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RISING: RADIO FREQUENCY IDENTIFICATION AND INERTIAL NAVIGATION FOR INDOOR LOCALIZATION IN EMERGENCY MANAGEMENT AND BUILDING MAINTENANCE

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ABSTRACT
In the last few years, several technologies have been introduced to improve personnel safety into the working environment during standard and emergency operations. According to this framework, the RISING (indooR localizatIon and building maintenance uSing radio frequency Identification and inertial NaviGation) project addresses this topic with a specific focus on emergency scenarios by exploiting Radio Frequency IDentification (RFID) devices.
RFID is a low-cost technology that uses communication via radio waves to identify and track objects. Generally, RFID systems include an active receiver (the reader) that sends an RF signal to transponders (tags), which backscatters specific messages for items' identification/tracking. Preinstalled into the working environment, RFID tags can be used to store useful information that emergency operators, equipped with RFID readers, can easily retrieve and use to improve their situational awareness about unknown operating domains. Data stored into RFID tags can include: information on possible resources (e.g., emergency exits), potential risks and/or hazardous materials (e.g., biological hazard, toxic or flammable gases) in the surroundings. In emergency scenarios, first responders can use this information to be early warned about hazards and resources which helps to facilitate navigation and select evacuation paths. Moreover, the RFID system can be used in combination with inertial navigation as viable solution for supporting Indoor Positioning Systems (IPSs). To this end, in the RISING approach the raw data collected by a waist mounted Inertial Measurements Unit (IMU) are integrated with information retrieved from RFID tags (i.e. tag's geographical coordinates, altitude, floor, etc.) to provide a reliable long lasting localization estimate about user's position. To test the effectiveness and the feasibility of the RISING solution, a pilot test in a real use case scenario inside the Università Campus Bio-Medico di Roma General Hospital will be considered.

KEYWORDS:
EMERGENCY MANAGEMENT, SITUATIONAL AWARENESS, PERSONAL INDOOR NAVIGATION, BUILDING MAINTENANCE, INERTIAL NAVIGATION, RFID

1. INTRODUCTION

The introduction of Internet of Things in society made possible the use of the connecting technologies to develop several solutions to improve the personnel safety into the working environment. The integration of existing technologies or approaches such as Mobile, Cloud and Virtual Reality applications (Marra et al. (2014)), Wi-Fi/ZigBee/Radio Frequency/Bluetooth Communication Protocols (Peng et al. (2014)), Near Field Communication technology, Big Data and Machine Learning algorithms (Jaselskis et al. (2014)), is today widely spread into different operating domains.

These technologies, that turn out to be extremely useful in standard conditions, are even crucial to better handle emergency situations. Whatever the origin of an emergency, a fast and effective response can indeed dramatically reduce losses and the potential rise of accidents into large-scale phenomena. Considering an emergency scenario where first responders navigate in a complex indoor environment, it is critical for their safety the knowledge of their location in addition to the position of both escape routes and potential risks (plants, hazardous materials, etc.).

Although a great effort has been performed around this topic during last few years, localization and tracking support in GPS-denied areas represents still a challenge for personnel operating in emergencies: so far there are not off-the-shelf solutions that provide location and information about local resources/potential risks for rescuers operating in deep indoor environments.

In this context, a potential solution is provided by the RISING project, supported by the Italian and the Basque Institutes for occupational Health and Safety (INAIL and OSALAN, respectively) in the framework of the EU FP7 SAF€RA – ERANET.

Starting from results achieved in the REFIRE project (Pascucci et al. (2013), Faramondi et al (2014), De Cillis et al. (2014)), RISING aims developing a situational awareness system able to support emergency operators by providing them real time information about surrounding resources and hazards, and to supply their localization and navigation tasks when external GPS signals fail.
The RISING solution is based on the integration of RFID technology with inertial navigation. A set of RFID tags, conveniently preinstalled into the working environment, can store information about their absolute position and local resources. This information can be easily retrieved by rescuers equipped with RFID readers and displayed on smart devices which the user is equipped (e.g., tablet and/or smartphone). Moreover, to reduce the installation overhead, RFID tags can be suitably embedded in pre-existing infrastructure, such as the emergency lights system. Emergency signs are indeed usually located close to the most important resources (hereafter referred as Point of Interest – PoI) and guarantee at the same time an effective coverage and the power supply.

