A Survey on Indoor Positioning Systems

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Abstract— **This paper aims to provide the reader with a review of the main technologies explored in the literature to solve the indoor localization issue. Furthermore, some systems that use these enabling technologies in real-world scenarios are presented and discussed. This could deliver a better understanding of the state-of-the-art and motivate new research efforts in this promising field. Finally, focusing on one of the major challenges in the indoor localization field, i.e., the indoor animal tracking, existing indoor tracking systems have been reviewed and compared by analyzing advantages and drawbacks.**

Keywords—Animal tracking; Indoor localization systems; RFID.

I. INTRODUCTION

In recent years, the use of indoor localization techniques has become increasingly important in a large number of applications and contexts such as healthcare, homecare, monitoring, tracking, etc. In outdoor localization contexts, the most well-known and widely spread technology is the Global Positioning System (GPS). It is able to guarantee excellent performance in outdoor scenarios but not work properly in indoor environments due to poor coverage of satellite signal. Moreover, obtaining position information in indoor environments is particularly challenging because of several reasons: errors by multipath and Non-Line-of-Sight (NLoS) conditions, presence of moving people that modify the indoor propagation channel, greater density of obstacles that cause a high attenuation and signal scattering, demand of a higher precision and accuracy.

In the choice of the best technology to design an indoor localization system, a large number of parameters should be taken into account (e.g., cost, accuracy, robustness, scalability, coverage, etc.). Obviously, a single solution that works fine for any scenario does not exist. Then, it is important to considerate the performance parameters of all technologies and match them with the user requirements, which have to be analyzed and described precisely for each application. Moreover, the values of the performance parameters are not univocally determinable since they in turn depend on various factors and conditions. Therefore, it is necessary to find the right trade-off among performance parameters, user requirements and environmental conditions in order to design a customized solution.

In the literature, there are several surveys dealing with the indoor localization. Some of them focus their attention on one technology. In [1], the considered indoor localization approach is based on the Wireless Sensor Network (WSN) technology whereas in [2] the Radio Frequency Identification (RFID) technology is explored. The paper analyzes twenty-one research projects, with the algorithm design, devices, test setup, and performance evaluation of each solution described in detail and provides directions for future research.

Several indoor localization techniques are investigated in [3], where four enabling technologies (i.e., RF, ultrasound, wireless sensor nodes, and smartphones) are compared taking into account several parameters. In [4] the authors present advantages and disadvantages of different indoor localization techniques whereas in [5], indoor localization systems are classified in active and passive and, for each of these two categories, several techniques are analyzed and discussed. Finally, [6] provides a categorization and classification of different indoor positioning systems and identifies some possible areas of enhancements.

The importance recently reached by the indoor localization is also demonstrated by the interest shown by Google in this direction over the last two years. The new Indoor Google Maps service lets to explore indoor environments such as shops, malls, museums, hotels, railroad stations, airports, etc. using a mapping contained within the application. In other words, the localization function, already existing in Google Maps, lets to navigate even in indoor environments that have a partnership with the Google company, providing their floor plans. This paves the way to many benefits for visitors to these indoor environments. For example, if a person goes to a hospital for a medical examination, the opportunity to walk virtually through the corridors will allow him/her to find immediately the right room. The indoor localization system proposed by Google has already been explored in the literature [7].

This paper aims to give an updated overview on the most popular enabling technologies and provide a short state-of-the-art on existing indoor localization systems in order to demonstrate that each applicative scenario requires a different technological choice according to the user requirements. Finally, in order to provide a practical example, the indoor animal tracking problem is analyzed more in detail and different existing systems are compared.

II. ENABLING TECHNOLOGIES

A number of alternative technologies have been proposed for indoor positioning systems over the years. The most commons include vision, infrared, ultrasound, Wireless Local

Area Network (WLAN), RFID, and Bluetooth. In this section, a brief description of these technologies is presented.

