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Markerless outdoor AR-RFID solution for logistics

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Abstract

The main objective of this paper is to describe the logistics processes improvement by use of AR (augmented reality) and hybrid RFID (Radio-frequency identification) technologies in outdoor environment. Augmented reality and RFID nowadays are well known and widespread technologies. It is possible to achieve functional and perspective system by merging these technologies together. The paper provides theoretical characteristics of logistics, RFID, AR technologies and offers theoretical model for idea implementation and approbation. Model depicts markerless AR-RFID solution for outdoor object tracking and 3D model visualization. Also physical structure and basic calculations are offered to provide necessary fundamentals for development of test platform and pilot product. Provision of outdoor object tracking and 3D model visualization may significantly impact and improve logistics processes in varies of fields.

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1. Introduction

Development of global communication and travel options, significantly improves the logistics and the logistics service all over the world. Providing large manufactory and international trade opportunities, it is necessary to significantly improve logistics and their relevant processes. As one of the major logistics systems are goods, assets or other objects delivered to the client. That is why there is a need for logistics to use accurate identification, real time tracking with location determination. All components together guarantee effective delivery time.

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By use of RFID technologies it is possible to identify each individual item; however RFID has limitations in longer distances, which narrows down use cases. The development of hybrid RFID technology helps to carry out objects tracking in an outdoor environment and to determine their location using a GPS (global positioning system). By use of GPS data and RFID tag identification ID it is possible to identify the location of objects and the object itself. To improve logistics processes, integrated functionalities can be enriched. RFID is capable of displaying an object ID, however, with single ID information may not be sufficient. It is a fact that analysts and warehouse employees make mistakes during their decisions based only on ID information.

AR (augmented reality) in environment is capable to display an additional data, for example, text based information, photo images, video frames, schemes and 3D models of real world objects. Determining the location of the object and object’s ID, AR can display selected virtual object in real environment, in real time. Augmentation process provides additional visual identification of data for current object, helping to reduce users’ selection errors among other objects. Quickly identification of contents ensures quick decision making which can significantly improve logistics processes by reducing value of time parameter.

In order to develop such system, it is necessary to overcome the obstacles which are associated with objects’ detection and display accuracy. For 3D (three dimensional) objects visualization an orientation and location values must be calculated. To achieve this in real time correct algorithm must be carefully identified. Such type of algorithm should calculate and analyse environmental data to determine where the 3D information must be displayed in real world environment. To introduce the idea, number of problems should be solved or taken into account. For example, in different weather conditions or geographical locations GPS signal from satellites can be disturbed. The core of idea is a development of outdoor AR-RFID solution for logistics where environments augmentation should be based on markerless technologies and instead of common RFID tags, hybrid RFID with GPS capabilities should be used.

2. Purpose of logistics and use of RFID

In today's world of business logistics is an essential part and a very important element in almost any company. Among other things, the importance of supply chain management is critical to increase the organization's ability to compete and profitability [1]. For organizations to be able to strengthen this critical point, they really need focus on logistics and strategic issues.

Business logistics determines the group of activities which provide objects movement and storage from sources of materials to the end user and consumer. Business logistics has its roots in the Second World War, relating to personnel and materials supply critical points during the war. In turn, the first university courses and materials were developed in the United States in sixties. The term logistics business characterized processes which determining the management system and coordinate all material flows from the factory to the end users [2]. At present, the term supply chain management related to client and organization presentation, which helps to create new channels. Those channels can be used for supply materials and products to end users and clients. Term logistics includes set of all those activities and more.

Most popular logistic definition is determined by CLM (Council of Logistics Oak Brook): logistics is the process of planning, implementing and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services, and related information from point of origin to point of consumption (including inbound, outbound, internal, and external movements) for the purpose of conforming to customer requirements [1]. If logistics is viewed from activities side, then term logistics can be described as process which makes access to the object in necessary quantity, in necessary time and for necessary clients.

An integral part of the logistics process is organization. Theory often deals with the material flow, without paying so much attention to the organization. Provision of logistics activities is important to organize all the organizations benefits and services. Organizing logistics process must achieve that all parts ensure the necessary customer expectations. For example, in logistics every service is providing an important operation.
Each service ensures operations with information, which helps to achieve overall supply organization. This level of organization provides setting up a system which ensures customers’ needs better than competitors, for example, the noticeable benefit for organization might be quicker delivery system than others [3]. Such level of logistics in company is significant tool for business and competition.