Concerning personal localization, the RISING system exploits the lessons learnt from robotics localization. Together with the RFID reader, the operator is equipped with an IMU. Data retrieved from the IMU (instantaneous acceleration and angular velocity vectors) are used to compute a rough estimate of the rescuer's position by means of the Pedestrian Dead Reckoning (PDR). To correct the drift and to assess the user's absolute location, the estimate of the position is then refined using data fetched from RFID any time that he/she is sufficiently close to a tag.

Besides representing a key tool in emergency, the RISING solution could also support users in infrastructures and buildings maintenance. Operators equipped with the RISING system can display on a smart device (i.e., tablet) pseudo maps for routes planning, PoIs identification and for assessing data about local resources on-the-fly (e.g., due date about last/next maintenance operations, last faults, last refueling date, etc.).

The feasibility of the RISING solution strictly depends on the compliance between data stored in tags and the environment actual state. Keeping information up to date is indeed mandatory for personal safety, both in emergencies and in standard conditions. Due to the relevance of this topic, a specific protocol able to guarantee a constant update of data stored into the RFID tags will be defined within the RISING framework.

This paper focuses on the RISING architecture; specifically, it is devoted to explain the localization algorithm developed to estimate the location of the rescuer and to show some preliminarily experimental results. The paper is organized as follows: Sec. 2 introduces the overall RISING architecture; in Sec. 3 the indoor localization algorithm is presented and compared with the State of the Art; in Sec. 4 the rising pilot is sketched; finally, Sec. 5 reports some conclusive remarks.

2. SITUATIONAL AWARENESS FOR EMERGENCY RESPONDERS

In the field of emergency management and response, there is a concept known as situational awareness. In very basic terms, situational awareness is being conscious about what is happening so you can figure out what to do

(Endsley (1988), Digioia et al. (2013)). Situational awareness can facilitate efficient and effective decision making, which is critical in emergencies. Improved situational awareness could strengthen emergency response by offering to emergency managers the information to guarantee the health, safety, and welfare of the public and of emergency responders. Currently, there is a gap between the information that emergency managers get and the information they need to enhance their situational awareness during emergency events.

For emergencies in large and complex indoor environments, first responders need to know their exact locations, the position of escape routes and the location of potential risks (machineries, hazardous materials, etc.), since the life and the safety of rescuer and rescued persons may depend on that. Moreover, properly localized and well informed about risks, rescuers can be also better coordinated, commanded and guided so reducing the possibility of disorientation and failure in victims' localization.

Solutions based on centralized maps do not appear feasible during emergencies due to issues concerning sharing and accessing data in real-time. More effective options are those that store information locally and are able to provide them autonomously (i.e. without the use of any infrastructure). In this schema, any rescuer inside an operative scenario may have information in real-time about risks and/or resources in his/her surround, hence operating in more effective and safe manner, even during potential lack of communication links.

The usability of the system needs to be carefully designed: the system has to be easy to use and handle by the operator. To this end, the weight of the device needs to be reduced so to make it comfortable to wear. Last but not least, the cost of the solution has to be limited, to gain a consumer distribution into public and private buildings.
In this framework, the RFID technology appears a good candidate due to its intrinsic features and costs. However, with respect to usual practice, the RISING architecture considers a flipside configuration about RFID system, where tags are installed in fixed and known location and the rescuer that moves into the environment wears the reader.
The reader, which is lightweight, can be easily worn (as shown in Fig. 1) without interacting with the usual rescuer's equipment. The position on the shoulder has been experimentally verified to be those more suitable to optimize the quality of the communication between the reader and the tag (assuming, as mentioned before, tags embedded inside emergency lamp and then located at about 2.1 m from the floor).

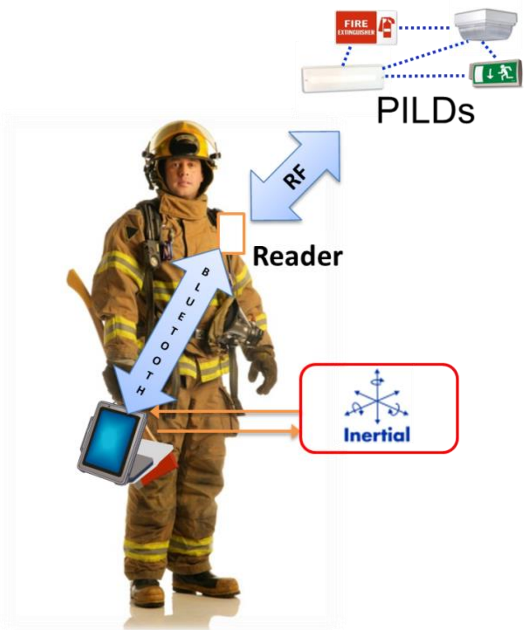

Figure 1 The RISING solution: rescuer equipment.

