CHEMICAL ENGINEERING TRANSACTIONS

VOL. 53, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Valerio Cozzani, Eddy De Rademaeker, Davide Manca

ISBN 978-88-95608-44-0; ISSN 2283-9216

DOI: 10.3303/CET1653056

Improving the Safety and the Operational Efficiency of Emergency Operators via On Field Situational Awareness

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In rescue missions, the situational awareness represents an essential tool in supporting rescue team operating in unknown and complex indoor environments. In case of fire in highly congested industrial scenarios (e.g., refineries, oil depots, petrochemical plants, etc.), the smoke may reduce the awareness of the rescuer about potential local resources/hazards, affecting both operational efficiency and personal safety. The mitigation of potential consequences arising from major accidents can be limited providing the emergency staff with tools able to foster their role on field. In this paper, we present the RISING (indooR localizatIon and building maintenance using radio frequency Identification and inertial NaviGation) project that is devoted to support on field operators supplying them with a system for situational awareness and personal indoor positioning. The RISING solution is based on the integration of the RFID technology with the inertial navigation. A set of RFID tags, conveniently preinstalled in the working environment, can store information about their absolute position and the site of local items. This information can be easily retrieved on-the-fly using RFID readers and displayed on smart devices with which the user is equipped (e.g., tablet and/or smartphone) to allow on field situational awareness.

1. Introduction

In case of accidents in Seveso establishments, the internal emergency squad plays its role in the time between the very first alert and the intervention of external firefighters. The squad operates in adverse conditions because of smoke, high temperatures and congested environment. On field early identification of emergency equipment (e.g. cabinets, fire extinguisher hydrants, etc.) and actuators to stop the potential leakage of hazardous fluids is essential when remote operations from the control room are prevented. Furthermore, the squad is in charge to avoid domino effects and to protect local plants, according to safety information about chemicals in the area. For the afore-mentioned reasons, emergency management could highly benefit from the adoption of advanced sensors supporting the Situational Awareness (SA) (Nazira et al., 2014).

SA is in generally described as the comprehensive understanding of what is happening into the environment and the ability to retrieve, understand and reuse the available information for enhancing the team response to specific situations. It is therefore clear that SA is closely related to the chance of having accurate, complete and real-time information about an accident. For emergency applications, data are usually scattered into closed and open databases, registers and data sources and the types/amount of data needed to fulfil all the information needs in emergencies are increasing in time (Leppäniemi et al., 2009). Especially when operating in unknown indoor environments, SA becomes crucial and increasingly challenging, as limited resources and communication channels become stretched (Engelbrecht et al., 2010). As stated by Leppäniemi et al. (2009), apart from challenges related to the development of specific tools for situational awareness, a cornerstone point is represented by the peculiar nature of the information needed in different phases of the emergency management cycle (i.e., mitigation & prevention, preparation, response and recovery).

Please cite this article as: De Cillis F., Inderst F., Pascucci F., Setola R., Tesei M., Bragatto P., 2016, Improving the safety and the operational efficiency of emergency operators via on-field situational awareness, Chemical Engineering Transactions, 53, 331-336
DOI: 10.3303/CET1653056

Among different kind of data, Wei et al. (2008) assert that the geo-referenced information plays an important role in every stage of disaster management and emergency response. Small scale, 2-D geo-data (such as maps or satellite images) is insufficient for urban areas. Often 3-D information about a building exterior, interior (i.e. room layout, type of construction, materials, etc.), utilities (pipelines, electricity switches), facilities (stairs, emergency exits, etc.) is necessary and highly desired. These data must be collected, processed, and visualized by the right person at the right time and in the most appropriate form. Among several requirements that such SA tools should provide, one of the most important is surely represented by the rapid and smart determination of the evacuation routes considering dynamic factors (such as, current availability of exits, stairs, etc.) (Wei et. al., 2008). Response missions in unknown indoor environments require on field operators to be aware about their positions/performed routes and to be conscious of potential local resources/risks (emergency exits, hazardous materials, etc.), since life and safety of the rescuer and rescued persons depends on that. Properly localized and well-informed about risks, rescuers can be better coordinated, commanded and guided reducing the chance of disorientation and failure in victims' localization.
Typical approaches for context-aware crisis management are based on centralised maps. Carrol et al. (2007) present the main requirements for a geospatial information system for collaborative planning of emergency response relied on shared maps. Geospatial mashups to visualize information provided by heterogeneous data sources for crisis management is described in Gupta and Knoblock (2010). Bader et al. (2008) use a tabletop to visualize large-scale maps with aerial or satellite views that allow users to manage tasks and understand the scenario. Nevertheless, SA solutions based on centralized maps do not appear feasible during emergencies due to issues concerning sharing, accessing and synchronizing data in real-time. More effective options are those that store information locally and that 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 surroundings, hence operating in more effective and safe manner, even during potential lack of communication links. For this purpose, the technologies that have being exploited the most are mobile devices, (such as PDAs, smartphones, tablet, etc.) that can be attached to or embedded in uniform and sensors deployed in the environment. For example, authors in Bergstrand and Landgren (2009) use live video to expand the situational perception to the commander. Jiang et al. (2004) present Siren, a peer-to-peer context-aware computing architecture that gathers, integrates, and distributes context data retrieved by local sensors on fire scenes to the commander post. Engelbrecht et al. (2011) propose digital tabletops to filter and visualize relevant information in decision-making in local command posts. Despite these remarkable results, most of the work on the topic concerns with emergency management commanders rather than on field agents.
The objective of the RISING project is to address on field SA by using the RFID technology to support a rescue team during response missions. Specifically, the RISING solution relies on the information retrieved from tags by means of a software application. Using such an application, a user equipped with a RFID reader can display on a mobile unit a meta-map about the broadly position of local items in the surroundings. In this way, the user is more aware about potential local risks/resources. Notice that passive tags usually present a limited storage capacity (i.e., less than one kB). To properly manage this constraint, within the RISING project we have devised a questionnaire for emergency management experts to elicit the most useful data and the best arrangement for their presentation, given that only very few studies in the literature focus on these topics. The proposed architecture for on field SA has been tested in large civil facilities, but is suitable also for Seveso sites (e.g., refinery, petrochemical complex, etc.). The rescuers that get inside a building could highly benefit from a smart system able to guide them inside highly congested plants, even in no visibility conditions.
The remainder of the paper is arranged as follows: Section 2 briefly describes the results inferred from the questionnaire; Section 3 provides the description of the RISING architecture. Section 4 and Section 5 illustrate the situation awareness and the indoor positioning system composing the RISING solution. Concluding remarks is illustrated in Section 6.

