, it will be possible to evaluate the adaptation that the user has with the system and also the accuracy and precision (of the system and user response to it) by the orientation aids it will receive (by the system) in order not to deviate from the original test course.

5.1.1 Chosen Test Courses

One of the test courses chosen to evaluate the **TSAG** system is located in Fornebu, Akershus, Norway, between the coordinates $(59.8950084N, 10.6296923E)$ and $(59.8957185N, 10.6285701E)$, which means a 100 meters test (with a straight track) course in a flat surface. In the surroundings of this chosen course there are a few buildings in order to provide some difficulty to the GPS

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[2] Source: `http://www.gpsvisualizer.com/`

system to obtain signal and subsequent positions, forcing the PDR algorithm to work as much as possible.

The second test course to evaluate the **TSAG** system is also in Fornebu, Akershus, Norway, between coordinates $(59.8962722N, 10.6274282E)$ and $(59.8958057N, 10.6262629E)$ which means also a 100 meters test course. The purpose in this test and chosen course is to evaluate the adaptation of the system regarding the ability to perceive curves and deviations that the athlete may make while contouring the course. Nevertheless, all the remaining components will also be tested.

5.1.2 Test Device

The device that will be used for testing the **TSAG** system will be the **BQ Aquaris E5**. The device has the 4.4.2 version of the *Android* Mobile Operating System (MOS) (also known as *KitKat*) but the system/application can work in devices with earlier versions. In this device, the TTS module is already activated but with no default language and the only location provider enabled is the device's GPS built-in receiver.

5.2 Results and Evaluation

The step estimation module obtained accuracy levels between 95% and $99,2\%$, meaning that the amount of steps obtained by this module are feasible and it is possible to consider it as fairly accurate. The difference between activities is quite noticeable by analysing the gap between peaks (a gap between peaks in a running activity is nearly half as a gap between peaks in a walking activity), but it does not influence the module behaviour. Although there were still a few steps miscounted in each activity (maximum of 6 steps miscounted in the tests), it does not undermine the overall performance of the module.

The distance estimation module obtained accuracy levels between 75% and 90%, meaning that the module needs a little improvement. The cause for these values can be related to the fact the stride factor it isn't properly defined and needs further adjustment due to the fact the system needs that calibration phase in order to perform at a optimal state, hence the 75% from the first test course up to the 90% of the second test course (the system had be used and therefore calibrated at least once).

The positioning estimation module obtained accuracy levels (distance estimation from the GPS coordinates) between 82% and 100%, meaning that, accuracy wise, the results obtained by the positioning module can be considered as feasible and also accurate. Regarding the precision test, the biggest gap detected (between the defined test course and course detected by both the GPS receiver and the PDR algorithm) was around $10m$, a high value, but it is due to the fact that the surroundings of these courses had a lot of obstacles (e.g. buildings) that can difficult the retrieval of a precise location.

The orientation test results were able to show us the ability of the **TSAG** system to perceive rotations beyond the ones the user's body makes, alerting the user of such event. The user correction was almost immediate, as shown in the charts, allowing us to conclude that the user was able to interact and adapt correctly with the system.

Overall, the system has shown fairly good results and good performance, as is shown above. However, there are few improvements that can still be made as well as more tests in the desired scenario - the race track.

6 Conclusions

Even today, visually impaired people have serious autonomy limitations performing various activities, such as in sports, due to lack of guidance systems. With this motivation, the work herein presented proposes a new tracking and guidance solution for visually impaired athletes autonomously so they can practise and compete in sporting events (e.g. running trials). The state of the art solutions have shown promising results by providing Pedestrian Dead Reckoning (PDR) algorithms, allowing to track and log an athlete's course, knowing its current position and orientation. Other complete systems even allow the visual impaired people to navigate freely using various types of feedback such as vibratory or auditory signals. However, these systems are not adequate to the practise of sports.

The proposed solution will have a tracking system which will track the athlete's step amount and orientation during a trial. Also, it will have a positioning component that uses the device's GPS built-in receiver as well as a PDR algorithm that is able to track the athlete's position in case of loss of GPS signal. Another feature implemented in the system is a feedback provider algorithm composed by vibratory patterns and a TTS module in order to inform the athlete of various events, but mainly it will alert the athlete in case of mispositioning of the athlete in the track lane, and it will guide him to correct the deviation, allowing it to maintain itself in the correct lane.

The system was subject to various steps in order to evaluate the components accuracy and precision, but also as an overall performance. User interaction and adaptability to the system was also taken into account, due to the fact that the feedback provider module must be quite efficient in order to be able to guide the athlete properly. The results obtained showed us that the general accuracy levels are between 80% to 99%, which makes it able to consider that the **TSAG** system provides fairly accurate results.

7 System Limitations and Future Work

A different approach that can be considered as future work is the retrieval of positioning coordinates. Instead of using the GPS built-in receiver to obtain the constellation and afterwards retrieve the positions (a procedure that takes several minutes), it would be possible to have alongside the track a base system that could give reference points regarding the athlete's position automatically.

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