A. Vision

This approach is based on the processing and evaluation of video data. Generally, the video-based localization can be performed in two different ways:

- *Fixed camera systems*. The environment can be equipped with cameras mounted in fixed locations. In this case, the objective is to locate a moving target (i.e., individual, object or animal) in images captured by one or several cameras. Features of the target being tracked must be used. In this way, if the salient features of the target appear in the field of view of the camera, its location can be calculated with respect to the camera's fixed position. The position of the target is estimated based on its position within the captured image, and the spatial distribution of its salient features.
- *Mobile camera systems*. The mobile target is equipped with a camera and the localization is performed by placing several landmarks in known positions (and orientations) or by extracting environment features. In the first case, if the mobile camera detects two or more landmarks, it can find out its own position and orientation. In the latter case, the localization process involves two stages. In the off-line stage, images of the environment are captured at predefined locations and each image is processed to extract its unique features that are stored in a database. In the on-line stage, the camera captures an image, and its features are extracted and compared to the stored features in order to estimate the location of the camera. In both cases, the objective is to estimate the position and orientation of the mobile camera.

Nowadays, the accuracy of camera-based indoor localization systems has reached appreciable levels [8] (i.e., between 10^{-6} m and 10^{-1} for high precision systems). Moreover, the increase in both data transmission rate and computational capabilities, as well as the development of high performance image processing algorithm make this technology very efficient. A drawback of this technology is that costs are still a bit high but, thanks to the new technologies, low-cost solutions are spreading and recently attention is increasingly directed towards localization systems that use camera-equipped mobile phones [9], [10].

B. Infrared

Infrared radiation (IR) is one on the most common wireless technology used to localize objects or people through infrared emitters and receivers.

An example of an indoor location system based on IR can be represented by a user wearing a badge, carrying a unique identifier code (ID), that emits an IR signals at regular intervals via an infrared transmitter. Infrared receivers, placed in well-known positions of the environment, detect the ID and communicates it to a localization software that calculates the badge position based on the proximity between transmitter (i.e., badge) and receiver.

This technology can provide several advantages. First, IR beam does not penetrate through walls then it is possible to obtain a confinement of the signals inside the room. Moreover, IR technology is characterized by the absence of radio electromagnetic interference and the power of transmitted IR signal can be easily adjusted to cover only the area of interest. Nevertheless, there are also several drawbacks. The multipath errors reduces drastically the localization accuracy and IR based indoor systems have expensive system hardware and maintenance costs. Furthermore, IR technology requires a Line of Sight (LoS) between transmitter and receiver to function properly.

C. Ultrasound

Ultrasonic technology use ultrasonic waves to measure distance between fixed-point station and the mobile target to localize. In order to implement such a localization system, multiple ultrasonic receivers are needed and they must be synchronized. The synchronization among receivers is done via IR or radio waves, because of the greater speed of the radio waves than the ultrasound ones. The transmitter sends a radio signal and an ultrasonic wave at the same time. Radio signal reaches receivers almost instantaneously, providing them with the synchronization signal. Receivers start to measure the time between the synchronization signal and the detection of ultrasonic waves, and then each of them calculates the distance between transmitter and itself. Advantages of this localization technique are the relative low cost and the capability to reflect most of the indoor obstructions. Disadvantages of an ultrasonic localization system arise from the multipath reception that could disturb measurements of the distance between emitter and receivers, and the complexity of a large-scale implementation. Furthermore, the temperature is the most critical influence on the sound speed. The dependency is given by the following formula:

$$v_{us} = 331.3 * (1+T/273)^{1/2} \text{ m/s} \qquad (1)$$

where v_{us} is the sound speed and T is the temperature in Celsius (°C).

For a typical maximum range of 10 m, a change of 1°C in the temperature causes a deviation in the range estimation of $2x10^{-3}$ m. Therefore, most ultrasound systems include sensors for automatic temperature compensation. Nevertheless, the true air temperature along the path between transmitter and receiver remains unknown. Minor influences on the speed of acoustic sound are the air pressure, the CO_2 content and the sound amplitude.

D. Wi-Fi

Wireless Local Area Network (WLAN) can be used to estimate the location of a mobile device within this network. Since WLAN infrastructure is widespread in many indoor environments, according to the increase in demand for wireless communications, this approach is widely used for indoor localization. For this reason, one of the main advantages of using Wi-Fi localization technique is its cost effectiveness due to the possibility to localize the position of almost every Wi-Fi compatible device without installing extra software. Another advantage of using WLAN is that LoS is not required. The most popular WLAN positioning method is to make use of Received Signal Strength Indicator (RSSI), which are easy to extract in IEEE 802.11 networks.

