BLINDTRACK: Guiding System for Visually Impaired
Locating System for Running on a Track

Ferdinand Kemeth[1], Sven Hafenecker[1], Ágnes Jakab[2],
Máté Varga[2], Tamás Csielka[2] and Sylvie Couronné[1]
[1]*Fraunhofer Institute for Integrated Circuits, Nuremberg, Germany*
[2]*Ateknea Solutions, Budapest, Hungary*

Keywords: Real-time Locating System, Angle of Arrival, Round-trip Time, Visually Impaired Runners, Guiding System.

Abstract: Visually impaired people need to renounce several social activities what the sighted people can enjoy. In this paper we refer to the project BLINDTRACK which has the major goal to develop a guidance system. A real-time locating system (RTLS) based on radio signals guides the runners with the highest level of safety by estimating the angle of arrival (AoA) and round-trip time (RTT). First results show the position accuracy of the proposed locating system with real-world data. BLINDTRACK provides an enormous freedom for the visually impaired runners in compare to the other solutions: Sighted and blind runners will have the opportunity to perform sport together without another person's assistance.

1 INTRODUCTION

In recent years the EU and all its member countries have committed themselves to create a barrier-free Europe. There are still many obstacles preventing people with disabilities from fully exercising their fundamental rights including their Union citizenship rights and restricting their participation in society on an equal basis compared with non-disabled people. Those rights include the right to free movement, to choose where and how to live, and to have full access to cultural, recreational, and sports activities. Regarding sports, particular running activities, visually impaired do not have equal possibilities.

The most common way of running is the so-called guided running in that blind runners train and race with a sighted runner with the help of a tether (American Foundation for the Blind, 2014). With the BLINDTRACK project the Consortium aims to raise the level of accessibility of visually impaired to sport to reflect the need for an effective assistive technology which would facilitate the well-being of visually impaired while decreasing their exclusion from sport and leisure activities. The proposed system helps visually impaired people integrate to the community with increasing confidence, better health condition and higher tolerance level of sighted people.

The aim of BLINDTRACK project is to develop a running facility embedded to a 400 m athletic track for visually impaired people to run without another person's assistance. BLINDTRACK will be able to bring significant changes in training opportunities for visually impaired. The objective is to increase the number of blind and partially sighted athletes with the creation of a tailored infrastructural facility that can be the first step to train without sighted volunteers. Although BLINDTRACK focuses on visually impaired users, the system provides online available training results to the sighted people: This enhances the market opportunities and further development for small and medium enterprises (SME).

In this paper we focus on the project's locating part as follows: Section 2 provides an overview for the proposed system and the project organization. Section 3 gives basics on the used locating techniques and Section 4 shows the locating performance of the system under development. The last section summarizes the paper together with the next steps.

(European Commission, 2010) (United Nations, 2007) (England Athletics Limited, 2012) (United States Association of Blind Athletes, 2014) (Competitor.com, 2014)

Kemeth F., Hafenecker S., Jakab Á., Varga M., Csielka T. and Couronné S..
BLINDTRACK: Guiding System for Visually Impaired - Locating System for Running on a Track.
DOI: 10.5220/0005143001830189
In *Proceedings of the 2nd International Congress on Sports Sciences Research and Technology Support* (icSPORTS-2014), pages 183-189
ISBN: 978-989-758-057-4

2 BLINDTRACK OVERVIEW

The BLINDTRACK system structure is intended to built up three main components:

- the BlackFIR (Fraunhofer IIS, 2012) unit which is a high precision locating system,
- the belt unit which is a vibro tactile belt and
- a Central Control Unit (CCU).

2.1 System Description

The BlackFIR has the responsibility to locate the athletes on the track in real time, while the belt unit coordinates the athletes with vibrations while running and helps them to avoid the obstacles and the collision situations. The CCU predicts and calculates the different trajectories for each athlete and also filters and singles out the right commands to be sent.

Figure 1 shows the general architecture of the complete BLINDTRACK system. It is necessary to create an own local BLINDTRACK network on the athletic field, which is completely separated from the local area network. This separation ensures to keep the BLINDTRACK server safe, prevents the undesired system overloads and shutdowns and makes the operation fast and continuous. The server has a Linux operating system and a runtime environment to fulfil the controlling tasks that includes the calculation of the trajectories, the selection and transfer of the commands. The CCU has also a client side, where one or more computers can connect to the BLINDTRACK server as client device. The client computer has a graphical user interface (GUI), which helps the operator who is the supervisor of the athletic field and the runners. The GUI is also responsible for the administrative issues and the statistical data display. All these tasks are not required real time conditions therefore they are detached from the BLINDTRACK server.

