RFID technology based object tracking system

Matea Božić-Kudrić, Petar Šolić, and Nikola Rožić

Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
University of Split
R. Boškovića 32, 21000 Split, Croatia
E-mail: {matea.bozic-kudric, psolic, rozic}@fesb.hr

***Abstract*—The paper presents the system for tracking objects inside the room based on RFID system and software application returning objects real-time position. RFID system is consisted of Alien 9900 RFID reader, four RFID reader antennas and RFID tags. RFID reader antennas are arranged inside the room in order to provide more precise location of an object. The software application is consisted of a Windows Forms Application and a MySQL database. Database is provided to manage all information about the taged objects based on tag IDs. Windows Forms Application is developed in C# language and using AlienRFID1.dll class library. We are proposing system that allows very precise objects locating in any environment. The preciseness of a system can be increased using more RFID reader antennas. There is also a possibility of integrating the object video presentation module to a software application to facilitate the user to locate objects. Experimental results confirm the basic functionality of the proposed system.**

***Index Terms*—RFID technology, Objects tracking and locating, Alien technology, C#, MySQL database**

I. Introduction

RFID is one of potential technologies which provide real-time inventory data, real-time asset, object or human tracking, control etc. A radio frequency identification technology (RFID) belongs to the fastest growing sector of the radio technology industry just because of pre mentioned applications. It enables radio detection and recognition of an objects associated with an unique ID number code carried by the RFID tag. These tags send back their unique code whenever they are interrogated by an RFID reader within range [1]–[4]. These tags have integrated circuit containing the tag's ID with RF antenna and possibility of battery integration. Passive tags have no independent source of electrical power to drive its circuitry and they are depending on the received power from the reader to support operation of their circuitry and to send information back to the reader. Semipassive tags, also known as battery-assisted passive tags (BAPs), provide a local battery to power the tag's circuitry but still use backscattered communication for sending information back to the reader and active tags have a local battery and they are acting like classical transmitters [5]. Semipassive and active tags are achieving better reading ranges in the tens of meters and they are more reliable in communication with the reader than passive tags but main disadvantage compared to passive tags is their high production price and maintenance cost as well as their bigger dimensions. RFID systems are distinguished by their frequency ranges. Low-frequency RFID systems operates between 30 kHz and 500 KHz and they are having shortest reading ranges and lower system costs. High frequency (13.56 MHz) RFID systems are having higher reading ranges compared to low frequency RFID systems and better reading speeds. UHF RFID systems operate within 850 MHz to 950 MHz, they are offering reading ranges in excess of 10 meters with very high read rates and microwave RFID readers (2.4 GHz) are having reading ranges more than 35 meters but they are also having huge energy losses. Communication between RFID reader antenna and tag is realized in a way that reader antenna launches an electromagnetic wave, whose intensity in the absence of obstacles falls off as the square of the distance travelled and induces voltage in the tag's circuitry. Inductive coupling between the reader antenna and tag falls as the tag moves away from the reader antenna.

Ineffective systems for locating objects can reduce productivity of an organization, spend production time and money especially in large production and supply systems. There are lots of applications offering tracking object based on GPS for outdoor positioning, Wi-Fi based real-time tracking, barcodes, WSN (Wireless Sensor Networks), ultrasound and infrared technology and video camera detection. Advantage of RFID UHF technology based on the EPC Gen 2 protocol is that its cost is decreasing with tag costs dropping by 70% and reader cost dropping last few years. The price of a Gen 2 passive tag ranges from a few cents to a few dollars for aggrandized, encapsulated model, whereas active tags can run from ten to over one hundred dollars [6], [7]. RFID system is also very easy to integrate in every system thus creating intelligent enviroment like it is proposed in [8]. In the papers [4] and [2] authors present possible objects tracking using RFID technology for example in preventing theft. There is also possibility of using RFID tracking system in hospitals for patients, visitors and staff monitoring, in automotive industry, manufacturing, military, transportation etc. like it is described in [9].

In this expert work is presented RFID technology based system for tracking instruments, books and other taged objects inside the room. We developed user friendly software application for real-time tracking objects based on Alien .NET API which is better described in section that follows. User can have better insight in objects usage, replacing and moving outside the room. Proposed system can be used in offices, laboratories, storages and similar places.