In a WLAN, a node emits/receives radio frequency signals to/from the wireless router, which can be used to determine precise location of any Wi-Fi enabled device. The WLAN RSS approach can use three basic ways to localize the target device:

- Cell of Origin (CoO) method: it works by knowing the coordinates of the access point (AP) to which the devices are connected.
- Triangulation method: the position of the target device is calculated by triangulating of signal strength information received at multiple receiver locations.
- Fingerprint method: it is the most viable solution for RSS-based indoor localization and works by mapping the observed signal strength of fixed routers placed in the indoor environment into a database (i.e., the radio map). The basic design of the fingerprinting method can be divided in offline stage and online stage. During the offline stage, RSS is collected at sampling locations to build the radio map for the specific environment. During the online stage, the physical location of the client can be estimated by comparing the measured RSS with the stored RSS values.

The accuracy of the Wi-Fi technology is between 20 m to 40 m, but it can be improved by dense deployment of wireless routers or by integrating other technologies, and recent results talk about 3-5 meters accuracy [11]. In addition to accuracy, many challenging issues in the WLAN localization technology are important. Among these, it should be mentioned the power consumption. In fact, since mobile devices are usually small and have battery power constraints, a challenging issue is how to reduce the power required for localization. Another WLAN limitation is the signal attenuation of the static environment like wall, movement of furniture, and doors.

E. RFID

The RFID technology is based on the use of an RFID reader equipped with one or more reader antenna and active or passive transceivers (i.e., tags). A summary scheme that shows how this technology works is reported in Fig. 1. Active RFID tags contain a battery and can transmit signals autonomously, whereas passive RFID tags have no battery and require an external source to emit a signal transmission. Typically, the data in the tag consist in a univocal serial number, but also additive information (e.g., positional information) can be stored in a tag. The amount of data that can be stored in a tag depends on the size of its memory. The features of this technology make it the ideal candidate for the traceability of several products, such as food or drugs [12], [13], [14] along the supply chain, but it is also used for many other purposes, including the indoor localization.

The RFID localization can be categorized into two types, i.e., reader localization, and tag localization depending on what, between reader and tag, needs to be localized. In the reader localization, the accuracy of the RFID system is highly depending on the density of tag deployment and the maximal reading ranges. In a probable localization context, a large number of RFID tags, which contain location information, can be deployed to cover an entire indoor environment. A person with a hand held reader could read the closest tag and obtain information about his/ her position. The disadvantage of this approach is the large number of RFID tags, which need to be used, and prerecorded with location information. Alternatively, the RSSI can be used for a coarse range estimation in order to apply multilateration techniques. On the contrary, the tag localization requires several RFID reader spread in the environment in known positions. Obviously, this method is more expensive and the cost increases with the increase in the number of used RFID readers.

The RFID technology works without direct LoS since the radio waves have the ability to penetrate solid materials, but strength of the signal depends upon the density of the objects in the building, and then accuracy is often limited. The typical frequency ranges used in RFID are categorized as: (i) Low Frequency (LF) at 125-134 kHz; (ii) High Frequency (HF) at 13.56 MHz; (iii) Ultra-High frequencies (UHF) at 860-960 MHz. In addition to the possibility to work in NLoS environment, other advantages of the RFID technology are high data rate, high security, cost effectiveness, and compactness. Main limitations of LF and HF RFID technology are related to a short reading range and to the ability to read only a few tags at the same time. Instead, regarding the UHF RFID technology, its drawbacks are mainly due to the absorption or reflection of RF waves in the presence of liquids

