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Localization of RFID tags for environmental monitoring using UAV

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Abstract— **The paper presents the experimental implementation of a method to localize RFID tags in an outdoor environment using UAV. During the installation phase, it is possible to measure the coordinates of the installation point using a topographic GNSS receiver. The tags positions can evolve with time and after a specific desired period of time (e. g. 1 month or 1 year) it is necessary to relocate them. This can be done estimating the distance between the tags and a UAV, exploiting the measurements of the Received Signal Strength Indicator (RSSI). The tags are placed over an outdoor test area and a large amount of RSSI measurements are made in different position, well distributed in space, using a UAV equipped with a specific tag reader. On such data, a multilateration-based localization algorithm is applied achieving good results. The description of RFID tags is reported together with the localization algorithm, the test description and the preliminary results.**

Index Terms— **RFID tags; UAV; localization; RSSI.**

DIFFERENT Wireless Sensor Networks (WSN) and RFID tags have been developed to monitor environmental parameters and to be installed in outdoor environment like a hanging glacier [1] [2], a landslide [3], a lake [4] or contaminated areas. At the same time UAVs are a definitely efficient and reliable technology in environmental and remote sensing research. They are especially useful to reach dangerous places where human operators devoted to environmental monitoring cannot operate in safety.

The structure of a WSN for environmental monitoring is quite simple: most of the realized networks are made by a set of RFID tags distributed on the territory and a single reader acquiring the measurements made by the tags. Each tag is equipped with measuring sensors and store locally the measured parameters. In the experimental network the reader is mounted on the UAV and through an appropriate communication protocols it identifies the tags, downloads the data and sent them to the Ground Control Station (GCS).

One of the main problems in such application is to identify RFID tags positions because it can vary with respect to their initial placement. There are a lot of techniques to recover a RFID position: they can use statistics, multi-lateration position estimation, GPS, ecc. Most of them require a qualified operator walking around and manually scanning for tags with a specific reader in different positions in order to have a sufficient dataset of estimated distance to obtain the RFID tag position with the desired precision (e. g. in [5]).

The idea proposed in the present paper is to use a UAV equipped with a RFID reader to fly over a field and scanning for tags. When a tag is detected, the UAV continue to rotate in the area performing Received Strength Signal Indicator (RSSI) measurements and acquiring its instantaneous position. Acquired data are sent to the operators, who process them to obtain the tag position. Some similar works are made in indoor environment (e.g. [6]) but in the present work the experimental activity was made in an open space.

In the following the tag description is reported together with the algorithm description, the test experiment description and the presentation and discussion of the preliminary results.

I. System Components

A. UAV Platform

The experiment was set up using a simple and economic four helix UAV, the 3DR IRIS, with a payload capability of 0.4 kg. This UAV is featured with the APM copter open source controller. It is possible to customize the parameters of the rotors according to the desired responsiveness and stability, and send real time fly data (telemetry) to a ground control station (a Notebook with a USB radio telemetry kit) running a compatible software like APM Planner 2.0, Mission Planner or Andropilot. Without any modification to the source code or to the UAV it was possible to acquire in real time the position measured by the onboard GNSS receiver. The GNSS receiver is an Ublox LEA-6H module, designed for low power consumption and low cost. The module works in standalone positioning mode with all the available satellite positioning systems and it is ready to support the European Galileo system via a simple firmware upgrade.

B. RFID Reader

The UAV Reader has a single antenna; it is independent from the UAV platform concerning the communications and power supply and permits the radio connection between the tags and the GCS.

The RFID reader is visible in Fig. 1; it is contained in a simple waterproof rectangular box fixed under the UAV. The

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antenna is a small form factor helix antenna inside the box. The reader acts as a bridge between tag and GCS and it carry out different tasks:

- Tag discovery: search for tags in the area sending a broadcast message that wake up the tags radio.
- Data download: automatically or manually download data from detected tags.
- Tag localization: during the localization procedure the reader continuously send a ping request to the tag and log the RSSI measurement of the reply.

Fig. 1. UAV and RFID reader.

C. *Ground Control Station (GCS)*

The GCS is composed by a Notebook, the USB to Radio interface, and the software (named “console”). The interface is visible in Fig. 2 where it is possible to see the different functionalities, like discovery operation, data download and tags localization. Different boxes show at the operator (starting from the first on the left) the numbers of the identified tags, the connected reader identification number, the queued tags waiting for download data, the sent commands and the log files automatically created downloading the data.

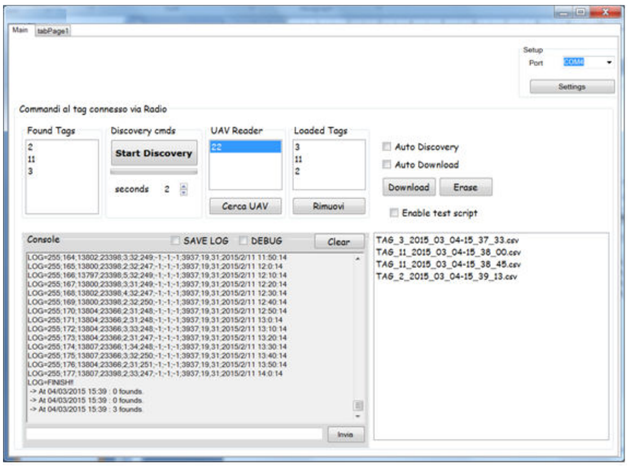

Fig. 2. Reader remote console.

