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# Real time outdoor localization of buried RFID tags through statistical methods

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*Abstract* – The problem that we have addressed with the presented study is the absolute localization of buried RFID tags in an outdoor environment where the tag is. This is the scenario that we have envisaged when the RFID sensors are installed inside a moving body like a glacier or a slow landslide.

During the tags dislocation it is possible to measure the depth of the installation and to define the absolute coordinate of the installation points using a topographic GNSS receiver. Afterwards the body evolves with time, moves and after a while (e. g. 1 month, 1 year) it is necessary to locate the sensors in order to quantify the absolute movement.

To find the new location we have decided to investigate a multilateration-based localization technique. In this paper we describe the approach to develop a low cost system for the reading of the tags and for their localization without the need of expensive radar systems (e. g. GPR) to locate them.

## 1 INTRODUCTION

Environmental monitoring through wireless sensor network or RFID tags has reached an advanced stage of development. For archeological sites it is possible to find sensors monitoring humidity, temperature; critical road infrastructures (bridges, galleries) are monitored with accelerometers or GNSS receivers joined in a real time network that support the geologists and engineers.

The scenario investigated by this article is quite different: we suppose to install the sensors inside a physical body and we try to locate those sensors using only statistical methods. Some cases where the technique is useful are the followings:

- Glaciers: the capsule with the RFID tag is located inside the ice and we want to follow its movement during a period of months and years. In this case the RF signal cross the air and the ice to travel from the reader to the tag.
- Inside the soil: the tag is inside a moving landslide or a desert dunes and it is necessary to locate it periodically to study its evolution.
- The tag can be set in the bottom of a river to monitor some parameters (temperature, pollution) and study the river transport. Also in this case the tag have to be periodically localized and georeferenced.

In order to get the absolute localization of the tag it is necessary to know the exact position of the reader and to estimate both the direction and the distance between reader and tag.

## 2 ALGORITHM DESCRIPTION

The basic idea is to use the reader and tag hardware to develop also the localization system without the need of extra equipment.

### 2.1 Distance estimation

The first information to gather is the distance between reader and tag. This information can be obtained by using the received signal strength indicator (RSSI) measured by the reader. Most common RF chips for mobile radio application have such indicator related to the received power. The higher is the RSSI value the farther is the rfid tag.

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - L_{TX} - L_{RX} - L_P \quad (1)$$

In equation (1) the received power ( $P_{RX}$  [dBm]) is obtained from the RSSI indicator, the transmitted output power ( $P_{TX}$  [dBm]) is defined by the firmware, the transmitter antenna gain ( $G_{TX}$  [dBi]), receiver antenna gain ( $G_{RX}$  [dBi]) and internal losses ( $L_{TX}$ ,  $L_{RX}$  [dB]) have to be evaluated in laboratory or estimated during measurements. The last term ( $L_P$ ) is the path loss measured in [dB]. We must consider that the propagation occurs in different mediums, so this term is the sum of the propagation losses in the different mediums crossed by the signal:

$$L_P = L_{Pm_1} + L_{Pm_2} \quad (2)$$

Equation (2) is an example of  $L_P$  evaluation in the case of 2 mediums with respective losses of  $L_{Pm1}$  and  $L_{Pm2}$ .

$$L_{Pm_1} = 20 \log_{10} d + 20 \log_{10} f + 20 \log_{10} \left( \frac{4\pi}{c} \right) + (1 - |\Gamma_{m1m2}|^2) + (1 - |N_{m1}|^2) \quad (3)$$

Each medium losses are composed by the loss propagation in free space (where  $d$ =distance,  $f$ =frequency,  $c$ =speed of light), the attenuation loss due to dielectric properties of the medium ( $N$ ) and the reflection losses due to the interface between the different materials as reported in equation (3).

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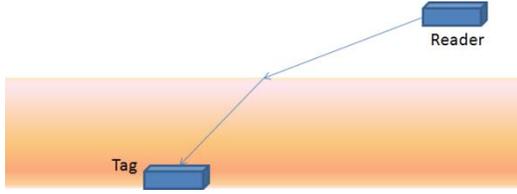


Figure 1. Tag-reader path

In Figure 1 it is schematically represented the path between the reader and a tag buried in the soil. Note that the hypothesis is to work with homogeneous materials, otherwise the equation have to include the losses and reflection coefficient between all interfaces.

One common example is a tag inserted in a glacier: in this case there are propagation in free space, interface air-snow, snow attenuation, interface snow-ice, and ice attenuation (common snow and ice parameters can be obtained as reported in [1]).

