UDC 6.64.641.05

Elżbieta Andrukiewicz, Kazimierz Waćkowski

Politechnika Warszawska, Poland

TECHNICAL FEASIBILITY OF THE SYSTEM FOR LOCATION AND TRACKING GOODS IN DISTRIBUTION CENTER BASED ON RFID AND UAV TECHNOLOGIES

The main problem is the development and implementation of an UAV indoor location algorithm. The paper presents the results of investigations by the algorithm based on information obtained from the regular grid RFID-tags. Special attention endowed research systems for identification and placement of a fixed infrastructure of RFID.

Keywords: *UAV, RFID, location, tracking, distribution center.*

Formulation of the problem

A major problem in large logistics warehouses (distribution centers) is the necessity of periodically performing the stock inventory ie. agreeing actual numbers of goods with figures obtained from the warehouse's information system. Such task is difficult to automatize, hence costly and time-consuming. A solution to this problem is described in this article.

RFID technology is an important part of constantly growing logistics industry used in solutions for automatic identification of goods.

A concept based on the RFID technology, not only for identification but for location and tracking goods in warehouses as well, has emerged. That way inventory processes can be performed in real or near real time. However, implementation of this concept would require significant investments upgrading the existing RFID infrastructure, which may be difficult to justify economically. Using RFID and Unmanned Aerial Vehicle (UAV) technologies together opens new opportunities to develop hardware and software systems with functionalities for identification as well as location and tracking goods in warehouses. The costs of the proposed solution is a fraction of those of building or extending fixed RFID infrastructure.

The main problem is the development and implementation of an UAV indoor location algorithm. In this article we present results of our research on an algorithm based on information from a regular grid of RFID tags.

New ways of improving the effectiveness of inventory processes in distribution centers

Introducing systems for the stock automatic identification improves supply chain's efficiency. Next generation of these systems based on Radio Frequency Identification (RFID) technology, ie. the identification of objects marked with the RFID tags using data transmitted by radiolink, opens several possibilities for improvement and optimization of storing costs.

Inventory is an area where the biggest reduction in operation costs can be obtained. Inconsistency of the actual inventory stocks with the records in the information system results in selling processes disruption and can be the source of inaccurate forecasts. Ensuring the consistency of the records and physical stock is time and resource consuming.

The automation of inventory process can be a source of significant savings. The system for location and tracking the stock in distribution centers ensures the inventory in defined scope and frequency, and saves the cost and time required for manual or semiautomatic inventory.

Object location based on RFID technology

Research on systems for object identification and location based on fixed RFID infrastructure are widely described in professional literature.

An algorithm using a set of RFID readers deployed in a room to form squares was presented in Reza et al [2011]. In order to reduce the location error additional diffusion algorithm was applied. It calculates the probability of finding the object in a given location. The research was conducted in two-, not tridimensional space. Obtaining an average location error of approx. 0,2m, within the research area of 64 m2, required installation of 25 RFID readers (plus antennas). The results were confronted with others including those using algorithms based on triangles, and the improvement of some parameters like the average location error was shown.

Our research concerning tridimensional installation using the scene-based algorithm described in Ting et al [2011], was improved by implementing an idea of virtual tags described in Zhao et al [2007].

We divided the research scene into square cuboids of dimensions 2m by 2m by 1,5m. 12 RFID antennas were placed in such a way that they formed 0,5m/0,5m/0,5m cubes. The measurements resulted in an average location error of 0,3m.

Based on the results described above, a traditional multi-antenna RFID infrastructure shows several constrains:

- Commonly recognized location algorithms used in outdoor environment (eg. triangulation) are difficult to apply in a closed space of the warehouse due to electromagnetic wave propagation properties;
- Applying algorithms for compensation for read errors caused by propagation properties ie. distortions, attenuation and reflection of electromagnetic waves, complicates and makes the infrastructure needed to obtain required location accuracy more extensive and hence more expensive (see below).

Research problem formulation

The idea of identifying objects labelled with RFID tags and locating them in the warehouse space using mobile RFID infrastructure ie. antenna/reader RFID circuit mounted on Unmanned Aerial Vehicle (UAV), commonly known as a drone, emerged as a result of analyzing technical issues described above and economic aspects of possible implementation.

