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Review

A survey of active and passive indoor localisation systems

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ABSTRACT

In recent years the need for indoor localisation has increased. Earlier systems have been deployed in order to demonstrate that indoor localisation can be done. Many researchers are referring to location estimation as a crucial component in numerous applications. There is no standard in indoor localisation thus the selection of an existing system needs to be done based on the environment being tracked, the accuracy and the precision required.

Modern localisation systems use various techniques such as Received Signal Strength Indicator (RSSI), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Angle of Arrival (AOA). This paper is a survey of various active and passive localisation techniques developed over the years. The majority of the localisation techniques are part of the active systems class due to the necessity of tags/electronic devices carried by the person being tracked or mounted on objects in order to estimate their position. The second class called passive localisation represents the estimation of a person's position without the need for a physical device i.e. tags or sensors.

The assessment of the localisation systems is based on the wireless technology used, positioning algorithm, accuracy and precision, complexity, scalability and costs. In this paper we are comparing various systems presenting their advantages and disadvantages.

1. Introduction

Indoor location determination has become a crucial component in many applications. Unfortunately a standard for indoor localisation does not exist yet. Various systems can estimate the position of a person or object. The selection of the technique to estimate location is application dependent. One can select the system which offers the accuracy and precision required for a specific application. Location aware systems can be a very important component for many scenarios such as asset tracking, health care, location based network access, games, manufacturing, government, logistics, industry, shopping, security, tour guides, and conference guides.

In this paper we classified the localisation systems into active and passive systems. Location tracking techniques can be classified into two categories: (1) systems requiring tracked persons to participate actively; and (2) systems using passive localisation. Fig. 1 presents the two classes which are also known as active and passive tracking systems. By participating actively, we mean that a person carries an electronic device which sends information to a positioning system helping it to infer that person's position. In some cases the electronic devices can also process recorded data and send the results for further processing to an application server running the localisation algorithm. In the passive localisation case, the position is estimated based on the variance of a measured signal or video process. Thus the tracked person is not carrying any electronic devices to infer the user's position.

Another classification can be done such as physical location, the place in the real-world i.e. meeting places, houses, offices, restaurants, or as a place online known as a virtual location [1]. The means by which people interact has changed dramatically. The number of people using social networks, online games or other online services increases each year. We refer to a virtual location as a "location" online where people can meet, chat or share information. This is not a physical location such as a GPS coordinate or a measurement that can pinpoint a user's location on a map, but rather it is represented by a location on the Internet, e.g. a web site. The physical location class is the focus of this survey thus various location estimation systems will be reviewed in this paper.

The physical location class can be broken down into three subcategories: descriptive locations, spatial locations and network locations [1]. A location related to geographic objects such as mountains, lakes, cities, roads, countries or other structures that have a description such as name, identifier, or number is known as a descriptive location. The spatial location represents a point expressed by two- or three-dimensional coordinates in a Euclidean space. Spatial location is used more in professional applications where a descriptive location does not provide enough details.

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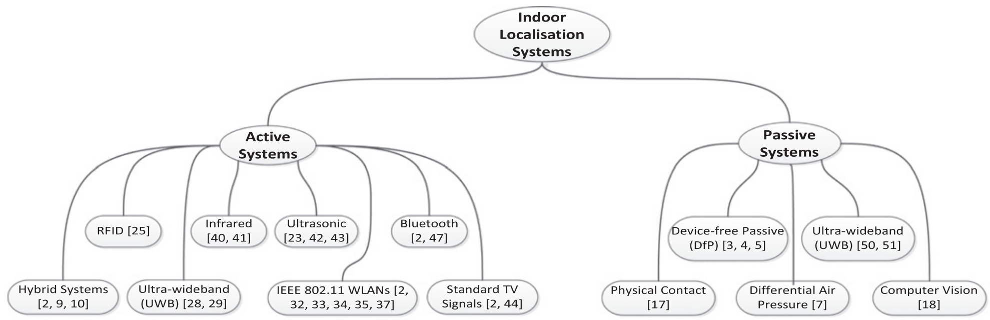

Fig. 1. Localisation techniques taxonomy.

Network location refers to a location based on the topology of a communications network. A user's device position in a network is achieved based on its Internet Protocol (IP) address. However in mobile networks a network location is achieved from the base stations used by the mobile terminal.

The localisation technologies proposed in the literature are also classified as indoor and outdoor localisation systems. The GPS [1–5] is widely used for outdoor position determination and this technology is currently implemented in many mobile devices. GPS however cannot estimate location in indoor environments due to the technology request for Line-of-Sight (LoS) when connecting to satellites. Thus systems were developed based on the proprieties of radio waves which can be used indoors. This class of localisation systems is the focus of this survey paper.

The well known GPS (Global Positioning System) is now used as a component in most of the mobile devices on the market. There are still many devices with no GPS support. In those cases network providers make use of existent base stations to estimate location [6]. Cellular networks such as GSM (Global System for Mobile Communications) or UTMS (Universal Mobile Telecommunications System) use tower cells as base stations. The techniques used to estimate location in a cellular network have been successfully used in Wireless Local Area Networks (WLANs) and Ultra-wideband (UWB) positioning systems. In the last two cases, access points (APs) or dedicated base stations are used to infer location. Existent systems include dedicated positioning systems where the techniques used are based on infrared, Radio Frequency Identification (RFID) or ultrasound technologies. Many location estimation techniques have been proposed over the years such as infrared, ultrasonic, bluetooth, radio frequency and also hybrid technologies [2,7,8].

Recently wireless indoor localisation has become a popular research subject. Many have focused on hybrid location systems combining two or more techniques in order to improve the accuracy and precision of the location estimation [2,9,10].

The first applications developed using location-aware systems were able to route a phone call to a phone located near to the user's location, to use the nearest printer or to display information based on the position of the user. Location information is also helpful for monitoring daily activities of a person [7].

The vast majority of these technologies have the requirement that the tracked person carries a physical electronic device, which in some cases can process some information and send the results for further processing to an application server running the localisation algorithm. Multiple wireless technologies can be used for wireless indoor location determination. These technologies may be classified according to the location positioning algorithm, the physical layer or location sensor infrastructure [8]. Location sensing approaches can be classified as follows: location fingerprinting (scene analysis) [11], triangulation, trilateration, hyperbolic lateration, proximity, and dead reckoning [2,7,8,12]. The metrics used in most of the approaches are: Received Signal Strength Indicator (RSSI), Time of Arrival (TOA)/ Time Difference of Arrival (TDOA), and Angle of Arrival (AOA) or Direction of Arrival (DOA). The following list represents a range of possible positioning technologies: (1) wireless local area networks (WLANs), (2) Ultra-wideband, (UWB), (3) Field strength systems, (4) Radio Frequency Identification (RFID), and (5) Next-generation indoor positioning systems [13].

The RSSI-based localisation techniques are considered more attractive because of their simplicity and robustness in environments affected by multipath compared to the techniques based on metrics like time or angle [14]. The RSSI-based position estimation can be classified as follows: terminal assisted, terminal based and network based [1,15]. The terminal assisted mode is based on RSSI measurements taken by the target and sent to a server which is managing the radio map and is running the localisation algorithm. For the terminal based mode, the radio map is built on the terminal and used to determine the target's position. The network based method uses measurements taken in the environment by access points (APs) or Basestations (BSs). Indoor localisation systems based on signal strength have the advantage of using the existing WLAN infrastructure, and therefore do not have any extra deployment costs [16].

UWB has some advantages compared to the WLAN location estimation such as: not affected by other RF signals, easy to distinguish correct signals from those generated from multipath, the UWB signals pass through walls. However interferences can be caused by materials like metal or liquid. The effects of metallic and liquid materials can be reduced with a good placement of the UWB readers. UWB technology is suitable for 2D and 3D location estimation. The most common methods used in a UWB localisation system are TDOA and AOA. A combination of TDOA and AOA can reduce the number of sensor required for a system using just TDOA.

The RFID position estimation is based on electromagnetic communication between RFID readers and RFID tags. The RFID tags can be passive or active. The range of the passive tags is limited to approximately 1–2 m and another drawback is the high cost of compatible readers [2]. The active tags have a much longer range around tens of meters which makes them suitable for larger environments.

The next-generation systems can be considered as hybrid system which will rely on mobile platforms to estimate location. Such systems are implemented today for mapping, vehicle navigation and robot navigation. Currently it is not possible to present advantages or disadvantages of these systems as the systems are known only as future work.

In [3–5,17,18] various functions that could be implemented for DfP (Device-free Passive) localisation systems are presented. These functions can be classified as follows: tracking, identification, multi-person and automatic construction of a passive radio map.

Our paper focuses on indoor active and passive localisation systems. Previous survey papers such as [8,19–23] classified indoor active positioning systems based on the technology and algorithms used. Our purpose is to provide key features of recent active and passive localisation systems. To the best of our knowledge passive localisation was not covered nor specified in any of the previous survey papers. We have described five passive localisation systems. The passive location estimation systems were classified based on techniques such as Device-free Passive (DfP), Ultra-wideband (UWB), Physical Contact, Differential Air Pressure and Computer Vision, used to estimate location information.