The communication protocol between the modules is based on novel wireless technologies where the high speed and reliability are crucial parameters. The communication with the belt unit will be implemented by Wi-Fi access points that provide easy and fast information transmission, and prevents the interference with the BlackFIR locating system. The belt consists of a driver module and an actuator part. The driver module is responsible for the communication towards the CCU and for the control of the belt actuators. This module also contains a power supply unit, which drives the complete belt and a compass module which determinates the relative orientation of each actuator to the north. The firmware of the belt has the responsibility for the translation of the relative to north commands to the actuator. This can minimize the intensity of wireless communication in the BLINDTRACK system.

BlackFIR is an innovative radio frequency (RF) based locating system, which is able to operate in real time and detects the exact position of each runner on the track. The BlackFIR system consists of several antenna units, mobile transponders carried by athletes and a central unit. The communication between the antenna units and the central unit occurs via Ethernet. The mobile transponder comprises a special transceiver chip to locate and identify the athletes.

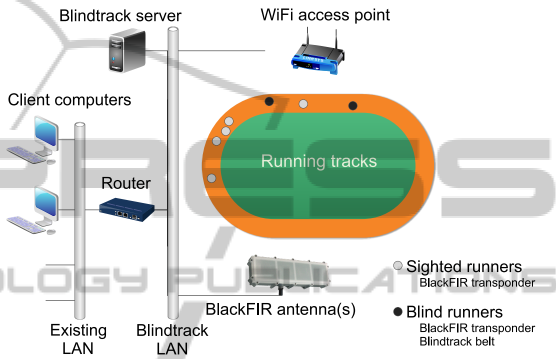

Figure 1: General system architecture of the BLINDTRACK.

2.2 Project Organization

BLINDTRACK project management structure was designed and agreed by the consortium members to ensure an effective and straightforward project management mechanism. The main principles were to set up and maintain an organisational structure that ensures the highest level technical and financial implementation of the project and the efficient exploitation of the project results and effective decision making structure. The partners represent several European countries such as Germany (PPS and Fraunhofer IIS), Hungary (Ateknea Solutions, BSK, INFOALAP), the Netherlands (Elitac), Norway (Adaptor), Spain (Eneso, IBV) and their professional experiences cover all the neccessary fields that are needed to conclude in a successful project result by the end of 2015. A more detailed partner description is found in the Appendix.

3 ADAPTED LOCATING SYSTEM

The BlackFIR system developed at Fraunhofer IIS consists of four mounted receiver units, upto 30 mobile units (transponders) and a central computing unit.

The communication between the receiver units and the central unit occurs via Ethernet. For identification and locating the nanoLOC transceiver chip (Nanotron Technologies GmbH, 2007) is used. The infrastructure measures the angle of arrival (AoA) and the round-trip time (RTT) using RF signals generated by the mobile units in the 2.4 GHz ISM frequency band. Using these two locating techniques every receiver unit estimates the direction and distance of active transponders and sends the results to a central unit, where the position is determined by combining all available locating information.

3.1 Basics of AoA

Adaptive antenna arrays allow estimating the angle of arrival of a received signal (Tuncer et al., 2009). The received signal source has to be in a far field condition. Far field condition results in signal propagation, which is nearly flat. Figure 2 shows the phase alteration on different channels of an antenna array.

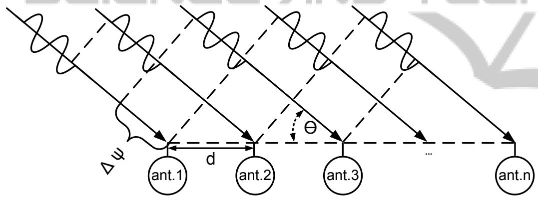

Figure 2: Received far field signal at the antenna array.