The cost comparison of equipping a medium-size distribution center with a RFID-based system for identification, location and tracking of goods, configured in traditional multi-antenna network (as proposed in Reza et al [2011]), and with the mobile RFID circuit mounted on the drone is presented in Table 1 (all estimations expressed in net values).

Table 1

Cost comparison for fixed and mobile RFID infrastructure

Fixed multi-antenna RFID infrastructure*							
	Number of devices needed for 1 rack	No of racks in a module	No of modules in an alley of 50m length	No of allays in 100m-width warehouse	No of devices needed for the warehoues	Unit price (euro)	Total cost (euro)
Antenas	12	4	34	10	16 320	82	1 338 240
Multiplexers (16-antennas)					1 020	267	272 340
Readers (4-inputs)					255	855	218 025
TOTAL:							**1 828 605**
One-antenna RFID reader mounted on UAV*							
UAV	1	no impact	no impact	no impact	1	1200	1 200
Reader	1	no impact	no impact	no impact	1	270	270
Antenna	1	no impact	no impact	no impact	1	20	20
TOTAL:							**1 490**
* own estimations based on list prices of chosen RFID producers							

However, applying UAV in an indoor environment requires solving the problem of developing and implementing a location algorithm for a drone itself.

State-of-art location solution for mobile robots

Mobile robot route control algorithms

Programming mobile robots to control their movement in two-dimensional space eg. on the floor is well documented and described in several sources. The robot should move autonomously in a controlled way and provide trustworthy information on its location, which could subsequently be used for assessing location of objects read by antennas mounted on the robot.

The simplest solution for controlling the robot movement, and one of earliest proposed is the one based on odometry ie. calculation of the actual route by counting the number of turns of the robot's wheels (Borenstein (1998), Kelly (2001)). However, this approach results in significant reading error, potentially cumulative in function of the route travelled. RFID technology has been used to compensate for the odometry reading error (DiGiampaolo and Martinelli (2012), among others).

RFID technology has appeared as the one of the most promising direction for mobile robots route-control algorithms due to availability, scalability and low cost. Variety of of this technology were proposed in many works. Park and Hashimoto (2010) and Sanda et al. (2014) used time-of-arrival and delay of the received signal strength (RSSI) parameters in their works. Chawla et al. (2013), Miah and Gueaieb (2014) built their algorithms on RSSI values, while Choi and Lee (2009) reduced their algorithm to a binary form: presence or absence of the reading. It is worth mentioning that strong influence of external factors on reading errors limits the applicability of many algorithms. Only the last mentioned algorithm is applicable without implementing advanced statistical methods for noise reduction. To increase the robot's "level of environmental awareness” Choi and Lee (2009) proposed the use of a sonar as an additional source of information. Multi-antenna configuration as a method for increasing the accuracy of readings was proposed by Niu et al. (2012).

Flying robot route control algorithms

Continuously growing popularity of UAVs enables expanding the reading area covered by a drone to the third dimension. Choi et al. (2012) presented an algorithm for the drone movement control by using a grid of RFID reference tags, placed on the floor.

Joint RFID and UAV technology implementation is currently an emerging domain. Majority of reported research was performed on a relatively small scene, previously examined and stored in the robot’s control unit memory. In particular, experiments and implementations of drones in distribution centers for locating and tracking of goods have not been described yet.

An innovative idea of the proposed algorithm lies in introducing adaptive system for the drone flight control which uses information from the receiving signal strength continuously acquired from RFID reference tags during the flight. RFID reference tags are mounted on racks in such way they form regular grid reflecting configuration of racks in the warehouse. Such placement of tags gives a surface of signal sources perpendicular to the UAV’s flight trajectory which allows to reduce the number of RFID tags required to obtain satisfactory level of accuracy of the algorithm proposed comparing to the one described in Choi et al. (2012).

The algorithm can be applied in distribution centers organized in high bay warehouses which ensure regular or at least ordered configuration of racks and shelves with the goods placed.