The remainder of this paper is organised as follows: Section 2 presents the comparison of methods used for deploying Active Localisation Systems, in Section 3 various passive localisation approaches are presented with examples. Section 4 concludes the paper.

2. Active localisation systems

The vast majority of indoor location estimation systems have the requirement that the tracked person carries an electronic device or tag, which in some cases can process information and send the results to an application server running the positioning algorithms for further evaluation and/or processing. Various metrics used in indoor localisation approaches are Received Signal Strength Indicator (RSSI), Time of Arrival (TOA), Time Difference of Arrival (TDOA) or Direction of Arrival (Angle of Arrival, AOA). Positioning techniques used are WLANs, Ultra-wideband (UWB), Field strength systems, Radio Frequency Identification (RFID), ultrasonic techniques, or hybrids of previous metrics. This section is focused on the comparison of various Active Localisation systems.

2.1. RFID

SpotON is an indoor 3D Location estimation technology based on Radio Frequency (RF) Signal Strength. The system is similar to the Microsoft Research (MSR) WaveLAN and the Pinpoint systems [24]. The authors in [25] indicate the possibility of achieving better resolution and accuracy compared to the MSR system and with a lower cost than the Pinpoint system. SpotON is actually based on a product called AIR ID sold by RFIDeas, a company from Illinois [26]. One of AIR ID's limitations is the RS232 basestation protocol. RS232 cabling is not ubiquitous, has a limited run length, and a limited number of serial ports existent on the server. In order to have more flexibility the system uses the Hydra microweb server (see Fig. 2). Hydra was developed at Xerox PARC but it is no longer an active project [27].

Fig. 2. Hydra microweb server [25].

SpotON is based on multiple base stations measuring the signal strength. A central server has the role of aggregating the values and estimating the position of the tracked object using triangulation. The estimated location is then available to a client application. The system presented in [25] is a prototype which only offers the immediate location of an object and does not store any data on the server. A visualisation client offers the possibility to view the estimated location. The limitations of the system are significant. The precision and accuracy are comparable with a rudimentary motion sensor thus the real-life applications are limited to the user's requirements [25]. SpotON can be used to deploy applications such as light control or similar applications which do not require a high accuracy. The authors in [25] mentioned that an object can be fixed to a position with an accuracy of around 3 m.

The measurement frequency for each location can take between 10 and 20 s. Significant data can be lost because of the long time required to get one measurement. Another aspect that can further limit the system is the power supply, with two lithium coin cell batteries providing 10 h of normal operation [25]. Although the system has significant limitations, the idea behind SpotON is that low cost off-the-shelf technology can help gain more experience in location estimation and the required parameters.

2.2. Ultra-wideband (UWB)

Ubisense is a commercial location estimation system. Ubisense has very high precision, approximately 15 cm for 95% of the readings due to the use of the active tags signal triangulation [28,29]. The main components of a Ubisense systems are: the sensors, the tags to be tracked and the software platform. The Ubitags use RF Radio (2.4 GHz) to coordinate the UWB (6–8 GHz) pulse transmission time. The system uses both TDOA and AOA in order to estimate the location of a specific tag. The 3D location of an Ubitag can be estimated using at least two receivers.

Ubisense does not require Line-of-Sight due to the UWB technology. The signal can be filtered and the multipath effect minimised. This is huge advantage because the multipath effect represents the main cause for low accuracy indoors. Ubisense can cover large areas and offers the possibility of tracking a large number of user in real-time. The spatial coverage is ensured using cluster methods running a large number of services with a fair usage of bandwidth. The system works in similar manner with a cellular network where the environment is organised into cells with at least four sensors/readers.

A drawback of Ubisense is the timing cable required for every Ubitag which can become challenging in some environments. Ubisense can estimate the location of the Ubitags with very high accuracy. However the price to deploy such a system is high, about $16.875 for the research package [21].

2.3. IEEE 802.11a/b/g/n WLANs

2.3.1. Ekahau real time location system (RTLS)

Ekahau is a commercial positioning system that uses WLANs and tracks electronic devices such as tags, personal digital assistants (PDAs), PCs, handsets equipped with wireless network cards. The estimated location is computed correlating space information with the signal strength measured when the device is connected to various access points (APs). In order to achieve this it is necessary to consider the propagation characteristics of the recorded signal and to use advanced probabilistic mathematics.

Various location estimation methods such as using the signal strength of standard Wi-Fi infrastructures are used. This method performs better in comparison with time-based methods which can be expensive considering the proprietary infrastructure required [2,8]. Another drawback is the poor performance of the time-based estimation methods indoors. The signal's short travel time and also common obstructions such as human presence, walls or other objects represent the main reasons for a poor performance. The Ekahau RTLS is actually a combination of tools (see Fig. 3) such as the Ekahau Client, Ekahau Positioning Engine, Ekahau Manager, Ekahau Planner, Ekahau Application Framework and SDK.

The Ekahau Client is running in the background on each device as a small service that allows the communication with the Positioning Engine implemented on a server. One of the benefits of using the standard Wi-Fi communication is that the Client can be embedded into any devices using an 802.11 radio. The Ekahau tags can be attached on assets or other devices without 802.11 radio communication or carried by people. Various systems are using similar electronic tags in the case of Radio Frequency Identification (RFID) or infrared (IR)-based systems. However the Ekahau tags do not need to be in close vicinity of a reader. The communication between the Client and the Positioning Engine uses a minimal bandwidth and processing power due to the fact that the only information sent is the Received Signal Strength Indicator (RSSI).

The application running on the server in charge of computing the device position is the Ekahau Positioning Engine (EPE). The Positioning Engine is a Java-based software that can estimate the position in two ways: as client location (x, y), floor, speed, direction or as logical information ("mail room", "meeting room").

Location maps can be created as positioning models using the Ekahau Manager. This is a stand-alone tool for drawing logical areas, testing positioning information and analysing the accuracy of the estimated location. After the positioning models are created, the models can be saved in the Positioning Engine. The Manager offers functions such as location maps management, performing site calibration, permissions for networks and APs, tracking rails management (provide improved positioning accuracy), displaying device locations and properties for administrative purposes, logical areas management (used to determine whether a client device is within a given area – proximity), saving and loading positioning models, sharing work by merging positioning models and analysing positioning accuracy.

The Ekahau application suite also includes a planning tool which can be used for Wi-Fi network design and deployment. The Ekahau Planner is based on a drag-and-drop Graphical User Interface (GUI) that allows the user to place access points (APs) on a floor map and shows the radio propagation.

A drawback of Ekahau is the impossibility to get location estimations in blind spots, areas not covered by the APs. A solution in this case is to install additional APs. However this will increase the cost of the deployed system. Another solution is presented in [31] where the location is predicted based on movement habits.

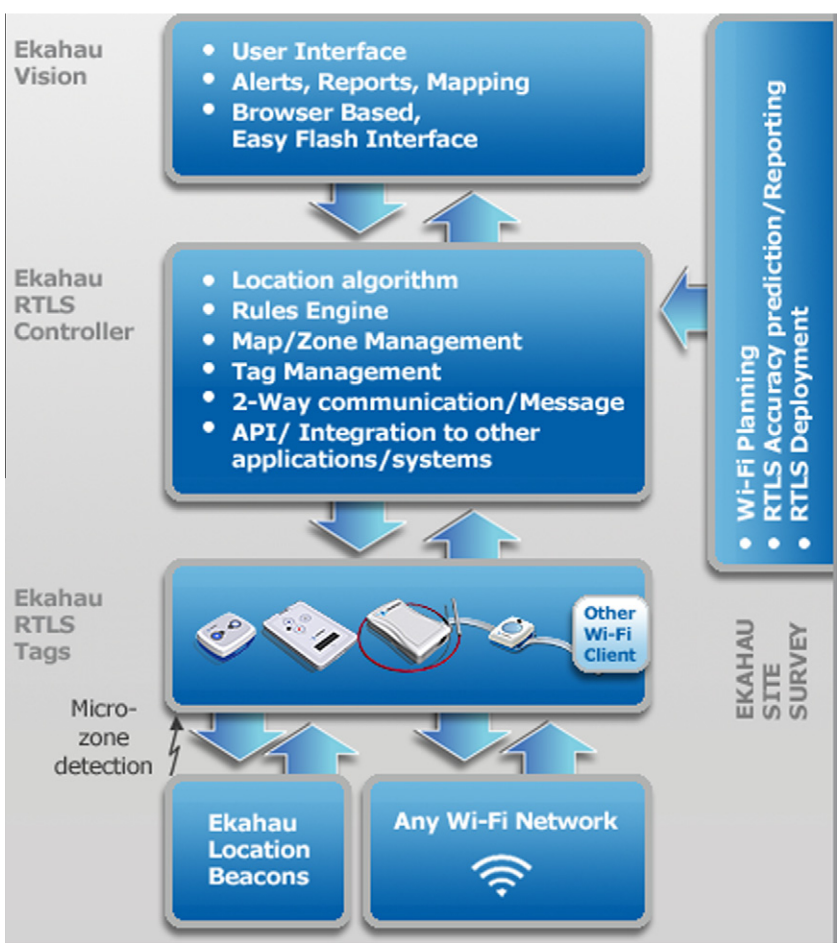

Fig. 3. Ekahau RTLS overview [30].