At the same time, RFID tags to be deployed in the environment are cheap and disposable. If passive tags are considered, no infrastructure is requested, since they are fetched by the reader and do not require any power supply. They can be deployed in any suitable locations inside the scenario due to their small size: nevertheless, as mentioned, they can be embedded in emergency signs that are located nearby valuable points (PoIs).

Emergency responders will be also equipped with a waist mounted IMU used, in cooperation with information retrieved from tags, in the localization procedure as better illustrated in the next section. As already mentioned, the RISING solution supports also the maintenance operators' activities (plants preservation, trials, refueling, etc.). In this context, maintenance specialists equipped with smart devices can examine on-the-fly data stored in locally by tags.
It is worth notice that the real feasibility of the RISING solution depends tightly on the compliance between the data stored in tags and the environment actual condition. Due to the relevance of this topic, specific maintenance procedures will be also defined in the project to satisfy the above-mentioned constraints.

In order to maximize the amount of available data, information stored in tags is encoded according to a protocol specifically defined during the RISING project. In details, three different set of data are considered:
1. General;
2. Resources;
3. Hazards.

The *General* data provides the identification code of the tag, its geographical coordinates and management information, while *Resources* and *Hazard* supply information about the different elements available on the scenario. All data provided are encoded depending on the nature of the item/s and the relative position between supplies/dangers and the tag.

Concerning the General data, the RISING protocol defines the follow information:
1. Tag ID;
2. RISING ID;
3. Geographical coordinates expressed in Cartesians coordinates with respect to a reference point;
4. Date of last update/inspection.

Regarding data stored into Resources/Hazards, few bits are used to indicate its/their nature and relative position with respect to the tag location. Specifically, 9 descriptors are used: Here, Left close, Left far, Right close, Right Far, Front close, Front far, Back close, Back far. Specifically, a resource/hazard is close to the tag when it is located in a range of 3 m, while it is far when the range is 3-10 meters from the lamp. Fig. 5 shows a mockup of the RISING user interface.

The main drawback arising with RFID tags depends on the detection of the coverage area, i.e., the area inside which the reader is able to fetch the tag. To partially overcome this limit, during the REFIRE project an extensive experimental campaign has been performed to feature the radiation pattern of the RFID system both in static and dynamic configuration. The results, shown in Fig. 2, demonstrate that the signal strength rapidly downgrade in the main radiation lobe in a range of 2.5 m.

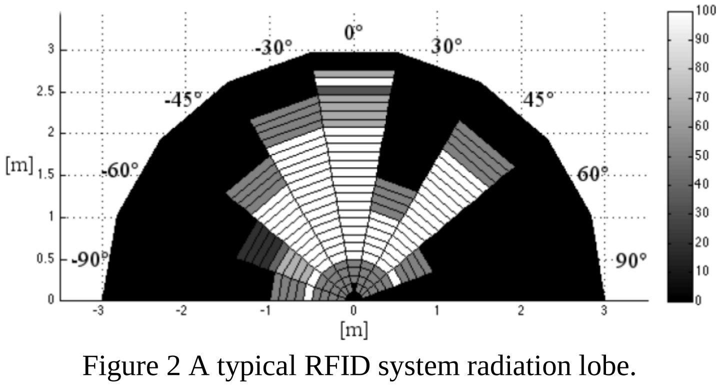

Figure 2 A typical RFID system radiation lobe.

The RISING project is also a means to support the activities of maintenance operators. These activities include data updating, plants preservation, trials, refueling, etc. The update of related data is a critical element of the system, because the feasibility of the system is based on the compliance between the data and the state of the environment. The frequency of the data update is included in the maintenance policy. Data verified long time ago are not useful and turn out to be dangerous in an emergency. Thus, the maintenance policies will include the methodologies to perform these procedures and the timeline.