To estimate the angle of arrival, different high resolution algorithms like Multiple Signal Classification (MUSIC), estimation of signal parameters via rotational invariance techniques (ESPRIT) or the Minimum Variance Cappon-Beamformer (Tuncer et al., 2009) can be applied. These algorithms use the covariance of the different received signals to estimate the angle of arrival. BlackFIR uses a MUSIC algorithm with an additional forward backward spatial smoothing (FBSS) which improves robustness against multipath non-line-of-sight (NLOS) signals. The result of the MUSIC algorithm is an angle spectra like shown in Figure 3; the maxima of the spectra show the estimated angle of arrival. The resulting peaks of the MUSIC spectra get narrower with an additional preprocessed FBSS. Inherent with this, an improvement of multipath-robustness against NLOS-signals is also realized.

3.2 Basics of RTT

The measurement of distances between a tag (”X”) and given receiver positions (”1”, ”2” and ”3”) allows

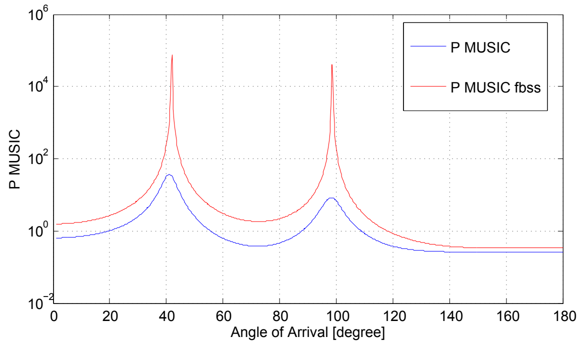

Figure 3: MUSIC (power) with and without forward backward spatial smoothing.

the calculation of the tag position, as shown in Figure 4. BlackFIR uses the nanoLOC transceiver chip to implement round-trip time (RTT) (Std 802.15.4a, 2007) based distances. The distance is measured by a so called two way ranging procedure. In this procedure time of flight (TOF) is measured by anchor to tag response time and vice versa. This gives the opportunity to compensate differences in the frequency reference of the tag and the anchor.

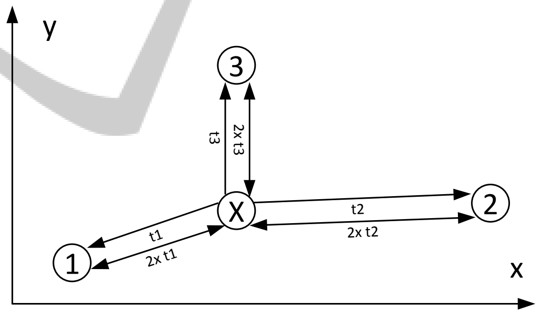

Figure 4: RTT-based calculation of position.

Another well-known method to measure distances is to calculate time of arrival (TOA) or time difference of arrival (TDOA). For TOA it is necessary to have synchronisation between receiver and transmitter which is often not possible in an adequate way. Due to that TDOA is a possibility, where only the infrastructure is synchronized such as in satellite based global positioning systems (GPS). Using TDOA does not require an extra reply signal which lowers the channel usage and minimizes the measurement time. However RTT requires no synchronisation techniques between the receiver units, what influences the system infrastructures as well as increasing the cost.

3.3 Infrastructure Setup

The BlackFIR locating system consists of a receiver unit estimating the AoA and the RTT. In order to calculate a two-dimensional position, it is necessary to use at least one of these receiver units. In practice the data is affected by multipath effects, fading and noise based error. To improve the estimates, more units are used at one scenario in a time duplex sequential measurement procedure as shown in Figure 5. All available sensor data are collected and combined by a central server were the position is then calculated by either a Kalman filter (Kalman, 1960) or particle filter (Sanjeev et al., 2002) based algorithms.

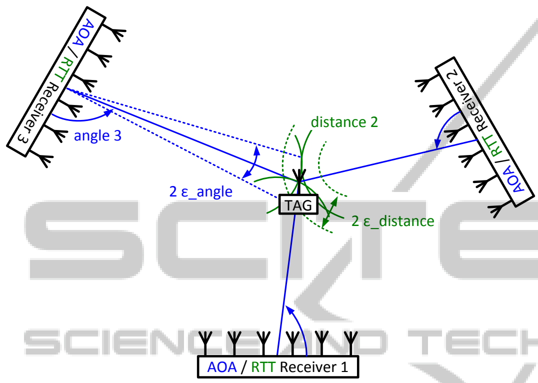

Figure 5: Principal abstract of BlackFIR RF locating.

4 EVALUATION

4.1 Measurement Campaign

In order to validate the performance values, a measurement campaign was executed in the Nürnberg stadium. The used test field is a standardised (DIN 18035-1, 2003) type ”A” all-weather running track with eight lanes and a length of 400 m as shown in Figure 6.

