Hardware-software geo-information system for positioning objects

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Abstract. The project is dedicated to the development of experimental samples of hardware-software complexes for seamless positioning of objects inside and outside the buildings to ensure the implementation of the principle “always and everywhere”. The work substantiates the need for developing a project dedicated to the creation of a hardware-software geo-information system for positioning objects. To achieve this goal, the analysis of shortcomings of existing technologies for object positioning is carried out. This analysis allowed identifying the main tasks that need to be addressed. A review of existing approaches to the development of geographic information positioning systems was held. The advantages of the developed geoinformation complex for object positioning are described. The main results and the effect of the project are characterized.

1 Introduction

Currently, there are many technical solutions to the problem of determining the location of a physical object in space. These systems are combined under a single term – positioning systems. Systems of global and local positioning are widespread at present time. The main advantages of global positioning systems, such as GPS, Beidou and GLONASS, include a large area of positioning (positioning in open areas) and fairly high accuracy (up to 2 meters for GPS, Beidou and GLONASS). However, the disadvantages of these technologies do not allow each of them to become a universal system for finding an object in an arbitrary location.

2 Review and analysis of the field

2.1 Analysis of the shortcomings of existing object positioning technologies

The shortcomings of existing positioning technologies include:

- closeness of the data (limited ability to receive data from the system owners, which are governments and commercial structures);

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- a weak signal receiving from global positioning systems inside buildings (e.g. shopping centers, underground parking lots, subways) due to the low level of noise immunity;

These disadvantages are absent in local positioning systems (LPS) if it is necessary to build location and communication systems within a limited area (in enclosed areas with reinforced concrete partitions, tunnels, basements, mines, where there is no possibility for direct unimpeded radio signal), but with high accuracy, about 0.1-1 meters. Significant differences in the accuracy of determining the coordinates and the lack of flexible solutions for the integration of global and local positioning technologies do not allow reaching the seamless localization of objects when moving inside and outside the facilities in real time mode with one centimeter accuracy range.

This problem manifests itself in various industries both in Russia and in other countries and covers multiple types of monitoring and management systems: transport and logistics, critical facilities, potentially hazardous infrastructure and dangerous goods, agricultural, environmental, nature management and ecological activities, land use and agriculture, forestry, road and water management, urban planning, threats of terrorism, man-made and ecological treats and other.

2.2 The main problems to be solved

The main trends that stand out in the process of analyzing the industry in Russia and other countries are:

- Improvement of consumer characteristics of local and global positioning systems in real time within the framework of existing technologies.
- Popularization and expansion of the range of services provided by local positioning systems in real time.
- Solving the problem of electromagnetic compatibility with other radio-electronic means operating in a similar frequency range.
- Creation of local positioning systems based on fundamentally new technologies.
- Finding ways to increase the economic efficiency of business projects that depend on the positioning of products in space and time.
- The transition from the use of individual technologies to hybrid systems, combining one or more technologies.
- Positioning in cellular networks.
- Wi-Fi positioning.
- Non-radio wave positioning methods.
- Positioning systems using passive radio frequency identifiers (RFID).
- Positioning systems using active RFID.
- Positioning based on using “near field” technology.
- Ultra Wideband (UWB) positioning.
- Positioning system using CSS and SDS-TWR.
- Positioning system using ZigBee network and MEMS accelerometers.

2.3 Review of existing approaches to the development of geographic information positioning systems

Indoor Positioning and Indoor Navigation Conference (<http://ipinconference.org>) is dedicated to the issue of indoor positioning, which indicates the relevance of the research problem.

Global positioning systems (GPS, GLONASS, Beidou) are the most widely used satellite navigation-based positioning system and provide location-based services such as navigation, cartography and related services. However, GPS \ Glonass \ Beidou are not suitable for internal positioning due to many obstructions.