3. INDOOR LOCALIZATION

Recently, a lot of efforts have been put in the development of IPSs. In this context, deep indoor scenarios represent the most challenging area for implementing application due to the unavailability of Global Navigation Satellite Systems (GNSS). IPSs usually require dedicated local infrastructure and customized mobile units. In such applications, IPSs have been designed and applied in some special and properly equipped buildings, based on Wi-Fi, ZigBee, RFID, Ultra Wide Band (UWB), Bluetooth, Pseudolite and 2G/3G/4G mobile communication systems. Unfortunately, such solutions appear not reliable to be used during emergency situations.

There are some attempts to develop solutions specifically devoted to emergency. Most of the proposed options for crisis support are based on proprioceptive sensors hybridized using networks of landmarks deployed by rescuers during the mission. These approaches mainly differ for the technologies used to implement the landmarks. In the EU Project LIAISON (Renaudin et al. (2007)), RFID tags are considered. In the FIRE project, the wireless sensor network SmokeNet is adopted (Wilson et al. (2007)). A similar approach is proposed in LifeNet (Klann (2009)). The Precise Personnel Location system (PPL) is based on multi-carrier wide-band device, which is carried by rescuers and sensed by receiving stations on the emergency response vehicles. In the EUROPCOMM project (Harmer et al. (2008)), a reference network is deployed outside the emergency area.
Although some solutions presented promising results, phenomenon as shadowing and no-line-of-sight, cost for supplies, installation and maintenance have limited their widespread adoption.

With the growing popularity of Micro Electro Mechanical Systems (MEMS), sensors such as compasses, accelerometers and gyroscopes have been gradually integrated into IMUs and used as a promising alternative technology for IPSs. Inertial systems can be worn by users: in this way it is possible to define the users' location by measuring physical quantities (acceleration, angular velocity), which are directly related to the motion of the body segment where the IMU is placed. As proprioceptive sensors, IMU is immune to interference and shadowing, thus can track users' motion without constraints. Nevertheless, one of the main issue in inertial navigation is related to the computation methodologies: the position is retrieved by time integrating signals from gyroscopes and accelerometers, including any sensor drift and noise affecting the sensor signals. Hence, the estimation errors tend to grow unbounded in time. Another drawback is that inertial sensors are not well suited for determining absolute location: the integration has to be started from initial conditions, which inertial sensors cannot help to compute (position, velocity), or disambiguate completely (orientation).

To overcome the limits of both approaches, the RISING solution uses a hybrid method to track the indoor location of users continuously. Specifically, a waist-mounted IMU is used to provide a rough estimate of the operator's relative position by applying the PDR algorithm to data collected from the IMU itself. To this end, the IMU is placed at pelvis level and fixed to the rescuer belt with body frame having x, y and z axes pointing to the left (Medio-Lateral), forward (Antero-Posterior), and upward (Vertical) direction, respectively.

A RFID beacon system is jointly used in combination with the inertial system for sensors drift compensation and for providing to user information about the surroundings and his/her absolute location. To this end, the rescuer is equipped with a RFID reader on the left shoulder.
Concerning the PDR approach, the proposed Rescuer Localization Algorithm (RLA) is a recursive procedure based on a prediction-correction schema illustrated in Fig. 3. Specifically, the prediction part of the schema is used to evaluate the position using a PDR algorithm. When a rescuer is close to a tag, the correction part of the algorithm refines the estimated location exploiting the information stored in the tag. The estimate is based on a

Bayesian filter (De Cillis et al. (2014)), in order to cope with the different accuracy of the sensor data.

Given an initial position, the user location is updated upon a motion event. To this end, the prediction step estimates the displacement and the heading of the user. Specifically, the heading is computed from the attitude of the IMU by simple rotations to map the body reference frame into the absolute reference frame; the displacement depends on the walking pattern. Thus, the prediction step is further decomposed into three phases: Attitude Estimation (AE), Pattern Recognition (PR) and Position Estimation (PE). AE computes the attitude of the IMU using data coming from accelerometer, gyroscope, and magnetometer by means of quaternions, as proposed in Sabatini (2006) and Faramondi et al. (2013). Once the attitude of the sensor module is available, the Vertical (V) acceleration along the gravity axes and the heading are computed. PR identifies different walking activities (actually, we considers 3 gait patterns: staying still, walking and going up/down the stairs). The pattern recognition is approached as a sequential decision problem under uncertainty and it is implemented by a decision tree algorithm.