Figure 6: All-weather running track used for testing.

Aim of the measurement campaign:

- Identify the performance of the system in the target environment.
- Evaluate the optimal infrastructure structure.
- Optimize the positioning algorithms.

To analyse the current system performance in different circumstances, the following scenarios were explored:

- **Walking Scenario.** A person was walking along the third running track. The sender was affixed at his inner shoulder. The scenario was repeated three times.
- **Running Scenario.** A person was running along the third running track. Likewise the walking scenario, the sender was fixed at his inner shoulder.
- **Scenario with a Bicycle Rider.** A person was riding a bicycle along the third running track. The sender was carried in the outer hand.

To get reference information for the positions an optical highly accurate system called iGPS (Nikon Metrology, 2010) was used. The optical component was mounted on a helmet worn by the athlete as shown in Figure 7. IGPS ensures point locating accuracy down to 200 µm.

Figure 7: iGPS probe mounting at the top of a helmet.

During the different scenarios various datasets of sensor information were recorded to analyse and improve the locating system.

The types of raw information are:

- In-phase and quadrature components of the RF signal received by the antenna unit
- Measured distances between mobile tag and receiver
- Estimated angle of arrival at the receiver units
- Battery life-time information

Four receiver units were placed arround the running track (one unit for every 45-degree bend) in order to ensure line-of-sight to the transponders and for coveraging the whole test field.

4.2 Analysis

In Figure 8 and Figure 9 the measured raw angle of arrival and raw distance data over the time are shown. Each signal of the different receivers is plotted in another colour.

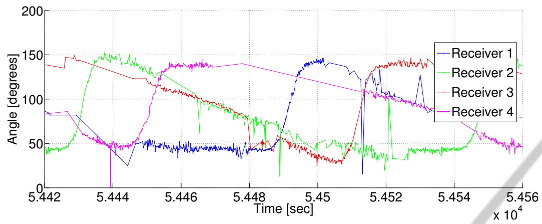

Figure 8: Angle results based on Angle of Arrival estimation.

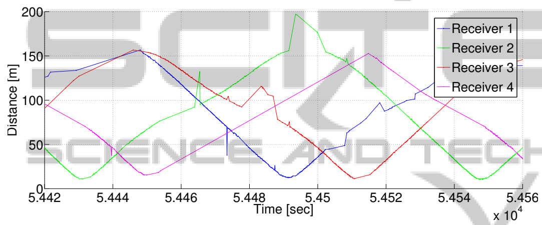

Figure 9: Distance results based on round-trip time.

Every single curve shows spikes depending on channel propagation, fading and multipath effects (e.g. Receiver 1 in Figure 8 at $5.451 \cdot 10^4$ sec). Because of the dynamic scenario caused by the runner's movement, these effects can be detected and compensated later.

Straight lines are representing gabs in the information caused by a poor wireless connection or interferers (e.g. Receiver 4 in Figure 8 in the time interval between 5.448 and $5.451 \cdot 10^4$ sec). Due to the system's high update rate and redundancy, it is not necessary to get information from every receiver unit at all times.

An exemplary view of the actual measured distances and estimated angles is presented in Figure 10: Each of the four receiver units is showing the estimated angle as a straight line towards the sensors' position. The circles around them are representing the measured distances. In best cases, all lines and circles are crossing in one single point: the athlete's position.

The iGPS reference system was installed in the right part of the stadium due to the need of reference values. The estimated system latency as well as the accuracy of the position is determined by the data observed in that part of the stadium. In contrast to that, the data rate was determined over all data stored in the corresponding scenario.

Figure 11 shows the position trajectory of the measured position values (green line) in the scenario with a running person for two laps. The red line represents the position given by the iGPS reference system which could only cover the right part of the running track. The position estimates have a small variance from the reference position. In addition, the estimates at the right part of the stadium have better performance compared with position estimates from the left part. Reason: The calibration process was performed in the right part, where the iGPS system was installed, so the left antennas were not calibrated as fine as the right antennas. The measurement results of the two laps are both similiar to each other and comparable to the described effects.

