Indoor positioning and navigation system for autonomous vehicles based on RFID technology

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Abstract. The localization and navigation systems play a very significant role in today’s world. They are commonly used in different fields of industry as well as in our daily life. Location of objects is crucial in logistics and transport to provide the real-time monitoring and management of process chain. There are numerous methods which allows to follow people and objects within defined area. One of them is Global Positioning System (GPS), which provides geolocation of objects on the earth as long as an unobstructed line of sight to four or more satellites is assured. As a consequence of this limitation, GPS cannot be applied for indoor environments. Recently, a couple of Indoor Positioning Systems (IPS) based on different technologies have been developed. Despite the drawbacks and limitations, these systems have been successfully applied for different fields of industry. Notwithstanding the above, reliable, accurate, cost-effective and simple indoor positioning methods are still in the area of scientists interest. Present paper provides a general overview of existing indoor positioning systems as well as authors concept of 2D wireless indoor positioning and navigation system dedicated for autonomous vehicles based on Radio Frequency Identification (RFID) technology.

1. Introduction
The last few decades have brought a great technological progress. At present time, a strong trend of automation and data exchange process within the production area can be observed. This tendency is considered as a 4th Industrial Revolution (called also Industry 4.0). The concept of Industry 4.0 is based on the production environment where people and machines create the cyber-physical system, within which they communicate, cooperate and self-organize their job [1]. It is worth to mention that one of the major direction of Industry 4.0 is Human Robot Collaboration (HRC). According to this concept, collaborative robots (called also cobots or co-robots) - equipped with safety and collision avoidance systems – assist the human co-workers in the most physically difficult and monotonic tasks within one workspace. No additional safety fence is required. In the face of above mentioned idea, reliable and accurate Indoor Positioning System (IPS) seems to be indispensable component of modern production environment. Tracking of goods during the production process, navigation and localization of people, robots and autonomous vehicles are only a few potential applications of IPS in modern production plants.

It is worth to mention, that not only the industrial environments have changed over last few decades. We are the witnesses of changing lifestyle and living conditions. Nowadays, our society lead sedentary lifestyle. A huge percentage of people spend our time sitting at home in front of their computers, TVs and smartphones. They do the shopping through the internet and even build the relationships. It is predicted that in the near future people will spend more than 70% of their lifetime within indoor environments [2]. Consequently, reliable and accurate indoor positioning systems are highly demanded to complement widely used satellite-based technologies and to ensure tracking
within outdoor environments. Such hybrid system would provide real-time monitoring of objects and people position regardless they are within in- or out-door environment.

The Global Positioning System (GPS) is the most commonly used localization system based on the satellite technology. Nowadays, GPS receivers are built-in most of everyday use devices, like smartphones, watches or vehicles. The GPS system contains mainly 31 satellites and receivers. The satellites are evenly deployed in the Earth orbit and constantly broadcast the radio signal about their position and current time. The signals from multiple satellites, which arrive to the receiver are processed in order to calculate its current position. The object position can be calculated as long as an unobstructed line of sight to four or more satellites is assured. As a consequence, GPS technology is not sufficient for indoor applications [3, 4]. Furthermore, indoor environments are usually more complex and susceptible for noises which decrease the reliability and accuracy of positioning systems. All the obstacles like, walls, furniture, electrical devices or human being influence the propagation of electromagnetic field. In reference to above mentioned issues, it can be stated that appropriate solution for positioning within indoor environments became a new challenge for the present day.

Recently, the real time indoor positioning systems have become an object of interest for many scientist centers. Despite the huge progress in regards to IPS that has been done over last decades, a reliable, accurate, cost-effective, simple and flexible indoor location system is still searched for [3]. One of the biggest challenge that must be faced nowadays is not only to develop reliable and accurate positioning system containing advanced and highly specialized sensors but also to implement hybrid system which would be based on currently existing technologies and commonly used devices [2]. WLAN-based (Wireless Local Area Network) indoor positioning system can be mentioned as an example of such approach. WLAN technology reuses the devices and networks which are widely used almost everywhere. Consequently, any additional equipment or infrastructure are not required to implement IPS utilizing WLAN. Another approach which comes from an idea of reusing already deployed technologies are smartphone-based IPSs [5]. These are only two examples of many different indoor positioning systems (based on IR, RFID, WLAN, Bluetooth and other technologies) which have been already designed and implemented. More examples of locating systems are given in the further part of this article.