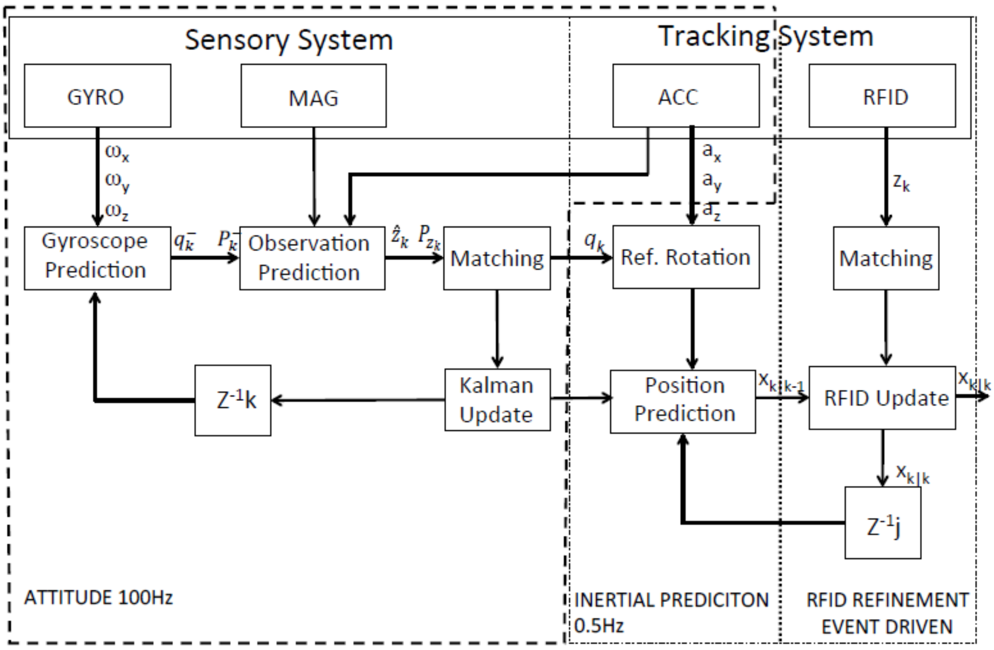

Figure 3 The Rescuer Localization Algorithm.

The correction step refines the position estimate upon tags detection. According to our protocol, the tag provides, among other data, its own position and orientation. Using this data, the position of the rescuer can be re-calibrated during long lasting missions. Since no ranging technique is adopted, only the position of the rescuer is corrected, due to observability issues. When a rescuer is in the main radiation lobe of the tag, the reader receives information from the tag and the position is updated according to different strategies. If the PDR estimates the position of the rescuer inside the main radiation lobe and the reader perceives the tag, no correction is performed. Otherwise, if the PDR estimates the rescuer position outside the main radiation lob and the reader is able to detect the tag, the user's position is updated to the mass center of the lob. Clearly, multiple tags detection allows a more accurate estimation of the user position.

4. THE RISING TEST PILOT

The RISING pilot test will be held in the new General Hospital of the Università Campus Bio-Medico di Roma, located in the South of Rome. The hospital, operating since March 2008, has been designed following the most modern guidelines to maximize the comfort for patients and the functionality for the health operators. It presents a quite large map composed by 3 self-similar square-like blocks interconnected buildings (Fig. 4).

Specifically, the trial holds at the Service floor located at the 2nd floor underground, representing a deep indoor scenario. It covers over 19.000 square meters, and over its ceiling an extensive number of hazmat pipes are located. The pipes' stopcocks are vital during the emergency management to stop any potential hazmat release or explosion, which could involve the emergency team. In the Service floor, there are also stockrooms of chemical/biological material and thermal, cryogenic, electric and medical-gas plants are located. To this end, the Service floor has been equipped with 10 passive RFID tags to support emergency responders to localize themselves and potential resources/hazmats.