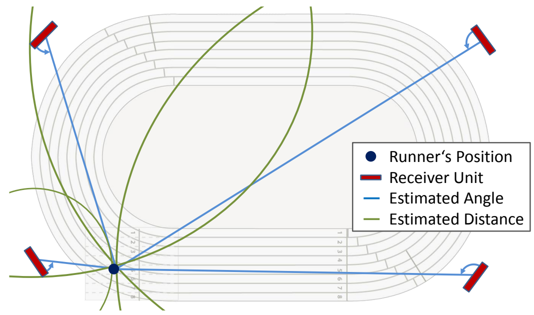

Figure 10: Position measurement with angle and distance estimation.

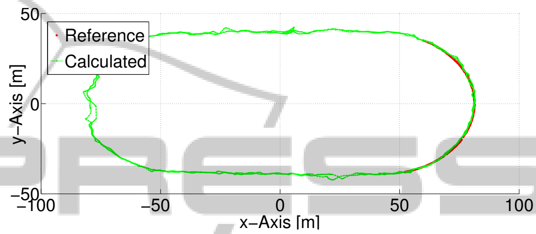

Figure 11: Measured position in the scenario with a running person.

The estimated accuracy of the position is determined by the data that where observed in that part of the stadium, where the iGPS reference system was installed due to the need of reference values. In contrast to that, the data rate was determined over all data stored in the scenario. Table 1 summarizes the measured system performance:

Table 1: Summary of measurement results.

Estimated latency	440 msec
Data rate	6.6 Hz
Mean deviation (MAE)	0.689 m
Maximum deviation	2.60 m

"Estimated latency" describes the delay between the athlete's actual and calculated position caused by wireless transmission, network traffic and proccessing time for the algorithms. "Data rate" describes the update rate of the estimated positions; the update rate for the beld commands sent to the athlete will be less.

The distribution of the measured position errors is shown in Figure 12.

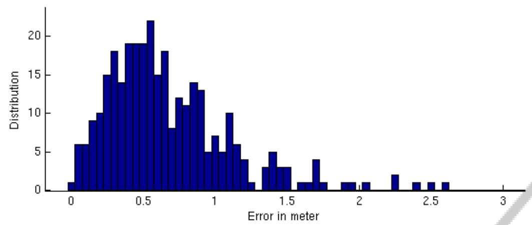

Figure 12: Distribution of the position error in meters.

5 SUMMARY & ROADMAP

In the scope of this paper, we presented an adaptation for the BlackFIR locating system to the project needs of BLINDTRACK. For a system using RTT and AoA technology, we showed detailed results on a measurement campaign and the accuracy of the calculated positions. Our system gives visually impaired people the opportunity to enjoy several social activities with simple installation complexity. Compared to visual tracking system, we are able to identify and track every runner, even in extreme situations, where the runner is surrounded by many others. In next steps, adjustments will be applied resulting in increasing the accuracy of the current system and further cost reduction. At the end of this project, the complete system will be tested and evaluated with blind and non-blind runners.

ACKNOWLEDGEMENTS

The project has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under the grant agreement No. 605821. It is a 24 months research project that was launched on 1st of January 2014 with the cooperation of nine partners.

We thank Mohammad Alawieh, Fraunhofer IIS, for supporting and revising the paper.

REFERENCES

American Foundation for the Blind (2014). Tips for runners with visual impairments. http://www.afb.org/info/living-with-vision-loss/recreation/running-2805/235.

Competitor.com (2014). Visually impaired runners ready to tackle boston. http://running.competitor.com/2014/04/news/visually-impaired-runners-ready-tackle-boston_98512.

DIN 18035-1 (2003). Sports grounds - part 1: Outdoor play and athletics areas, planning and dimensions.

England Athletics Limited (2012). Running & sprinting with guides. http://metroblindsport.org/downloadlibrary/guide-running-v2.pdf.

European Commission (2010). European disability strategy 2010-2020: A renewed commitment to a barrier-free europe. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0636:FIN:EN:PDF.

Fraunhofer IIS (2012). *BLACKFIR 2.4 brochure*.

Kalman, R. (1960). *A New Approach to Linear Filtering and Prediction Problems*. Journal of Basic Engineering, 82 (series d) edition.

Nanotron Technologies GmbH (2007). *nanoNET Chirp Based Wireless Networks White Paper.*

Nikon Metrology (2010). *iGPS datasheet: Priciples of operation / Scalebar / i5 Probe kit / Dynamic tracking kit.*

Sanjeev, Arulampalam, M., Maskell, S., Neil, G., and Clapp, T. (2002). *A Tutorial on Particle Filters for Online Nonlinear/Non-Gaussian Bayesian Tracking.* IEEE Transactions on Signal Processing, vol.50 edition.