Fig. 1 presents the idea of a new algorithm.

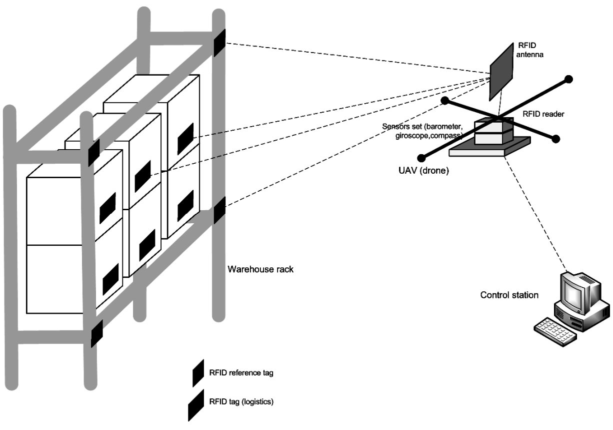

Fig. 1. System for location and tracking of goods by using UAV and RFID technologies – general concept

RFID reader prototype mounted on UAV

RFID Antenna/reader set should fulfill additional, above-standardized requirements stemmed from specific needs of mounting the set on UAV and necessity for stable reading of radio signal from the distance between the rack and the drone’s flight trajectory. Those requirements relate to the following RFID parameters:

- an antenna with satisfactory gain and polarization, sufficiently light and small,
- radiation power comparable with fixed RFID devices,
- two-way communication with the control station in real time,
- and the device itself:
- minimal total weight (due to limited UAV payload),
- small dimensions (due to limited space for additional equipment on the drone’s board,
- impact resistance of the device’s housing (protection from falling),
- standalone power source or connectivity to the UAV power module.

A device with above mentioned parameters was not available on the market hence own prototype has been developed and implemented.

Basic parameters of the prototype are presented in Table 2.

Table 2

The prototype basic parameters

RFID Prototype	**Description/Value**
RFID antenna	
─ polarization	circular
─ gain	5,5 dBi
─ weight	120 g
RFID reader module	
─ reader type (OEM)	CAEN 1270B
─ communication protocol with control station	802 11b
─ class protection for housing	IP 54
Prototype’s total weight	580 g

Technical feasibility of UAV location algorithm using information from RFID tags

Scene arrangement

To verify possible use of the RFID antenna/reader device as information source for the UAV location algorithm for indoor applications a measuring field in large sports arena was arranged (see Photo 1 and 2).

The field (see Photo 2) consisted of four temporal adjusting tubes with RFID reference tags mounted on them in a way to imitate typical grid of racks in the warehouse.

Confidex Survivor RFID tags designed for logistics applications were chosen as reference tags. Reference tags were placed on adjusting tubes on the height of 1,65m. The distance between two tubes was 2,0 m. Commercially available UAV model 3DR RTF Y6 from 3DRobotics was used in trials.

Photo 1. RFID reader module
(mounted at the bottom of UAV)
and RFID antenna (mounted at the front of UAV)

Photo 2. Measuring field arrangement

The UAV travelled the route of 8,05m (denoted at charts as axis Y) with average velocity of 0,95m/s. Trials were conducted for following settings:

- The UAV flight's trajectory distance from RFID tag was: X1=1 m, X2=1,5 m, X3 = 2 m
- The UAV flight's trajectory height was: z1 = 1,65m, z2 = 1,2m

The RFID on board reader's parameters were:

- 4 channels of width of 200 kHz and central frequencies in the bandwidth of 866-868 MHz, according to ETSI EN 302 208,
- Radiolink: TX PR-ASK F=40kHz ; RX Miller M=4 LF=320kHz
- Reade output power: 27 dBm

Measuring software developed exclusively for this purpose continuously collected data in the form of RSSI readings from subsequent RFID tags identified through unique electronic product code (EPC) during the drone flight. The frequency of reading was 200 ms.

The drone flights in the measuring field are presented in Photo 3 and Photo 4.