This method can be used only if the tracked users repeat a task regularly. A similar method was implemented for outdoor location estimation using GPS. The location of a car entering a tunnel can be predicted based on a map, the direction of movement and the speed.

2.3.2. Microsoft research radar

Radar is probably the first example of a positioning system using IEEE 802.11 networks [32,33]. The main issue to be addressed in this case is the noisy characteristic of the wireless radio which can be affected by multipath fading, reflections, and obstructions. In order to address the noise problem, Radar uses the fingerprinting method which is an offline method that involves recording a radio map of the environment. This map is built based on the radio strength of the wireless signal in specific locations in the environment. Thus the radio characteristic is linked to a physical location in the environment. The Radar system computes the location by monitoring the signal strength of the tracked devices and comparing the value with the database entries used to create the radio map. This method represents the empirical method used by Radar. A second method is a mathematical model based on measuring the radio propagation properties of the environment to be monitored. In the mathematical method the radio map was replaced with the indoor propagation properties and layout information of the environment.

Radar has an accuracy of 2–3 m (approximately the size of an office room) with a probability of 50% using scene analysis. A second deployment uses lateration with an accuracy of 4.3 m and a similar probability as the scene analysis. Another drawback of the Radar system is the change of the indoors radio propagation whenever significant changes of the environment occur [33]. The only method to overcome this problem is reconstructing or creating a new signal strength database. Radar can be used to detect the direction and orientation of the user. The system also allows the user to select his position by clicking on the map of the environment. No privacy issues can arise using Radar due to the fact that the device computes its own location and the estimated location is not shared with other devices.

The Radar system has limitations in that the devices require a radio chip implemented, which in some cases (very small devices or due to power constrain) is nearly impossible, also multiple levels buildings can cause the estimation of the user on another level and the human body can cause obstructions of the wireless signal.

2.3.3. AeroScout

AeroScout is a Wi-Fi-based localisation technique [34]. An existent wireless infrastructure is used to compute the location of any mobile devices using the 802.11b/g standards and can also track the AeroScout tags. The system uses Time Difference of Arrival (TDOA) for larger indoor environments and outdoors, and Received Signal Strength Indicator (RSSI) for smaller size indoor environments. The AeroScout receivers are used differently based on the localisation technique implemented. Thus for TDOA the receivers are long-range Wi-Fi readers and for RSSI the system uses the same receivers or in some cases it uses Cisco access points as readers.

The AeroScout system presented in Fig. 4 can be deployed using AeroScout Wi-Fi tags, location receivers, exciters and an AeroScout Engine.

AeroScout tags are battery-based tags with a long battery life which can be extended if the tags are switched off whenever their location is not within the monitored area. The tags use standard wireless communications enabling the possibility to compute the location of people and assets which otherwise are not connected to a 802.11 wireless network. They are equipped with wireless or serial interfaces which can be used for remote programming. Traditional RFID require dedicated readers in comparison to AeroScout which uses standard wireless access points as long-range readers in order to estimate location. Long-range tracking is deployed using standard wireless access points as readers where for short range the tags can be triggered by the AeroScout Exciters. The range covered by the exciters is approximately 6.5 m. In order to extend the coverage area multiple exciters can be linked together behaving as a single exciter.

AeroScout requires TDOA measurements in order to compute the position of the tracked tag or device. AeroScout receivers have the main role to record the TDOA measurements of standard 802.11 messages and send this information to the AeroScout Engine. Each receiver has the capability of processing approximately 300 measurements per second. For the case when RSSI measurements are required the AeroScout system uses the existent wireless infrastructure. AeroScout can be deployed as a indoor-outdoor localisation system using a mixture of access points and AeroScout receivers.

2.3.4. Intel Place Lab

Intel Place Lab [2,35] represents another active localisation approach using the Wi-Fi to compute the location. Place Lab works both indoors and outdoors [36]. Once the user has a Wi-Fi

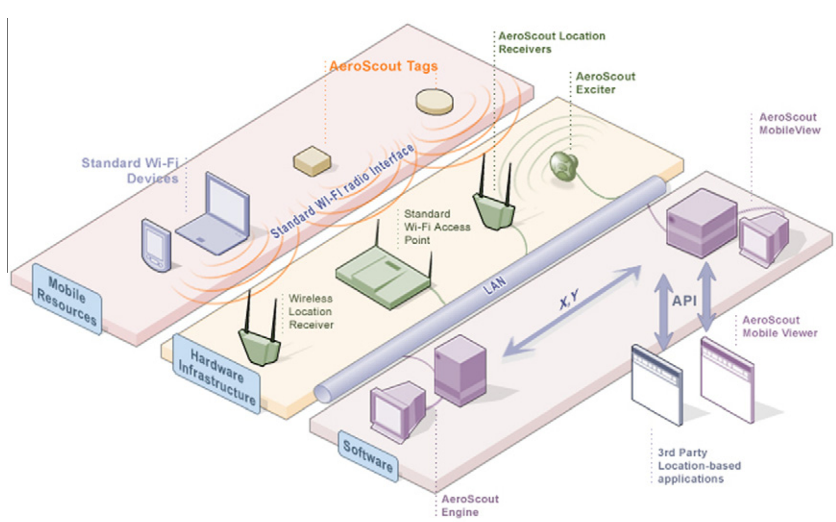

Fig. 4. AeroScout architecture [34].

connection there is no need for extra hardware transforming the Intel Place Lab into an inexpensive localisation system. Nowadays the number of devices with integrated Wi-Fi has increased, thus the user can download the localisation software for free from the Place Lab web site. This localisation system uses the unique ID broadcast by the access points whenever a user is trying to connect. Even though this unique identifier seems useless for many users it can be used as a parameter connecting the device to a specific location where the AP is deployed.

The majority of the localisation systems using Wi-Fi require line-of-sight from the device to the APs. Place Lab does not need line-of-sight to determine the location and offers an accuracy of 20 m. Fig. 5 presents an overview of the Intel Place Lab components. A client running on the user's device which does a survey of the area to be monitored searching for APs and recording the unique IDs of the APs found. The unique IDs are linked to the GPS position of the AP, building a map of the available APs. The method to compute the location of the user's device is triangulation by comparing the unique ID sent by the APs with the entries recorded in the database and extracting location information. The database containing the APs is built by having people driving around the area to be tracked and listening for available 802.11 APs. The accuracy of the system can be improved increasing the number of existent APs. The benefit of using the Place Lab is the fact that you have the software available for free and no new hardware is required for using the system. The difference between this approach and other localisation systems (e.g., Ekahau) using Wi-Fi is that the Place Lab does not require a radio survey or fingerprinting and does not require that the position of the APs to be fixed.

One drawback of deploying an 802.11-based location system is the reduced number of existent APs in less populated cities or areas [2]. In order to overcome this problem, the Intel Place Lab started using Global System for Mobile Communications (GSM) and Bluetooth devices in parallel with the 802.11 APs providing an accuracy of 20–30 m.

The key components of a Place Lab system are: radio recordings also known as beacons, databases containing the location information of the beacons and clients estimating current location based on the data from recorded in the databases.

The user's device is listening for beacons sent by Wi-Fi, Bluetooth, and GSM and compares the unique ID received with the database entries of a precomputed map where the ID is directly linked to a physical location.

The Place Lab does not encounter privacy issues as the location of user's device is computed entirely on the device itself using segments of the database of known beacons from that specific location. Whenever a new client starts up or an existing client is moving to a new location the device downloads segments of the database representing beacons from the APs in the surroundings. The user can receive relevant information such as closest restaurant, hotel, and post office based on the location of the device.

The accuracy of Place Lab is estimated to be within 20–25 m due to the minor calibration required which is about ten times worse than other location estimation systems using a more detailed radio map based on fingerprinting [2]. The accuracy and the area monitored is dependent on the number of APs sending beacons existent in the monitored area. The Place Lab clients do not need to send data to the APs. An alternative technology that can be used with the Place Lab system is Bluetooth. The drawback of this technology is the fact that it requires the user to do a scan in order to detect the beacons in the area. An important requirement of the Place Lab system is the existence of the database containing details of the beacons' position. An existent AP will not improve the accuracy if the location of the AP is not recorded in the database.