The sections are organized as follows. In section II is more detail described mentioned software application as well as Alien RFID technology. Section III presents description of experimental system set-up. In section IV we discussed experimental system results we obtained. At section V we adduce some possible system extensions and section IV provides some conclusions.

II. Object Tracking System

A. Alien RFID Technology

Alien Technology is one of the industry's most experienced, quality suppliers of RFID innovations, technologies and products. In this work we used Alien 9900 RFID Reader. The most basic function of the RFID Reader is to read RFID tags and to give to the user or application access to a list of tags. The RFID Reader is designed to perform this function either connected to a host via serial cable (RS-232), or via network connection (TCP/IP). RFID reader which is used in this work has flexible GPIO (General Purpose Input/Output) system which allows simultaneous communication with up to 12 external devices (4 inputs and 8 outputs) and controls various gates, switches and devices. It has possibility of automatic parameter adjustment switch thus ensures optimum inventory settings, filtered tag data options, tag streaming, I/O monitoring and streaming. The loss of power or LAN connectivity does not lead to the loss of critical tag data because reader can catch up to 2500 tags records in non-volatile memory, preserving data even in the event of a power loss. The reader is compliant with the EPC Gen 2 Dense Interrogator specification, which reduces interference impact on other readers. Its Dense Reader Mode (DRM) significantly reduces the channel noise introduced from the outside. Its maximum radiated power is 31.6 dBm.

In this work we used network communication with the reader. TCP/IP communication requires a network connection via reader's Ethernet port and allows the reader to operate like a Telnet server. Alien Development kit includes two circular polarized antennas which we used along with two Favite UHF RFID antennas.

B. Object Tracking Software Application

Real-time RFID based object tracking software application is accomplished by using Alien .NET API (Application Programming Interface). The software of an Alien RFID Reader can be controlled using different systems and languages. For application developing we used software development environment Microsoft Visual Studio, AlienRFID1.dll class library and Alien .NET SDK which are part of the Alien Development Kit. The class library contained within AlienRFID1.dll provides classes for discovering readers connected via serial ports or network as well as for monitoring tags status read by the reader antenna [10].

Few classes and methods that are used will be described hereafter. The class *clsReader* is the main class for interaction with an Alien RFID reader. The classes *clsReaderMonitor* and *clsReader* use storage types to pass information to the functions and user applications about the state of readers connected to the system. The *clsReaderMonitor* is a class that can automatically search for and discover readers. *ReaderInfo* class contains key information that allows a software system to identify and contact a reader. It provides information such as the reader name, type and address. *TagInfo* is a type for holding information about tags. This type allows tracking the Tag ID, the CRC (Cyclic redundancy check) for the Tag ID, the date and time the tag was last observed by the reader as well as the number of times tag has been observed. Functions such as *AlienUtils.ParseTaglist()* return arrays of *TagInfo* objects from raw string data read by the reader.

In interactive mode the reader can read multiple tags at once using the *get TagList* command. *TagList* can be represented in several formats: text format which is default one, XML, Terse, or custom. The *AlienUtils* class provides static methods for parsing tag list strings into an array of *TagInfo* objects. The *CAlienServer* class provides methods for listening asynchronous messages as Alien Notifications and/or Tag- and IO-Stream events sent by the reader over the network. *CAlienServer* maintains a collection of established connections identifying each connection with an unique identifier (GUID) and precedes all event messages with this connection specific GUID.

The program which is Windows Forms Application is developed in C# language and has an access to a MySQL database. C# language is very simple object-oriented programming language which applications are easy to implement. MySQL is a leading open source database management system. It is a multiuser, multithreaded database management system [11]. ADO.NET is an important part of the .NET framework. It is a specification that unifies access to relational databases and other application data. A MySQL Connector/Net is an implementation of the ADO.NET specification for the MySQL database. *Connection*, *Command*, *DataSet*, *DataProvider* and *DataAdapter* are the basic elements of the .NET data provider model. The *Connection* creates a connection to a specific data source. The *Command* object executes an SQL statement against a data source. The *DataReader* reads streams of data from a data source. The *DataSet* object is used for offline work with a mass of data. It is a disconnected data representation that can hold data from a variety of different sources. Both *DataReader* and *DataSet* are used to work with data. *DataAdapter* is an intermediary between the *DataSet* and the data source. It populates a *DataSet* and resolves updates with the data source.