The following paper contains a general overview of currently existing indoor positioning systems as well as the authors concept of 2D wireless indoor positioning and orientation system dedicated for autonomous vehicles based on Radio Frequency Identification (RFID) technology.

2. General characteristic of indoor positioning systems

The purpose of indoor positioning system (IPS) is to determine continuously in real time the position of followed objects and people within defined workspace [3]. There are many different technologies and methods which can be used to create the indoor positioning system. Each of them has some advantages and limitations which are mentioned in further part of this section.

2.1. Location methods

There are a couple of methods which can be applied to determine the position of object within indoor environment (figure 1). They have been widely described in papers [2, 3, 4]. In this sub-section only the general principles of existing techniques are given.
2.1.1. Triangulation
The position of object is calculated based on the geometrical properties of triangle. The principle of method is shown in figure 2. If the geometrical positions \((x_i,y_i)\) of at least three reference points are known \((A, B, C)\), then the coordinates of object \((O)\) can be calculated. The location can be determined either by measuring of distance between the object and reference points or by computing angles in relation to reference points [4]. Time of Arrival is considered as the most accurate methods, since it allows to filter out unwanted multi-path effects.

![Figure 2. The principle of triangulation methods to determine the object position.](image)

2.1.2. Fingerprinting
Another technique which has been applied for tracking systems is fingerprinting (called also mapping or scene analysis) [2]. The implementation process of fingerprinting method into indoor positioning system consists of two main stages: offline and online stage. During the offline stage the database of features (fingerprints) at known locations in relation to reference points is built. An example might be the measurements of Received Signal Strength Indication (RSSI) in different locations within the indoor environment in relation to the access points (figure 3). Other example of location-related feature might be the strength of magnetic field in relation to reference points where the coils are installed. In the online stage the same features are measured and then compared with those collected during the offline stage. Based on that, the location estimation is made. The fingerprinting technique is commonly used for localization systems, however it can be also deployed for tracking purpose [2]. The main disadvantage of described method is time-consuming offline phase as well as necessity of regular database up-dates which are essential to compensate the changes that have been done in the indoor environment.
2.1.3. Proximity

The proximity-based localization systems are usually built-up from grid of antennas which cover the indoor environment [4]. The positions of antennas/detectors are known. When the followed object gets into the range of particular antenna, then its position can be detected, since it is related with the well-known position of antenna. The accuracy of the method is strictly related with the density of detectors grid. The principle of proximity method is presented in the figure 4. The followed object (O) is placed in the range of detector 2 (D2). Consequently its position can be collocated with the known position of detector 2.

2.1.4. Vision analysis

This technique is based on the image processing of view which is usually captured by cameras which cover the whole indoor environment [3]. The cameras positions are known. The followed objects must be pre-defined in the database. When the tracked object gets into the range of particular camera, it can be identified and its position can be estimated.

2.2. Types of information provided by Indoor Positioning Systems

Depends on the application and the structure of IPS, different location information can be provided by the system. According to the [3], mainly three types of IPS information can be distinguished (figure 5). To provide the absolute information by IPS the map of indoor environment must be prepared and stored in the IPS. The map consists of reference points, according to which the object location can be estimated. The absolute location information is required for tracking and navigation systems, where exact position of the followed object must be determined. The relative location information is determined according to its own reference points [4]. An example of relative location might be the tracking of car door to check whether it is closed or open [3]. In such case, the relative position
between the tracked point (placed on the car door) and reference point (situated on the car body) is given. The exact position of the object is not always required. For some applications only the general information about the presence of the object within defined area is needed. This kind of location information is defined as a proximity. It provides only the information about the place where tracked object is [3]. As an example the tracking of medical equipment and patients within the hospital can be given.

![Figure 5](image)

**Figure 5.** The types of information which can be provided by the indoor positioning systems [3].

### 2.3. Technologies used for Indoor Positioning Systems

There are different criteria according to which the IPSs can be distinguished. One of them might be the type of location information provided by the positioning system. Furthermore, indoor location systems can be divided into network-based and non-network-based [4]. However, the most natural and intuitive classification refers to the technology based on which the object location is determined (see figure 6). Like it was already stated in the present paper, different technologies have been already used for development of indoor positioning systems. A short characteristic of each technology is given accordingly.