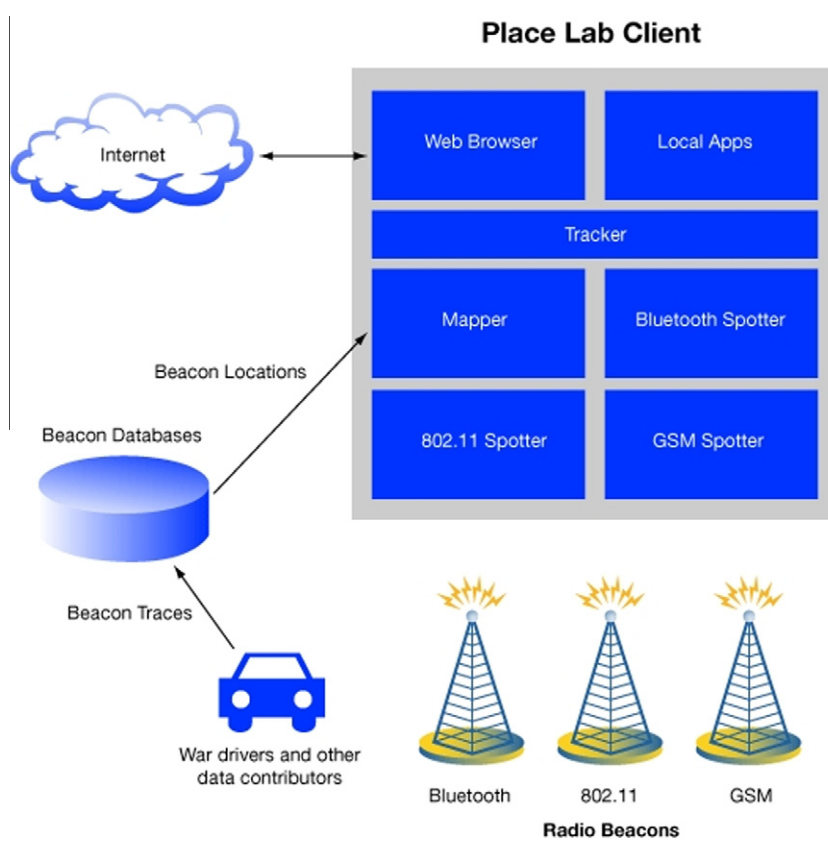

Fig. 5. Intel Place Lab Overview [37].

The database is built by driving around the area to be monitored and detecting all the APs based on their unique ID and on their GPS location as well.

Place Lab Clients are usually built from three components: *spotters*, *mappers*, and *trackers*. The spotter is the component that has the task of monitoring the radio interface and to listen to beacons in the environment. The mapper is designed to record the location information (latitude and longitude) of the discovered beacons. The last client component but not the least is the tracker. The tracker takes the information provided by the first two components and computes the estimated location of the tracked device.

Intel Place Lab is not supported nowadays but it represents one of the approaches reviewed often in the literature. Place Lab played an important role in the growth of the Wi-Fi usage enabling new applications for various scenarios.

2.3.5. PinPoint 3D-iD

PinPoint 3D is a commercial product from RFTechnologies [38]. The previous system was estimating the location based on RF code and phase [25] with good accuracy and high scalability. PinPoint has the disadvantage of being quite expensive [22]. The tags provided (see Fig. 6) with the RTLS are small and can be worn using a lanyard or clipped to the belt. Location information is obtained with a touch of a button on the tags. The system is advertised as having fast response due to the Help Alert software. PinPoint RTLS has high scalability and can cover an entire enterprise. The PinPoint RTLS can be deployed using the existent Wi-Fi infrastructure or using the ZigBee network option for environments without Wi-Fi infrastructures.

PinPoint 3D-iD is a commercial system, thus many technical details are not available. More details are given in [39] where a system for asset and personnel tagging utilising GPS is presented. PinPoint system requires two main components, an array of antennas (multi-antenna interrogator) and the tags to be tracked. The multi-antenna interrogator sends 2.44 GHz beacons interrogating the tags. The tag being interrogated receives the 2.44 GHz signals, mixes the carrier up to 5.8 GHz, filters the result and replies to the interrogator with a low power 5.8 GHz signal. PinPoint is designed for indoor asset or personnel tracking where GPS does not work. Authors in [39] present an extension of the PinPoint system using low-cost GPS chipsets and differential GPS techniques to improve accuracy for outdoor applications.

Fig. 6. Pinpoint RTLS tag [40].

2.4. Infrared localisation

One of the first location estimation system was developed at AT&T Cambridge. The Active Badges system [41,42] was deployed using small tags emitting infrared beacons every 10 s that had to be carried by the person to be tracked. The data is collected by a central server and saved in a database. The user can have access to the location information using an API provided by the central server.

The range of the IR tags is approximately 6 m and it is known that the IR signals are not travelling through walls. The IR technology is inexpensive which represents an advantage for deploying IR-based localisation systems. A disadvantage of the Active Badges system is the reading frequency used which is 15 s in [41]. However this time window is suitable indoors where the persons tend to move relatively slow. One possible application described in the literature is a system which can help a telephone receptionist find the nearest telephone extension.

The Active Badges system was limited to just providing location information. The location of a badge is just symbolic i.e. the room where the badge is located. The system is affected by fluorescent lighting and direct sunlight, having difficulties to get location information. The cell size for a detected badge is limited to small or medium size rooms [23]. Larger environments can be covered by multiple infrared beacons. The functionality can be extended using low-power microcontrollers or other more complex technology which can offer support for more functions. A tag can be used as a key for secure areas but the drawback is the possibility to copy the signal used.

2.5. Ultrasonic localisation

A second localisation system developed at AT&T Cambridge is the Active Bats system [43]. The Active Bats system uses physical devices such as ultrasonic badges sending information to a receiver mounted each square meter. Based on the data received the system computes the user's location. The system can estimate the location of the user providing also orientation information. The location is computed using TOF (Time of Flight) triangulation based on the receivers mounted on the ceiling. The receivers are connected using a wired network. The wired network gives the possibility to reset the receivers at any time.

The location of the bats is computed based on the ultrasonic pulse emitted after the bat was triggered over the wireless network. The wireless network can also be used to reprogram the bats. The high number of receivers can achieve a high accuracy around 9 cm for 95% of the readings in a 3D location estimation scenario using 100.000 measurements within a 10 m^3 volume [44]. A statistical rejection algorithm is used to eliminate distance measurements with large errors caused by objects reflecting the ultrasonic signal.

A drawback of the Active Bats system is the cost involved and scalability of the system due to the fixed infrastructure placed on the ceiling that requires very precise positioning [23]. Also, there is a limited number of timeslots which must be distributed efficiently between the existent Bats. A location update is done every 20 ms, thus 50 timeslots are available per second for each base station [44].

There is a large number of possible applications such as connecting a call to a telephone extension near the user, location-based advertisement or controlling a computer if the tag is placed in a specific place and many other.

2.6. Localisation using standard TV signals

Another technique to estimate location information is Rosum TV [2,45]. Rosum is estimating the position of receivers based on standard TV signals broadcast. The receivers can be in a fixed position but can also be implemented in mobile devices such as phones, computers, vehicles, etc. Rosum can be used in many applications to monitor expensive assets or as a help for emergency responders whenever they go in a building. The system is based on the synchronisation information included in the TV signals in order to compute the location of the receivers. The technique used to determine the distance is called multilateration and it needs at least three transmitters located in fix positions (also known as trilateration) [2,7,12].

Rosum requires precise time measurements to determine the distance from the transmitter to the receiver. Next the time measurements are compared with known data recorded in a database which helps to calculate the device's location. The drawback of Rosum TV is the impossibility to scale the location detection to a 3D localisation system. There is not enough information to estimate the device's vertical position in a building.

Fig. 7 shows a second deployment which is a hybrid localisation system named Rosum TV-GPS based on the same technology combined with GPS information capable of estimating the location indoors and outdoors. Rosum offers support for most TV standards available globally.

The components required to deploy a Rosum TV localisation system [2] are a Rosum TV Measurement Module (RTMM), location server, monitor unit, communication channels and a pseudo-TV transmitter (see Fig. 8).

The RTMM is a chip integrated in the devices to be tracked. The TV tuner integrated in the RTMM chip receives the standard TV signals and forwards these signals to the digital signal processing module. Other components integrated in the RTMM chip are logic blocks and memory. The time needed by the signal to get from the transmitter to the receiver is measured and sent to the location server as pseudo-range measurements. Based on the pseudo-range measurements the role of the location server is to estimate the position of each RTMM chip.

The costs involved in deploying a localisation system such as Rosum could be considered as another drawback in comparison to other localisation systems which do not require any new hardware such as Wi-Fi-based localisation technologies.

2.7. Bluetooth localisation

BLIP Systems is built on top of a managed Bluetooth network (Fig. 9) known as BlipNet [2,48,49]. The BlipNet network offers access to LAN/WAN via Bluetooth. The components required for deploying a BlipNet network are as follows: mobile devices with bluetooth integrated, BlipNodes, a BlipServer, and a server running the tracking application. The devices found in the proximity of a BlipNode can connect to that BlipNode in three ways. One approach is to register a service called Serial Port Profile (SPP) on the BlipNode, service that will be used by the device to establish the connection.

A second method is to continuously query from the BlipNodes the devices in range and make a selection of the devices that can be used in the BlipNet network. These methods require some information from the device such as the Bluetooth address, information necessary to establish a connection using one of the existent protocols.

The last method to connect a device to a BlipNode is using a LAN connection sending HTTP requests for a specific URL. Whenever the device sends an HTTP request, the Bluetooth address can be verified by the BlipServer. BlipServer passes the connection data to the application running on the device.

BlipNode represents a Bluetooth access point (AP) which offers LAN access via Bluetooth to the mobile devices. BlipNodes require an operating BlipServer. A BlipNode establishes a connection to the BlipServer through LAN, Internet, or through a link to another BlipNode. The BlipServer represents the core of the Blip System and it is in charge of configuring, monitoring, and controlling the BlipNodes in the BlipNet network. Fig. 10 shows the architecture of the BlipServer. An open Java API is available offering the possibility for third-parties to develop applications to interface with the BlipNet. Through the BlipNet API, the application has access to location information gathered from the Bluetooth devices. The API can be used to configure a BlipNode to start or stop the detection of devices using Bluetooth communication. Location information can be accessed using the API and based on that information various events can be triggered such as opening doors, sending specific content based on the location of the user and so on.