D. *RFID Tag*

The RFID tag was designed in the laboratory of Envisens Technologies s.r.l., with the goal to realize a general purpose tag with different interfaces (both digital and analogical) to connect various MEMS sensors, a radio transceiver operating at 433 MHz (suitable for outdoor and through ice, snow communication), a programmable microcontroller and some memory. The result is a flexible and low power consumption platform built around the TI (Texas Instruments) CC430 family microcontroller that allow for the implementation of a large set of low power consumption strategies switching on/off the proper interfaces. For the presented experiment, the board hosts an accelerometer, a magnetometer and an analog temperature sensor (PT100) and can be interfaced with common SPI or I2C sensor like humidity or pressure sensors.

II. ALGORITHM DESCRIPTION

A. *Link Budget*

The link budget equation for the radio communications system is used in the algorithm to compute the approximate distance from the received power:

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - L_{TX} - L_{FS} - L_{RX} \qquad (1)$$

Where the received power (P_{RX} [dBm]) is obtained by the RSSI indicator at the receiver, the transmitter output power (P_{TX} = 0 dBm) is set via software, the transmitter antenna gain, the receiver antenna gain (G_{TX} = G_{RX} 2.15 dBi as theoretical value) and internal losses (L_{TX} = L_{RX} = -10 dB) are estimated taking into account the characteristics of the components (e. g. due to connectors, antenna mismatch, antenna installation position). By inverting the equation (1) it is possible to obtain the free space loss or path loss measured in [dB]. Knowing then the common equation of free space attenuation (2), it is possible to get the estimated distance where d = distance, f = frequency, c = speed of light.

$$L_{FS} = 20\log_{10} d + 20\log_{10} f + 20\log_{10}\left(\frac{4\pi}{c}\right) \qquad (2)$$

B. *Preliminary assumptions*

The basic idea behind the experiment is that the UAV can move in the space in the 3D domain and check for the RFID tag hundreds of time per minute. The operator could hypothetically try to find the RFID tag by searching the maximum RSSI, but in our case the objective was to implement a statistical method to find the final position of the tag. Such methodology can be applied in any contest (urban, campaign, mountain) by simply using rotating or fixed wings UAVs.

Before introducing the localization algorithm, many assumptions have to be made:

- The transmitted power is considered constant during the whole trial; the received power is measured in different instant of time and the radiated power could be changed.
- The antenna radiation pattern is constant in all directions. Whereas the reader moves through the space, the antenna gain and the Tx/Rx antenna mismatch significantly affect the RSSI value.

- Other propagations effects, like multipath, diffraction or fast fading that strongly affect the results are not considered during this preliminary trial.

C. Localization Equation

The range information obtained from (2) can be used to unambiguously localize the tags using the multilateration method. It is sufficient to collect N+1 measures in N-dimensions space. In the 3-dimensional space the equation can be defined:

$$(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = d_i^2 \qquad (3)$$
$$i = 1, 2, \ldots, N \; with > 3$$

During a single measure, it is possible to automatically associate the coordinates of the reader (thanks to the information provided by the GNSS receiver on board of the UAV) and the "approximate" estimated distance from the tag (from (2)). With multiple measures it is possible to build a N × 3 matrix. Assuming a random location of the reader, the coordinates of a tag are obtained using the least-square solution of the derived system. Visually we can imagine the problem as in the following Fig. 3 where each distance d_i is a Euclid distance.

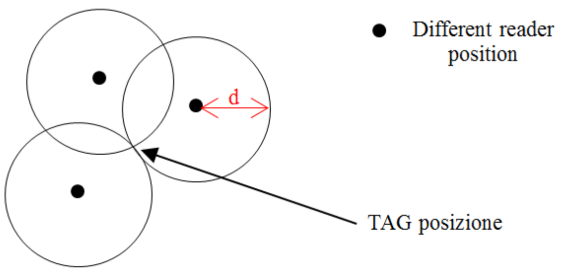

Fig. 3. Tag localization algorithm

III. Trial Description

In this section we describe how the on field trial has been set up, leaving out the calibration of the system. Before the test the intrinsic losses of the system where determined, at first by measuring the different components and then using a statistical calibration exploiting the RSSI indicator.

A. Test Description

The test was performed in a countryside site, during the spring season above some meadows and along a dirt track. The tag was equipped with an omnidirectional antenna and was fixed to a wooden fence at 110 cm from the ground with the antenna radiation pattern free along the horizon at 360° in order to guarantee a good signal.