![Figure 6](image)

**Figure 6.** Classification of indoor positioning systems in relation to the technology based on which the object/human location is determined [3, 4].

#### 2.3.1. RFID

The Radio-frequency Identification (RFID) technology ensures a wireless communication between reader and tags (called also transponders). These are two main components of RFID systems. The reading range depends on the RFID technique and operating frequency [6]. Strictly defined radio frequency and protocol are used to transmit and receive the data both, by reader and tags [4]. There are two types of tags: active and passive. The passive transponders are powered only by the electromagnetic field transmitted by reader. No additional battery is needed. This is the main
advantage of passive tags, as well as small size and low cost. The passive RFID technology has been replacing gradually barcodes [3]. In opposite to the passive tags, the active ones have built-in battery. The tags works as transceivers which transmit their ID or further data (saved in chip) in reply to signal emitted by reader. One of the characteristic features of active RFID tag is wide reading range, even up to 100 m for Super High Frequency technology [6]. Furthermore, active transponders have usually larger memory and smaller antenna than passive tags. The batteries of active RFID tags have to be replaced periodically, what can be considered as main of their disadvantage.

2.3.2. IR
Infrared technology provides the wireless data transmission by the means of infrared radiation. The IR-based positioning systems requires unobstructed line-of-sight between transmitter and receiver. Moreover, the interference from strong source of light is not allowed [3]. For that reason the infrared indoor positioning systems are limited to transmission within single room. It is worth to mention that hybrid indoor location systems combining IR and RF technologies have been developed. Such combination takes the advantage of both mentioned techniques which increases the accuracy and applicability of the location system.

2.3.3. WLAN (IEEE 802.11)
Wireless local area networks operate usually in 2.4 GHz band. Over last years the WLANs have become very popular for domestic as well as commercial applications. Nowadays, WLAN technology has been implemented in almost all possible public areas, like department stores, hospitals, schools, universities, train stations, trains, offices, etc. The main advantage of WLAN-based indoor positioning systems is low cost of implementation, since they reuse already existing infrastructure. In the most of WLAN-based positioning systems the object location is determined by the measurements of received signal strength from a device (which is installed in the followed object) to a few access points [7]. The position of an object is calculated in relation to the known locations of access points. It must be noted, that the accuracy of WLAN-based indoor positioning systems is significantly affected by the environmental conditions. All the elements of indoor environments like walls, doors, furniture, electrical devices, human body and overlapping access points affect negatively the accuracy and reliability of RSS-based WLAN indoor positioning systems [3]. According to [4] the accuracy of positioning for typical WLAN-based location system using RSS measurements is approximately 3 – 30 m with refreshing of position information in about a few seconds.

2.3.4. Bluetooth (IEEE 802.15.1)
Bluetooth is one of the technologies which are used for wireless personal area network (WPAN). Bluetooth operates in a 2.4 GHz ISM band and depend on the signal power, provides wireless communication up to 100 m [2, 3]. Bluetooth standard is commonly used in mobile phones and has successively replaced the IR communication. Moreover, Bluetooth modules have been implemented into other devices, like laptops, TVs, printers, tablets, etc. Each Bluetooth tag (which works as a transceiver) has its own unique identification number and consequently it can be used to track the device in which it is installed.

2.3.5. Ultrasound
The design of ultrasound-based positioning systems is inspired by the bats which use the ultrasound signals for navigation purpose over the night. Ultrasounds are defined as waves with frequency above 20 kHz – which cannot be heard by human [8]. The systems based on ultrasound technology consists of tags which emit the ultrasound signals and receivers with known-position [3]. The location of object is calculated based on triangulation technique. The main disadvantage of ultrasound technology is the range limitation. The ultrasound signals are reflected by the walls [9].

