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# Real-Time Wireless Location and Tracking System with Motion Pattern Detection

Pedro Abreu<sup>a</sup>, Vasco Vinhas<sup>a</sup>, Pedro Mendes<sup>a</sup>,  
Luís Paulo Reis<sup>a</sup> and Júlio Garganta<sup>b</sup>

<sup>a</sup> *Department of Informatics Engineering,  
Faculty of Engineering of Porto University*

<sup>b</sup> *Department of Soccer,  
Faculty of Sport of Porto University  
Portugal*

## 1. Introduction

The Location and motion pattern detection concerning people or assets is an issue currently present in many business areas. Over the years, this task has been addressed under many different perspectives; however, due to their active consciousness, human beings are extremely unpredictable and so, the majority of these methods failed to provide accurate data that could be used for industrial purposes.

In the past years, tracking systems constituted an important research challenge for scientists and engineers in different areas of knowledge (e.g. computer science, sports, medicine, simulation, robotics), as well as industrial tracks. The ability of locating an object in a specific scenario in real-time and the capability to estimate its trajectory in a defined time frame constitute the two main goals and interests in this domain. Work in this field has gained a significant leverage in the recent past, mainly due to the emergence of consumer high performance computers, the development of low-budget high-quality tracking technologies, and the growing need for automated object location analysis. Over the past years, researchers in the robotic area still face two main tasks in this context: locating objects in the real world and relating that information with the corresponding item in a simulated environment, according to information retrieved through robotic sensors; and using this data to apply navigation algorithms and methodologies that allow a robot to navigate on an unknown world. On the other hand, these tracking systems also find interesting applications on scenarios where the context environment is already known. In this situation, data mining techniques to detect motion patterns or behaviors assume a crucial role.

Nowadays, there are many types of tracking systems. All of them have their strengths and flaws regarding factors such as coverable area, occlusion problems, equipment costs, and so on. The most classical approach is camera-based (video surveillance systems). These solutions are usually cost-effective, with the advantage of providing complete digital

storage and processing. Even though the video feed does not directly provide data on the positioning of entities, the use of image processing techniques will allow the extraction of entity positioning and additional information. Other tracking systems based on wireless emitter and receiver equipments emerged in the market with the advantage of providing clean data at a semantic level, displayable and storable in a straightforward manner, like GPS, Wi-Fi, RFID or Bluetooth, among others. The coverable area and the error involved are also important factors to be considered as well as the required resources, such as power and equipment density.

This research work proposes a system that takes advantage of typical redundant Wi-Fi networks and is based on a positioning engine built on top of these. This solution assumes that the client somehow carries an emitter device within the covered area. This system was tested using two distinct scenarios: a traditional retail indoor environment tracing clients through a commercial area; and in the sports area, more specifically in a soccer outdoor field, where this solution could constitute an important measurement tool for a professional soccer coach in the training sessions. The system presents a visualization platform of such data on real-time. The information can be displayed through several perspectives, including fully scalable concentration grids, clean positioning of the elements at hand or even a vision inference assuming that the items to be tracked are associated with people or robots. This application also works as a data collector, by storing appropriate information on a database. Using this datasets as a base, it is possible to reconstruct the paths taken by the elements and, therefore, predict and categorize typical routes and/or behaviors.

The remainder of this chapter is organized as follows: Section 2 describes the related work in the tracking system area. Section 3 presents all concepts involved in the system architecture that was proposed and their main functionalities. Section 4 exposes the results achieved and finally in the last section the conclusion are presented and future work trends are discussed.

## 2. Related Work

In the past years, tracking problems have constituted an important research challenge for scientists and engineers in different areas (e.g. computer science, sports, simulation or robotics, as well as industrial tracks). In the robotic area, for better modeling the world, it is extremely relevant to accurately process the signals received by the multiple sensors involved. Mapping real world objects to modeled ones is a critical task for the use of navigation algorithms and methodologies. Following these advances, the work published by Hyunwoong Park (Park et al.2006) presents a new kind of sensor system with multiple rotating range sensors. Such system allows a robot to guide itself on an unknown world. However, the ability of locating an object in a specific scene (where the context environment is already known) in real-time and the opportunity to estimate its trajectory in a defined time frame constitute the two main goals and interests in this domain. The emergence of consumer high-performance computers, together with the development of low-budget high-quality tracking technologies, and alongside with the growing need for automated object location analysis, provided the affirmative leveraged context for work in this field.

Nowadays, location and tracking systems represent a powerful tool in different scenarios such as:

- Consumer Pattern Recognition - detecting and representing a complete path of an object in a scene;

- Surveillance and Security – detecting suspicious behaviors or activities in a specific place;
- Autonomous Vehicle Navigation – helping in the prediction and avoidance of obstacles in a real world scenario.
- Sports Area – helping the club coaches optimize the performance of their athletes in a training session or during a match.

Despite the advances in this field, leading to noteworthy breakthroughs, some issues still remain to be addressed. From these, one ought to point out, in the first place, those concerning occlusion, which are classifiable in three distinct categories: self-occlusion, where part of the object to trace, typically articulated ones, occludes another part; inter-object occlusion where two traceable objects occlude each other; and occlusion by the background scene where the physical space's properties propitiate a camouflage of the object to track. For the inter-object occlusion research works like (MacCormick & Blake, 2000), (Elgammal et al., 2000) exploit the a priori knowledge of the object's position and attempt to predict possible occlusions and solve them smoothly.

Considering other domain issues, the hurdles that arise when tracking entities with non-linear movements must be addressed as this point constitutes one of the major problems in tracking persons in non controllable environments. A pragmatic approach to this situation could point out to time resolution diminishment in which tracking is achieved or the loosening of the real time requirements. Dealing with flexible layouts can also be problematic, as this situation may require constant system recalibration. This last step, in some cases, does not involve any level of reuse of the previously gathered data, making the whole process more time consuming than what it should be.

When the solution is based on video feed processing, there are some additional problems directly related to the inherent technology. The scene's illumination should be adequate so to facilitate the image binarization processes and the network, to transfer data from cameras to processors, should be enhanced and optimized in order not to become a system's bottleneck.

Summarizing in the next subsections a group of generic of-the-shelf and academic tracking systems shall be presented.

## **2.1 Generic Tracking Systems**

In the literature there are many generic tracking systems that emerged over the past few years. These solutions are divided in two distinct groups: image based and non-image based

### **2.1.1 Non-Image Based Systems**

Created by the US Government, the Global Positioning System (GPS) is a satellite-based solution, constituted in terms of hardware, by a twenty four satellite constellation with the ability to transmit all over the world. In the beginning, it was used solely by U.S military forces to aid in the planning of military operations. After the 80s this technology became available for the general public and so, many were the organizations that based their solutions on it.

Nowadays GPS is commonly used to perform real time detection of different types of vehicles and as a base tool to analyze their motion (Yu, 2005),(Nejikovsky et al., 2005). Yet in

this scenario, the technology is applicable in three distinct ways: Cellular Based Tracking is a solution based in a conventional mobile phone with a GPS receiver that emits the vehicles position every five minutes. Wireless Passive Tracking has core advantage in using GPS, because once it is set up, there is no monthly fee associated, and with it is possible to collect information like for instance, how many pit stops are made by a vehicle in a given route and how fast is it moving. Although, Satellite Based Real Time Tracking is the most costly one, it enables different types of information collection such as long travel logs including details on duration, routes taken, pit stops, etc. Its worldwide coverable area constitutes an ideal solution for transporting companies.

The radio frequency identification (RFID) is a non-standardized wireless tag location method. This technology requires a RFID receiver and a set of tags which can be divided in two different groups: Passive - only detectable on a 13-meter radius from the receiver (e.g. new U.S.A. passports); Active Group - have their own internal power source, offer both reliable detection on a larger scale, and more resilience to occlusion problems caused for possible obstacles in the environment. The two major issues about this technology are the receiver's cost and the active tag's average unit price, mainly due to the need of an independent power supply (Chao et al., 2007).