BlipManager is a Graphical User Interface (GUI) tool, a component of the BlipServer having the role to configure and manage the BlipNet network. All the configurations modified using the BlipManager affects the BlipServer directly.

As an advantage the Bluetooth location estimation offers the possibility to locate any Bluetooth mobile device without the need of any additional hardware. BlipNode can handle up to 21 connection at the same time which for large environments or large number of mobile devices can be seen as a limitation. Another disadvantage is the Bluetooth range which depends on the Bluetooth Class. The maximum range is approximately 100 m for

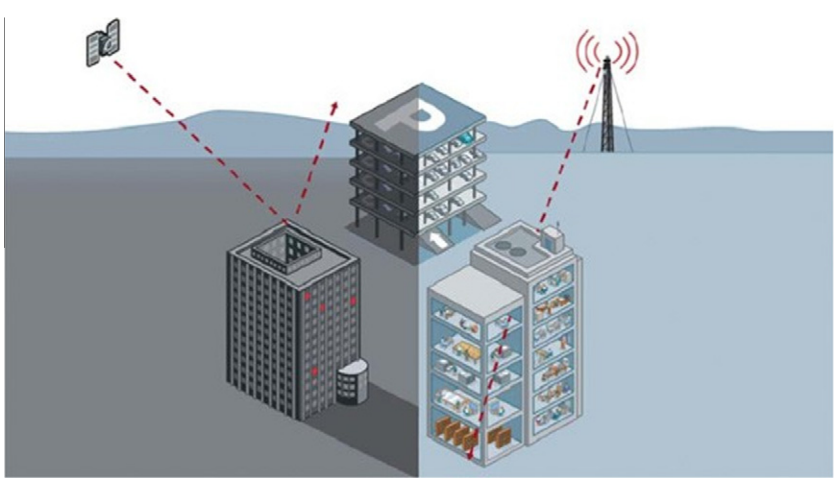

Fig. 7. Rosum TV-GPS overview [46].

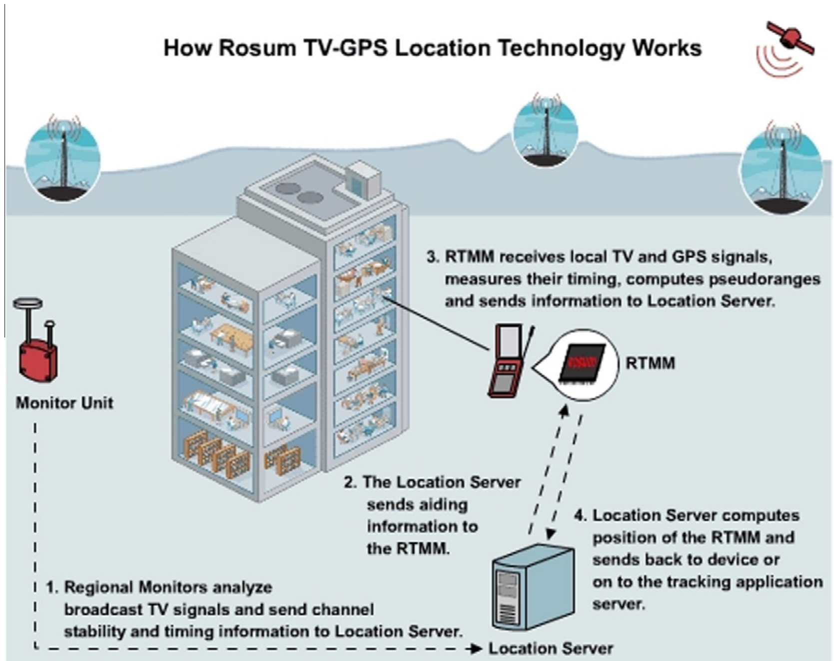

Fig. 8. Rosum TV-GPS components [47].

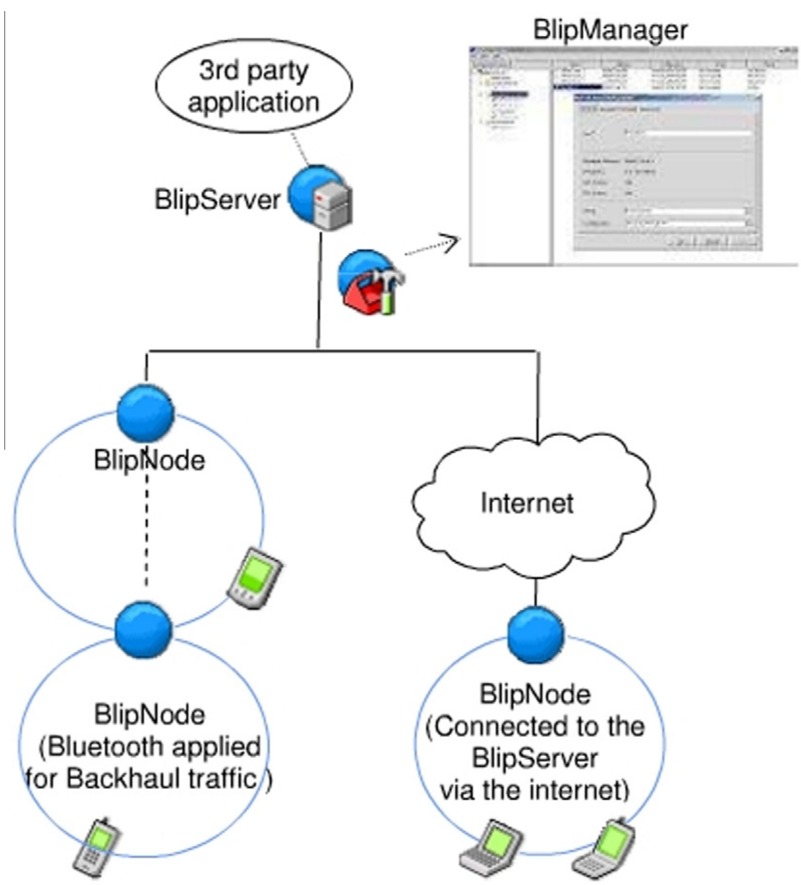

Fig. 9. BlipNet overview.

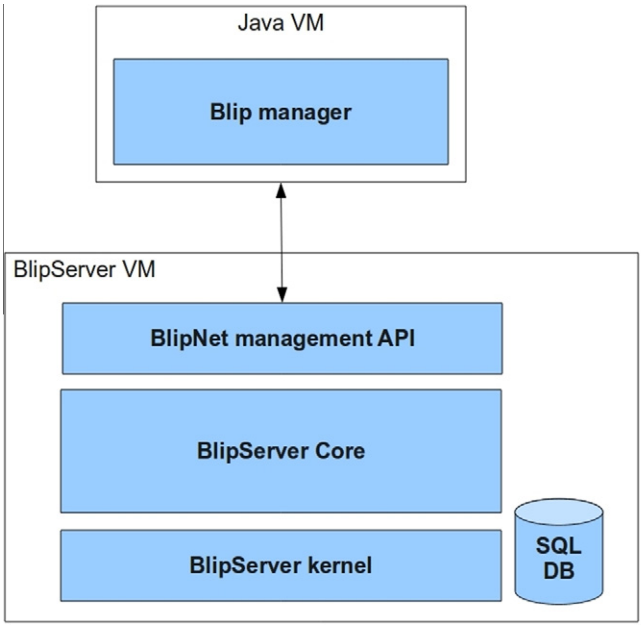

Fig. 10. BlipServer architecture.

Bluetooth Class 1. The range can be extended with directional antennas and signal amplifiers but this increases the cost to deploy a Bluetooth-based localisation system.

2.8. Hybrid systems

2.8.1. MIT Cricket

The hybrid system MIT Cricket is an indoor localisation system developed by MIT [2,9]. The system is composed of the Cricket hardware (beacon and listener), software-based algorithms, and an API for location-based applications running on various mobile devices. The Cricket system has an accuracy of 1 m to 3 m and supports multiple target discovery. The user's position is not shared unless the user accepts advertising that information. Thus there are no privacy issues due to the location being estimated on the mobile device. MIT Cricket can be used on various mobile devices such as smartphones, handheld devices, laptops, and sensor nodes. The mobile devices are listening for information published by the beacons (see Fig. 11), small devices installed at fixed locations in the monitored environment. The beacons are sending specific information about the environment, information used to compute the location.

The position of the user is calculated using a mixture of radio frequency (RF) messages and ultrasound pulses. The beacons are wall-mounted or ceiling-mounted using a 418 MHz AM band to send location specific information. Each RF message is followed by an ultrasonic pulse. Upon the receiving of the RF messages the listeners use the ultrasonic pulse to estimate the distance from the beacons. The beacons used in the Cricket system are active and the listeners are passive, thus the system has a couple of benefits. First, the scalability of the system will not be affected by increasing the number of listeners. Second, the location is estimated on the device using the information received from the beacons, which means Cricket is not a centralised tracking system. As previously mentioned the beacons are small devices mounted on the ceiling (or other location) in the environment that offers line-of-sight with the listeners. The beacons are organised in a grid with 1.5×1.5 m cells, thus it can give location granularity of 1.5×1.5 m. The listeners are devices such as handheld devices, mobile phones, sensors listening for the messages send by the beacons and infer their location based on the details received. After the location is estimated the listener uses the API to inform the software. The listeners can be static or mobile.