2.3.6. Ultra-wideband (UWB)
The RF-based indoor positioning systems have limited scope of applications due to the multi-path distortion of radio signals reflected by walls - which affect greatly the accuracy of location. In ultra-
wideband technology the short-term pulses, less than 1 ns, are generated which allows to achieve wideband emission [3]. Consequently, the reflected signals can be filtered which increases the reliability and accuracy of the positioning system. Furthermore, ultra-wideband technology is characterized by low power consumption and fast data transfer.

2.3.7. Magnetic positioning systems
There are a few approaches where the geomagnetic field is used to find the device orientation [10]. Unfortunately, within the indoor environments many sources of disturbances can be found, what affect significantly the accuracy of the location system. Among others, the electrical devices, wires, piping or steel shell of buildings can be pointed out [10]. It can be stated, that geomagnetic field is useful for indoor positioning system only if it is stable over the long period of time. Another solution to determine the position of an object might be the measurement of artificially generated magnetic field [11]. This kind of positioning system contains electric coils with known positions and sensor of magnetic field attached to the followed object. If the strength of magnetic field from at least three coils is measured, then the triangulation principle can be applied to determine the position of object.

2.3.8. Vision systems
The vision systems provide the positioning and tracking of people and objects, even in the complex indoor environment. Furthermore, vision systems can recognize human or particular objects by their characteristic features. Such systems contain mainly the high resolution cameras which capture the view in the real time and CPU which is needed for image processing [12]. One of the advantages from vision system is lack of any additional tags or sensors which usually have to be carried by the objects which are followed [3]. Notwithstanding the above, it must be noted that vision systems have also a couple of limitations. Firstly, high computing power is required for in real-time image processing. Secondly, the vision systems are susceptible for noises which might be caused by reflecting light or changing the lighting level. What is more, the vision-based positioning systems are not suitable for dynamically changing environments and to track a few persons simultaneously [3].

2.3.9. Hybrid systems
As it was already highlighted, each technology has its advantages and limitations. Usually, the indoor positioning system implemented to a particular environment cannot be applied to different one. To overcome above mentioned problems, the hybrid systems combining different technologies are developed. An example might be IR-based positioning system with UHF-based positioning system or combination of RF with IR signals [4].

2.4. The application examples of indoor positioning systems
There are many fields and potential applications where the indoor positioning system could be implemented. Among others, the following examples can be pointed out:
- tracking of medical equipment within the hospital to prevent them from being stolen,
- monitoring of unauthorized access to restricted areas, for example in the hospitals [13],
- tracking the patients in the hospital to improve their flow and reduce transfer time [13],
- tracking of goods in the warehouse,
- tracking of goods and assets within the production plant,
- tracking of firefighters in the buildings where the rescue operation is conducted,
- navigation of cars in the parking to assist the drivers in finding the free place to park,
- navigation of customers within department stores to assist them in finding the shops they are searching for,
- navigation of readers in the library to assist them in finding the book they are searching for,
- navigation of people in the offices,
- navigation of collaborative robots which are dedicated to assist the human,
- tracking and navigation of elderly people,
tracking and navigation of forklift and automated guided vehicles (AGV) within the production plant.

2.5. The examples of indoor positioning systems

Over last few decades, quite many indoor positioning systems - based on different technologies described in previous subsection – have been developed. Some of them have found a commercial application, others can be considered only as a scientific approaches. A couple of researches containing comprehensive overview of existing indoor positioning systems have been prepared recently [2, 3, 4, 9, 14, 15]. In these papers different indoor positioning systems based on variety of available technologies are described. The authors of above mentioned researches present the pros and cons of existing indoor location systems as well as try to evaluate their applicability in order to find the potential fields of implementation. In further part on this section only a few examples of indoor positioning systems are given with main focus on RFID-based IPSs.

2.5.1. COMPASS

COMPASS is an example of WLAN-based indoor positioning system which reuses existing WLAN infrastructure [16]. The position estimation of user is done by measurement of received signal strength in relation to different access points (APs) located in the indoor environment. The blocking effect caused by human body has been handled by digital compasses which detect the user orientation. Application of digital compasses has improved significantly the accuracy of the system [16]. The COMPASS system uses the fingerprinting method to determine the user position. The main principle of the COMPASS system is to sample the signal strength for preselected orientations at each reference point during the offline phase [16]. All collected data is stored as histograms in the database. In the online phase the measured values are compared with those collected in the offline stage. Consequently, the specific signal strength distributions for each positions can be calculated to improve the accuracy of position determination. The system has been tested in the hallway of an office building with the area of 312 square meters. There were six access points deployed within testing area. During the offline phase the measurements were conducted at 166 reference points (with approximately 1 m spacing). According to the authors results, the average positioning error less than 1.65 m was achieved. It has been proven by the authors that training set of 20 measurements at each reference is sufficient [16]. Further increasing of training set doesn’t improve significantly the accuracy of positioning.

