A Tracking Topology to Support a Trajectory Monitoring System Directed at Helping Visually Impaired on Paralympic Athletics

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Abstract. The study reported by this article was based on previous studies about the development of assistive technology for visually impaired athletes and aimed to evaluate a tracking topology that can be applied for the location and orientation of visually impaired on Paralympic Athletics. The paper presents the tracking topology and its integration in a trajectory monitoring system able to provide vibratory stimulus to visually impaired athletes. Moreover, the paper also presents the results of an experiment that was set up to evaluate a trajectory monitoring system prototype by eight visually impaired athletes when performing their training activities.

Keywords: Assistive technology · Visually impaired athlete · Trajectory monitoring · Sensing network · Sensory replacement · Paralympic athletics

1 Introduction

Within Paralympic Sports, human guides are essential to help the visually im-paired in athletics races by using ropes that are attached between them and the respective athletes. However, the guides indirectly influence the athlete's performance, mainly if there are substantial differences in the physical capacity of the athletes and their guides. When this occurs, the athletes may be harmed in their performance. As it was observed by the study reported in [1], the visually impaired athletes are not effectively guided by using a

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rope tether. Moreover, problems such as affinity, professional treatments, or the absence of the guides for any reason can cause disruptions in training. Therefore, if there are systems aiming to help visually impaired runners on their normal line or trajectory, the guides would no longer be needed [2].

This study is part of a long-term project aiming the development of digital solutions with tactile sensory feedback to help visually impaired athletes. Categorically, this article presents a tracking topology to be used in a trajectory monitoring system composed by a wearable vibrotactile device and a wireless sensor network, aiming to provide visually impaired athletes with information regarding the correctness of their trajectories during athletics races. Moreover, the article also presents the results of an experimental set up that involved eight visually impaired athletes to determine the adequacy of the proposed concept as the basis of a trajectory monitoring system to support training activities.

In the following sections, this article introduces the research problem, the methods that were used, the proposed trajectory topology and its integration in a trajectory monitoring system, the experimental evaluation, and a discussion and conclusion of the results.

2 Problem and Foundations

The realization of a movement in space is nothing more than the change of a mobile reference relative to a fixed reference, comprising information about location, orientation, and approach. In turn, mobility is the ability to identify the relationship between one's position and the objects of an environment and then move autonomously, safely, and efficiently.

The most common mobility tool for the visually impaired is the white cane, which is the most traditional and is the universal symbol of visual impairment. However, this tool does not provide the necessary information, such as speed, volume, and distance from objects near the respective user [3]. The other tool option that provides a better route for the blind is the guide dog, as the animal is trained to detect and analyse the complexity of situations such as crossing streets, going down or climbing stairs, potential hazards, among others.

Considering the tremendous developments of information and communication technologies, during the last decades, other types of mobility tools can be envisaged, since navigation and orientation systems are commonly noticed in the automotive, nautical, and aviation industries.

When it comes to accessibility and autonomy for visually impaired people, several researchers consider correction devices using a virtual interface for orientation. For instance, in [4] a virtual interface for indoor environments using accelerometers from Nintendo Wii controllers is introduced.

Other approaches are based on the use of virtual reality and audio as auxiliary tools that provide spatial auditory perception [5–7]. The idea is the possibility of visually impaired people build mental models of the environment from systems that provide auditory information about controlled spaces, objects, or people. In this respect, article [8] presents an interface based on virtual reality, and audio containing information about boundaries and obstacles. Such an application al-lowed the visually impaired to explore environments, discovering points of interest, as well as the development of personalized navigation strategies.

Moreover, computational vision techniques are also being used. For instance, in [9] the topic is viewed as a computational vision issue comprising pattern recognition techniques, advanced spatial resolution, and accelerometers as sensors to obtain references of orientation from guide systems. In this context, the authors point out five measurements for obtaining data that have information about the relative distance between two points: rotation angle, minimum and maximum frontal distances, and lateral distances (i.e., left and right distance) [9]. With this information, it is possible to establish indicators of relative distance and can support the orientation of visually impaired people.