Wi-Fi IEEE 802.11 technology allows establishing connectivity between a set of devices allowing an easy setup of wireless data networks in academic campus, industrial facilities, public buildings, etc. The technology behind these networks can also be used for designing a tracking system. By reusing commonly existing data networks and a low level protocol it is possible to create a tracking system on top of this infrastructure. Another advantage of this technology is the possibility of tracking an object by using a single access point, though the precision will weaken due to the lack of signal triangulation. Because of its technical details, the impact of issues such as occlusion and signals loss is reduced to a residual level especially in environments, which do not have high concentration of metallic materials (Mingkhwan, 2006).

Bluetooth is a wireless protocol available on any modern mobile equipment, allowing data exchange between multiple devices. It is exclusively used for short-range communications, which is the cause for its poor applicability on tracking systems. The battery consumption is also remarkably high (Jappinen & Porras, 2007). Despite the undeniable receivers' availability, the previously mentioned issues together with the non-transparent and possibly intrusive connection establishment process make this protocol inadequate for a efficient and reliable tracking system.

Some applications have infrared technology as a base for their location systems. The price attractiveness is one of the biggest advantages of it when compared with others, although there are no objective means to overcome occlusion issues especially in presence of opaque objects between the receiver and the target (Krotosky & Trivedi, 2007).

### **2.1.2 Image Based Systems**

Thermal signature systems are one of the most expensive technologies for locating an object on a scene.

The main purpose of these solutions is the reconnaissance and processing of thermal images. These systems attempt to recognize specific thermal signatures of the entities being tracked although some items might not have them. Consequently the applicability of this approach is limited though the US Army made good use of it to train their night vision

dependent operatives (LaFollette & Horger, 1991) and biology researchers, to monitor fauna in the ocean (Raizer, 2003).

Multi-camera video surveillance is a technique that uses a set of cameras to track entities in a given environment. By accurately crossing the information coming from cameras which have intersecting frustums one can enhance the precision of the system, despite the possible processing overhead (Mittal & Davis, 2003). Camera calibration and its positioning on a tridimensional space may be performed/inputted manually (Collins et al., 2001), (Cai & Aggarwal, 1999) or even automatically despite the obvious errors that may occur if the last method is undertaken on an unsupervised way (Lee et al., 2000), (Khan & Shah, 2003). Although these systems are actually used in some scenarios, some issues still persist. The need to have a dedicated network for the system, the expenditure required for high-resolution equipment and the computational demands, are still major concerns.

In the literature, some research work tries to optimize the performance of these systems by minimizing the need of brute force computation (Mittal & Davis, 2003) and by using overlapping camera views (Huang & Russel, 1997), (Javed et al., 2003), (Kettner & Zabish, 1999).

## 2.2 Sports Video Analysis

One of the major research areas in the Colective Sport Games (CSG) is the sports video analysis. In football/soccer domain researchers had focus their work in problems like shot classification (Gong et al., 1995), scene reconstruction (Yow et al., 1995), structure analysis (Xie et al., 2004), (Xu et al., 2001), event extraction (Baillie & Jose, 2003), (Naphade et al., 1998) and rule-based semantic classification (Tovinkere & Qian, 2001). These approaches used the image transmitted by the television and recorded them for posterior processing (after the match ended).

These kinds of systems are categorized by Ekin (Ekin et al., 2003) in two main groups: cinematic and object-based ones. The object based uses algorithms to detect objects in a video while the cinematic uses features from video composition and produce rules.

### 2.2.1 Cinematic Approaches

Xu et. al (Xu et al., 2001) present a cinematic approach using for it the feature dominant color ratio to segment video. They defend that video reports should focus on play yard to extract game situations.

Xie et. al (Xie et al., 2004) used a Hidden Markov Models approach to detect two restricts events: play and break, in a video game. The complexity of this process is higher than in other sports like tennis or volley because for instance in soccer it is hard to determine if the game is stopped by a decision of the referee or by other highlights of the game-goal, corner, kick, shot, etc.

Other works like (Ren & Jose 2005) tried to expand Xie's work and detect more game events like focus and replay in order to define new features/structures that they called Attack.

### 2.2.2 Object Base Approaches

The object base approach demands more computational resources but it allows more high-level domain analysis. In order to detect a large number of game events the work developed by Gong et. al (Gong et al., 1995) analyzes the ball's trajectory and the relationship between

the players' moves over the match. In the literature there are also many works that tried new approaches like merging audio and video information (Baillie & Jose, 2003). Although this kind of approach could constitute more high-level domain analysis one big issue is the asynchronies between audio and video queues.

### 2.2.3 Real Time Tracking Systems

Over the past few years new approaches appeared that use a multi camera tracking system to track players which promote new kinds of features like a near real time analysis. By comparing with classic approaches analyzed in the previous subsections, this system uses a fix number of stationary video cameras placed in a traceable environment. This type of approach increases the overall field of view reducing the dynamic occlusion problems and improves the accuracy and robustness of the information collected.

Cai and Aggarwal (Cai & Aggarwal, 1996) and Khan et. al (Khan et al., 2001) track the object using the best view camera and if the trackable object leads the field of view they change it to a neighbored camera. Other authors like Stein (Stein 1998) and Black (Black et al., 2002) assume that all trackable objects are in the same plane and compute the homography transformation between the coordinates of two overlapping images captured with uncalibrated cameras.

In the Xu et. al (Xu et al., 2004) work eight cameras were used and were calibrated in a ground plane coordinated system using Tsai's algorithm (Tsai 1986). Unfortunately this work presents some technical difficulties like problems with sparse landmarks in the coverable area that decrease the accurate calibration and data association and situations involving more than two players grouped in the same game region.

Summing, in CSG and more specifically in soccer the unique tracking systems that already exists in real environments are camera based. As demonstrated previously these systems still have to optimize some features like occlusion problems, computational demands, material cost and lack of portability.

## 2.3 Global Comparison

All the presented technologies have their optimal usage scenarios and with the purpose of choosing the best suited for this project a comparison using different parameters has been made. For this matter six different parameters have been defined: cost involved which comprises the unit price per tag and the receiver's cost; accuracy that concerns the location error involved and the coverage area defined as the maximum area that an approach is capable of covering within acceptable values of the previous parameters. Energy consumption is also an evaluation parameter and it is especially relevant in technologies, where an external power source is required. Finally the response time is the time interval that goes from the acknowledgement of the last known good location of a tag and current one. Legal issues concern to the existence of legal aspects on system's implementation.

Also in this evaluation a scale with four distinct values (low, medium, high and very high) and two initials NA (not applicable) and A (applicable) are used.

By analyzing Table 1 one can conclude that Wi-Fi technology is the better option: it presents high levels of accuracy, in average less than 2 meters, it does not have any legal issues involved with its use and presents a very competitive hardware price. The possible reuse of an existing network infrastructure is another advantage to be taken into account since it has

direct impact on the involved cost, despite the eventual need for a network strengthening to enhance triangulation possibilities. In addition to what was stated one could also mention that Wi-Fi is relatively immune to most of the occlusion that arise with other approaches.

	Costs		Accuracy	Coverage Area	Energy Consumption	Response Time	Legal Issues
	Tag	Receptor					
GPS	Medium	NA	Medium	Vey High	Medium	Low	A
RFID Passive Tag	Low	High	Low	Low	NA	Low	A
RFID Active Tag	Medium	High	Medium	Medium	Low	Low	A
Wi-Fi	Low	Low	High	High	Low	Low	NA
Bluetooth	Low	Low	Medium	Low	High	Low	A
Thermal Signature	NA	NA	Medium	Medium	NA	Low	NA
Infrared Sensors	NA	Low	Medium	Low	Low	Low	NA
Multiple Cameras	NA	Medium	Medium	High	Low	Medium	A

Table 1. Technology Comparison Table

RFID is the second best tracking solution analyzed. The use of active tags increases the coverable area – forty square meters using a single receiver – and increases accuracy levels. In spite of this obvious advantage, RFID still lacks standardization which naturally emphasizes the necessary integration process and supplier evaluation. Occlusion problems are not transparently solved and so there is some notorious interference in spaces with liquids and metals structures.