2.5.2. Active Bat

Active Bat is an ultrasound-based indoor positioning system which use triangulation method to determine the object or human position [17]. The system consists of tags (transmitters of ultrasound pulses) and receivers. The tag (called Bat) with size 7.5 x 3.5 x 1.5 cm is carried by the followed object [17]. The Bats are powered by 3.6V batteries which has to be replaced every 1.5 year. Each Bat has its own unique 48-bit code. The signal emitted by the Bats is captured by the receivers which are fixed to the ceiling. The receivers are situated in a grid with spacing of 1.2 m [17]. If the signal generated by the Bat arrives to three or more receivers, then the position of object can be determined. The orientation of an object can be calculated, if the relative positions of at least two Bats (attached to the followed object) are found. The tests of the system were conducted in the indoor environment of around 1000 square meters. The area was covered by 720 receivers. According to the authors the system can determine simultaneously the 3D position of 75 objects with accuracy around 3 cm [17].

2.5.3. ViNav

ViNav is a vision-based indoor navigation systems dedicated for smartphones [18]. The general idea of the system is to build 3D model of an indoor environment (in a form of 3D point clouds). According to this concept the 3D models are created and updated using crowdsourced visual and sensor data which is collected from smartphones [18]. Based on collected data an indoor space of interest is created by using SfM technique. Afterwards, the path meshes are created for path planning considering the obstacles that have been detected on 3D models. The representation of an indoor
environment created by this method may be imperfect and characterized by uneven points density distribution. To improve the system functionality, tracking of users (by motion sensors built-in the smartphones) and integration of registered paths to the navigation meshes have been proposed by authors [18]. System can be also implemented in the multi-stage buildings thanks to the barometric pressure sensor. With the 3D models made in SFM technique it is possible to determine the user location and face direction by using the picture taken in situ. Fast location of ViNav system is provided by the combination of image-based localization and fingerprinting method [18]. The 3D model is split into multiple smaller models based on the density of 3D points collected during an offline stage. The user send a request for location which contains picture and Wi-Fi fingerprints captured on site. These fingerprints are compared with fingerprints stored in the database. When the match is found, the location of user can be calculated. Once the destination is defined by user, ViNav can calculate the route based on the navigation meshes using path finding algorithms.

2.5.4. Non-satellite positioning system for vehicles

In paper [19] a non-satellite vehicle positioning system is presented. Despite the fact is not dedicated for indoor environment the authors of present article decided to mention it since it is based on RFID technology. The idea of described system is to determine the position of vehicle (equipped with RFID reader and antenna) on the road by reading the data saved in RFID tags which are placed on the road signs, traffic lights, trees, buildings etc. [19]. According to this concept the coordinates of tags are known and predetermined by any existing satellite positioning systems (like for example GPS). The map of tags with its coordinates must be pre-defined and stored in the database. The present RFID-based system can navigate the vehicle by determining the route from the nearest point (tag) where vehicle is located to the destination point through all the tags located between and saved in the database. The tags can also store in their memory information about permissible direction of driving, speed limitations, traffic signs, etc. To increase the reliability of the system there may be a few tags assigned to particular area coordinates. That would minimize the risk of missing the information saved in only one tag, in case the radio waves are reflected by any randomly occurred obstacle.

2.5.5. A RFID-based indoor positioning system using passive tags

A different approach of RFID-based indoor positioning system is described in paper [20]. In this concept the localization system takes the advantage of RSSI. The tags can be located on the floor or ceiling. In the experimental set-up the authors created a path of passive tags with spacing of 1,2 m. The vehicle with installed reader move forward parallel to this path at a distance of 2 m. A Kalman filter was implemented to decrease the reader location error. The average absolute position error achieved by the authors is about 0,1 m and the average absolute tag-reader distance error is 0,055 m [20]. The accuracy of the system can be improved by reducing the distance between adjacent tags or by decreasing the distance between the reader and path created from tags.