When connected to a discovered or manually added reader the application first saves reader's configuration, then prepares it for sending streaming messages and after checking corresponding check-boxes acquires incoming messages. Reader is streaming for tags and parses all discovered tags information into *DataGridView* which displays data in a customizable grid every few seconds. Notify time is defined by the user. All changes are saved into predefined MySQL database. Database includes next values: tag ID with a white space between each pair of bytes, tag CRC, discovery time of tag, last seen time of tag, antenna ID that the tag was last read from, tag read count, Rx antenna receive antenna the tag was last seen, Tx antenna is antenna the tag was last seen at, information about tag's protocol, tag data, Numbering System Identifier (NSI), tag data array, Pc word, tag speed which impacts tag reading performance, tag RSSI measurement, direction ("+" - approaching, "-" - receding, or "0" - stationary), reader name, host name, reader's IP address, reader's MAC address and reader performing frequency. Part of developed database can be seen at the figure 1.

ID	TagID	TagCRC	DiscoveryTime	LastSeenTime	Antenna	ReadCount
1	E200 1021 3406 0192 1790 5BEF	-	2013/05/23 14:45:07	2013/05/23 14:46:31	1	332
2	E200 1021 3406 0192 1850 535D	-	2013/05/23 14:45:07	2013/05/23 14:46:31	0	332
3	E200 1021 3406 0192 1910 4DCF	-	2013/05/23 14:45:07	2013/05/23 14:46:31	0	351
4	E200 1021 3406 0192 1850 535D	-	2013/05/23 14:46:31	2013/05/23 14:48:19	0	353
5	E200 1021 3406 0192 1910 4DCF	-	2013/05/23 14:46:31	2013/05/23 14:48:20	0	348
6	E200 1021 3406 0192 1790 5BEF	-	2013/05/23 14:46:31	2013/05/23 14:48:20	1	353
7	E200 1021 3406 0192 1850 535D	-	2013/05/23 14:48:20	2013/05/23 15:00:19	0	2840
8	E200 1021 3406 0192 1910 4DCF	-	2013/05/23 14:48:20	2013/05/23 15:00:19	0	2806
9	E200 1021 3406 0192 1790 5BEF	-	2013/05/23 14:48:20	2013/05/23 15:00:19	1	2840
10	E200 1021 3406 0192 1850 535D	-	2013/05/23 15:00:19	2013/05/23 15:14:52	0	2820
11	E200 1021 3406 0192 1910 4DCF	-	2013/05/23 15:00:19	2013/05/23 15:14:52	0	2242
12	E200 1021 3406 0192 1790 5BEF	-	2013/05/23 15:00:19	2013/05/23 15:14:52	1	2820
13	E200 1021 3406 0192 1850 535D	-	2013/05/23 15:14:52	2013/05/23 15:15:59	0	213
14	E200 1021 3406 0192 1910 4DCF	-	2013/05/23 15:14:52	2013/05/23 15:15:59	0	202

Fig. 1. Part of MySQL database

At the user interface user selects the objects from the objects list and gets the information about that object. The information about its location is based on antenna ID that the tag, which is attached to the object, was last read from. User also gets information about last seen time of an object if the one is not currently inside the room. At the figure 2 it can be seen three user interfaces of the program. After opening application window user needs to click button to add reader and to start tag streaming.

III. Experimental System Set-up

For testing of the proposed system we used four RFID UHF antennas along with Alien RFID reader and BAP tags. Three of four antennas were set on the dashboard which is connected at the ceiling supporter and one antenna is attached above the door. Three antennas attached for the dashboard are directed towards the taged objects inside the cabinets and on the desk and antenna above the door tracks the objects and people entering and leaving the room. We used two Alien RFID antennas with right hand circular polarization, 8.5 dBiC gain and 865 - 960 MHz frequency range and two Favite RFID antennas with left hand circular polarization, 8 dBiC gain and 865 - 870 MHz frequency range. RFID UHF reader output was set to 30 dBm. All objects inside the room were equipped with one RFID BAP tag. Testing environment can be seen at the figure 4 and its scratch at the figure 3.