GPS's overwhelming worldwide coverage area conjugated with high levels of accuracy seemed to make this technology the elected one. Despite its advantages, its main purpose is for outdoor domains, instead of confined spaces where its relative accuracy is considerable lower. This fact associated with its significant tag cost relegates this technology as a third choice for indoor real-time tracking systems.

Although Bluetooth and infrared sensors represent good overall solutions in terms of cost, the coverage area is somewhat confined and the medium levels of accuracy invalidate the application of any of these systems in this project.

### 3. PROJECT DESCRIPTION

In this section, the undertaken project is described in detail in what regards its several components and analysis perspectives.

Having this in mind, and in order to have electricity support in the outdoor traced environment (the soccer field) an electrical infrastructure is detailed and after that the system's global architecture is depicted, in order to have an overall glimpse. In the indoor environment there is no need for an additional electrical infrastructure. The database model is further explained and the final three subsections are dedicated to the tool's individual description.

#### 3.1 Electrical Infrastructure

Most of professional soccer coaches state that the training session should have the same length as a conventional soccer match-ninety minutes. Consequently any training support



system should stay active for all of this period. To fulfill this goal an electronic system was designed. In this approach a conventional 45A car battery is used directly connected to a 600w UPS. The UPS battery is also connected to the car battery in order to increase the autonomy of the system. This electrical infrastructure (Fig. 1) is capable to provide power for more than 120 minutes.

In order to increase the WI-FI network's density, a star topology approach is used. A router is connected directly to the battery's electrical extension and it is placed behind the goal. The access points (APs) were placed in specific points of the penalty box as shown in Fig. 1.

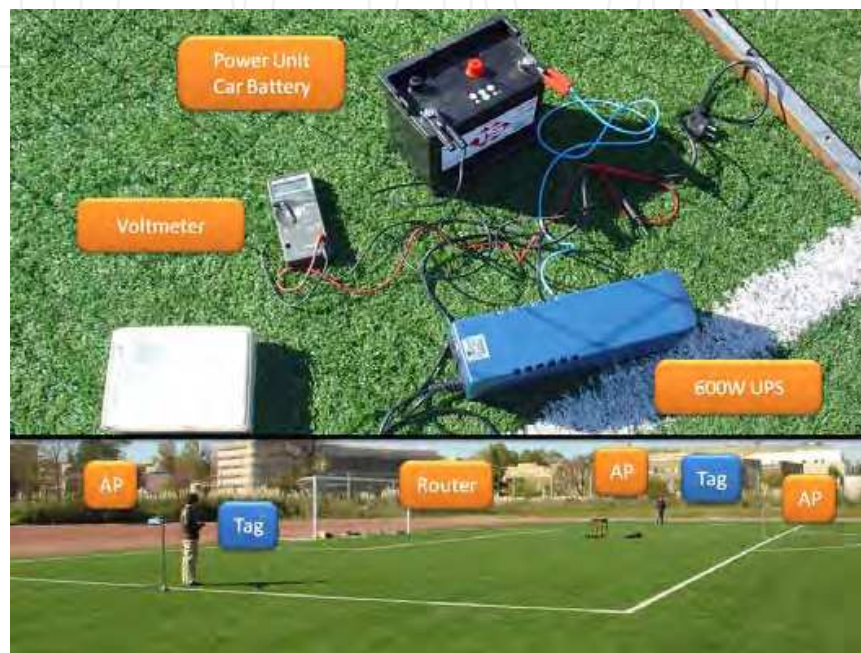


Fig.1. Electrical Infrastructure and WI-FI Network

### 3.1 Global Architecture

This subsection is dedicated to the illustration and depiction of the system's global architecture, concerning, not only its individual components, but, giving a particular emphasis on how they interact with each other and, therefore extract not only system module dependencies but also information flow analysis.

As revealed through Fig. 2, the elaborated technical design contemplates several independent modules that communicate in order to achieve a systematic unit.

Having the above mentioned in mind, and paying a closer attention to the numbers in figure, one is able to identify the system's modules as follows: Offline map editor; Wi-Fi enabled localization tag; Position Engine; Database for data integration and storage; Real-time monitoring application and Web enabled real-time and historical business intelligence.

Although most of these elements are object of further explanation in the next subsections, one ought to undertake a brief description of those whose nature is not obvious and, in order to, clarify their interaction.

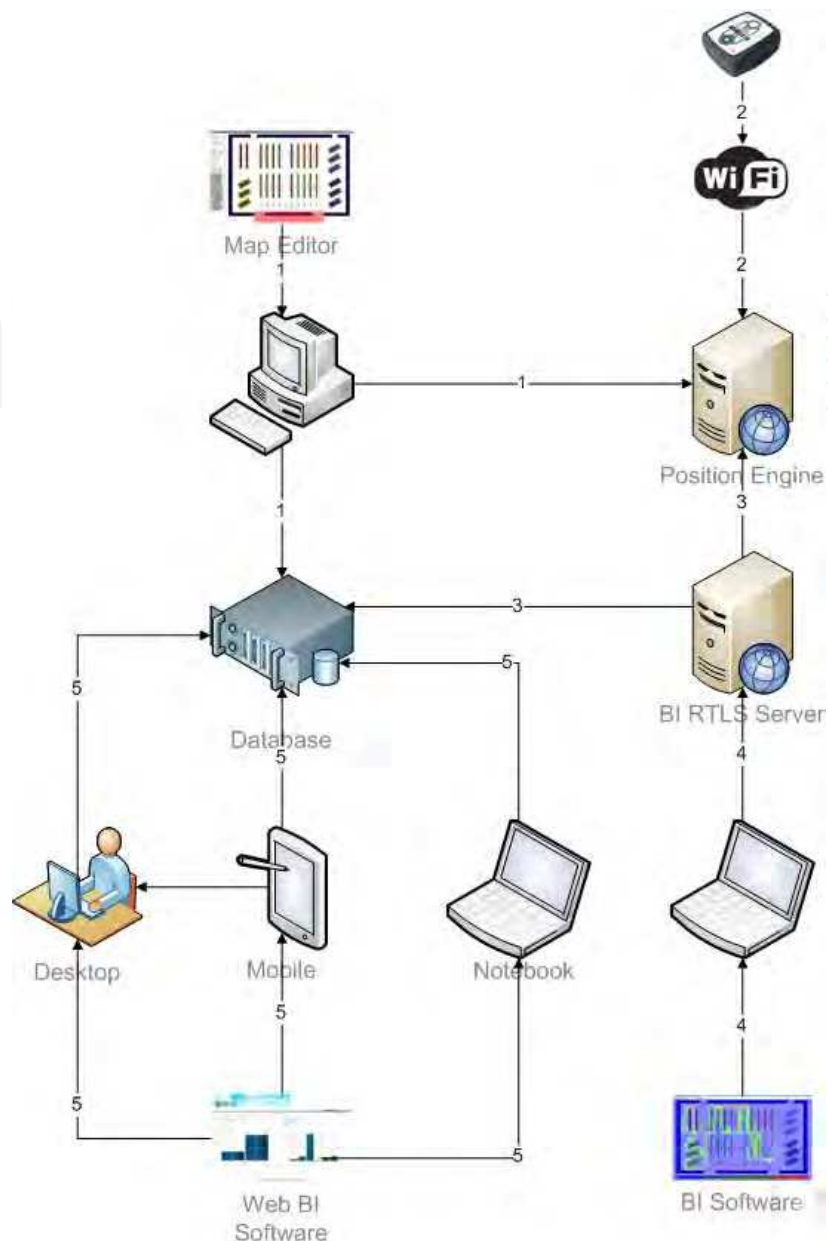


Fig. 2. System's Global Architecture

The first action, that ought to be conducted, in offline mode, consists in conducting a complete map creation\edition. The user shall specify, amongst other details, depicted in subsection Map Editor, the image file representing the shop floor or soccer field layout. For the first scenario, the user shall also specify the used scale and identify, by using a draw-like tool, what items are to be visible by visitors as well as spawn areas. This information is compiled in a XML file for both the position engine and real-time monitoring tool and submitted to the mentioned database for the historical BI application.