2.5.6. RFID-based navigation method

In the patent [21] a RFID-based positioning system was proposed. The navigation apparatus consists of RFID reader connected with three directional antennas and control unit. First antenna is mounted in the front of the object. Remaining two antennas are placed on the left and right side at angle of 45 ÷ 90 degrees to the front antenna. The tags with unique identification numbers and saved-in coordinates are placed along the roads/paths where the followed object is moving. The current object location and moving direction can be determined if at least one tag is read by at least one of the directional antenna connected with reader. Received signal strength is measured in order to estimate the object position. Based on this method also the navigation service can be realized.

2.5.7. RFID-based indoor positioning system combining tag detection probability and statistical distribution of measured received signal strength indication

An interesting approach for localization within indoor environments is presented in patent [22]. The room, in which the location was provided, had been covered by reference passive RFID tags with known positions. A couple of antennas (at least three) connected to the RFID reader are placed in
selected points in order to cover the entire room by their range. The reader is connected with the central computing unit. The system is based on the learning method (fingerprinting). The central unit provides the location determination by measuring the received signal strength indication (RSSI) and considering the detection rate fingerprinting of reference tags. The location process consists of offline and online phase. At the offline stage (learning phase) the received signal strength of reference tags is measured. Then, the map with the positions of reference tags is created and saved in the database of central unit. In the online phase the real time localization of followed object is ensured by the system. The tracked object must carry two UHF RFID tags with different reading range. The tag with lower reading range is used to find the “zone” within the room in which the object is located. It can be stated that it is used for rough position estimation, since most likely it would be detected only by one antenna. The second tag has the same reading range like reference tags and it is used for exact position determination of the followed object. The RSSI of this tag is measured and then compared to the fingerprints saved in the database. Based on that, the exact position of an object can be easily determined. One of the advantages of presented system is shortened learning phase. The RSSI of tag attached to the followed object doesn’t have to be measured at different positions within the indoor environment to create the database of fingerprints. The RSSI of reference tags is measured instead, what significantly speed up the learning process. Furthermore, thanks to the fixed reference tags the map can be easily “refreshed” and adopted to the indoor environments which is usually very complex and changes dynamically.

3. The concept of RFID-based indoor positioning system dedicated for autonomous vehicles

In the present paper the authors concept of RFID-based indoor positioning system dedicated for autonomous vehicles and robots is presented. The operation principle of the system is shown in the figure 7 and figure 8.

![Figure 7](image)

**Figure 7.** The operation principle of RFID-based indoor positioning system according to the authors concept, 1) indoor environment; 2) landmarks (tags) which cover the operational area; 3) autonomous vehicle; 4) right-side reader antenna; 5) left-side reader antenna; 6) range of right-side reader antenna; 7) range of left-side reader antenna; 8) landmarks (tags) detected by the reader antennas; 9) landmarks (tags) which are at the border of the antenna range; 10) a defected landmarks [22].
Figure 8. The scheme of control unit of present RFID-based indoor positioning system, 2) landmark (tag) which is not detected by the reader antennas - situated outside the operating range; 3) autonomous vehicle; 4) right-side reader antenna; 5) left-side reader antenna; 6) range of right-side reader antenna; 7) range of left-side reader antenna; 8) landmarks (tags) detected by the reader antennas; 11) UHF RFID reader; 12) Central processing unit [23].