Cricket presents a number of advantages with some known limitations. Using active beacons and passive listeners has important benefits. First it does not rely on databases and centralised controllers record the information from users and devices. There are no privacy issues as the devices learn where they are and choose if and where they want to advertise the information. The communication between the Cricket beacons does not require any infrastructure. The system also scales well when the number of devices increases. Cricket's limitations are the absence of a centralised management and monitoring functions. The computational requests are also quite high, which means a high power consumption in order to synchronise the ultrasound pulse and RF data.

2.8.2. Skyhook

Skyhook Wi-Fi Positioning System (WPS) is the first indoor-outdoor metropolitan localisation system that uses Wi-Fi instead of satellites or cell towers to accurately estimate location [10]. Skyhook deployment is not expensive due to the use of existent wireless infrastructures.

In [2] Skyhook and Intel Place Lab are described as map-based pinpointing approaches. We have included Skyhook WPS in the

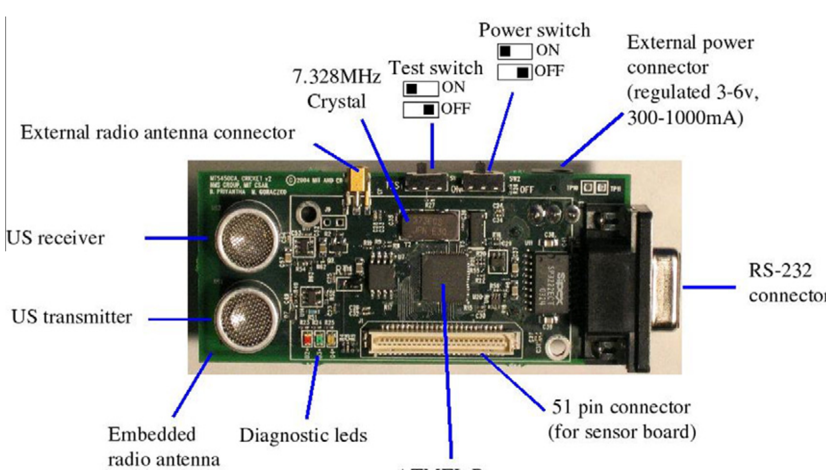

Fig. 11. Cricket beacon [50].

hybrid systems category as this system combines data collected from APs with information about APs location collected by war drivers using GPS. There is no cost involved in the usage of discovered APs. Skyhook exploits the capability to obtain the unique ID of almost all APs. This is the default configuration of almost all access points. The triangulation method is used to pinpoint the location of a device. This is based on the time it takes for a device to receive a reply from any AP available in the area after a scan request was sent.

Skyhook's Core Engine is software-based localisation system estimating location with an accuracy of 10–20 m. Raw data is collected from available Wi-Fi APs, satellites and cell towers. The data is processed afterwards using hybrid localisation algorithms. By using raw data from more than one location technology the best location estimation is provided. A Skyhook client running on the mobile device collects data from the sources and sends it to the Location Server which returns the estimated location. In order to minimise data cost and maximise battery life the client communicates with the server only if the location cannot be obtained locally.

Skyhook's Core client provides location information to the applications or devices requesting it. Power optimisation, synchronisation, and location estimation are the features managed by the client. The server provides the most up-to-date location information to the client whenever this is required. The Core Engine does not require any new hardware minimising deployment cost and time.

Skyhook has a publicly available Software Development Kit (SDK), free of charge, which allows developers to design their own location-enabling applications. The SDK is available for various operating systems and can improve location information accuracy available on mobile devices.

Table 1 shows a comparison of current Active Localisation Systems. The most used positioning technology for open areas is WLAN due to the low cost implementation. RFID is more suitable for dense environments. Technologies such as: ultra-wideband (UWB), infrared, ultrasonic, standard TV signals, bluetooth and also hybrid systems were presented in this section.

3. Passive localisation systems

Many applications could be developed using passive localisation: such as detecting intruders in the home or any other area of particular security interest [3,4,**?**], helping emergency responders, military forces, or police arriving at a scene where entry into a building is potentially dangerous [51,52].

3.1. Device-free Passive (DfP)

The radio frequency used by the nodes is 2.4 GHz. The human body contains more than 70% water and it is known that resonance frequency of water is 2.4 GHz [4,53]. Thus the human body is reacting as an absorber attenuating the wireless signal.

The Device-free Passive (DfP) Localisation technique [54–58] (or variance-based tomographic imaging (VRTI)) focuses on identifying a person's location without the use of sensors, thus it can be included in spatial locations subcategory [3–5,51,59,60]. It is called 'passive localisation' as the person being tracked is not carrying any electronic device such as tags or sensors. VRTI is an extension to the technology denoted in the literature as 'radio tomographic imaging' and is so-called due to its analogy to medical tomographic imaging.

Ref. [3–5] presents various features of DfP localisation systems. The features can be classified as follows: tracking, identification, detection, multi-person and automatic construction of a passive radio map. Some of these features are considered as future possibilities. The research done in this direction determined that the DfP technique can use a standard Wi-Fi infrastructure to offer valuable location information.

Table 1
Comparison between active localisation systems

System	Location Technologies	Positioning Algorithm	Accuracy / Precision	Complexity	Scalability / Space dimension	Cost
SpotON (2000) [25]	Active RFID RSSI	Ad-Hoc lateration	Depends on the cluster size	Medium	Cluster at least 2 tags/2D	Low
Ubisense (2005) [28,29]	UWB TDOA, AOA	Least square	approx. 15 cm/ 99% within 0.3 m	Moderate	Good 2D, 3D	Medium
Ekahau RTLS (2002) [2]	WLAN, RSSI IEEE 802.11a/b/g/n	Probabilistic algorithm	2–3 m/ 50% within 2 m	Moderate	Good/ 2D	Medium
Microsoft RADAR (2000) [32,33]	WLAN, RSSI	kNN, Viterbi-like algorithm	2–4.3 m/ 50% within around 2.5 m and 90% within around 4.3 m	Moderate	Good/ 2D, 3D	Medium
AeroScout (2011) [34]	TOA triangulation, TDOA, RSSI in IEEE 802.11	AeroScout positioning server/engine	1–5 m/ NA	Medium	Good/ 2D	Low
Intel PlaceLab (2004) [2,35,36]	Triangulation, IEEE 802.11	Map-based triangulation	20–30 m / NA	Moderate	Good/ NA	Low
Skyhook WPS (2011) [2,10]	WLAN, GPS cell towers	Hybrid location algorithms	10–30 m / 99.8% within 10 m	Moderate	Good/ NA	Low
PinPoint 3D-iD (2011)	UHF (40 MHz) TDOA (old version); IEEE 802.11, IEEE 802.15.4 (new version)	Bayesian approach (old ver.); NA (new ver.)	1 m/	Medium	Good/	High
Active badges (1992) [41,42]	Infrared beacons	Lateration	NA / NA	Moderate	Poor/ 2D	High
Active Bats (2001) [23,43,44]	Ultrasonic beacons, TOA	Triangulation	9 cm/ 95% within 9 cm	Moderate	Good/ 3D	Medium
Rosum TV (2006) [2,45]	Broadcast TV from TV towers	Multi-lateration	30–50 m indoors 5 m outdoor / NA	Medium	Good/ 2D	Medium-High
BLIP Systems (2003) [2,48]	Bluetooth, RSSI	NA	10 cm–10 m / NA	Moderate	Good/ 2D	Low
MIT Cricket (2000) [2,9]	Beacons, RF (418 MHz) +ultrasound	Least Square	approx. 10 cm 99%within 0.3 m	Moderate	Good/ 2D, 3D	High

Ref. [3] evaluates the performance of DfP system in a real scenario. A maximum likelihood estimator (MLE) was used to process the recorded RSSI. The results showed an improvement on the performance of the system by approximately 10% in a real environment compared with two other methods. The two methods used in the comparison with the MLE are: Moving Average Technique and Moving Variance Technique [4].

The Moving Average Technique is based on the comparison of a long term behaviour/static environment to the short term/current state behaviour. If there is a change in the radio signal that overcomes the threshold, an event is detected. The second algorithm, the Variance Based Detection, compares the variance of the raw data to the variance of the static environment. If there is a significant difference between the two streams an event is triggered based on the selected threshold.

The Moving Average and the Moving Variance Techniques were evaluated in a controlled environment where the achieved recall and precision was 100% for some values of the parameters. The drawback is that in real scenarios the RSSI measurements are affected by the motion of people, multipath, reflection, changes of the objects' position, Non-Line-of-Sight (NLOS). More details about the radio propagation indoors can be found in [7,61–64]. The algorithms used to detect an event in a DfP scenario have two phases: the offline training phase and the online tracking phase. During the offline phase the radio map of the environment is recorded. This method is similar to the fingerprinting method used for the active localisation system. The difference between the two methods is represented by the monitored parameters. The passive radio map is built recording the RSSI for a static environment, where the fingerprinting is the method to record the RSSI of the electronic tags/sensors in specific locations in the environment.