The Wi-Fi tag consists in a miniaturized active 802.11 a/b/g board with a couple of power batteries attached. These are configured to connect to a specific Wi-Fi network - security, DHCP but another network configurations are also possible - in order to directly communicate with the position engine. By using this kind of wireless technology, it is possible to reuse partially or totally the spot's arena network infrastructure, having only, for

special requirement, a high density of access points as the accuracy naturally increases with this factor.

The used position engine periodically collects data from the tags and updates their position against a pre-loaded localization model. This model is very similar to the produced from the map editor differing only in the available information regarding visible objects. This model also requires a previous offline site survey for measuring Wi-Fi signal strength and for network items – routers and access points – precise localization. The engine is also web-enabled and supports a HTTP/XML API so that third-party applications can interact with it, therefore accessing localization and status information regarding each individual registered tag.

Using this communication protocol, the developed real-time monitoring server is responsible for gathering, at a specific periodicity – typically equals to the position engine frequency – every tag's valid location data. With this information, this module is directly responsible for updating the database and caching the session's data for the real-time monitoring application.

Having the continuous up-to-date database as a solid information reference, it was possible to enable both real-time and historical business intelligence applications. For real-time knowledge extraction, it was only used data referring to active sessions, for historical analysis, and delegating all the process effort to the database engine, specific and dynamic time windows were used to filter data. Despite the additional explanations that are given in subsection Real-Time and Historical BI Application, the versatility of such application must be referred as it congregates both web-enabled features and zero data process – it is all delegated to the database engine and allocated in a dedicated server – enabling its usage in a wide range of devices, including PDAs and mobile phones, alongside with traditional notebooks and desktop computers.

As a synopsis, one might refer the system's architecture as fairly distributed, where offline information regarding shop floor layout or soccer field layout, and wireless network definitions team up with a real-time web-enabled position engine, which enables third-party applications to collect and store data, so that diverse specific end-users can access both real-time and historical knowledge in a wide range of equipments, therefore enhancing management and coaching efficiency levels.

### **3.2 Database Model**

In this subsection, the designed database model is revealed and justified.

Having into consideration the specific reported system's application in the retail and soccer domain – usually characterized with heavy data production and numerous simultaneous clients or for players movements all over the field respectively, combined with the project's idiosyncrasies – specifically in what concerns to localization tracking frequency – the database model paradigm followed consists in a hybrid form of a data warehouse star architecture with a slight normalization “flavor”, as illustrated in Fig. 3.

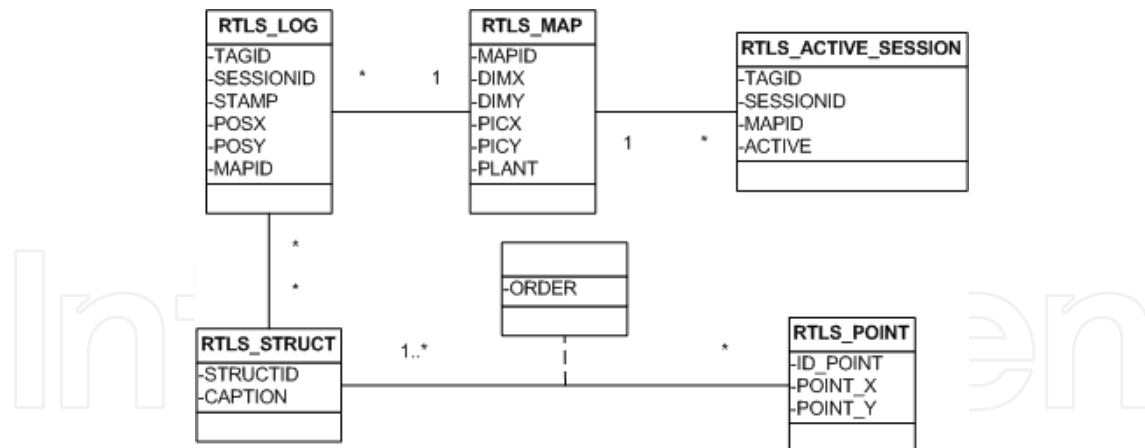


Fig. 3. Database Model

Regarding the strong star model, it is supported for the high data production levels, and perhaps most important, the fact that all data insertions are machine responsibility, as depicted in the above subsection, therefore preventing human error. It is also vindicated by historical analysis need that may cover hundreds of thousands and even millions of records. On the other hand, some database normalization was introduced in order to cope with real-time requirements that would not be compatible with computing hundreds of records out of a table with millions of records, in a continuously systematic way. Another argument in favor of database normalization resides in shop floor or soccer field layout and visible structures definition.

Referring to specific database model items, one shall point the central relevance of `rtls_log` as central table responsible for storing all localization data. For each pair of tag/session identification, it is recorded each particular position in a given layout with a specific timestamp. The concept of session for the retail world is very similar to the concept of a client visit to a retail environment and, in an analogous way, the tag identification correspond directly to the physical entity, so that one particular tag can be used by several shop clients in non-overlapping time frames. On the other hand for the soccer scenario this concept may be different in each training session according to coach's decision. A new session could be related to three distinct situations: a player substitution (when a player is substituted by a colleague), a player out of the field (for instance to receiving medical assistance) or other situation when the player is out of the limits of the region that was defined by the coach for a specific situation in training session. In order to achieve real-time requirements, some redundancy has been introduced in what concerns active session identification, so that active shop floor clients or soccer players identification could be easily, and most important, efficiently retrieved. The main normalization features for the retail scenario, reside in layout definition – as it is stored one time in one table – as well as visible structures definition. These items can assume the shape of any kind of convex polygons and at each particular timestamp, a pair of tag/session can consistently perceive several items following the vision algorithm described in subsection Vision Algorithm.

### 3.2 Map Editor

In spite of the map editor tool being often referenced along this document, it is considered useful, for the sake of method replication, that it is further detailed, in this subsection.

As illustrated in Fig. 4, Map Editor is a traditional, network enabled, desktop application responsible for complete layout definition. The end-user (a shop manager or a soccer coach) shall open an image file and provide the interface with the drawing scale – in order to convert pixels to meters and vice-versa. Afterwards, the tool offers the possibility to pinpoint and draw, over the original layout, both visible structures (only in the retail scenario) and spawn areas – concept of regions where tag is hold between clients, e.g. cash registers, parking lots or entry/exit portals or concept that will allow the detection of new sections.

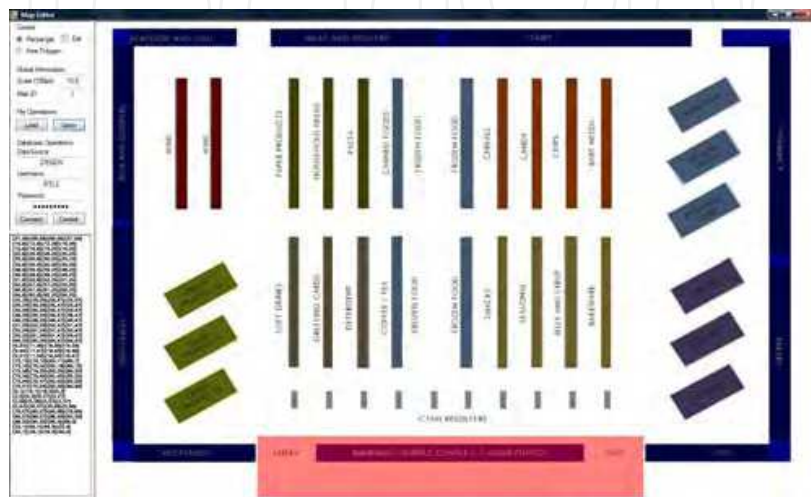


Fig. 4. Shop Floor Layout Complete Definition

Once the layout is completely defined, the user is able to save map characterization in a XML file in any available location and/or commit it to a specified database – with the previously described database model implemented.

The XML file will be an input for both the position engine and the real-time monitoring server, and, on the other hand, the committed database information is ground for historical computation and analysis.

Summarizing, the Map Editor constitutes itself as an auxiliary tool, vital for system's setup and dynamic enough to cover all the analyzed layouts. Its dual output enables a flexible usage for several system components and, simultaneously, due to XML openness, enables third-party development and integration.