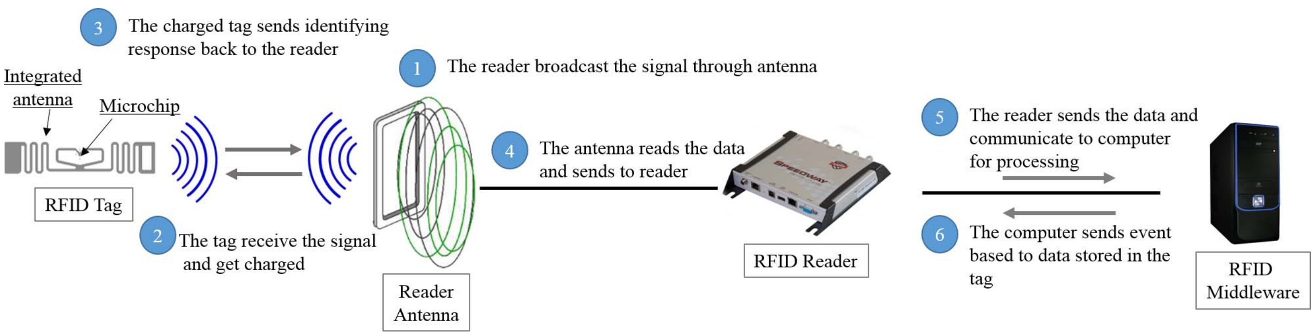


Fig. 1. A schema of the RFId technology working.

or metals, respectively.

F. Bluetooth (IEEE 802.15.1)

Bluetooth is a wireless standard for Wireless Personal Area Networks (WPANs) and operates in the 2.4 GHz Industrial, Scientific and Medical (ISM) band. Compared to WLAN, the range is shorter (typically 10–15 m). On the other hand, Bluetooth is a “lighter” standard, ubiquitous because it is embedded in most devices such as mobile phones, personal digital assistants (PDAs), laptop, desktop, etc. Then, the use of the Bluetooth technology in location sensing permits to reuse the devices already equipped with Bluetooth technology, so adding a new user to such a system does not require any additional hardware. Since Bluetooth is a low-cost and low-power technology, it is efficient in order to design indoor localization systems. In addition, Bluetooth tags are small size transceivers. As any other Bluetooth device, each tag has a unique ID, which can be used for locate the Bluetooth tag.

Finally, a last emerging technology used for indoor localization is iBeacons, the Apple's implementation of Bluetooth Low Energy (BLE) wireless technology to provide location-based information and services to iPhones and other iOS devices. The indoor localization via iBeacon offers significant advantages in building complexes that do not have a fixed wireless infrastructure. The position within a building can be determined using iBeacon combined with software solutions. The use of BLE technology enables the use of batteries for months, without having to resort to external power supplies.

One of the drawbacks of using Bluetooth technology in localization is that, in each location finding, it runs the device discovery procedure; due to this, it significantly increases the localization latency (10–30 s) and power consumption as well. For this reason, Bluetooth device has a latency unsuitable for real-time localization applications. Another disadvantage of a Bluetooth-based localization system is that it can only provide accuracy about from 2 m to 3 m with a delay of about 20 s. Furthermore, the Bluetooth localization systems suffer from the drawbacks of the RF localization technique in the complex and changing indoor situations.

G. Other technologies

There are several other technologies able to perform indoor localization. Among these, it is worth mentioning ZigBee, FM radio and the emerging inertial sensors technologies.

The indoor localization exploiting ZigBee technology is based on the creation of a ZigBee network consist of multiple reference sensor nodes with known physical positions and a target node, also called the sink node, without the location information. Since the nodes can communicate with each other, the radio signal strength received by the reference sensors is commonly used for positioning. For these networks exist different localizations algorithms that may obtain different results and achieve diverse performance in different testing environments [15].

The FM radio technology is used in [16] in order to address the limitations of the Wi-Fi technology. In particular, authors propose to use FM broadcast radio signals to augment or even replace Wi-Fi signals for fingerprinting indoor environments.

With the term of inertial sensors refers to sensors that exploit the inertia to measure linear acceleration (i.e., accelerometer that exploits the inertia to linear motion) or angular velocity (i.e., gyroscope that exploits the inertia to angular movement). In this regard, an inertial navigation system (INS) is a navigation aid that uses motion sensors and rotation sensors to continuously calculate the position, orientation, and velocity (i.e., direction and speed of movement) of a moving object without the need for external references [17]. Modern smartphones are equipped with inertial sensors (i.e., accelerometers and gyroscopes) and this makes possible the realization of low-cost indoor localization systems [18].

H. Comparison among technologies

In order to choose the most suitable technology (or a combination of them) for the design and implementation of an indoor localization system, a comparison among the alternative technologies is very useful.