## 2.2 Devices characterization

In the previous paragraph we have introduced the propagations aspects during one single measure. Now consider to move in the space (over the surface where the tag is supposed to be installed) and collect  $N$ -measures. Considering Figure 1 we can imagine that the orientation of the devices will change. The antenna gain and the Tx/Rx antenna mismatch significantly affect the RSSI value. For this experiment we have considered a mean value. Other propagations effects (e. g. multipath, diffraction or fast fading) that may strongly affect the results are not considered.

## 2.3 Localization algorithm

To localize the tag we have used a statistical method. The multilateration method consists in solving the system of equations composed by  $N$  equations, where  $N$  is the number of measurements, by using the mean square algorithm. In a 3-dimensional space (with  $x$ ,  $y$ ,  $z$  coordinates) the equation for the determination of the exact position of the tag can be defined as in equation (4):

$$(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = d_i^2 \quad (4)$$

$$i = 1, 2, \dots, N \text{ with } > 3$$

To increase the robustness of the solution, it is sufficient to acquire a large amount of measures (i. e., increase  $N$ ) of RSSI values from different place well distributed in the space.

## 3 DEMONSTRATION TRIAL

### 3.1 Equipment description

The RFID tag and reader used in the trial is the one developed during 2014 in the MALATRA' projects (details in [3]). The two components are based on the same electronic board (a Printed Circuit Board, PCB, with size 110 mm x 40 mm, 4-layer). The tag can record data from different interfaces (e.g. Digital RS232 standard, Digital I2C standard, Analog input) and store them in an internal solid state memory. Tags have an RF channel operating at a frequency of 315 MHz and frequency selection was driven by the propagation properties of UHF frequencies in snow and ice. The single RFID tag works with a common lithium batteries and low power consumption techniques guarantee a 5 year operations life acquiring data once a day.

The reader is composed by the PCB board connected to a standard notebook acting as RF gateway, the ad-hoc developed software named Console and a GNSS receiver running in RTK mode. The GNSS is a crucial part of the algorithm: the operator need only to move on the surface and inquire the tag trough the Console that automatically stores in a log file a record composed has follow:

- Time;
- x y z coordinates of the reader;
- RSSI value

The used GNSS receiver is a low cost, single frequency USB receiver allowing reaching accuracy lower than 30 cm in movement. The coordinate referred to the GNSS antenna are scaled to the position of the reader antenna and converted in ECEF coordinates.

### 3.2 Operational procedure

The trial has been performed during the winner 2014-2015 over a flat and snowy terrain with 2 m snow. To ensure a good result of the localization algorithm we chose to perform the test after a fresh snowfall, because the attenuation at 315 MHz is very poor and we don't need to discriminate between the distance traveled by the signal in air and the distance in snow. Otherwise the localization procedure could be divided in more steps:

- Run the localization procedure normally acquiring RSSI measurements around the area.
- Run the localization software once to find the approximate position of the tag.
- Run the localization procedure placing the reader in contact with the snow near the approximate position of the tag.

- Launch again the localization procedure introducing the attenuation parameters of the snow [3].



Figure 2. Snowy terrain where the tag was installed

#### 4 RESULTS

To run the localization algorithm we measure a RSSI value per second walking around the tag installation area, for less than 9 minutes. More than 500 RSSI values in the space are acquired.



Figure 3. Typical random walk during localization procedure

In Figure 3 it is possible to see the typical random walk of the operator during the localization procedure. After acquiring a significant number of RSSI values, it is sufficient to start the mean square

algorithm to solve the system of equations and obtain the absolute coordinate of the tag.

During the test we tried two times the experiment obtaining a mean error of 80 cm in plan (x-y error) and an error of 130 cm in height. The error along the  $z$  direction is higher due to the difficulty in the estimation of the height of the snow. Moreover it is to consider that RSSI measurements are taken along a plane and don't allow for a compensation of the errors. Also the GNSS position of the reader as a greater error along the  $z$  direction that contribute negatively to the result.

#### 5 CONCLUSIONS AND OUTLOOKS

The results obtained in this trial are encouraging. The statistical approach works even in presence of many sources of error. The fresh snow seems to be almost transparent at 315 MHz frequency. If the attenuation had been higher probably the depth estimation would be better as well as reflections due to the discontinuity at the interface air-snow.

The RTK GNSS technique is robust and gives a high accuracy of the reader position. The only drawback is the continued need for a GPRS connection that in mountain areas is not always available.

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