### 3.4 Real-Time Monitoring Application

This system's module is, in conjunction with the web historical BI application, the project's core.

This unit is responsible for accessing location data from the online position engine and, simultaneously, using a multithread sliding-window approach, commit new data to the database and compute data into visual information following distinct approaches. Each of these tool's facets is mapped into a distinct GUI tab enabling independent analysis.

Before BI extraction, there are two mandatory configuration requirements that must be met: the first was already mentioned in previous subsections and consists in loading the layout; the second – except in debug mode – consists in establishing a HTTP connection with the position engine. The third, optional, requirement resides in opening a database connection

for online data insertion. If this is not met, there is a virtual infinite number of application's instances that can be run at the same time, enabling simultaneous BI extraction for numerous organization's members.

Taking into account, the enunciated tool's facets in what regards BI extraction, one shall pay closer attention to the aptitude of tracking, in real-time, all the clients present in the environment, alongside with their paths; demographic concentration with dynamic grid aperture; and visible structures concentration – these last two features have two modes of operation: strictly real-time and session history enabled.

Each of these tool's elements are subject of further description in the next subsections.

### 3.4.1 Real-time Tracking

This feature enables complete item tracking by overlapping current item's position directly over the loaded map information. This capability is independent of the GUI's windows size and/or shape as the coordinate systems are always synchronized.

As depicted in Fig. 5, it is also possible to enable session's path history directly over for instance a shop floor image, therefore enhancing visual perception of both current positions and session routes.



Fig. 5. Real-Time Tracking with Visible Path in a Shop Floor

In the presented screenshot, it is possible to see that at the time it was taken, there is only a single client/robot in the shop, whose location is near the layout center and that his visit concentrated mainly in direct routes in the north corridors.

If there would be more clients/robots present, it would be possible to perceive their current location by their blue dots representation as well as, optionally visualize their session routes. This feature tries to emulate a bird's eye view of the all shop floor, with the possibility of recalling all the client's routes as if they left a visible trail while they are touring the facility.

### 3.4.2 Demographic Concentration

The demographic concentration feature enables space division using a completely dynamic, in terms of cell size, matrix grid that is colored according to demographic concentration at

given time. Once again, this computation can be performed using only strictly real-time positions or by recalling all current session's route positions.

Each cell is then colored following a three-color gradient where blue stands for lower levels of concentration, green for intermediate levels and red for high levels. A special remark is due to the fact that the entire color spectrum is used for the mentioned purposes.

As illustrated in Fig. 6, the concentration matrix is drawn, with a partially transparency, over the shop floor plant. In this practical example, the illustration corresponds to a situation where there were two clients/robots present in the shop, and it was selected, for concentration calculus concerns, not only current position but all routes' positions.

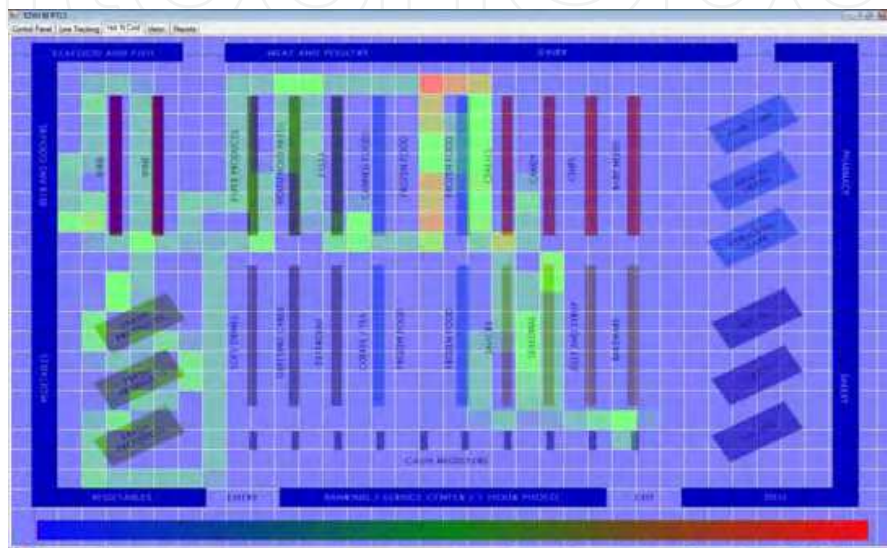


Fig. 6. Demographic Concentration with History in a Shop Floor

This tool's feature enables swift, yet effective, hot and cold zones analysis, current bottlenecks, unvisited versus most visited areas and online queue alerts and management. Also, in the soccer environment, this type of analysis specially the hot and cold zones ones, could represent good indicators for the principle coach measure their athletes performance in a specific training exercise. Also, as reported in the previous subsection, all the graphical information is independent of the GUI's window size or shape.

### 3.4.3 Vision Algorithm

In retail, in particular, and in many other domains, it is important, not only where the client is at a given moment, but also, and perhaps most significant, what is he seeing and/or paying special attention to (in the case of soccer, this analysis is focused on evaluating the decision-taking process by a player, which is related to his field vision in a specific time frame). Having this in mind, the authors decided to implement an efficient - due to real-time restrictions - yet effective vision algorithm, so that the defined visible structures would be able to contribute with a semantic business intelligence meaning.

Visible structures computation is based on client's orientation; conic field of view and occlusion calculus. Client's orientation is calculated having into consideration the last two valid locations. Using these two points, a simple vector is drawn from the previous valid position to the current point of observation. The conic field of view is projected in 2D, thus resulting in a parameterized triangle with flexible field of view and aperture angle. Once

shall also state that the world was slightly simplified and was considered to be a 2,5D reality, what in a retail practical example is admissible due to shelves' height being considerable greater than humans.

Having a valid point of observation and a triangular field of view defined, every potential visible structure identified in the given layout that intersects or is contained in the field of view is elected as a candidate for perception.

From this set of candidates, a proprietary occlusion detection algorithm based on trapezoid projections of the most apart vertices is run and those remaining candidates that are contained in this projected polygon are excluded from the set. After the algorithm conclusion, the remaining polygons are considered to be visible by the client.

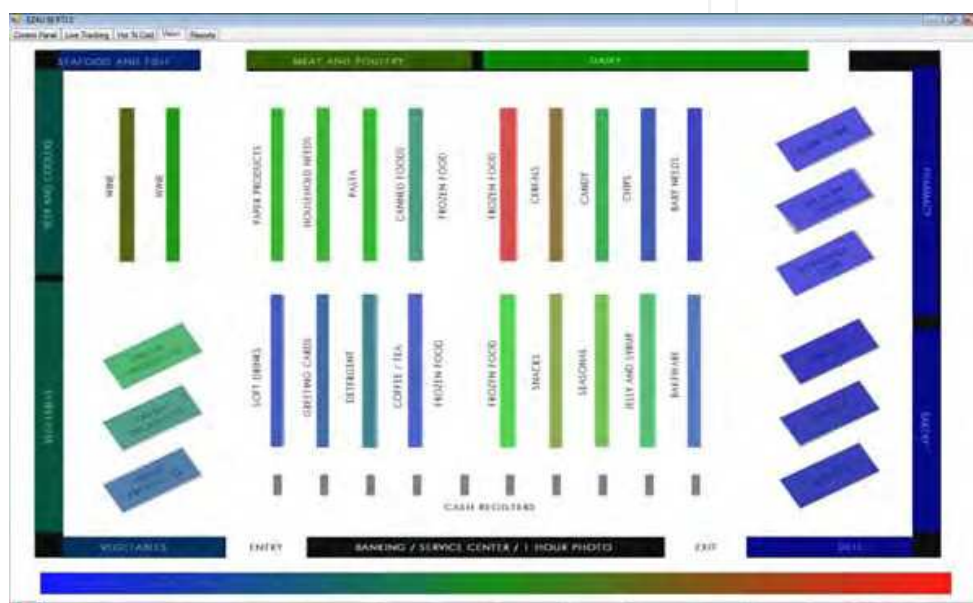


Fig. 7. Visible Structures Concentration with History in a Shop Floor

With this processing effectuated, a method similar to the one conducted in demographic concentration visualization, depicted in the last subsection, is performed. In other words, an absolute frequency auxiliary array is used to accumulate vision hits, each entry corresponding to a particular layout item. After the array update, to each item is assigned a color from the frequency spectrum - once again similar to subsection Demographic Concentration.