Many technological approaches have been suggested in literature for solving problems with positioning in the room [1-7]. In recent years, a significant increase in publications in the field of indoor positioning research has been noticeable. According to the SCOPUS database, the number of articles on “indoor positioning” by the current year has tripled compared to 2010. At the same time, over the past two or three years there has been a doubling of the number of articles devoted to various aspects of solving the problem of indoor positioning. The problem of indoor positioning has been discussed in articles since 1994. A comprehensive picture of the current situation is given in the articles of 2007-2014 [1-12]. For example, Davide Dardari, Pau Closas and Petar M. Djuric [1] have shown that for all existing technologies of radio frequency positioning and positioning by using separate sensors of speed, earth magnetic field and acceleration, the maximum achievable accuracy is tens of centimeters at a significant cost. Thus, the authors of the study [1] conclude that the use of hybrid multisensor systems based on MEMS technologies is an urgent task of the future, which is not currently implemented. In subsequent publications, the authors also indicate that improving the accuracy and speed of positioning is a very actual and unresolved task [1-13].

In the past decade, outdoor positioning technology and research in this area have shown explosive growth in achievement [2, 6-9, 10-13]. At the moment, similar trends are observed for indoor positioning technologies, and it can be noted that indoors people spend more than 70% of their lives. The reason for the popularity of such studies is the need for reliable and highly accurate real-time positioning systems that can work indoors, complementing systems based on satellite technologies such as GPS. The internal environment is very complex, and as a result, a wide variety of technologies are offered in studies and literature to solve indoor positioning problems, but so far no solutions have been found that can be considered established. It can be argued that the problem with internal positioning is more difficult than the problem of localization in the room. The reason is simple: from a set of measurements it is necessary to estimate not one location, but a series of correlated locations of a mobile node.

The number of studies in the field of indoor positioning research is expected to increase. These studies are aimed at developing new technologies and introducing technologies in new subject areas. The use of indoor positioning technologies is widely expected to complement and expand the capabilities of pedestrian and car navigation systems in the field of intelligent transportation systems, automated vehicles, robotics and location-based services [1-7, 13]. An important direction of work is the fusion of information that comes from the existing infrastructure and information that will be provided from newly deployed systems or collected through the growing distribution of smartphones (crowd sensing). An important problem is to adapt the computationally intensive and expensive methods for practical use in a wider range of real-world applications. The emergence of new technologies will continue to drive the rise of new research in the field of indoor positioning. One of these technologies is the Internet of Things (IoT). The IoT will become a very large network of devices, sensors and facilities that will communicate with each other to provide new services with additional features. Furthermore, the network will be dynamic and many applications of the IoT will be found in various facilities, including smart homes and smart buildings. An important part of the information in many applications will be the tracking of “things” in the network. In the IoT paradigm most of these operations will require a distributed implementation, that means lack of a specific central unit.

Within this scenario, another important goal is to create networks that can identify and track low-cost and non-volatile devices (tags) attached to objects / persons. This will require the development of energy-efficient solutions or solutions with zero consumption (for example, using passive tags) for the full integration of RFID and RTLS technologies. All known indoor positioning technologies allow to determine the location of an object, and all of them have their own characteristics, the most important of which are: accuracy, range of work, energy consumption, cost and quality of work inside rooms.

There are two global approaches to indoor positioning: the use of technical vision and the use of radio frequency methods. Existing indoor positioning systems are based on optical solutions and technical vision conception. They largely depend on the environment, do not have high speed and are expensive due to the need to use highly sensitive cameras for collecting high-resolution data.

Technologies based on RFID tags, Bluetooth tags and on measuring the signal strength of Wi-Fi access points and cell towers are of low accuracy (accuracy of the best samples is about 10-20 meters) and do not work in real time mode (firstly the “almanac” of locations and signal levels have to be built , and only after that it is possible to navigate) [10-12].

Positioning technologies using ultra-wideband data transmission are expensive and also do not provide centimeter-accurate positioning. The best existing commercial example is the DecaWave DW1000 microchip provides positioning accuracy of about 10 centimeters and a range of action up to 290 meters in open space with a prototyping cost of about 1000 euros.