Finally, knowing that humans can feel different frequencies of tactile vibrations, the literature reports the use of a tactile stimulation mechanism to help visually impaired people to decide the direction to be followed [10]. This was the approach followed in the study reported by this article.

3 Methods

3.1 Issues

It is public knowledge that visually impaired athletes perform racing activity on the track by using ropes that are attached between them and their guides. Even if the rope allows the execution of sports activity, the guides indirectly influence the athlete's performance [1]. Moreover, in the study reported by [11], the authors analysed a set of 186 official championship videos (i.e., World Champion-ships, Paralympics Olympic Championships, and national and regional events) related to 100m sprint races, involving 186 pairs of athletes and guides, to identify the incidents associated to the orientation process based on the rope connection between the visually impaired athlete and the respective guide.

Considering the results of this analysis, in almost half of the races some incidents affected the dynamics of the athlete-guide pair. In turn, by analysing the incidents that were identified, it was concluded that, when it comes to location, the main issue is to obtain an accurate measure of the position of the athlete and, when it comes to monitoring, the main issue is related to athlete's trajectory [11].

3.2 Proposed Solution

Within the context of Paralympic Athletics, a digital solution to help visually impaired was considered to provide an accurate measure of their position in the track to give them security and to indicate them the status of the track. The solution should also get information about the athlete's direction, position, and provide trajectory monitoring.

In this respect, it was designed a tracking topology composed by coordinating nodes and anchor nodes, which was integrated in a system aiming to locate the athletes and to track their trajectories. In addition to the tracking topology, this system comprises: i) a wireless sensor network; ii) a computational algorithm for trajectory correction based on motion capture interfaces; iii) a pairing interface for the location network and actuation devices; and iv) a vibrotactile feedback wearable device to aid visually impaired athletes allowing them to develop a controlled and oriented pace in the race.

3.3 Experimental Evaluation

An experimental set up was conducted involving eight visually impaired athletes to evaluate the tracking topology in the context of the athlete's training activities. The experiment took place in Manaus Olympic Village, Amazonas, Brazil.

By using the system prototype the athletes should not leave the limits of the lanes in which they developed their gaits on the 100 m course and the experimental evaluation aimed to determine the degree of success when using a trajectory monitoring system based on the proposed tracking topology.

4 Tracking Topology and Trajectory Monitoring System

In general, there are monitoring systems that use a set of information to estimate the coordinates of a point in different environments, whether outdoor or indoor, employing signal processing techniques in a given communication network. A point where its estimated location needs to be inserted in the coverage area of a communication network and this one, in turn, needs to contain referenced information regarding location.

The employment of a triangulation technique for the establishment of a location system requires at least three fixed points with a known location (i.e., in the context of a communication network, there should be three computational nodes that receive the signal from an emitting node) that are defined as the origin of the coordinate system.

In terms of the types of processing algorithms of location, there is a combination of centralized and distributed models [12]. Concretely, a network with a large number of nodes is subdivided into smaller networks or clusters that each have a central node for processing the location. Within the cluster, the unknown nodes are located together, and the central node of the cluster is responsible for transmitting the information to the central processor of the network that performs the global location process [13]. By properly balancing the number of nodes in each cluster, it is expected to be possible to save energy through a greater balance between the required processing and the required bandwidth across the network without compromising the result of the location.

In a direct correlation, unknown nodes are defined as mobile nodes; the central node of the cluster as the coordinating node is responsible for the estimation technique defined by [14] as collaborative multilateration: "[…] for each location iteration an unknown node from three reference nodes, there is a possibility that one or more unknown nodes do not have reference nodes in their neighbour-hoods. For this reason, a distributed type processing algorithm converges for greater fault tolerance and less possibility of bottleneck formation in the central node of the associated cluster".