The presented system is based on the fingerprinting technique. An autonomous vehicle (3) is equipped with UHF RFID reader (11) connected with two directional antennas, on the right (4) and left (5) side. The range of reader antennas is marked by broken lines and hatched (6, 7). The vehicle moves within the indoor environment (1) which is covered with “landmarks” (2). Each “landmark” consists of two RFID tags with different reading range: one with short reading range and second with long reading range. The tags can be attached on the floor randomly. There is no need to create any regular pattern or grid. During the deployment process of tags their positions (coordinates) are not known. The entire implementation process of described system consists of two phases: offline and online stage. Once the tags are situated in the indoor environment the offline learning process (mapping) can be started. In this process the coordinates of landmarks are found. The vehicle controlled remotely starts the mapping process from the known position (origin of the room coordinate system). It moves through the indoor environment and scan the whole area searching for the tags with short reading range. If the moving direction of vehicle and its distance from the origin are known, the position of each landmark can be determined. The angle of moving direction and distance can be measured by separate sensors built-in the autonomous vehicle. Once the tag with short reading range is detected, its position is calculated and saved in the database of central processing unit (12) which is connected to the UHF RFID reader. These coordinates are also saved in the memory of associated RFID tag with long reading range. When the map of landmarks is prepared and saved in the database of central processing unit, then the online navigation phase of vehicle can be started. In this process the vehicle drives and scans the area in search of RFID tags with long reading range. If at least two landmarks are detected by each antenna, the localization of vehicle can be determined. Nevertheless, it is worth to mention about the disruptions which can occur and affect negatively the functioning of described localization system. One of the potential risks is a failure of tag with long reading range. Then, during the localization or navigation process the landmark with defected tag (10) would be not detected by reader antenna. Secondly, the landmark which is at the border of the antenna range (9) at a specific moment can be detected randomly. It also brings some uncertainty to the navigation process. Finally, in RFID-based systems the false negative reading (FNR) phenomena can occur [22]. It means that a particular tag might be not detected despite the fact it is covered by the antenna range. To face above mentioned problems, it is recommended that landmarks should be situated in the way that in every possible position of vehicle more than two of them can be detected by each antenna. The higher density of landmarks located in the indoor environment, the higher system accuracy and reliability.
The presented RFID-based indoor positioning system allows also to detect pre-defined obstacles situated within indoor environment where the localization and navigation are provided. The obstacles must be covered with the RFID tags with long reading range. The unique identification numbers of these tags must be saved and stored in the database of central processing unit. If the vehicle meets an obstacle, its trajectory can be changed to avoid the collision. The obstacles don’t have to be situated in fixed locations. As an obstacle, also moving objects and human can be considered. Even if an obstacle is moved to another position within the indoor environment, it can be still detected by its unique identification number. However, to ensure this collision avoidance functionality the third antenna in front of the vehicle should be installed to cover its whole surrounding. In the same way the border of room can be marked to avoid the collisions with walls or another building structures. Within one indoor environments a navigation function can be provided to many vehicles what might be especially useful in the production plants. Then, each autonomous vehicle must be marked by tags to avoid the collision between them. It must be noted, that the vehicle does not detect randomly occurred obstacles which had not been pre-defined in the database of central processing unit.

4. Conclusion
In this paper the general overview of indoor positioning systems was presented as well as technologies and methods used to deploy of IPSs. Due to the quick development of new technologies the localization of human and objects has been getting more and more relevant. The application examples and potential areas where IPS could be deployed, were given in former sections of this paper. It is predicted that the global market value of indoor positioning systems can reach 10$ billion a year in 2024 [2]. That shows the relevance of this field of science and brings the attention of many scientific centers and researchers. The main development direction are IPSs based on the existing technologies and reusing already deployed infrastructures, if it is possible, like for example WLAN-based localization systems. Notwithstanding the above, simple, inexpensive, reliable and battery-free (energy efficient) solutions like RFID-based IPS still play a significant role.

The authors concept of RFID-based indoor positioning and navigation system dedicated for autonomous vehicles and robots was described. The following advantages of above mentioned indoor positioning system can be pointed out:

- low cost of the entire indoor positioning system,
- simplicity,
- wireless communication between the reader and landmarks (tags),
- battery-free design of tags based on RFID technology (the RFID passive tag, which constitute the main part of the sensor, is powered by electromagnetic field emitted by the reader),
- simultaneous communication between the reader and dozens of RFID tags,
- quick data processing,
- low computing power demand for signal processing,
- flexibility and adaptability of the system,
- reliability which increases with the density of deployed landmarks,
- once the map of indoor environment is done, it can be reused by other vehicles, robots and human for navigation purpose.

In further steps the experimental set-up of presented concept should be developed in order to define the technical characteristics like accuracy and repeatability of positioning etc. The reliability and resistance for disturbances must be investigated as well.

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