In Table I, some parameters have been selected for the comparison, i.e., accuracy, coverage, cost, complexity, and typical applicative environment. The values of these parameters have a purely indicative meaning as the real values, which depend on many factors, should be evaluated case by case. Instead, a graphical overview of all these technologies in dependence of accuracy and coverage is given in Fig. 2. In

TABLE I. COMPARISON AMONG INDOOR LOCALIZATION TECHNOLOGIES

		Parameters				
		Accuracy[m]	***Coverage [m]***	***Cost***	***Complexity***	***Typical Environment***
Technologies	***Vision***	$10^{-3}\div10^{-1}$	1-10	High	High	Indoor
	Infrared	$10^{-2}\div1$	1-5	Medium/High	Low	Indoor
	Ultrasound	10^{-2}	2-10	Medium	Low	Indoor
	Wi-Fi	$1\div10$	20-50	Medium/Low	Low	Indoor/Outdoor
	RFID	$10^{-1}\div1$	1-10	Low	Low	Indoor
	Bluetooth	$1\div10$	1-30	Low	Low	Indoor/Outdoor

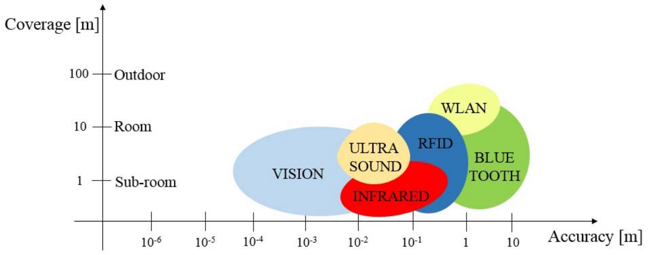


Fig.2. Graphical overview of the technologies enabling the indoor localization in dependence of accuracy and coverage.

both cases, coverage is to be intended as the direct measuring range of an unextended implementation. The scalability that many system approaches offer has not been taken into account.

III. Indoor Localization and Tracking Systems

In the literature, there are several attempts to realize indoor localization and tracking systems using the described technologies. The choice of the technology to be used varies from case by case, depending on the specific application and user requirements especially in terms of costs and accuracy.

Camera-based indoor localization systems are the most popular. These systems differ depending on the specific technique used to perform the localization and can be based on: (i) reference from 3D or 2D building models, (ii) reference from images, and (iii) reference from deployed coded targets.

In the method based on the reference from 3D or 2D building models [19], [20], [21], the localization system relies on the detection of objects in images captured from the indoor environment and on the match of these objects with those stored in a database. The database contains position information of the objects in the building interior. An advantage of these systems is that the deployment of sensor beacons is not needed, as well the installation of a local infrastructure. The reference from images method exploits sequences of images preliminarily captured by a camera along certain routes in the indoor environment and stored in a database [22], [23]. In the localization phase, the images that appear in the current view of the mobile camera are compared with the images previously stored in the database. In these systems, the computational load required for the images identification is very high. Finally, systems that use the reference from deployed coded targets technique calculate the unknown position by exploiting dedicated coded markers or labels placed in the environment [24], [25].

Among vision systems, there are also systems able to observe position changes of objects, humans or animals directly, which do not require the use of external references. For example, in [26], an indoor monitoring video-based system used in eldercare to assist the independent living of elders and to improve the efficiency of eldercare practice is presented. The system exploits an algorithm able to extract the human silhouette and track the human displacement in the indoor environment. It is also able to extracts important statistics on daily activities. In the literature, several works aim to improve the performance of video-base localization and tracking systems. In [27], authors introduce two methodologies to increase the energy-efficiency and battery-life of an embedded smart camera by hardware-level operations when performing object detection and tracking. Instead, the problem of visual occlusions that make the current observation totally or partially unavailable for some time interval is addressed in [28], in which a complete framework for multiple people tracking in video surveillance applications in presence of large occlusions is proposed.