All cabinets inside the testing room were filled with the instruments and books all equipped with the one BAP tag and arranged inside randomly. According to the antennas radiation diagram we arranged objects inside the cabinet in a way that they are covered by the antenna radiation. At the figure 5 it can be seen antennas horizontal and vertical radiation diagram compared to the horizontal and vertical position of one cabinet inside the room. It can be seen that at the angels of the horizontal cabinet position radiation falls for 7.5 dB and at the angels of the cabinet vertical position antenna radiation falls for 9 dB. Those are calculations for one cabinet inside the room.

We test proposed system in a way that we moved instruments and other taged objects between the cabinets and desk

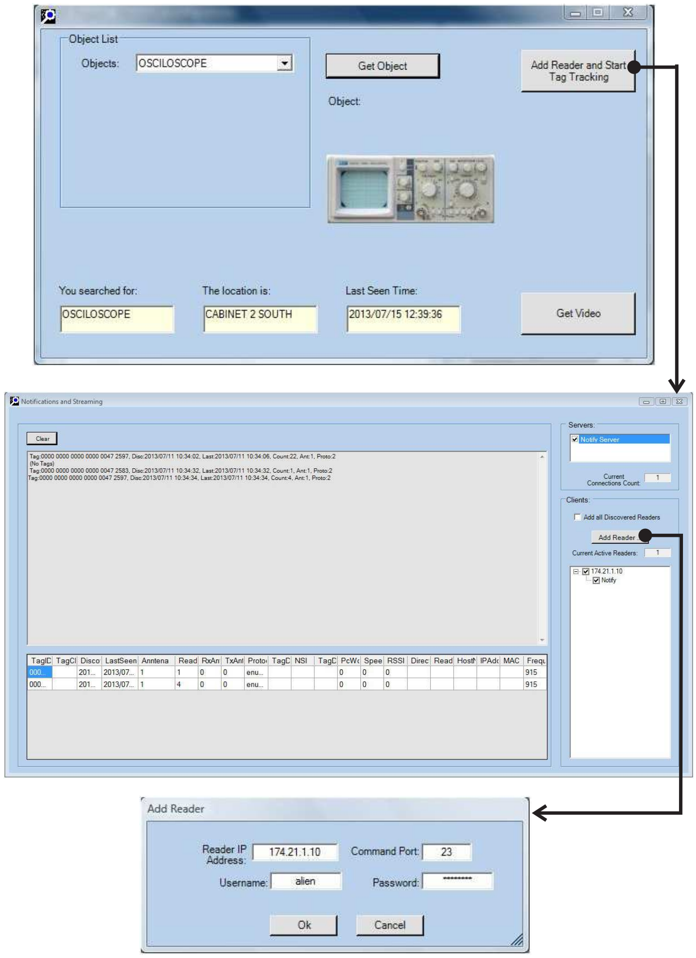

Fig. 2. User interfaces of the object tracking software application

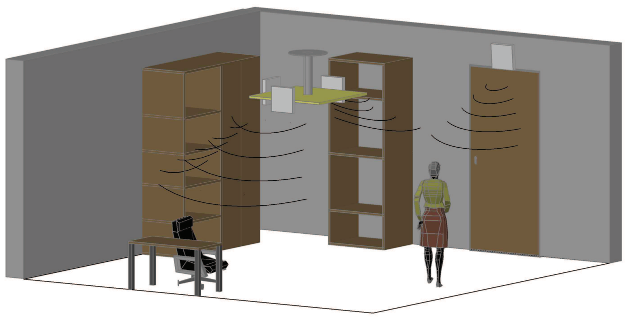

Fig. 3. Measurement and testing set-up scratch

and followed results we obtained by the software application. We also moved objects to and from antennas to see what is the reading range of antennas inside the room.

Potential problems can occur if tag is covered with some person or other object, or if one tag is very close to other tag because of field interference but still we are having very reliable communications with the reader because of BAP tags usage. After some period of time which is determined by the battery's lifetime BAP tags need to be replaced with new tags.