Wi-Fi navigation technology uses data about loss of signal power. This technology implementation requires preliminary work on the exact setting of the coordinates of each Wi-Fi router. The accuracy of Wi-Fi navigation technology is up to 2 meters. It has shortcomings one of which is related to the problem of protecting devices from advertising surveillance.

Geomagnetic positioning technology is based on the orientation of the Earth’s magnetic field and employs the geomagnetic anomalies as criteria for geomagnetic positioning (anomalies arise due to heterogeneity of the geomagnetic field). According to this technology geomagnetic anomalies are fixing and plotting on the map of the territory on which orientation will be performed. Afterwards navigation is performed on the map made by the device, in which the magnetometer is embedded. The high complexity of implementation and low accuracy make this solution non-scalable and inefficient in most cases.

When talking about positioning, we must bear in mind that hybrid technologies are actively developing today. The GLONASS / GPS receivers operation is now supported by other positioning technologies and inertial systems that can provide positioning in any conditions, including indoors navigation. There is much to develop, and the duration of the horizon of hybrid technologies elaboration is estimated at 20 years. At the same time, the goal is to ensure stable seamless positioning “always and everywhere”.

Today's users are only partially satisfied with the way positioning technologies work; LBS services require greater reliability and accuracy. Positioning inside buildings is called the “gold rush” in the modern market of navigation services. The mentioned disadvantages of existing solutions can be eliminated by using positioning based on all (or most of all) the methods listed above. Such approach will allow achieving a synergistic effect from methods and technologies collaboration. Efficiency is achieved due to the fact of using of several coordinate determination vectors at once, which helps to compensate for errors and improve the accuracy of determination of coordinates. GLONASS / GPS chips are no longer innovative products, at present they are offered by both the “grandees” of the global semiconductor industry and start-up companies from Asia. Therefore, from our point of view, the perspective is different. There is an intense need to develop new solutions, create

hybrid, more sensitive receivers and sophisticated algorithms for next-generation navigation products.

Thus, the theoretical approaches described by the authors of analytical reviews [1–7] for solving the problem of indoor positioning do not allow solving the problem of positioning centimeter accuracy in real time inside buildings, do not provide integration with outdoor positioning technologies. All of the above substantiates the relevance and feasibility of the development of new algorithms, hardware and software components of seamless internal and external positioning of centimeter accuracy in real time.

3 Main results

3.1 The advantages of the geo-information object positioning system being developed

The uniqueness of the automated software complex created as a part of the considered scientific and applied project lies in the fact that the development of components of this complex is based on the new algorithms for seamless hybrid positioning of objects inside and outside the buildings with the highest accuracy in the centimeter range in real time. The novelty of the proposed engineering solution is associated with the creation of the unified methodology for positioning objects inside and outside the buildings and ensuring the seamless location of the object. The technical feasibility of hardware solutions for the proposed precise positioning technologies in Russia is confirmed by the presence of the element base for navigation equipment on the national market. Moreover, domestic samples of high-precision positioning (navigation) equipment demonstrate a positioning accuracy of no worse than 10 cm in real time mode.

The system developing within the project allows excluding almost completely the possibility of impact on the system in order to distort or steal the navigation data. It provides the accuracy of positioning objects up to 10 cm in total, and in three-dimensional space. Potentially, the proposed technologies can become a basis for the development in the field of anti-theft systems implementation, in protecting from jamming, in traffic monitoring systems, including unmanned vehicles, as well as objects that are poorly visible to GLONASS satellites, for example, in open pit mining.

3.2 Solvable tasks

The project solves the following tasks:

- creation of an experimental sample of an automated software complex of high-precision radiofrequency 2D positioning of objects inside buildings;
- creation of a complex of seamless hybrid positioning of increased accuracy for objects inside the buildings in real time;
- creation of a complex of hybrid positioning of objects inside and outside the buildings;
- creation of a complex of high-precision radio-frequency positioning of objects inside and outside the buildings;
- creation of a test bench for a high-precision radio frequency 2D positioning complex for indoor objects.