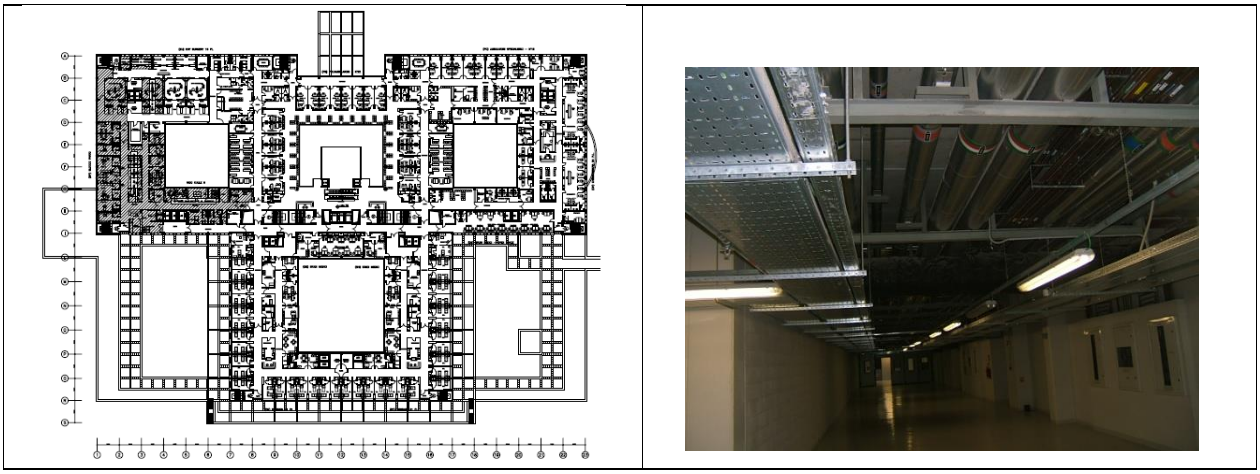

Figure 4 The RISING pilot test scenario.

Figure 5 shows a sample of the data retrieved by a tag and displayed on the smart device which the operator is equipped. Specifically, it is assumed that the operator stands in front of a tag and starts the acquisition procedure using the button on the left down corner. This modus operandi should ensure that the user is adopting the pose that maximize the communication efficiency between the reader and the tag. If it is the case, in the center of the screen (orange box) is/are displayed the symbol/s of resources/hazards in the surroundings. The user interface provides also information about the relative distance (close proximity and proximity, i.e., less than 5 m and up to 10 m, respectively) and position (up, down, left and right) between the surrounding items (orange box) and other potential resources/hazmats (red and red-purple line for close proximity and proximity, respectively).

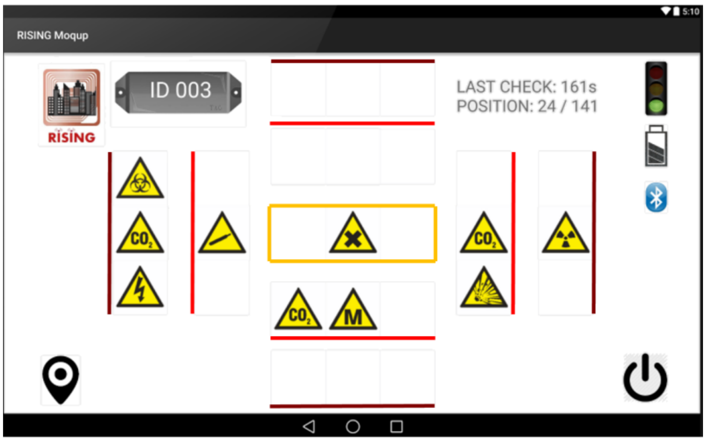

Figure 5 The RISING graphical user interface.

The user displays also information about the tag ID and its position expressed in term of Cartesian distance with respect to a reference frame. The semaphore indicates the reliability of the displayed information; by pressing the button on the left down corner, it turns green if the user is keeping his/her position and the information is retrieved from the tag in real-time. If the user is moving in the environment around the tag, it turns yellow if the reader is able to detect the tag, while it is red when the tag is no more available.

Some preliminarily results about indoor localization has been achieved during the REFIRE project, showing the effectiveness of the proposed methodology. Specifically, in Fig. 6 it is depicted the path performed by a rescuer that executes 500 steps overall, covering a distance of up to 300 m and traversing up and down stairs with several resting periods. During experiments, the rescuer is equipped with a waist-worn IMU MPU9150 MotionFit SDK device connected to a laptop PC via high speed USB. A CAEN RFID reader is connected to the same laptop via Bluetooth. The sampling frequency of the IMU is 50 Hz, the one of the RFID reader is 5 Hz, and a step is detected at 0.7 Hz.