According to this approach, the communication network consists of communication modules with defined functions named mobile nodes, coordinating nodes, and anchor nodes (Fig. 1). Real-time data is sent to the anchor nodes located in the vicinity of the track, performing the triangulation from the processing of the signal indicating the position emitted by the mobile node (athlete). Such anchor nodes transmit information regarding the position of the mobile node to the coordinating node, whose purpose is to establish communication for control action through an interface or actuator according to a given communication protocol.

The logic comprises the reception, processing, and transmission of the signal through the wireless network and consequently the estimation of the coordinates of a mobile node, considering the entire length of the track, that is, the sectors of straight segments, semi-circular sectors, and the eight lanes, thus defining each sector of location. As shown in Fig. 1, the visually impaired athlete when running on the athletics track is posed as the mobile node in the tracking network. A signal transmitted through appropriate communication hardware soundly placed in the athlete's body, is received by the anchor nodes. The processed packet must contain an indication of distance defined in terms of signal strength transmission of the mobile node to all the anchor nodes. In sensor networks like this, the received signal strength indication (RSSI) is used to establish a relationship be-tween the loss of power of the signal transmitted by the athlete when received by the anchor node and the distance between them [15].

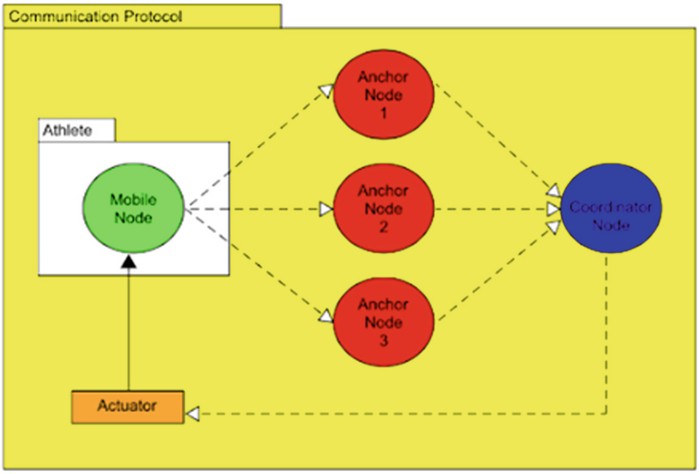

Fig. 1. Tracking topology.

In this context, the following propositions were posed:

- Each anchor node in a given location section on the athletics track has defined coordinates.
- Every mobile node transmits a signal to the anchor nodes based on the RSSI.
- Every anchor node when receiving the RSSI from the mobile node processes the received power, indicating the distance value in meters to the coordinating node for each location sector.
- Every coordinating node, when receiving the distance value, performs the triangulation using the solution proposed in [15] and sends the control signal for guidance to the mobile node.

The resulting tracking topology was applied in a trajectory monitoring system. For the implementation of the respective prototype a Zigbee network was considered. In turn, for the orientation device that receives the signal from the network and promotes the vibration that is represented by a linguistic code, it was used a device that was well accepted and presented reasonable results as an orientation tool in indoor environments with barriers [16]. It is composed by a set of vibrational actuators in contact with the athlete's skin (e.g., with his backs in the suit mode, or with its arms in the bracelet mode) on both left and right body sides, through which is possible to guide the athletes about the respective directions in order to execute their paths with safety and autonomy.

5 Experimental Evaluation

The system prototype was object of an experimental evaluation in the context of training activities of visually impaired athletes in order to determine the adequacy of the proposed tracking topology. In this experimental evaluation, the system feedback was provided by bracelets with vibratory stimulus. It should also be noted that a frequency of 250 Hz was initially considered for the vibratory stimulus, as recommended by the scientific literature [10]. However, after the preliminary test of the vibratory device by the athletes when running, they suggested higher vibratory frequencies.

Due to safety reasons, the system was used in addition to the traditional guidance method (i.e., a rope tether).