Logistics nature and its essence is to determine activities of the logistics. Logistics activities are the main functionality which determines same logistic systems. It is important to properly organize this functionality, as well as understand their interdependence. In field of logistics everyone should be careful with functional principles, because making changes in one functional principle can change actions in the rest of the system. Logistics activities main goal is guarantee system’s performance at the lowest cost [3]. The development of modern technologies ensures that in logistics widely and successfully RFID (radio frequency identification) capabilities are used. RFID provides that data are being read from a distance and at the same time can be read up to one hundred units. The development of RFID technology helps shrinking components and equipment costs, increasing RFID technology usage and RFID solution development. Using RFID technology benefits, their applications can be used in almost all areas.

RFID system architecture is composed of several parts, each part is very important and any damage to one part can destroy all system. RFID information systems can be designed individually which can do special or unusual activity or can be used already designed system. To create RFID technology information system requires such key components: tags, reader, writer, and interface or management system.

Ensuring full functioning and working RFID system RFID tag and RFID reader must use radio frequencies. Radio frequencies ensure data transfer between RFID components. RFID system by use of radio frequencies determines RFID tag, RFID reader size, reading distance, price and RFID system usage. RFID technologies work in four different frequencies [4]: LF – low frequency, HF – high frequency, UHF – ultra high frequency and MW – Microwave.

RFID technology has not a standard that would be used throughout the world. One standard which can be used all around world is preventing by usage of different frequencies in many countries. But there are several institutions which have developed standards that can be customized in several countries at the same time. Such organizations are: ISO - International Organization for Standardization, IEC - International Electrotechnical Commission, ASTM International, EPCglobal [5]. Of course, there are also a number of industries that have set the standard guidelines. For example, the FSTC (Financial Services Technology Consortium) standard developed by information technology object tracking with RFID technology, CompTIA (Computer Technology Industry Association) standard for certifying RFID engineers and IATA (International Airlines Transport Association) standard of use of RFID tags in the airport baggage needs [5].

RFID tags that provide inventory information can also provide other services as well. Security scanners at building exits can let your system know instantly when any product leaves the premises, allowing you to spot theft or misdirected shipments quickly and correct the problem. Likewise, scanning RFID tags at entry and exit points allows confirmation of shipping and delivery of goods, allowing you to trace a shipment as it moves through your logistics chain, and provide accurate estimates of arrival to customers or other business units [6].

To implement new RFID system in organization’s already existing system can be tricky task and critical point. Best solution must be determined. This is important since implementation of RFID system in an existing system can be not enough beneficial, especially for small companies. RFID implementation should be correctly prepared. In new RFID system users must be provided with training, to achieve imposed targets. For the introduction of RFID technology in a new system, it is necessary to set out a common framework and carefully implement it. This will reduce the costs of RFID system’s implementation into the existing system [7]. Although RFID in logistics is a highly recognized technology, but there is always a possibility for some specific situations to organize processes more effectively, that is way in this paper new technological aspects are carried out.
3. Widespread of AR technologies and limiting factors

AR (augmented reality) is directly or indirectly real world environment which is complemented by visualized entities accrued out with special hardware, software and accessory elements. The definition of augmented reality stays for all activities which main goal is to augment the real world environment with virtual information that enriches human senses and abilities. AR is able to combine virtual information with the real world [8]. The AR concept actually alters real environment with virtual imaginary. This technology is commonly used in real time and semantic context with environmental elements [9]. For example, while television channel broadcasts sport translation, television screen displays real sport activity with table of results or other computer (not video) based information. This is simplest and typical example of AR where captured video information becomes interactive and digitally manipulated.

Thanks to simplicity and successful tests of AR marker based systems, widespread use of AR applications on PC computers and mobile devices are available for indoor use. However in outdoor environment there are some solutions as well. Devices which are equipped with internal sensors can use geolocation information for outdoor augmentation processes. For example, Townwear system uses pre-defined packages of fiber-optic gyroscopes which provide high-quality precision and low redeployment. In turn, the Global Positioning System (GPS) technology uses direct links position in outdoor environment [10]. Also video capturing which gets information from frame image can calculate highly accurate outdoor environment for virtual object placement.