System architectures for indoor positioning based on IR signals can use: (i) active beacons; (ii) natural infrared radiation or (iii) artificial light sources. The active beacons approach, explored in [29], [30], [31] uses fixed infrared receivers placed in known positions in the indoor environment and mobile beacons whose position is unknown. The localization accuracy depends on the number of receivers placed in the environment. For a location with an accuracy of a single room, one receiver is placed in each room. For higher accuracy, it is possible to place multiple receivers in each room. Localization systems that use natural infrared radiation are known in the literature as passive infrared localization systems. Sensors operating in the spectrum from 8 x 10^{-6} m to 15 x 10^{-6} m (i.e., the thermography region) are able to obtain an image of the surrounding world from natural thermal emissions, then without the use of active infrared sensors. The infrared thermic radiation can be used to obtain the temperature of humans or objects remotely, without any need for wearing tags or emitters [32], [33]. As a drawback, passive infrared approaches are compromised by a strong sun radiation. Finally, optical IR systems for indoor localization based on artificial light sources and IR Charge-Coupled Device (CCD) cameras are used as alternative of camera-based systems operating in the visible light spectrum. With regard to this approach, the sensing device known as Kinect [34] uses an infrared projector and camera and a special microchip to track the movement of objects and individuals in three dimensions in any ambient light conditions.

IR indoor localization systems are used to track objects and humans in several scenarios. In particular, systems based on high resolution infrared sensor are able to reach a sub-mm accuracy, whereas system based on active beacons or natural infrared radiation are mainly used for a single room precision.

Ultrasound indoor localization systems estimate the distance between a transmitter and a receiver by calculating the Time of Arrival (ToA) of ultrasound pulses that travel between them. In particular, the emitter position is calculated by using the multilateration technique, according to the position of three or more fixed receivers placed in known locations. The ultrasound approach is typical of indoor environments for tracking of humans and objects [35], [36], [37] and it is rarely used in outdoor because of limited distance measurements (of about 10 m) and frequent changes in temperature that limit the system accuracy. In the literature, some attempts are made in order to improve the accuracy of ultrasound-based indoor localization systems [38].

With regard the WLAN technique, the Strongest Base Station (SBS) method is the simplest solution in WLAN RSS-based indoor localization systems [39], [40]. The user's location is estimated as the position of the nearest AP. This method has no computational issues and is applicable in most networks. However, the SBS method could not achieve good accuracy because of the complexity of indoor WLAN environments and limitation of the AP coverage. In the propagation model method, the RSS information and, in particular, the signal path loss is taken into account to estimate the location of a mobile user. The system commonly uses a propagation model to convert the RSS path loss value in physical distance from the base station and geometry techniques (e.g., trilateration and triangulation) in order to determine the coordinates of a user [41]. Recently, WLAN RSS fingerprinting becomes one of the most exploited techniques in WLAN-based indoor localization [42]. Compared to the SBS and the propagation model, the fingerprinting method is easy to deploy and is tolerant to wireless signal noise, then can achieve a highest accuracy (between 2 m to 50 m). Regardless of the specific method, the indoor localization based on WLAN is used when stringent accuracy requirements are not required.

As mentioned in Section II, an RFID-based system suitable for indoor localization can use both active and passive RFID technology. In [43], an active RFID system is developed in order to establish an indoor/outdoor localization system for vehicle and pedestrian navigation. Active RFID tags are used also in [44], in order to design a 3D indoor localization algorithm and in [45] to improve the accuracy of active RFID-based positioning systems. The passive RFID solution is adopted in [46] to design a hybrid method for tracking mobile objects with high accuracy and low computational costs. A location estimation method able to guarantee better accuracy in indoor environment localization systems by using angulation techniques and passive tags attached at known locations is presented in [47]. In [48], the passive UHF RFID technology is used as supplementary support for the navigation and localization of robots.

RFID technology is often combined with other enabling technologies in order to improve the system accuracy. In [49] and [50], systems using both active RFID and video technologies for indoor positioning and tracking purposes are presented.

Bluetooth is a promising technology in the development of indoor localization systems and several attempts are addressed in the literature to overcome the limitations imposed by this technology and already discussed in Section II. An elaborate discussion on fingerprinting-based Bluetooth localization algorithms is provided in [51]. In [52], authors propose a Bluetooth positioning system exploiting both RSSI and triangulation methods. Finally, fingerprint and lateration methods are used in [53].

In Table II, all references discussed in this paper are classified according to both the explored enabling technology and the purpose for which the proposed system has been developed (i.e., person localization and tracking, object recognition and localization, robot navigation, animal tracking, etc.).