As Fig. 7 illustrates, the layout is now drawn in grayscale mode, and items are colored, in a semi-transparent way, representing the attention concentration. In the given example, it is clear that the top central shelves are the most viewed followed by the northwest corner while, on the other hand, the clients did not pay any attention to the selves on the right.

This vision concentration example is the outcome of the demographic concentration illustrated in Fig. 6.

### 3.5 Real-Time & Historical BI Application

In order to extract significant business intelligence knowledge based on historical data and not only real-time information, the authors decided to make an immediate use of the raw position data stored in the database.



Taking advantage of using Oracle as equally laboratory and production database, Oracle's Application Express was used to generate a web application responsible for processing data and, most important, aggregate information in an understandable way.

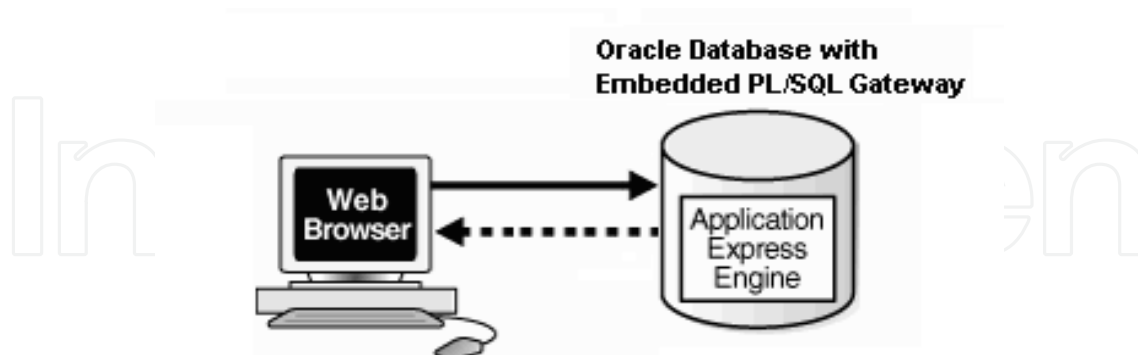


Fig. 8. Oracle Apex Embedded PL/SQL Gateway (Various Authors, 2008)

As depicted in Fig. 8, the Apex's engine is directly embedded to the database, thus directly dealing with client's web requests. With this architecture, several systems can easily access BI application as all heavy processing is database server's responsibility, leaving the client with only chart rendering computation.

Despite extensive tool's analysis being object of discussion in the next section, by using the described architecture and technology, several practical measures were considered for extraction, namely: hot and cold zones, average visit duration and distance and number of visits.

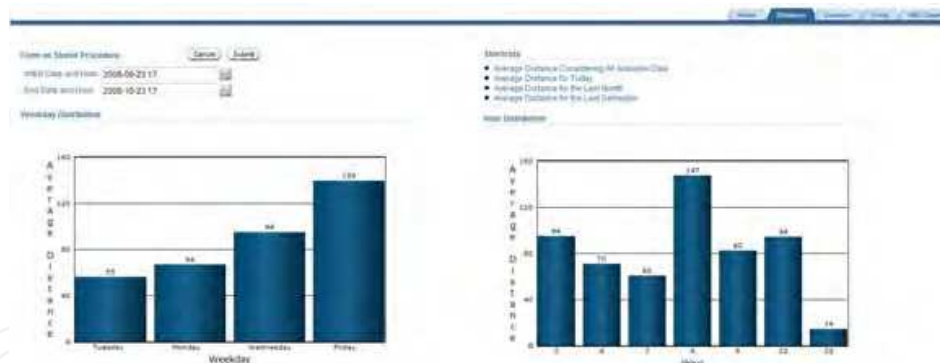


Fig. 9. Average Visit Duration Charts

All these benchmarks can be targeted to use only real-time data or recall specific historical time windows. A typical tool's screenshot is presented in Fig. 9, where a average visit duration charts are presented, considering data from the last month. On the left chart, data is aggregated by weekday and on the right by hour. Nevertheless, further details on this will be given in section 4.

## 4. Results

The obtained results are fairly positive both in terms of the developed infrastructure's operability and regarding the significance of the obtained data for analysts and managers.

On the first matter, one is able to state that the system performs swiftly as a whole as its constituting parts are able to exchange data harmoniously both in laboratory and production environments.

The first tool to be used in the entire process is the map editor. Its repeated use revealed that it is possible to fully sketch the plan of any layout with a coverable area that can go from just a few dozen square meters to hundreds of them, by the system being discussed in this document. The plan definition also includes allocating certain polygonal areas, as potentially visible structures, in the purpose of passing this information to the vision algorithm, mentioned in the previous sections. Doing so does not involve any remarkable additional complexity, in what concerns the tool's functionalities.

Surveying the space also proved to be an easy step to overcome, although more adequate equipment may be required for larger spaces, for instance when there is the need to use more than one calibration equipment simultaneously or when the space is large enough to justify the usage of an auxiliary trolley cart.

As for the core tool, the real-time monitoring application, it was observed that the displayed data is quickly interpretable, thus making its purpose: enabling real time business intelligence. In fact, just by looking, for instance, to the grid tab, managers are able to see what the current hot and cold zones are and make decisions based on such information. According to the retail store managers, whose identity was asked not to be revealed, by using the application one is able to, on a real time basis, assess the effectiveness of several decisions, namely: the store's layout, the number of open cash registers or even the work being carried out by employees in the zones where the customer service is made face-to-face.

The database model, used for the matter, proved to be adequate as the web application is able to present results within a maximum five seconds delay having the HTTP server and database service running on a machine with only two gigabytes of RAM. This can even be considered to be a poor server configuration for Oracle's 11g standards. The data in which these statements are based is an obfuscation of a real dataset and considers the central table of the star model to have about one million records.

Having already exposed the results obtained from the integration between the several parts of the system, in the remainder of this section some data collected from both scenarios will be presented and briefly discussed.

Fig. 10 represents the retail store grid concentration which has the layout as shown on Fig. 4. The data comprehends one week of activity where each chart entry corresponds to the number of accounted presences, on a specific zone, every two seconds. The zones are numbered from one to the number of rows times the number of columns. Zone 1 is located on the top left corner and the numbering grows a unit horizontally from left to right. All the cells are evenly distributed.

By analyzing the exposed charts, some interesting aspects on the customer's behavior when visiting the shop, can be assessed. For instance, although zones 13 and 14 correspond to the store's entry, it is observable that very little time is spent by the customers in those spaces. This aspect has economical relevance because all clients must pass through the entry zone at least once, and there seems to be no products at that point to capture their attention. Another interesting point resulting from this analysis concerns the zones where more presences were accounted. All of them - zones 2, 6 and 10 - include central corridors, which are naturally part of the paths that clients have to cross to reach the products they are searching for. Zone 6's high value can also be explained by a promotion conducted by the

shop on the products being sold there. On the opposite way, Zone 4 did not have a single client visiting it. This is probably explained by the poor attractiveness of the products present in that area as well as by the fact that its location is the farthest from the main entry point.



Fig. 10. Web Application - Zone Distribution



Fig. 11. Web Application - Zone Distribution

The next evaluated measure concerns the number of visits made to the shop in the same time frame considered before. This data is represented on Fig. 11. Relating to this chart, one shall conclude that most of the clients that participated on this survey visited the shop at 3p.m.. The choice of conducting the survey at this time was optimal since this period is

already post lunch time and still before the rush hour that occurs usually at 5p.m.. Counter measuring this, the shop manager also tried to conduct the study at lunch and dinner time but the clients were not so cooperative in those periods and the overall affluence is also not so intensive compared to the first referred period. On full scale usage, the used tags shall be placed directly on the shopping carts, being completely transparent to customers. Finally, the last type of information, discussed in the scope of this document, is the average distance walked by the clients, still considering the same time frame as before. By analyzing the chart in Fig. 12, it is evident that although there were few clients accepting to participate in the study at lunch time, those few walked about 400 meters within the store. Another interesting aspect is that the clients participating in study near the mentioned rush hour probably had very little time to shop since their walked distance is beneath 180 meters.