AR solutions are using various techniques for data projection and depiction. In mentioned marker system [11] one easy-to-read and stable marker is used which serves as an identifier for the point where the augmented reality object will be placed. With the video output device and the video camera, the user can see an object of augmented reality on the real environment’s object. For identifying the 3D model RFID solution can be used which identifies the object itself and associated 3D model. When identification is done, system can display 3D model on marker. This solution also has its weaknesses. Video camera must see the marker very clear and in limited angle to place a 3D model on it. Problems in seeing markers are caused by light glare, light angle, camera rotation, vibration, video camera quality and other factors. In turn, markerless systems can identify a point where to show data by use of location of visual elements in video frame or a sensor data such as GPS coordinates. Markerless systems can also use the above mentioned methods together to provide a more precise location determination and usability of outdoor environments. In order to implement such solution, there is a need to provide fast algorithm and data processing with good performance, stable lighting conditions, angle of view, scalability. The main differences between the marker and markerless solutions are viewing distance and object placement.

4. Hybrid RFID systems and markerless solution

Accounting, tracking and storage of computer systems are very useful and necessary to have data about subjects’ movement and location. This kind of information is very significant and essential in almost any system which is tracking objects flow. Further hybrid RFID technology with integrated GPS technology will be explored and description will be given for AR markerless solution integration as well.

Whenever there is a necessity to work in outdoor environment and there is a need for location determination, then GPS is the most suitable and cost effective technology to be used. However, the position determination process can be limited by several circumstances where most of them are related to the sensors and visibility issues to receive signal from LEO (Low Earth orbit) satellites.

4.1. Structure of hybrid RFID systems

In most hybrid RFID solutions active RFID tags are used. Active RFID tags can provide faster data exchange and higher capacity. Such kinds of systems use LEO satellites for tracking and identification variety
types of objects, for example, containers, cars, construction parts, animals and so on. System is based on typical RFID technology’s architecture, which is extended with GPS components. GPS operations are based on the GPS sensor readings.

The active RFID tag from Savi Technology is programmed to activate several times per day, then send its GPS determined latitude and longitude information to the nearest LEO satellite via data channel. Whether operating as an active RFID tag or as a satellite tag, the hardware unit transmits its unique identification number. The active RFID tag serves as the master component, leveraging a set of algorithms developed by Savi Technologies that can intelligently determine whether to operate in active RFID or satellite communications mode.

When the tag is in the supply chain where there are nearby RFID readers, the tag will automatically shut off the satellite controller. And the tag is smart enough to know, when a container leaves a depot and is not within range of an RFID reader, to automatically flip on the satellite controller. However each time the tag communicates with the satellite system, a fee is charged [13]. At the other end today must be web based application, which is easy to use for end user and more important, application is cross platform compatible, thereby it does not matter whether user uses desktop PC, Android tablet, iPhone or other device (see fig. 1).

As depicted in fig. 1 modern nowadays logistics hardware units feature also other sensors to provide traceable objects’ temperature and inadequate local movement via satellite data channel or multi band cellular network.

Even more, analysing nowadays logistics systems, tracing an object is not important only on global scale. More and more popular becomes solutions which can trace object in very short distances. If typically warehouse objects are registered from one spot to another or objects’ status is changed, then now modern systems provide visualised real time object tracking with RTLS (real-time locating system) in indoor environments (see fig. 1). Detail level is so accurate, that it is possible to see remotely real time animation how object is picked up by warehouse worker from the shelf and is placed on trolley and moved around warehouse territory.

4.2. Implementation and best practices of hybrid RFID systems

A number of examples approves that use cases of hybrid RFID technology becomes more and more widespread. A remote tracking solution implemented and managed by Impeva Labs leverages devices that act like RFID tags and communicate via satellite and cellular communications is helping ensure troops in other countries receive their necessary supplies. The solution uses an Impeva device known as a Global Sentinel Unit (GSU), which is mounted onto a truck and, like an active RFID tag, transmits a unique serial number and GPS data, thereby identifying the vehicle and its location. Rather than communicate with an RFID reader, however, the GSU transmits its data via global satellite and multi-band cellular networks. The Global Sentinel Units, which can also store each truck's manifest, are battery-powered and contain a GPS receiver, as well as the satellite and cellular modems. The units can be programmed for more than 40 user-defined geographic zones,
and can be set to initiate a communication if a GSU travels outside of those zones. The devices can also be queried at any time. The GSUs forward their data to servers at the Global Sentinel Device Management Center, located in an Impeva Labs data centre within the United States. The servers run Web-based software that processes and stores all of the information collected by the GSUs and, eventually, the RSUs. All cargo-related data and continuous GPS position reports are encrypted before being transmitted over the satellite or cellular communications link. The U.S. military can securely access this information via a Web-based application that leverages Google maps created by Agility. By entering a specific truck's serial number, the military can determine that vehicle's location, as well as what is on the truck, by reviewing the description [15].