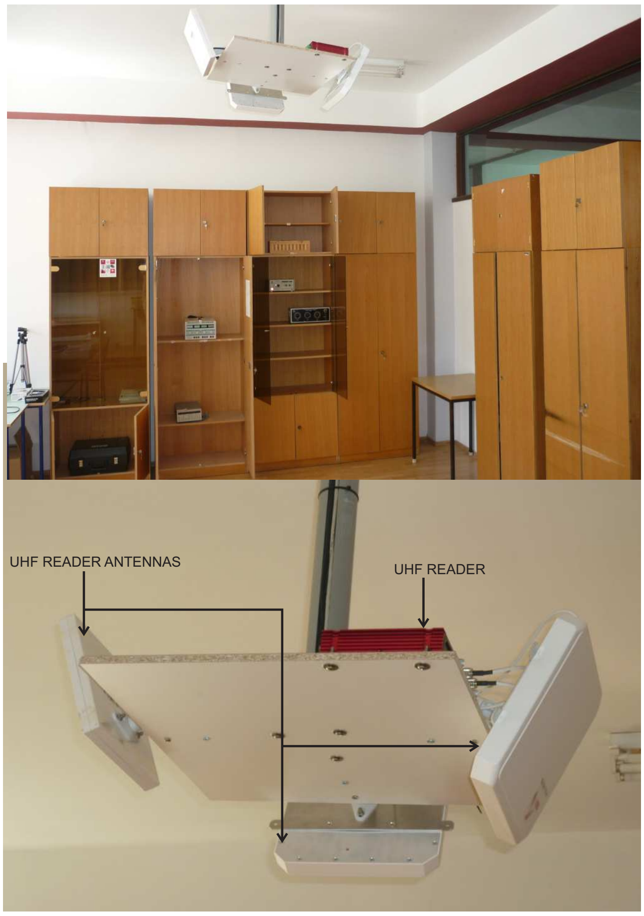

Fig. 4. Measurement and testing set-up

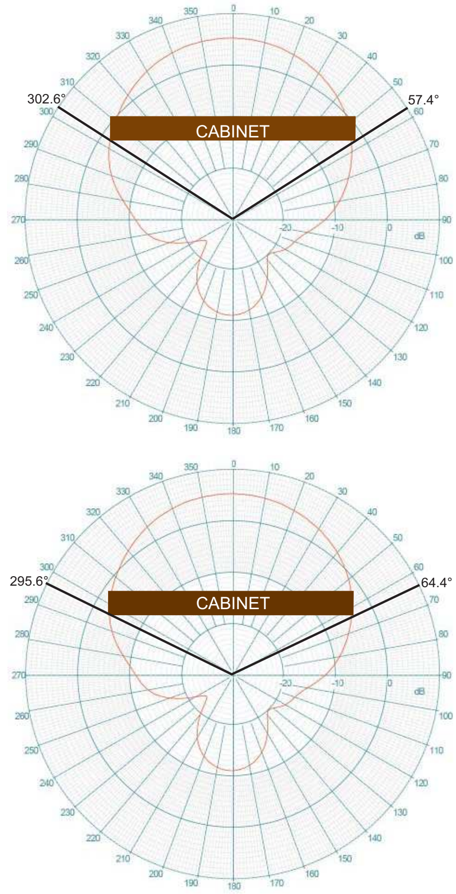

Fig. 5. Horizontal and vertical radiation diagram of Alien RFID antenna compared to the cabinet position

IV. Experimental system results

We preform testing with passive and battery assisted passive tags. In first measurement scenario we attached pure passive tags to the instruments and books and tested communication between antenna above the door and antennas that are attached for the ceiling supporter and passive tags. When objects were moved through the door they were detected by the antenna above the door if the person carrying object was very close to the door. Person can hold object at any hight but tag shouldn't be covered with many obstacles because it would be invisible for the antenna. Reading of the tag also depends on how fast person is passing the door because when the person quickly passes the antenna passive tag won't be read. For testing ceiling antennas we attached passive tags for the instruments and randomly arranged it inside shelves of two cabinets and on the desk. It can be seen that tags were read only if they were attached at the front side of an instrument, when they weren't in the nearby of some metal surfaces or when taged instruments weren't set at the cabinet marginal shelves. Antennas also didn't detect objects when they were moved through the room at great distance form the antennas.