Fig. 12. Web Application – Number of Visits

Regarding the outdoor scenario tested in this project (the soccer field), a training exercise with four players involved was organized. The exercise's purpose was to train a player's shot accuracy after receiving a pass from a winger. In order to accomplish that, a goalkeeper, two wingers and a striker participated in this experience, having each of them a Wi-Fi tag attached to their shirts.

The penalty box was also divided in a 10\*4 grid for calibration purposes and also to guide the site surveying process. The following picture (Fig. 13) exposes how the exercise was conducted.

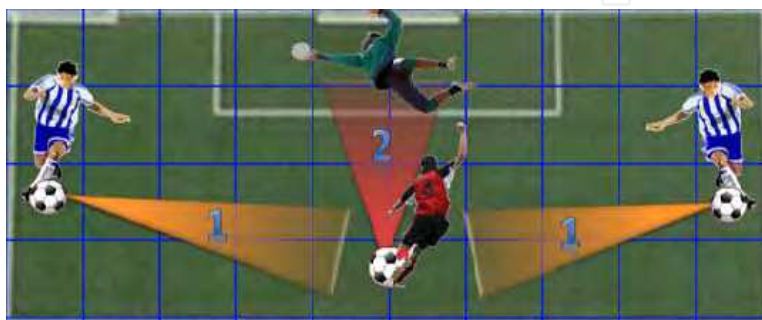


Fig. 13. Soccer Exercise Conducted

To clarify the Wi-Fi network's density one ought to first specify the access points' positioning. A router was placed behind the goal as well as the batteries and the entire electrical infrastructure described in the previous section. The remaining three access points were also used and positioned over the center of the remaining lines that define the penalty box (excluding the one which contains the goal line). To maximize the signal's strength all the Wi-Fi devices emitting a signal were put on top of a structure that allowed them to gain 1.20 meters of height. They were also put twenty centimeters away from the real lines so that the players' moves were not affected by their presence. Fig. 14 shows the signal's strength and noise levels on this particular scenario.

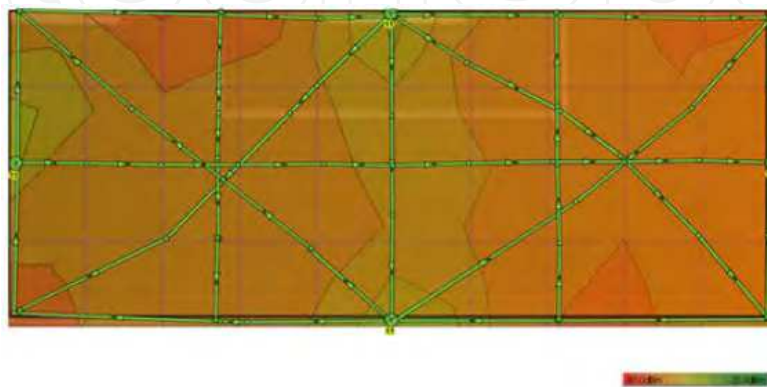


Fig. 14. Signal Strength and Noise for WI-FI Network

Since this is an outdoor environment the authors believe that the gathered noise values are the main cause for the error on the player detection because they are not being compensated by refraction and reflection phenomena which are typical in indoor environments. One ought to point out that this test was conducted with high-end devices and so there is a high probability of diminish the noise's impact just by changing the hardware to high-end artifacts, as their value mostly differs on the applied power on signal emission.

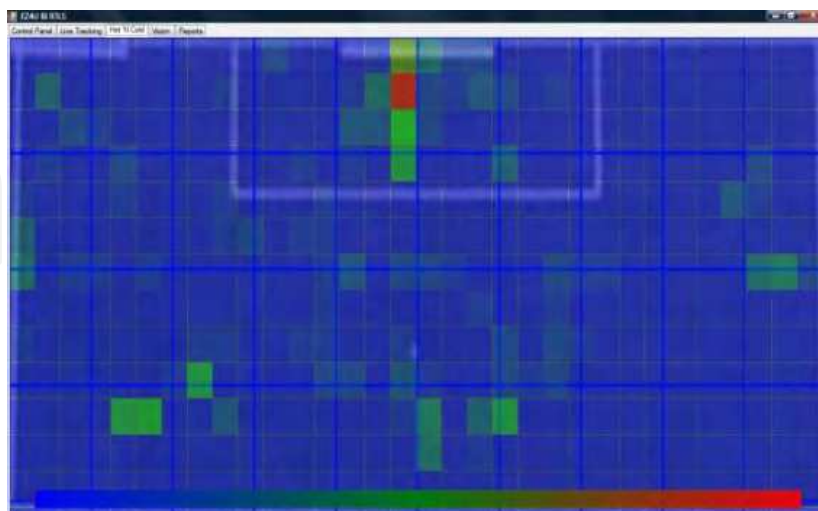


Fig. 15. Box density over an exercise

Even so, the next figures clearly demonstrate that the system was able to track the players during this exercise which lasted about thirty minutes. For instance, on Fig. 15, showing the

box's density over the entire exercise with the scale depicted at the bottom of the picture, one can observe a red cell on the goal area which undoubtedly corresponds to the goalkeepers' presence waiting for the striker's shots. The neighbor cells are also highlighted as the goal keeper moved a bit during the exercise in order to better cover the striker's shots on goal. The other highlighted cells demonstrate how the other three players moved during this training session.

Fig. 16 shows a real time screenshot of the player density where one can observe the wingers' position after having one of them pass the ball.

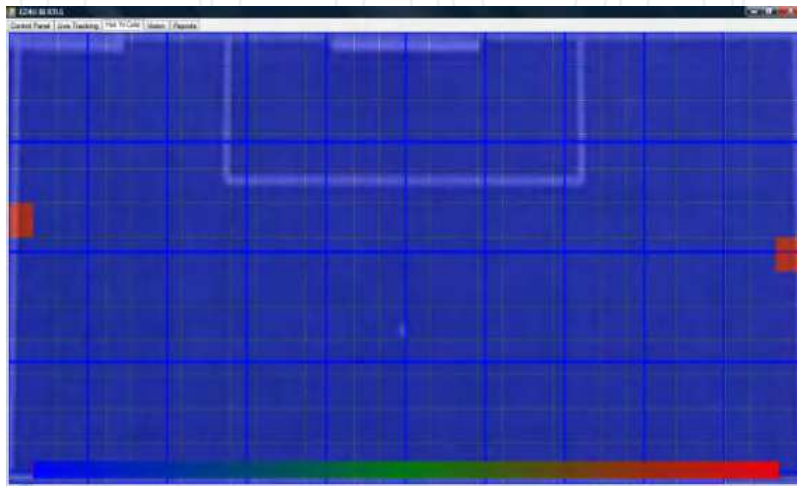


Fig. 16. Player density in the game field

And finally on Fig. 17, one can observe the left winger's and striker's position during a pass. On this particular figure the player's are represented as blue dots over the field. In this case the error between the obtained position and the real one did not exceed two meters for each player, which also justifies the fading green cells on the box's corner (shown on Fig. 15) as the wingers could decide from where they wanted to perform the pass as long as their distance to the box's limits did not overcome three meters.