Presentation of results

Following charts show results for chosen trials. Horizontal axis represents the distance travelled by the UAV expressed in milliseconds, while vertical axis gives RSSI values expressed in dBm (fig. 2 – 5).

Photo 3. Drone flight at z=1,65m

Photo 4. Drone flight at z=1,2m

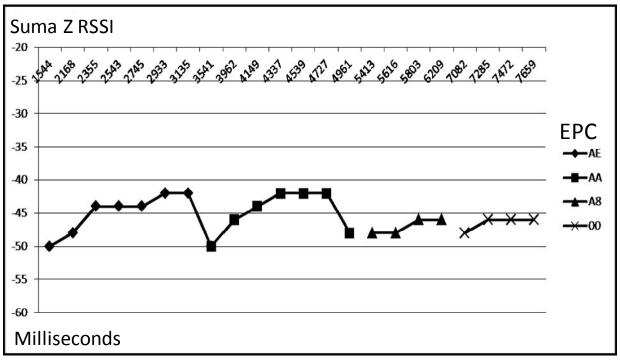

Fig. 2. Received signal strength in function
of the route travelled (UAV trajectory distance
from RFID tags x = 1,5 m, flight height z = 1,65 m

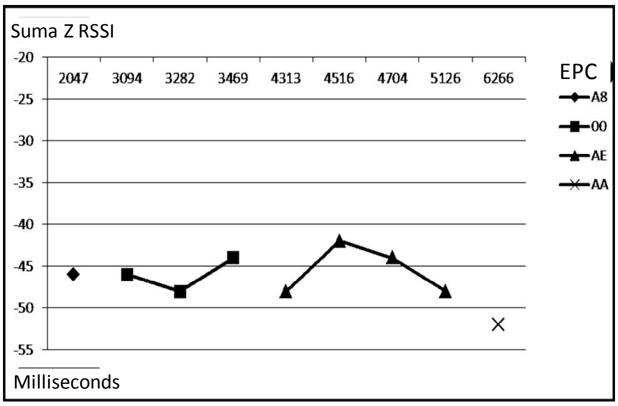

Fig. 3. Received signal strength in function
of the route travelled (UAV trajectory distance
from RFID tags x = 1,5 m, flight height z = 1,2 m)

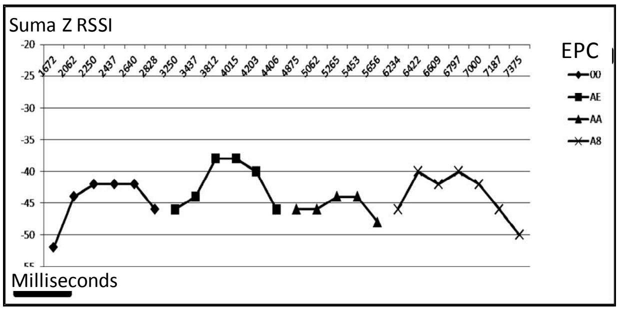

Fig. 4. Received signal strength in function of the route travelled (UAV trajectory distance from RFID tags x = 1 m, flight height z = 1,65 m)

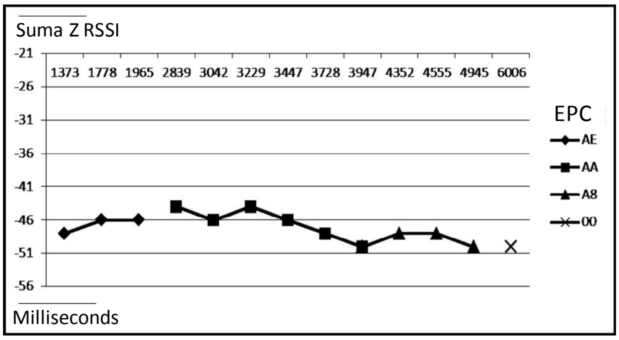

Fig. 5. Received signal strength in function of the route travelled (UAV trajectory distance from RFID tags x = 2 m, flight height z = 1,65m)

Conclusion

The research on technical feasibility of the RFID and UAV based system for location and tracking of goods in distribution center was successful. The possibility of using RFID tags to provide additional information on location for UAV and therefore enable automatic movement of the UAV within a distribution center was confirmed. Clear characteristics of RSSI for all measured tags were obtained for smaller distances between drone trajectory and the racks. For bigger distances, time slots for which no measures were obtained exceeded 1s, which could prove too much for the software controlling the flight to unambiguously evaluate current UAV location. In this case, however, increasing the density of reference tags may provide a solution. From the UAV location algorithm perspective it is possible to take into account not only whether the reading is present or not but RSSI values measured in function of distance from the source which could reduce the accuracy error.