The measurements recorded during the offline phase are compared with the signal recorded during the online phase. If a person entered the room a variance of the RSSI will be generated. Based on the selected threshold an event can be triggered. In order to track a person, deterministic and probabilistic algorithms were used and probabilistic algorithms outperformed deterministic algorithms [5].

3.2. Ultra-wideband (UWB)

An alternate technique to perform a tag-free localisation is the ultra-wideband (UWB). UWB active localisation systems use an electronic tag/device which emits short UWB pulses to track an object or person while in the passive localisation case, the system monitors signal changes introduced by the tracked object/person in the environment. The FCC's classification of the UWB imaging category was as follows [65]:

- GPR – Ground Penetrating Radar, detecting buried objects.
- Wall Imaging – detects objects within dense walls; dense means here the possibility to absorb the transmitted pulse.
- Through-wall Imaging – detects entities located on the other side of the wall such as people inside a room.
- Medical Imaging.

The advantages of using UWB are the simplicity of the hardware used, the decreased interferences and reduced susceptibility to multipath fading. There are also concerns about using UWB because of the broadband nature that can reduce the impact on receivers with a narrowband.

One of the first through-wall surveillance system was designed to work on a frequency band operating between 902 and 928 MHz [66]. Two types of antennas were used: a high gain directional antenna with a gain around 9 dB and an omnidirectional antenna. Each antenna has a transmitter/receiver unit (TR). The sensitivity to motion was limited to between approximately 0.15 m/s up to 1.52 m/s which covers a common motion of a person. [66] describes six scenarios of real-life applications using the Motion Detection Radar (MDR) which proved that this technology can help law enforcement agencies. Whenever motion is detected the receiver emits a sound alerting the user about the event. The system has limitations such as walls with mirrors, wet and lead based paint, or other metallic objects in the environment which are not penetrated by the UWB pulse.

The technique called through-wall imaging (TWI) (also called through-the-wall surveillance) was also presented in [51,52]. Through-wall imaging has garnered significant interest in recent years for both static imaging and motion detection. This technique is considered to be an extension of the 'radio tomographic imaging' due to the correlation with the medical tomographic imaging. The goal of through-wall imaging is the ability to monitor objects or persons through building walls and other obstacles which has become a very important aspect for law enforcement agencies [60]. High resolution images showing the location of an object and other parameters like shape can be accurately reproduced using multi-frequency data [59].

Ultra-wideband (UWB) through-wall imaging has attracted recent interest due to its ability to penetrate walls. In [51] the authors present imaging results based on the virtual elliptic curve imaging method using the UWB pulse system. The systems based on UWB TWI methods can reproduce images with very high resolution. The UWB methods use short duration pulses with frequencies for TWI assigned by Federal Communications Commission (FCC) at below 960 MHz and from 1.99 GHz up to 10.6 GHz, frequencies with the ability of walls penetration.

Ref. [67] presents a new low cost UWB radar with applications in military and civil scenarios. The radar can provide features such as: high resolution images, image enhancement algorithms, image reconstruction, image segmentation, feature extraction, low cost manufacturing platform, and fast data acquisition. The system works by sending short UWB pulses, then it waits for the echoes from various objects or persons. The main component of the transmitter is a pulse generator sending short pulses via a 1–18 GHz horn antenna, where the the receiver is a 16-element antipodal Vivaldi array [68]. More details about the short UWB pulse can be found also in [69,70]. [70] affirms the challenging aspect of the UWB radar is the data acquisition due to the high sampling rate required by the Nyquist's sampling theorem, a rate of over 2 GS/s for 1 GHz bandwidth. The rate exceeds 10 GS/s in order to have a 1 cm resolution. The high sampling rate is required for a practical real-time See-Through-Wall (STW) system.

Ref. [71] introduced a UWB short pulse radar for through-wall surveillance using the finite-difference time-domain (FDTD). The results in this work are based on simulated data for a UWB short pulse radar trying to detect a box in a 2.36×3.59 m simulated room with concrete walls. The simulation was done using the FDTD numerical method which is a solution of the time dependent Maxwell's curl. The radar images were obtained from the simulated FDTD signals using a Back Projection Algorithm. They conclude that the proposed solution is a viable solution for a through-wall monitoring system.

Two other approaches that can be classified as sensor-less passive localisation are physical contact and computer vision [5].

3.3. Physical contact

Ref. [17] presents a simple and low cost two-dimensional location estimation system based on capacitance measurements called TileTrack. The system is said to be unobtrusive, an aspect that is not considered in other localisation systems.

The system measures the changes in the capacitance between floor tiles (transmitting electrodes) and two types of receiving electrodes (plate electrode and wire electrode) and uses a single-chip architecture. Tests showed that the best location for the transmitting electrodes is on the floor as close as they can be brought to the user, because this increases the capacitance between the floor tile and the person's feet. The prototype used to demonstrate the performance of the TileTrack system is based on 9 floor tiles which means 9 transmitting electrodes. The tiles are 60×60 cm square-shaped made from a 3.85 cm thick chipboard with thin steel coating (0.5 mm). The tracking area is built as a square of 3×3 tiles, with a 5 mm spacing between the tiles.

The number of receiving electrodes is arbitrary. TileTrack requires the receiving electrodes to be connected together to the same measuring circuit. [17] evaluated two types of receiving electrodes called plate electrodes and wire electrodes. The plate electrode was built from a copper plate and was attached to a wooden frame next to the floor tiles. The wire electrode is a standard power-line cable installed vertically from the floor level to approximately 190 cm height.

The provided tracking area of 1.8×1.8 m achieves an accuracy of 15 cm for a person standing and approximately 41 cm for a person walking. The solution is considered to be low cost due to the fact that the transmitting electrodes can be constructed using plain aluminium foil with a plastic cover. The hardware used is also not very complex or expensive. They use a Capacitance-to-digital converter AD7746, the ATMega8 microcontroller and a multiplexor. The update rate of the system is 10 Hz. However increasing the number of tiles will affect the update rate. More information about hardware cabling and the conversion capacitance-to-digital can be found in [17].

The concept of measuring the pressure caused by a person that steps onto the floor called the Magic Carpet was first introduced in 1997 [72]. The ORL Active Floor [73] was also presented in the same year. The first system was based on piezoelectric wires while the second one used pressure sensitive sensors, both placed under the floor. A few years later a new technique for pressure measuring was introduced [74]. The technique was based on the Electro Mechanical Film (EMFi) which is a thin, flexible, low-price electret material. Z-Tiles [75] is another implementation of sensitive floor using pressure measurements to detect the person's location. It uses multiple force-sensitive resistors on each node with the ability to detect pressure. A network of sensitive nodes establishes the tracking area with a varying size and shape. The Smart Carpet approach in [76] explores the possibility to enclose electronic components in textiles such as carpets in order to detect a person's location. Smart Carpet is based on a network of 180 nodes with one node connected to a PC. Each node is a capacitive sensor with a sensing wire placed in a 15×15 cm square and there is a 5 cm space between the nodes. [77] used a matrix of thin planar electrodes placed below the surface of the floor. When a person steps on a tile, that tile will behave as a transmitter increasing the current flow to the other tiles which are providing the return path to the ground.

3.4. Differential air pressure

AirBus [7] is a passive localisation system based on detection of airflow disruption indoors caused by human movement. The environment, e.g. a house, is considered to be a closed air circulation environment with central heating, ventilation, and air conditioning (HVAC). The air pressure sensor is placed within the HVAC unit (see Fig. 12) where can detect and record the pressure variation. AirBus can detect when a door is opened or closed with an accuracy up to 80% (HVAC in operation) and 68% (HVAC not in operation). These events can be used to estimate a person's location in the house.

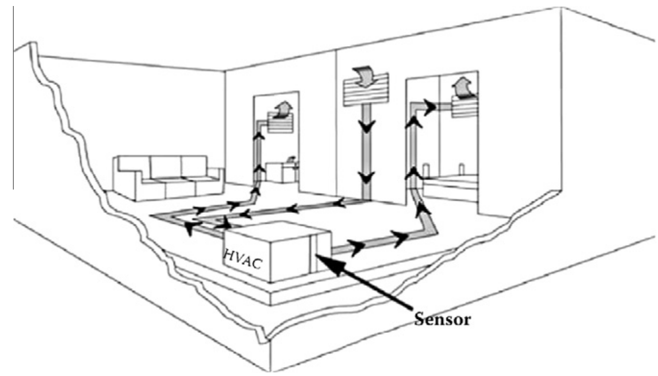

Fig. 12. AirBus overview [7].

An alternative to AirBus is to install multiple motion sensors to directly detect and determine the person's path.