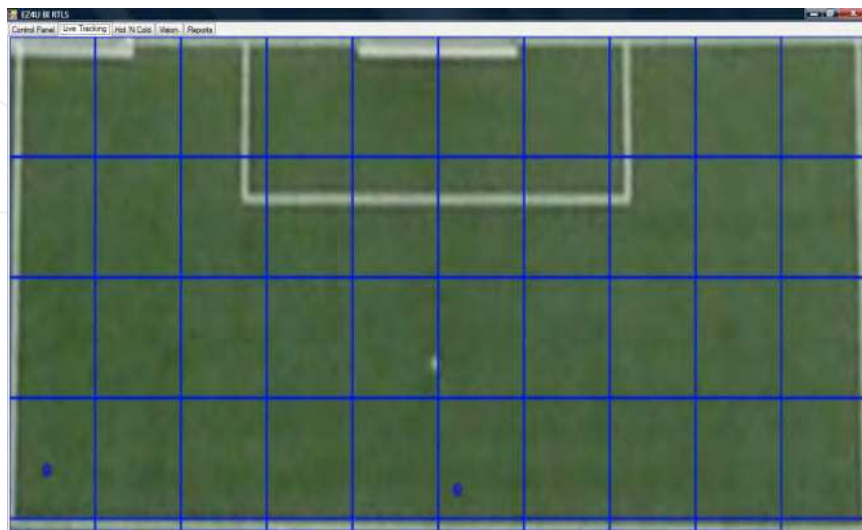


Fig. 17. Striker Position during a pass

Overall the system remained stable during the whole training session thus confirming its robustness and applicability as a tool for scientific soccer analysis.

## 5. Conclusions & Future Work

This section is dedicated to present and specify the project's main conclusions as well as identify and further detail major future work areas and potential collateral applications.

Admitting the first topic and having the conjunction between the project's module description, section 3, and its main results in the above section, one ought to affirm that all the most important goals were fully accomplished. In order to further support this statement, a brief hypothesis/result comparison shall be undertaken in the next few paragraphs.

First, a fully functional item real-time location and tracking system was pursued – without strict error-free requirements. The Wi-Fi based solution, not only complied to the specifications – real-time issues and non-critical error margin: less than 3 meters as maximum error – but did it reusing most of the client's network infrastructure (in the retail case) or using low brand equipments- router and access points (in soccer case). With this inexpensive tracking solution any team's coach has detailed reports about the performance of a specific player or the all team in a training session or even in a soccer mach. The possibility of having real time player positions in a specific situation and historical player paths constitutes an important tactical indicator for any soccer coach.

Secondly, the designed system's architecture proved to be reliable, efficient and, perhaps, most important, flexible enough to contemplate vast and diverse application scenarios. Also within this scope the distributed communication architecture performed as predicted enabling computation across distinct machines, therefore improving overall performance and reliability. This feature also enabled simultaneous multi-terminal access, both to the real-time analysis tool and the historical statistical software.

Taking into consideration the project's tools – real-time and historical – both were classified, by the retail company's end-users – mainly shop managers, marketing directors and board administrators and for sport experts – mainly clubs directors and academic experts – as extremely useful and allowed swift knowledge extraction, preventing them the excruciating, and not often useless – process of getting through massive indirect location data. The immediate visual information provided by the system proved to be effective in direct applications such as queue management and hot and cold zones identification, and most significant, in what concerns to visit's idiosyncrasy pattern extraction – as duration, distance and layout distribution – across different time dimensions, thus enhancing marketing and logistic decisions' impact. Also, in the sports area this system constitutes an important tool for measurement athletes' performance all over a training session.

Finally, in what concerns to direct results' analysis, one must refer to Oracle's APEX technology adoption. It has demonstrated to be able to allow multiple simultaneous accesses and, consequently, dramatically enhancing analysis empowerment, while, at the same time, eliminated heavy data computation from end-users terminals, concentrating it in controlled and expansible clusters. This characteristic allows through its web-based interface, accesses from unconventional systems such as PDAs, smartphones and not only notebooks and desktop computers. This particular feature is of great importance for on floor analysis and

management and also for technical staff that for instance is spread through the soccer stadium in a match.

Regarding future work areas, and divided the two scenarios analyzed in this study, there has been identified a set of potential project enhancements that would be able to suppress some hurdles and, somehow, wide potential new applications.

For the retail environment, the first facet to be developed would be map edition oriented and should contemplate the possibility of defining multi-store and multi-location layouts in a single file. Also within this scope, it would be useful and technically straightforward – the definition of alarm/restricted zones where the entrance of a given tag or set of tags would trigger an immediate system response.

Secondly, considering business intelligence extraction, it would be useful to build or reuse an inference engine capable of determining the odds of a given customer turn right or left in the next decision point, taking for that, into account his past actions and comparing them to other customers' action that are classified in the same cluster. This aspect should be also applied to historical data so that efficient customer clusters would be defined and maintained.

Perhaps the most essential system enhancement would be the capability of, by dynamically change shop floor layout, and predict its impact in customers' routes and visits' parameters – duration, distance and financial outcome. This feature would make what-if scenarios possible to be run and immediate impact feedback would be given. Taking into account the current project's features and also the identified future enhancements, there have been identified several application domains that go beyond the retail segment.

In what concerns to soccer area one feature that could be interesting to explore as future work is the transformation of the actual system in a complete support decision framework for soccer coaches. For that purpose it is necessary to build a hybrid tracking system made by two synchronous modules. One module will be responsible for tracking the players and for this the actual system could be a solution and the other one should be responsible for tracking the ball. In this last problem one of two solutions could be adopted: a camera based classic solution with the advantage of only needing to track a specific object (with particular dimensions and color) decreasing so, the occlusion problems or adopt a new type of approach using, for instance, a chip inside the ball.

The second step for this new system will be the construction of soccer ontology. This point has particular importance because it helps to define concepts relationship with events of the game like: a pass, a shot, a corner etc. After that it is possible to construct a tracking system that will be capable to automatically detect game events, calculate historical player paths and in an advance face automatically detect player behavior relationship not only with their positioning but also with ball's. This system will definitely fill a gap in the market.

Taking into account the current project's features and also the identified future enhancements, there have been identified several application domains that go beyond the soccer or even CSG.

Amongst these, one shall mention the possible system's adoption by large warehouse management where traffic jams are not unusual. The proposed system would permit live vehicle tracking that in conjunction with a planning module would enable efficient traffic control, therefore avoiding bottlenecks, without compromising warehouse storage capacity.

Another possible application would reside in health care institutions where it would be useful for medical staff tracking around the facilities, in order to efficiently contact them in



case of emergency. Also within this domain, especially in mental institutions, patient tracking could be a great advantage.

Security applications are also easy to imagine, not only to track assets in a closed environment but also potential human targets such as children in public areas – such as malls hotels or conventional centers.

As a summary, it is fair to state that the project's initial ambitions were fully met and that the close cooperation with an important stakeholder in the global retail market and with an important university in the sports area was extremely important for better measuring the system's positive impact and potential firstly unseen applications. The technology transparency, allied with the future work areas, is believed to greatly improve potential applications in several domains, thus significantly widening the project's initial horizons.

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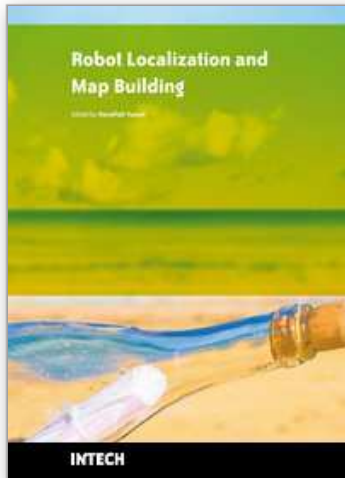
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## **Robot Localization and Map Building**

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Localization and mapping are the essence of successful navigation in mobile platform technology. Localization is a fundamental task in order to achieve high levels of autonomy in robot navigation and robustness in vehicle positioning. Robot localization and mapping is commonly related to cartography, combining science, technique and computation to build a trajectory map that reality can be modelled in ways that communicate spatial information effectively. This book describes comprehensive introduction, theories and applications related to localization, positioning and map building in mobile robot and autonomous vehicle platforms. It is organized in twenty seven chapters. Each chapter is rich with different degrees of details and approaches, supported by unique and actual resources that make it possible for readers to explore and learn the up to date knowledge in robot navigation technology. Understanding the theory and principles described in this book requires a multidisciplinary background of robotics, nonlinear system, sensor network, network engineering, computer science, physics, etc.

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Phone: +86-21-62489820  
Fax: +86-21-62489821

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