IV. Focus on the Animal Tracking Issue

Assuring automatic and effective localization and tracking of animals, represents a priority for many reasons: food security and safety policies, study of natural migration phenomena due to pollution, foodborne risk assessment, and laboratory behavior analysis, are only a few of the possible examples. When medium/large size animals have to be monitored in large outdoor environments, as for the migration study case, GPS-based as well as radar-based approaches are promising. Nevertheless, none of such technologies can be adopted when animals living in an indoor environment must be monitored. In this case, the more spread technologies are vision and RFID.

In [54], the video technology is used in tracking of rodents in order to determine their motion pattern whereas in [55], a video tracking system for detection of position and orientation of mice's limbs is designed. This system can be useful in the evaluation of physical therapy to be adopted in the case of mobility handicaps (e.g., due to spinal cord injury). There are also many video-based commercial products able to track animals. Among these, EthoVision [56] is one of the most used and complete. With use of a camera positioned above animals, it detects and tracks animal movement, activity, and behavior (Fig. 3). EthoVision can be used for several behavioral experiments, with different animals (i.e., rodents, farm animals, fish, etc.), in any kind of arena. The main disadvantage of commercial video-based systems is the high cost. Moreover, they are not very user friendly. In fact, the ease of use is limited to simple basic functionality, whereas the use of advanced features is more complex.

In the field of animal tracking, RFID-based systems are very common and different frequency bands have been explored in the literature (i.e., LF, HF and UHF). In [57], an attempt to use the RFID technology in LF band for mice tracking is proposed. In this paper, the developed system is used to monitor the behavior of mice as transgenic model for Alzheimer's disease reconstructing a semi-natural environment. The system has its limitations. In fact, LF band cannot exploit the advantages provided by the EPC Class1Gen2 standard [58], such as the native management of multiple and simultaneous reading of a lot of RFID tags. Moreover, a LF RFID system is characterized by a very short reading distance (approx. 1×10^{-2}

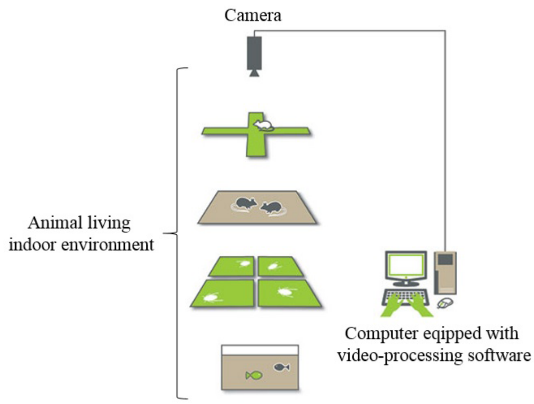


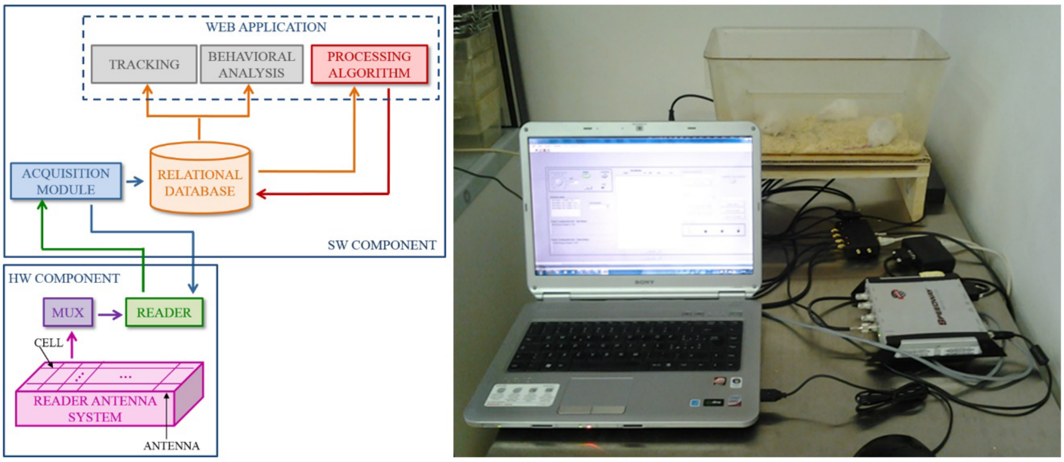
Fig.3. A schema of a video-based system for indoor animal tracking.