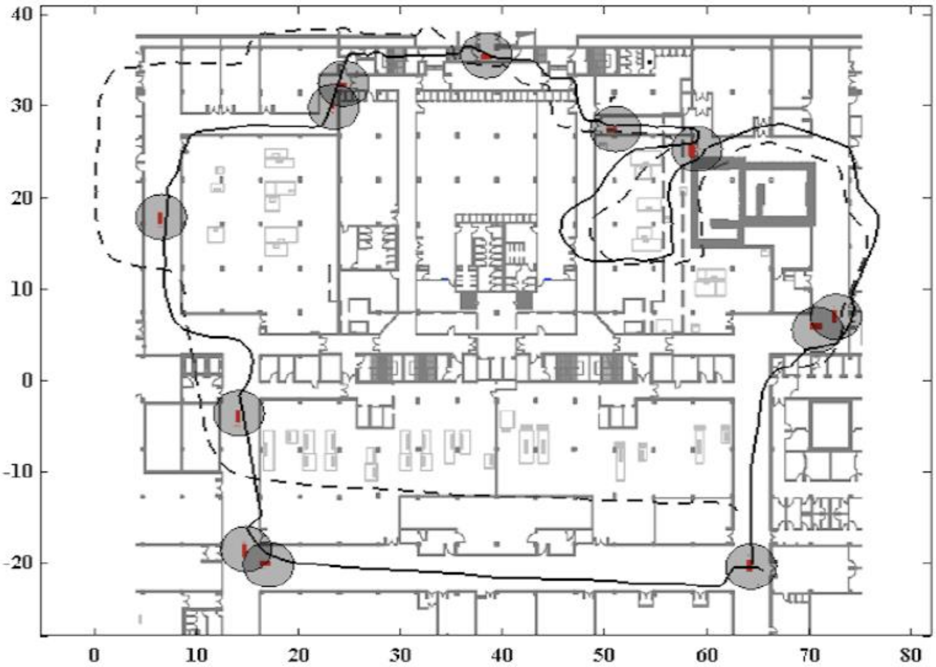

Figure 6 Results about indoor localization from the REFIRE project: PDR path (dashed line), RLA estimate (solid line), tags (red square), main radiation lobe (grey circles)

The data collected during the experiment have been post-processed using MATLAB. Specifically, the dashed line shows the path of the rescuer computed by the PDR without RFID corrections. It can be noted that PDR is not suitable by itself for deep indoor localization: the positioning errors grow along the path and at the end of the experiment the accuracy is highly downgraded. The PDR estimate is improved remarkably when tags are used (solid line) and the target performance (i.e., room level localization accuracy) is achieved.

5. CONCLUSION

The objective of any crisis management team is to gain the control of the situation. This can only be achieved by establishing situational awareness and getting ahead of the decision/action cycle. In this way, decisions can become pro-active rather than reactive in nature and the crisis management team can drive activity to stop or control the crisis. Currently, there are some limitations on achieving situational awareness, due to a gap between the information collected by emergency managers and the information that emergency managers need. To partially fill this gap, RISING solution takes advantages from smart environments, where RFID tags are embedded in the emergency signs/lamps. These tags are able to provide in real time useful information about resources/hazmats in the surround and, together with inertial measurements, room-level accuracy for localization. In such context, the integration of the RFID system within pre-installed devices (emergency lights) and its synergic integration with professionals' equipment enable rescuers to assess risk in real time, pave the way to new dynamic risk management procedures in emergencies.

In order to validate the feasibility of the RISING solution and its effectiveness both in normal and emergency scenarios, further tests will be performed in tight collaboration with first responders of the Italian and Spanish Fire Department. Although some successful experimental results prove the effectiveness of the approach, there is still room for improvements. This regards the support to communication among rescue teams, the standardization of the information stored into tags, the simplification of the architecture but mainly the localization capabilities.

The prediction step could be further enhanced by introducing more locomotion activities and by using more sophisticated discrimination tools. The correction step can be refined by introducing different exteroceptive sensors. Finally, the use of complex map, capturing both qualitative and quantitative characteristics of the environment, could help for mission planning and map matching.

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