Another successful example comes from Siemens IT Solutions and Services. They conducted a proof of technology test on RFID based equipment that can be utilized to monitor shipping containers while they are at sea. Tests demonstrated that technology closes a gap found in commercially available cargo monitoring RFID systems that provide RFID data only while on land. Now it is possible to continuously monitor containers from the time they leave the harbour to their final destination. To develop the system, Siemens IT Solutions and Services teamed with Nokia Siemens Networks, which provided the solution's GSM telecommunications infrastructure, a smaller version of a cellular phone network. TriaGnoSys developed the satellite communications elements [16].

International oil and gas company BP created RFID and GPS system that determines each item on board. Items' shipping starts in Europe and destination point is in Korea. The system uses EPC Gen 2 RFID tags with additional labels which are mounted on each unit. Labels are basically 2D bar codes and these bar codes can be read with mobile reader. Bar code use in this system is alternative object identification method. Items on board can be placed in different ways, for example, small boxes in long line. To read each object in the system passive and active RFID tags can be used. Tags are equipped with GPS transmitter which determines the location of item with accuracy up to 1 meter. End user receives graphical information about items location on world map and descriptive information about warehouse entities [17].

Systems mentioned above are only some of example systems which have approbated RFID and GPS potential. In turn, this paper describes the theoretical issues of the system which uses additional functionality exploiting AR (augmented reality). AR will identify object’s contents and, actually, display it on the screen of mobile device, tablet or HMD (head mounted display). 3D model of selected item will help a user (warehouse operator or customer) to approve he have chosen the appropriate container or other type of packed object. Such type of system would also require a real-time GPS data and technologies for correct model projection on top of real view video frames.

4.3. Merging AR and hybrid RFID technologies

System of hybrid RFID technology has a high accuracy and punctuality. If the designed system is as accurate as possible then this system is able to dramatically improve the objects’ control, equipment’s usage and decrease costs. To carefully design, install and control system, attention to data duplication, data delivery, RFID tag mounting and other components must be paid by developers.

If GPS data are received by the system, RFID tag location can be determined. If the system knows RFID tag location, system can use the same location information to calculate coordinates for in virtual space for real space appropriate augmentation with two or three dimensional data. As mentioned previously, the RFID identification information can be sent to the system using two data communication paths: one is through satellite or cellular network, other - through RFID reader. When the necessary data are received by the system and the items is in user’s field of view, the real item can be augmented or replaced with virtual information via screen of mobile phone, tablet or HMD (head mounted display). To correctly project virtual elements, it is not enough with longitude and latitude numbers. Also viewer’s location and orientation must be used for calculations. Environments viewer in this case is camera capturing real-time video and integrated position sensors to follow the interaction between an object and viewer where both can be stationary or in movement.
Hybrid tracking is a method which combines GPS location data with camera orientation detection in real time [10]. GPS precision is an important issue and GPS accuracy could be increased with differential GPS which brings the accuracy of readings to within 1-3 meters of the object, as compared to the 4-20 meters of normal GPS. DGPS works using a network of stationary GPS receivers. The difference between their predefined position and the position as calculated by the signals from satellites gives the error factor. This error component is then transmitted as a FM signal for the local GPS receivers, enabling them to apply the necessary correction to their readings.

Main benefit in markerless AR-RFID concept usage is flexibility and availability, because no special elements like markers are needed. AR engine has enough with real environment in reasonable distance for 3D model realistic placement. The systems performance and immersion level depends on the operating algorithm and accuracy and frequency of gathered data. To calculate distance and orientation between two GPS points in real environment Thaddeus Vincenty’s formulas can be used which are used for calculations in geodesy and are based on two related iterative methods.

For logistics markerless solution based on GPS coordinate calculations is considered in this paper, however in some cases video frame recognition can be used. To some extent it is pseudo markerless, because real world objects are used as markers instead of specially prepared markers. By analysing each video frame, edges of stationary and movable objects can be recognized and used as basis for virtual object placement. In outdoor environment it is more suitable for large scale objects like ship containers or cargo trailers.