Development of the new algorithms, software and hardware for hybrid seamless indoor and outdoor positioning based on radio frequency and multisensory positioning methods that provide:

- to increase the speed and accuracy of horizontal positioning to centimeter values at a speed equivalent to the average speed of traffic in industrial and urban areas;

- to increase of accuracy and speed of vertical positioning at speeds exceeding current requests from industrial consumers;
- to provide customers with the functional capabilities of using the developed positioning technology for solving high-precision local positioning problems without reference to global coordinate systems;
- to provide tools that implement high-precision positioning algorithms to a wide range of consumers, which contributes to the development of autonomous transport systems technologies in various subject areas;
- no need to use expensive and medium-dependent optical positioning systems, as well as the development of the domestic element base and software as an independent commercial product and intellectual property.
- In the course of the project are developing:
 - a complex of high-precision radiofrequency 2D positioning of indoor objects;
 - a complex of seamless hybrid positioning of increased accuracy for indoor objects in real time.

4 Conclusions

The obtained results will improve the accuracy of the developed navigation devices, in particular, for locating outdoor vehicles within buildings, moving people in industrial zones and urban areas, for geoinformational support of agricultural work.

The developed experimental samples of the hardware-software complex of high-precision radio-frequency positioning of indoor and outdoor objects could be applied in the following industries and fields of activity:

- at industrial enterprises to optimize the work of warehouses;
- in robotic production, in large medical institutions;
- as a navigation system for shopping centers and industrial enterprises;
- in marketing research based on information about user movements for more accurate analysis of the market basket;
- in the field of security: analysis of the public Wi-Fi network traffic for the presence of illegal information (terrorist propaganda, anti-government slogans, organization of unauthorized rallies, etc.) along with the ability to track its origin.

Ensuring increased accuracy and the possibility of sharing several global and local positioning technologies will improve the efficiency of problem solving in a number of industrial sectors:

- improving the efficiency of technological and business processes;
- obtaining a visual picture of the movement of people and material objects involved in the process to optimize the reengineering or regulation of complex interrelated processes;
- identification of key objects, by the behavior of which in the future it is possible to judge the course of the technological process and receive timely signals in case of deviations;
- monitoring compliance with delivery schedules for complex products and complexes (including monitoring the movement of component assemblies in the shops and sections of the enterprise);
- prompt notification of deviations from the schedule and displaying the location of critical for the technological process objects;
- instrumental control of the movement of the object along the technological chain allowing recording in detail the process (up to the numbers of components and performers of each operation);
- reducing risks and minimizing the consequences of emergencies;

- positioning in time and space of the attendants, vehicles, and also potentially dangerous objects;
- ensuring the spatial orientation of people with significant anatomical and physiological limitations on vision;
- prompt identification of the location of people in the scale of the affected area, tracking of their further movement after the occurrence of an emergency;
- monitoring the implementation of measures for the evacuation of personnel from the affected area;
- the ability to analyze archived information when investigating the causes of an emergency and analyzing personnel actions in the process of its elimination;
 - security of protected areas and objects:
- ensuring instant notification of the fact of the penetration of personnel or guests into the zones prohibited for them with the identification of the offender;
- the possibility of integrated use of local positioning and video surveillance systems in order to identify an object that has fallen into the video camera review sector, due to its identification and positioning by the system label;
- automating the identification of objects in order to reduce the burden on personnel, decrease the likelihood of identification errors and pass the intruder, a false alarm, as well as penetration of the object with the captured employee;
 - control of the movement of valuable, hazardous objects, as well as objects (including information carriers) associated with a commercial or state secret:
- operational and flexible formation of zones, routes and rules governing the behavior of objects, as well as the introduction and termination of the established regulations;
- ensuring quick inventory of tagged objects (for example, during the transfer of a shift), as well as instant search for the desired object.
 - providing information for carrying out an objective analysis of situations and processes (including the analysis of attendance of an object, traffic routes, etc.).

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