Results are not explicitly positive for measures taken from flights on the height below the line of RFID tags, but still the algorithm based solely on detecting the presence of tags is applicable.

The research results provided a base for a new project on applicability of RFID and UAV technologies for inventory tasks in high-bay warehouses.

Bibliography

1. *Bornstain J. Experimental Results from Internal Odometry Error Correction with the OmniMate Mobile Robot / J. Bornstain // IEEE Transactions on Robotics and Automation. – December 1998. –Vol. 14, No. 6. – P. 963-969.*
2. *Chawla K. Real-time RFID localization using RSS / K. Chawla, C. McFarland, G. Robins, C. Shope // 2013 International Conference on Localization and GNSS (ICL-GNSS), Charlottesville 2013.*
3. *Choi B. Mobile robot localization scheme based on RFID and sonar fusion system / B. Choi, J. Lee // IEEE International Symposium on Industrial Electronics, Daejeon 2009.*
4. *Choi J. Indoor localization of Unmanned Aerial Vehicle based on passive UHF RFID systems / J. Choi, S.R. Byung, H.K. Kang, D.H. Lee // 9th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), Daejeon 2012.*
5. *DiGiampolo E. A Passive UHF-RFID System for the Localization of an Indoor Autonomous Vehicle Industrial Electronics / E. DiGiampolo, F. Martinelli // IEEE Transactions on Industrial Electronics. – 2012. – Vol. 59, issue 10. – P. 3961 – 3970.*
6. *Kelly A. Linearized Error Propagation in Odometry / A. Kelly // International Journal of Robotics Research. – Feb 2004. – Vol 23, No 2. – P. 179-218.*

Надійшла до редколегії 22.03.2016

Рецензент: д-р техн. наук, проф. Ф.В. Новіков, Харківський національний економічний університет, Харків.

ТЕХНІЧНА РЕАЛІЗАЦІЯ СИСТЕМИ ДЛЯ РОЗМІЩЕННЯ ТА ВІДСТЕЖЕННЯ ТОВАРІВ В ДИСТРИБУЦІЙНОМУ ЦЕНТРІ НА БАЗІ RFID І UAV ТЕХНОЛОГІЙ

Є. Андрюкевич, К. Вацьковський

Ключовою проблемою сьогодення є розробка і реалізація алгоритму з метою розташування UAV технологій. У статті представлено результати досліджень за алгоритмом на основі інформації, отриманої від регулярної сітки RFID-тегів. Окрему увагу наділено дослідженню систем для ідентифікації та розміщення об'єктів на основі фіксованої інфраструктури RFID.

Ключові слова: *UAV, RFID, місце розташування, відстеження, розподільний центр.*

ТЕХНИЧЕСКАЯ РЕАЛИЗАЦИЯ СИСТЕМЫ ДЛЯ РАЗМЕЩЕНИЯ И ОТСЛЕЖИВАНИЯ ТОВАРОВ В ДИСТРИБУЦИОННОМ ЦЕНТРЕ НА БАЗЕ RFID И UAV ТЕХНОЛОГИЙ

Е. Андрюкевич, К. Вацьковский

Сегодня ключевой проблемой является разработка и реализация алгоритма с целью расположения UAV технологий. В статье представлены результаты исследований по алгоритму на основе информации, полученной от регулярной сетки RFID-тегов. Отдельное внимание уделено исследованию систем для идентификации и размещения объектов на основе фиксированной инфраструктуры RFID.

Ключевые слова: *UAV, RFID, местоположение, слежение, распределительный центр.*