TABLE II. CLASSIFICATION OF INDOOR LOCALIZATION SYSTEM BASED ON TECHNOLOGY AND PURPOSE

		Person localization and tracking	**Object recognition and tracking**	**Robot navigation**	**Animal tracking**	**Not specified**
Vision	*Recognition from buildings model*	[9], [19]				[20], [21]
	Recognition from images	[10], [22]		[23]		
	Recognition from deployed targets					[24], [25]
	Without reference	[26], [28]	[27]		[54],[55], [56]	
Infrared	*Acteve beacons*			[29], [30]		[31]
	Natural IR	[32], [33]				
	Artificial light source	[34]				
Ultrasound			[36]	[37]		[35], [38]
Wi-Fi	*Strongest Base Station*	[7], [40]				[39]
	Trilateration	[41]				
	Fingerprint	[11]				[42]
RFID	*Active*	[43]	[44], [45]			
	Passive		[46]	[48]	[57], [59], [60], [61], [62], [63]	[47]
	With video support	[50]				[49]
Bluetooth	*Fingerprint*					[51]
	Hybrid					[52], [53]

m), so that mice are forced to follow obligatory paths in order to detect their passage and track correctly them. In [59], the HF RFID technology is explored in order to track a species of lobsters and to study their behavior. The animals are equipped with a passive transponder working in HF band, attached to their tail. HF RFID systems show almost the same drawbacks as those in the LF band, i.e., difficulty in simultaneous reading of several tags and short reading range (i.e., about a few cm) when applied in real indoor localization contexts. Finally, a first attempt to use passive UHF RFID technology for indoor animal tracking is presented in [60] and in other subsequent works [61], [62], [63] of the same authors. The proposed system is able to overcome the limitations of indoor animal tracking systems based on both video and RFID in LF or HF bands. In particular, the passive UHF RFID technology is exploited in order to design and develop a complete indoor localization system for simultaneous tracking of many small laboratory animals, especially mice. The system assures the animals' tracking without forced paths and it is able to extract behavioral information. It consists of a hardware component and a software component. The hardware component consists of the RFID reader and antennas system whereas the software components consists of two modules: an acquisition module and a Web application. The acquisition module is responsible for the configuration and management of the hardware component. Moreover, it detects raw tracking data coming from the RFID system and store them in a MySQL database. The Web application, exploiting a processing algorithm, processes the raw data in order to obtain accurate positional information and provides the end-user with both statistical information about the behavior of observed animals and a video of the movements of the mice in the cage. In Fig. 4.a, a schema of the system architecture is presented whereas the Fig. 4.b shows a photo of the prototypal tracking system. The overall system has been tested on real mice demonstrating that it is able to provide a high accuracy, offering a low-cost solution.

As conclusion of the presented overview, it is possible to state that, in designing an indoor animal tracking system some basic requirements should be satisfied. First, the system should be able to track the animals without changing their living



(a) (b)

Fig. 4. An RFID-based indoor animal tracking system: (a) the architecture of the system; (b) a photo of the prototypal system.

environment in order to preserve their natural behavior. Then, the system must be accurate enough to ensure an animal tracking as close as possible to reality. Finally, the cost of the system must not be too high. Based on a thorough analysis of the state-of-the-art, among all the discussed technologies, RFID is the one that better satisfies these requirements (in particular, the passive RFID technology in the UHF band). Hybrid systems, which use both the RFID technology and vision techniques, are also very promising because they are able to enjoy the advantages of both technologies.

V. CONCLUSIONS

The attention towards the indoor localization is still very strong in the literature and more and more efforts are made to search more effective solutions able to overcome the limitations of the enabling technologies. The choice of the suitable technology, or a combination of them, differs case by case and depends on both the specific application context and user requirements in terms of accuracy, coverage area, cost, required infrastructure, robustness, scalability, and so on. In fact, a solution that is suitable for a specific scenario, can lead to failure for another. This paper is intended to provide an overview on recent technologies for tracking indoor and related systems. Particular attention has been turned to systems for indoor animal tracking, since the research of efficient solutions for this issue is a challenge for many researchers. This can serve as a starting point for further ideas and future developments in this research field.

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