When the training activity consisted in sprints, it was evident that the tracking had a significant delay comparing with the current position of the athlete. How-ever, when the training activity did not imply sprints, the experiment showed that the feedback of the system prototype was consistent with the feedback that the guides provided to the athletes through the ropes. Considering, this scenario, Fig. 1, 2, 3, 4, 5, 6, 7, 8 and 9 (round trip in blue colour and back in red colour) present the performance of the eight visually impaired athletes involved in the experience. The training activity was developed considering the 100 m sprint as denoted at the Figs. 2, 3, 4, 5, 6, 7, 8 and 9 bottom.

Athletes 1, 2, 3, 4 and 8 developed a straight/satisfactory gait in the course, while athletes 5, 6, and 7 had deviations in the course.

In a more detailed analysis, the paths of athlete 2 (Fig. 3) and athlete 3 (Fig. 4) showed satisfactory results regarding the sense of orientation indicating a straight gait. For athlete 1 (Fig. 2) there was a delay in acting in quartiles 2 and 3, both on the outward and the return routes. Moreover, for athlete 4 (Fig. 5) there was a slight deviation in quartiles 2 and 3 in the outbound direction, although the way back was straight. Finally, despite slight deviations in quartiles 1 and 2 in the round trip (Fig. 9), athlete 8 remained within the limits of the lanes.

In turn, for athlete 5 (Fig. 6) there was a sharp deviation in quartiles 2 and 3 on the return route without exceeding the limits of the lane, while the going route of athlete 6 (Fig. 7) was a straight gait, but the return route presented deviations in quartile 2 and 3 since the athlete reached the lateral limits of the lane. Finally, athlete 7 (Fig. 8) had sharp deviations in quartiles 2 and 3 both ongoing and back route.

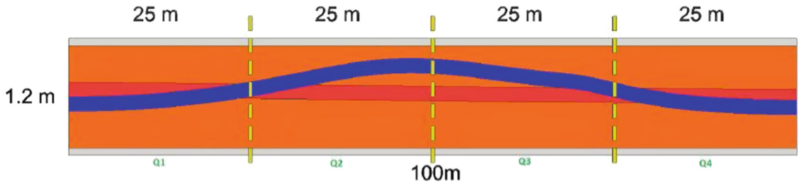

Fig. 2. Athlete 1.

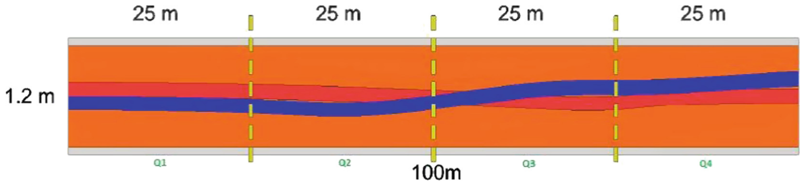

Fig. 3. Athlete 2.

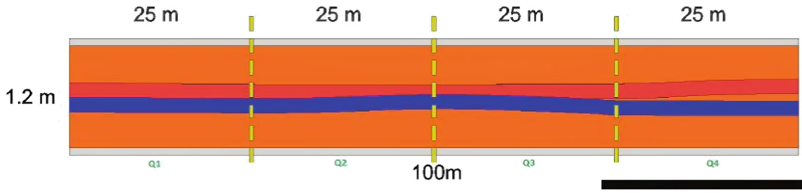

Fig. 4. Athlete 3.

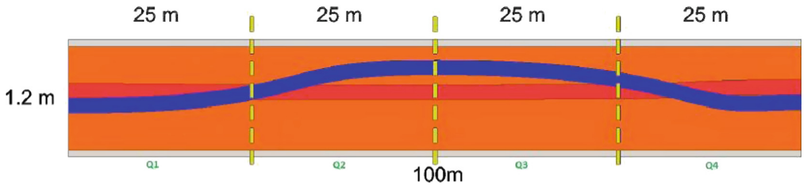

Fig. 5. Athlete 4.