At second measurement scenario we used battery assisted passive tags for objects taging. Like in the first measurement scenario first we tested communication between antenna above the door and taged objects. It can be noticed that objects were read at greater distances compared to the objects that were equipped with passive tag. Person carrying object don't have to be close to the antenna so that antenna detects it, which can also be a problem because person can carry object around the room and still be detected by the antenna. That means that someone can get wrong information about that object position. That problem can be solved with increasing resolution of the system. This means that we can add more antennas around the room. Testing of ceiling antennas was preformed in a same way like in the first measurement scenario. Results for BAP tags were different compared to passive tags. BAP tags were read when they were attached at the top of the instrument not only on its front side, they had better communication with the reader when they were in the nearby of some metal surfaces and they were read better even at the position inside the cabinet where the antenna radiation is weaker. At the figure 6 we can see battery assisted passive tag with it's battery and at the figure 7 it can be seen the passive tags we used to preform system testing.

V. Proposed system evaluation

The proposed system for tracking and detecting objects can be evaluated in more ways. To increase accuracy in locating objects inside the room we can use more RFID antennas. With more antennas inside the room system can provide

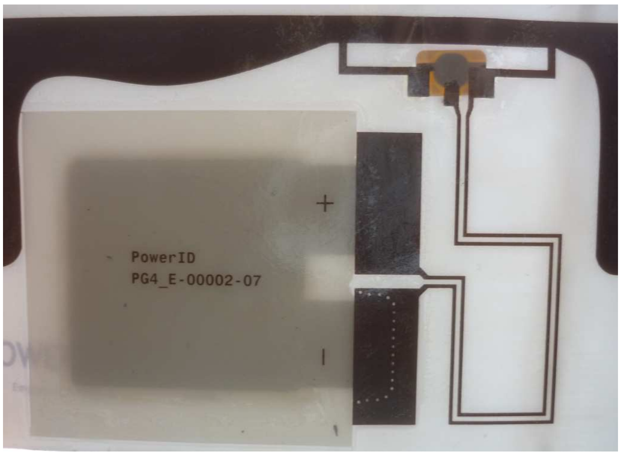

Fig. 6. Battery assisted passive Gen2 UHF tag

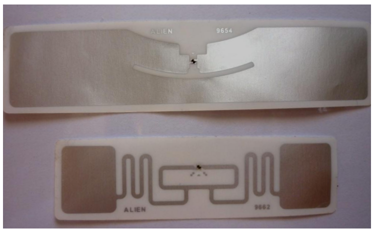

Fig. 7. Passive Gen2 UHF tags

more reliable results. Objects position is determined by the antenna which detects tag attached to the object. Thus more antennas means more precise object location. Antennas can be distributed all over the floor not just in one room and thus system can provide monitoring the entire floor or building.

Furthermore, instead of BAP tags which are used in the proposed system we can use inductively powered passive tags like it is proposed in [12]. Those tags operating lifetime isn't limited by the battery lifetime. Also the use of passive tags which are powered in mentioned way can reduce system price if we are looking at the longer period of time. There is also possibility of using the sensor equipped UHF RFID tags with high read ranges and reliability. That means that system can be used in some surroundings where objects have to be placed in some exactly temperature determined places.

The software application of the proposed system can be extended by integrating module for video presentation of found object.

VI. Conclusion

We proposed system for tracking and positioning objects based on RFID technology. There are a various types of RFID technology applications but the most widespread are radio detection, tracking and object recognition applications. We developed software application which is used along with RFID system to locate objects inside the room. This system can be used in large laboratories or storages which are equipped with lot of instruments, for big offices where there are many documents and books on the cabinet shelves or for any similar surroundings. This is also very low cost solution because the RFID technology is one of the most rapidly expanding technologies which prices are reducing every day. The proposed system is reliable in finding objects due to reliable communication of RFID reader with BAP tags we used. The system is feasible and can be integrated easy according to the user needs. This means that its resolution and robustness can be user defined.

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