Once fixed the tag, it was sufficient to fly over the area of interest (wide roughly 10.000 square meters) with the UAV and the reader in discovery mode to identify it. The UAV pilot was able to see on the console the RSSI and started turning continuously over the area in order to not lose the connection, otherwise the tag fall in sleep mode because of low power consumption mode. In Fig. 4 it is possible to see the random trajectory, of the UAV together with the acquired RSSI values. The generated log file joins in each record the timestamp, latitude, longitude and height of the aircraft and the RSSI. Sampling the data with a frequency of 1 Hz in less than 5 minute of flight we obtained 265 measures in random positions and heights.

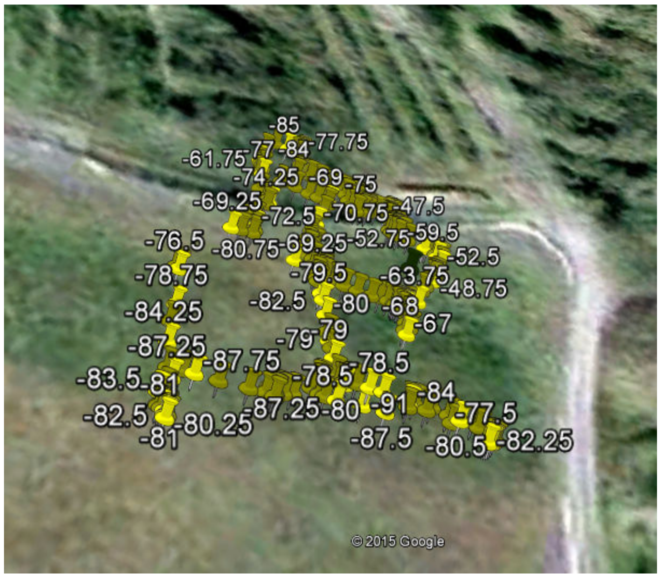

Fig. 4. RSSI values logged by the console and reported over a Google Earth© map.

B. Results

When a significant number of measures have been taken the operator can stop the localization procedure. If the UAV can move freely in the space and collects equally distributed measures over the alleged tag position, 100 RSSI values are enough to run the algorithm with good results. In these conditions it takes roughly only one minute and a half of fly time. The software runs the least squares algorithm to solve the system of overabundant equations, to obtain the estimated position of the tag in the 3D domain in WGS84 coordinates system.

In Fig. 5 it is possible to see both the estimated tag position (label with capital *E* letter) and the real position (label with capital *R*) within the random track followed by the UAV, identified by white squared waypoints. The three dimensional localization errors between the real and estimated coordinates are equal to $\varepsilon_{3D} \approx 6$ m. It is to note that all the measurements are taken completely random, and there is no relationship between the localization error and the height of the UAV.

We outline that in this experiment a single frequency GNSS receiver was used with an intrinsic precision of the order of some meters. However the obtained results are encouraging and demonstrate that, although there are many assumptions and source of errors, the proposed mathematical approach and implemented system and algorithm lead to a good result.

Fig. 5. Results reported over a Google Earth© map.

IV. CONCLUSIONS AND OUTLOOKS

A preliminary trial of a real time localization technique was presented, even if the whole system realization is still in progress. Great effort was dedicated to the characterization of the RF components of the system and much more can be done in order to take into account for the radiation pattern of the antenna. In fact it may lead to a wrong localization, especially at the receiver. However all the errors may be very well compensated by increasing the number of measurements, other than using sophisticated research strategies (e. g. regular grid measurements at different heights). Moreover, also the UAV position measurement can be improved by adopting a dual frequency GNSS receiver stand alone or in RTK mode (Real Time Kinematic) that allow to reach centimeter accuracy.

REFERENCES

[1] K. Martinez, R. Ong, and J. Hart, "Glacsweb: a sensor network for hostile environments", First IEEE Communications Society Conference on Sensor and Ad Hoc Communications and Networks, Santa Clara, USA, 2004.

[2] O. Rorato, G. Greco, S. Bertoldo, C. Lucianaz, M. Allegretti, M. Curtaz, A. Roasio, S. Barone and G. Perona, "An ad-hoc RFID tag for glaciers monitoring", IEEE APWC 2014, Palm Beach, Aruba, 3-7 August 2014, pp. 864-867.

[3] C. Lucianaz, O. Rorato, M. Allegretti, M. Mamino, M. Roggero, F. Diotri, "Low Cost DGPS Network", IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications, Torino, 12-16 September 2011, pp. 792-795

[4] M. Allegretti, "Concept for Floating and Submersible Wireless Sensor Network for Water Basin Monitoring", *Wireless Sensor Network*, Vol 6. No. 6, pp. 104-108, 2014.

[5] S. Subedi, Y. D. Zhang and M.G. Amin, "Precise RFID Localization in Impaired Environment through Sparse Signal Recovery", Wireless Sensing, Localization, and Processing VIII, May 28, 2013.

[6] J. S. Choi, B. R. Son, H. K. Kang and D. H. Lee, "Indoor Localization of Unmanned Aerial Vehicle based on Passive UHF RFID Systems", 9th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI) Daejeon, Korea, 26-29 November 2012, pp. 188-189.