3.5. Computer vision

Computer vision is considered to be a DfP system because the tracked person is not carrying any devices or tags. The focus for such a system could be transforming a simple environment into an intelligent environment [18]. The EasyLiving project [78] aims at developing a system that could trigger events based on the location of a person, such as: locating and switching on a device near to the user, understanding the behaviour of the person in a room in order to invoke users preferences like light in the room and playing music. Fig. 13 shows the architecture of the system built with 3 PCs and two sets of colour cameras. Each camera is connected to a PC, the third PC being used for running the person tracker algorithms. EasyLiving estimates the location with a 10 cm error and allows partial occlusions. The update rate is about 3.5 Hz. Examples of applications for computer vision systems are face recognition, game development, intelligent environments and security scenarios.

Various applications were developed in order to demonstrate the effectiveness of the EasyLiving project. One of the applications is a game called "Hot/Cold", where a person needs to guess a point in the room previously selected by a second person. The person

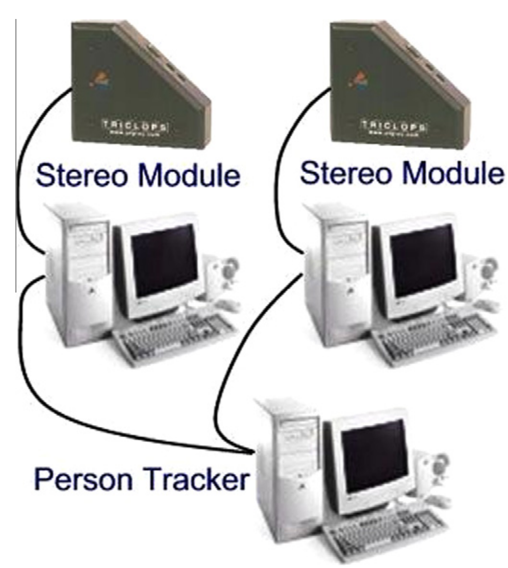

Fig. 13. Easy living hardware overview: two Triclops stereo cameras each connected to a PC running the stereo module. The two stereo modules both communicate with the person tracker application running on a third PC [18].

guessing receives clues such as "You are warmer" or "You are colder" as help to find the location. A second application uses a wireless mouse which is rerouted to control a computer in the near proximity. The third application is a pair of cartoon eyes following the persons in the room based on the person's position. The fourth application plays/stops a DVD player when a person leaves or enters the room. The application can also reroute the content of the DVD onto other displays/TVs based on the user's location in the room. These applications are just some examples to demonstrate what can be achieved with such a system. EasyLiving has the possibility to trigger events based on location information such as: playing a various devices, selecting music or other preferences, and also assisting a person after noticing a specific behaviour.

The environment where the experiments took place was organised as a common living room with sofas, tables, a PC, multimedia devices, and LCD displays. The Person Tracker is the application that has the role to track the persons in the environment. The output of the tracker is the location information and the identity of the persons. The concept of identity refers here to an ID each person is assigned with, not to the absolute identity of the person.

The EasyLiving tracker is built from multiple components as mentioned above, such as: colour Triclops stereo cameras [79], with each camera connected to a PC; the Stereo Module gets the output of the cameras, analyses it and organises the blobs in people-shaped blobs after a background subtraction is done; the Person Tracker receives the person-shaped blobs and starts tracking the people. Colour histograms of the blobs are used to distinguish people when they are separated by a small distance.

A calibration of the Triclops cameras position and orientation is necessary for a computer vision tracking system such as EasyLiving. There are two methods for calibration. The first technique is to use an application that allows a user to select a point in the room for each camera. Based on the selected point the correspondences and ground plane points are determined. The second technique is to record a person's path with each camera and to use calibration software that calculates the best overlap of the two paths. After calibration, whenever the system is operational, an important aspect is the background subtraction and the foreground image computation. The images resulting after these operations are depth images that are insensitive to shadows and changes of the illumination.

The depth images obtained after the background subtraction are represented as a list of pixels corresponding to the people in the room. Four connected pixels close to each other are called blobs. The blobs are then organised as people-shaped blobs using graph theory in order to calculate length of the arcs between the blobs. The identity of a person is maintained using colour histograms. The user is assigned a unique ID whenever he enters in the environment. Assigning an ID works well for people separated by a certain distance but it is not enough for people very close to each other. In order to cope with the last aspect a colour histogram is used to identify the person during the experiments.

The experiments demonstrating the performance of the EasyLiving project usually last approximately 20 min. The system performs well for three persons, based on their behaviour. In the case of more than three people the possibility of obstructions is very high. The users do not have the requirement to wear special clothes, but the system could encounter a problem with users wearing similarly coloured clothes. EasyLiving can detect people standing, sitting, walking through the room, or staying very close to each other.

Research in computer vision area is active with various systems using vision-based localisation techniques. Some characteristics of such systems are discussed in [78], such as: recording the location information and the identity of a person based on parameters (e.g. colour), the updating rate needs to be high enough to offer a fast and smooth response to any change of the user's location, the possibility to work when the environment is occupied by more than one person, multiple cameras to cover the entire environment, long tracking periods and tolerating partial obstructions.

Similar work in the vision-based area is discussed in [80–82] where the W^4 system can track separated persons using grayscale cameras [80], separated persons using stereo cameras [81] achieved with the W^4S system or clumped persons using grayscale cameras [82] achieved with the Hydra system. A mixture of these systems achieves most of the characteristics discussed in the EasyLiving project [78].

Ref. [83] introduces a system using colour stereo cameras with face detection.

In [84] a system based on multiple cameras was deployed to track multiple persons in a parking lot. Each person have a software agent assigned. The agents communicate checking if they are not assigned for the same person.

Carnegie Mellon University (CMU) developed a video-based monitoring system under the DARPA Video Surveillance and Monitoring (VSAM) project (1997–1999) [85]. The surveillance system based on multiple cameras have pan, tilt, and zoom functions and can track multiple persons and vehicles outdoors.

Ref. [86] uses a single camera for a tracking system that covers aspects such as object tracking, 3D movement evaluation, and action identification.

The implementation of a multi-person tracking for active localisation systems is relatively straightforward with the aid of electronic devices such as tags or sensors. The challenge however is implementing multi-person DfP systems. The DfP vision system [18] can track multiple persons using two sets of colours cameras. However the multi-person multi-camera method has limitations such as the number of people in the room at the same moment

Table 2
Comparison between passive localisation systems

System	Location Technologies	Positioning Algorithm	Accuracy/ Precision	Complexity	Scalability/ Space dimension	Cost
Through-Wall Motion Tracking (VRTI) (2006) [51,52]	Passive RSSI, IEEE 802.15.4	Kalman Filter	0.45 m/ NA	Medium-High	Good/ 2D	Low
EasyLiving: Multi-camera Multi-person (2000) [18]	Video Images	Video Processing Algorithms	approx. 10 cm/ NA	Medium-High	Good/ 2D	High
Device-free Passive Localisation (2007) [3–5]	WLAN, Passive RSSI, IEEE 802.11 a/b/g/n	Bayesian Inversion	approx. 18 cm/ NA	Moderate	Good/ 2D	Low
TileTrack (2009) [17]	Capacitance between multiple floor tiles and receiving electrodes	Centroid of	14.3 cm -Standing 40.7 cm - Walking/ 80% within 10 cm	Moderate	Poor/	Low
AirBus (2008) [7]	Differential air pressure	Feature Extraction Algorithms	68%-80%/ NA	Moderate	NA/ NA	Low

and tracking is problematic if persons are wearing similar coloured clothes. The work in [17] describes a location estimation system based on capacitance measurements. The authors discuss the possibility of multiple person detection if people are separated by at least one tile. The test bed used has only nine tiles, thus the implementation of multi-person tracking is not possible but simply considered as future work for a large scale implementation.

Table 2 shows a comparison of current passive localisation Systems. Active localisation uses measurements taken from sensors or tags actively involved in the localisation where passive localisation is based on differential measurements such variance of the signal or noise to estimate the position of assets or persons. Computer vision is the only technique presented which does not use differential measurements but is part of the passive localisation category as the object or person being tracked does not carry any electronic device.

4. Conclusion

This paper surveys various active and passive localisation techniques. Comparative tables showed important aspects reported by developers in the literature. In some cases, a few details have not been found or were not provided by the developers.

Fingerprinting is the most used method to deploy indoor localisation systems. Low cost localisation systems using WLAN-based techniques are dominant indoors. These systems are using existent wireless infrastructure and do not require new or proprietary hardware. However the RFID is more suitable for dense environments. There is no standard for indoor localisation. The selection of a localisation system depends on the granularity and accuracy required for a specific type of environment.

More hybrid systems such as Skyhook based on various localisation technologies are needed. Skyhook integrates indoor and outdoor localisation which increases the efficiency and robustness of the positioning system. Some localisation aspects such as accuracy, precision, required time to deploy a system can still be improved using smart hybrid algorithms and combining various techniques.

Passive localisation is the second type of localisation analysed in this paper. Currently, the number of passive techniques is still reduced compared with the active localisation systems. Passive localisation can be used to detect and track entities without requiring attached electronic devices or tags. A new concept called Device-free Passive (DfP) Localisation was introduced recently. DfP can detect a person monitoring the changes of the RSSI signals in the wireless communication.

Techniques such as DfP can be used to deploy systems with security applications helping the emergency responders, military forces, or police arriving at a scene where entry into a building is potentially dangerous.

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