The principles how to calculate projection coordinates against viewer (video camera) are explained by Comport based on Asuma calculations [19, 10]:

\[
\Delta = \sum_{i=1}^{N} (s_i(r) - s_i^*)^2 = \sum_{i=1}^{N} (pr_\xi(r, 0 P_i) - s_i^*)^2
\]

where,
- \( P \) - instance and \( 0 P \) are coordinates of 3D object’s points in object’s frame;
- \( r \) - camera’s detected coordinates and orientation in frame;
- \( s^* \) - visible data;
- \( pr_\xi(pr, 0 P_i) \) - projection model according to the intrinsic parameters \( \xi \) and camera pose \( r; \)
- \( N \) - number of considered features.

5. Markerless AR and hybrid RFID use in logistics

The industrial sector of logistics influences all parts of the traditional industries in some manner and it is hardly possible to acquire consumer products which have not gone through several chains of logistic systems. Presence of logistics observed everywhere, starting from transporting mechanical parts, food or clothes from one end of the world to the other, as well as gathering of small parts for assembly lines. Such occasions creates increasingly complex networks of transportation and has turned into a fast expanding global industry. Putting human workers in the middle of logistic chains in warehouses creates the risk of bottlenecks in systems where the worker cannot live up the often hard time constraints. Errors may cause very high costs when for example wrong parts are manufactured into a pre ordered car or sent to the other side of the earth. For this reason the workers are under high pressure and many systems are designed to ease their work by making them more efficient and to create fewer errors.

Today, different techniques are used to prepare the information for the order picker. But they all have disadvantages and depending on the respective technology the error rate is between 0.1 and 0.8%. This means that 1-8 order items within 1000 are faulty. There are different types of errors, e.g. a wrong item is picked or the amount is incorrect. Even one error within 1000 is usually not acceptable to the customers (e.g. original equipment manufacturers), because each mistake can lead to the stop of the production line [20]. AR systems
might have the potential to ease the burden of the workers and reduce the number of errors.

Fig. 2 presents basic flow chart diagram for markerless AR-RFID system which is based on selection of appropriate entity’s 3D model from database and calculate object’s coordinates based on GPS location data, before that, user is navigated to the object at close enough distance. If GPS signal is too weak and location cannot be notified, other markerless method can be used based on video frame recognition. Regardless of the selected markerless method, the core idea is to develop a universal outdoor AR projection solution which integrates different types of nowadays AR methods.

In such kind of systems active RFID tags must be used. These tags may contain more data in memory and provide faster data flow. Active tags work in any frequency and can handle faster data flow and data capacity over passive or semi passive tag.

As inspiration for idea (see fig. 3) Siemens IT Solution and Service RFID and GPS [16] system was used. System allows increasing the level of security in the ports and shipping services. A lot is done for identification and registering services, but more can be done by visualizing the important elements of the logistics’ processes, because not all employees are familiar with logistics cues, especially new ones.

The logistics augmentation idea with visualizations can be used in different scenarios. Not always
everything should be visualized, not every element must be in 3D format, but by evaluation of company’s current practice, the visualisation demand and level can be determined.

6. Conclusions

Logistics play a very important role in today’s world of business and trade. Logistics has extensive history and logistics can be used almost in all fields of economics. Also widespread technologies including logistics and related processes must be in nonstop development for new improvements.

As described by previous research on the field of logistics by Ginters [11], logistics can be applied by merging different technologies, like RFID and augmented reality. Main benefit is products or other warehouse objects’ recognition, detection and identification process. By improvement of these processes logistic system can reduce items’ pick up errors, because augmented reality approves correctness of selected item. AR main duty is to display to a user an additional data about specified item. Workers by augmented information on the screen or HMD always can be sure for correctly selected item. Previous results were implemented in indoors environments and thanks to innovative idea, it was important to bring it outdoors.

In order to implement this technology in outdoor environment, it is more appropriate to uses AR markerless technologies together with hybrid RFID. Developers should pay attention to GPS system signal strength, hybrid RFID tag placement and mobile device capabilities when choosing these technologies. Hybrid RFID with AR markerless system provides logistics’ processes in outdoor environment with additional security level, easier object identification, objects contents display and faster item flow in the system. Practical implementation is a future task for laboratory of Vidzeme University of Applied Sciences. To develop such a system offered theoretical models will be used and practical realization will be based on the results of two already developed AR pilot products in Sociotechnical Systems Engineering Institute of the Vidzeme University of Applied Sciences.

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