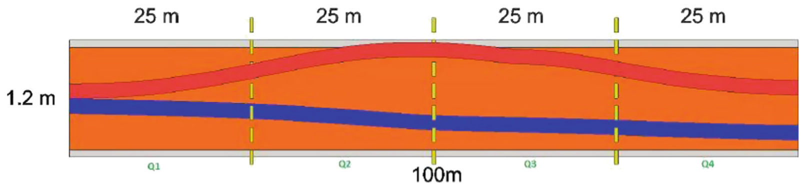

Fig. 6. Athlete 5.

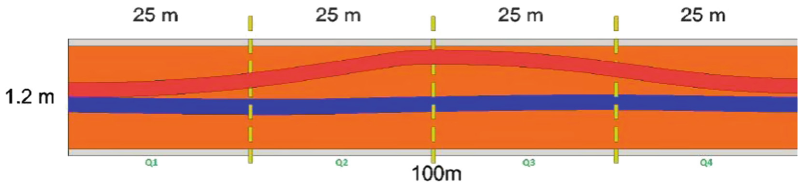

Fig. 7. Athlete 6.

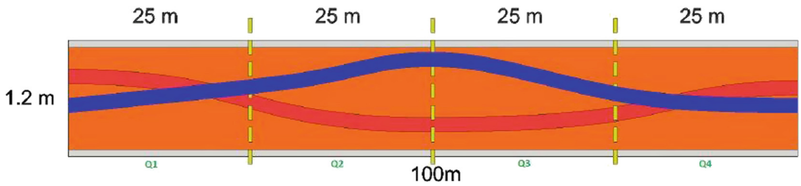

Fig. 8. Athlete 7.

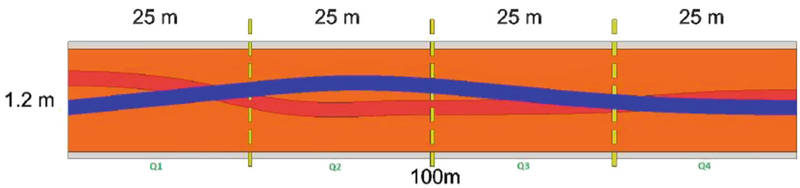

Fig. 9. Athlete 8.

6 Discussion and Conclusion

According to the experimental results it is possible to conclude that, in terms of trajectory monitoring, the tracking topology is adequate since it was found a correspondence between the human guide feedback and the feedback provided by the system being evaluated. However, for sprints there is a significant delay, but the causes of this delay are related to the performance of the communications technology being used (i.e., Zigbee) and not to the tracking topology.

In this respect, it should be noted that, when in the presence of sprints, there was a non-linearity and inconsistency of the signal power as a function of the displacement, which directly influences the location estimation process. There-fore, it seems that the topological model and related algorithms are adequate and can be used in terms of some of the training activities of visually impaired athletes. Nevertheless, as a future path, it should be considered the implementation of the proposed tracking topology with other communication technology.

Considering the performance of the athletes, five of the eight visually impaired athletes participating in the experiment presented satisfactory performance in terms of linear perception, as they remained within the limits of the streak by actuation of the vibratory device. In a focused analysis of the form of communication, deviations in paths are justified, because conflicts of information and temporal failure in data transmission can occur. In any case, this temporal failure in data transmission does not justify the differences between athletes. One hypothesis is that the vibrating device interface presents some limitations in terms of interaction with their users. This justifies further studies on the usability of the proposed system.

One of the relevant aspects that should be considered in a possible usability assessment is the frequency of the vibratory stimulus. In fact, the vibration frequency for the tactile stimulus was initially established as 250 Hz, according to literature recommendations [10], but the athletes required higher vibration frequency. This finding leads to the need to determine the appropriate frequency and to question whether the appropriate vibratory frequency for a running visually impaired should be different from the frequency considered when the same individual is standing or walking at low speed.

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