Std 802.15.4a (2007). *IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - LANs and MANs - Specific Requirements - Part 15.4: Wireless MAC and PHY Specifications for LR-WPANs - Amendment 1: Add Alternate PHYs*. IEEE Std 802.15.4aTM-2007 edition.

Tuncer, T., Friedlander, B., and Yasar, T. (2009). *Classical and Modern Direction-of-Arrival Estimation*. Academic Press.

United Nations (2007). Convention on the rights of persons with disabilities. http://www.un.org/disabilities/default.asp?navid=13&pid=150.

United States Association of Blind Athletes (2014). Sports adaptations. http://usaba.org/index.php/sports/sports-adaptations/.

APPENDIX

SME Participants

INFOALAP-Informatics for the Visually Impaired Foundation - Hungary

INFOALAP is actively involved in system specifications, based on its experience with IT for visually impaired, and supports the technology optimization by providing direct evaluation feedback for. They also support hardware and software development by the evaluation of ergonomic aspects by its low vision IT engineers, as well as being active in system tests.

PPS GmbH - Germany

PPS is the supplier of the technology that is capable of real-time detection of the running people in the running track. It closely cooperates with Fraunhofer Institute IIS during the research period and supplies the prototype of the project. PPS defines the prototype in regard of later products and assists the development partners in defining the real use cases as well as the general evaluation of the developments.

ELITAC - Netherlands

Besides supervising, ELITAC's role comes at the phase of tactile belt research and manufacturing. They strongly cooperate with IBV while they are working on the development of the tactile belt. ELITAC has already developed tactile devices but none of them was for the blind.

Eneso Tecnología de Adaptación S.L. - Spain

ENESO is a distributor of BLINDTRACK system. They have a deep knowledge of the accessibility market in Spain, so they will be very active in promoting and placing the system. They will also contribute their experience by testing and validating the product.

ADAPTOR HJELPEMIDLER AS - Norway

ADAPTOR plays a significant role in the consortium as the employer of visually impaired and distributor of assistive products and provides the research partners with tangible information on the needs of the market and assist field testing.

RTD Participants

ATEKNEA Solutions Hungary Kft. - Hungary

Ateknea Solutions brings together four research and innovation companies operating at a European level for over 15 years. The group pools the expertise and know-how of more than 130 professionals working in five different locations: Barcelona, Brussels, Budapest, Krakow and Valetta. The innovative companies have successfully participated in more than 150 different projects financed by the European Commission. ATEKNEA is the coordinator of the project and responsible to ensure fluent project flow.

Fraunhofer Institute for Integrated Circuits IIS - Germany

The Institute has a first prototype research result, called RedFIR® know-how and experience that is a state-of-the-art wireless tracking technology that locates people and objects in real time and with high precision. Its main role is to select the best fitting localization technology for a successful project. Compared to current video-based approaches, this radio-based technology offers a major advantage: its tracking capability is not diminished by obstacles obscuring the line of sight. The RedFIR® real-time tracking system is more responsive, accurate and flexible than any comparable technology. Position data is made available in fractions of a second and automatically analysed using pattern recognition and event detection methods. User-specific data preparation and visualization modes are provided in real time. It has an accuracy of a few centimetres, making event detection results and automatically generated statistics highly reliable. In the consortium Fraunhofer will develop a system based on RedFIR® but fulfilling the special needs of visually impaired people and find out a solution that is still affordable and marketable with not forgetting the basic need: maximum accuracy with minimum price.

IBV - Biomechanics Institute of Valencia - Spain

IBV do research to understand the tactile sensing and the perception mechanism in different conditions. Measurements are taken to define the sensitivity of the skin from the density and the intensity point of view as well. They aim to find the optimal sensing positions on the perimeter of the trunk to feel directions with confidence and define the number of the vibrating elements on the belt, and their control to guide a person to the direction we intend to. They have to cooperate closely with Elitac in order to manufacture a defined number of prototypes for testing. A continuous cooperation with the control and communication circuit designer RTD during the control circuit development is also essential.

Other

Budapesti Sportszolgáltató Központ - Hungary

During the project preparation and implementation Budapesti Sportszolgáltató Központ help with practical advices of blind running behaviour and critical points of their secure training. In the testing phase it will make the field available and will actively take part in the validation and dissemination.