2. The RISING questionnaire

To identify the most suitable information to provide on field emergency operators and the best way to display such information on-the-fly, we disposed an online survey for experts operating in the emergency management field (first aid staff, emergency operators, fire brigade, etc.). The questionnaire consists of 19 questions in which we asked the experts to express their opinion using a five-point scale (5 essential, 4 very useful, 3 useful, 2 uninteresting, 1 useless). Questions focused on three main aspects:

- The first part of the survey (questions 1 to 4) focused on the chance to have information about the absolute/relative pose of the operator within the environment;
- Questions from 5 to 10 pertain the knowledge of the nature and the position of potential Points Of Interest (POIs, i.e. hazards and/or resources) in the surrounding area;

- The last part of the survey (questions 11 to 19) regards the way in which such information should be provided to on field operators, based on their experience.

Experts were invited to participate the survey via an invitation email. The survey has been opened for 9 weeks from January 11th to March 13th, 2016. A total number of 50 experts have been invited, and 26 responses have been received, with a response rate of 52%. For the sake of space, we summarized the most relevant results in Table 1.

Table 1: Main results inferred from the RISING questionnaire.

TOPIC	RESULTS
Absolute/relative pose of the operator and team members within the environment	• Be aware about the real-time relative pose of team members is essential for the 60% of responders • For the 55% of the interviewees, communicating the operator position to the command center is essential • Knowing the operator absolute pose in real-time is essential for the 35% of the operators • Having the chance to acquire the operator pose in real-time on a pseudo map of the environment is essential for the 45% of the responders
Knowledge about the position of potential POIs in the surrounding area	• For the 60% of the operators knowing POIs relative position with respect to the operator pose is essential • The 40% of interviewees think that having knowledge about POIs absolute pose in the environment is essential • Knowing POIs location on a map of the environment is essential for the 40% of the operators
About the distance of the POIs to be aware	• The 52.6% of the operators consider essential knowing the position of the POIs located in a range of about 16 m with respect to the user position • Information about POIs relative distance when superior to 25 m with respect to the operator is assumed to be quite useless by the 36.8% of the respondents
Preference about technologies for information providing	Acoustic messages through earphones (40%), visual information by means of a tablet (30%), holographic images through smart glasses (15%), smart watches (10%), tactile feedback (5%)
Preference about information visualization	Graphic representation (70%), grid (20%), textual representation (10%)
Preference about POIs description	Icon with short description (70%), short textual description (15%), icon (15%)
Potential hazards, emergency devices, plants and environmental design elements to be aware	• It is essential to know the presence of explosive materials (75%), voltage points (45%) and fair spots (60%) • It is very useful to have knowledge of chemical (55%) and bacteriological materials (45%) • It is essential to be aware of emergency exits (80%), hydrants (55%), fire extinguishers (40%) and first aid kit (40%) • It is considered essential knowing the location of electrical panel (60%) and high voltage socket (50%) • It is very useful have knowledge of water plants (40%), central fire detection points (50%), UPS (50%) and stairs (45%) • The awareness on local heating-cooling systems (35%) and thermal power plants (35%) is considered useful • The opportunity to select on a Graphic User Interface (GUI) the POIs to display and to navigate to the POIs are both considered essential by the 65% of the responders

3. The RISING Architecture

As pointed out from the survey, rescuers need to improve their location awareness during emergencies. Specifically, they need to know their own position, the location of POIs, and the safer path to reach injured people. According to these requirements, the RISING project developed an Indoor Positioning System & Situational Awareness System (IPS & SAS) to support first responders during rescue missions providing position, tracking and navigation. Moreover, the system is able to detect and to show the location of POIs to rescuers. The RISING architecture foresees wearable devices (i.e., Smart Devices - SDs) for rescuers and a low-cost infrastructure (Passive and Semi-Passive/Active RFID Tags - PTs, SPATs) pre-installed in the indoor environment. The SD is composed of a waist-mounted Inertial Measurement Unit (IMU), a mobile unit for computing and displaying information (i.e., tablet/smartphone) and a chest-placed RFID reader. PTs and SPATs are deployed in the environment: they are embedded in emergency supplies (e.g., emergency lights and/or signs). The IMU is used to form a rough estimate of the rescuer position during the mission by

Pedestrian Dead Reckoning (PDR). The estimate error is bounded by the information retrieved by the reader from the PTs and SPATs. It is worth mentioning that the classic RFID approach envisages fixed environmental receivers and moving transponders. On the contrary, the RISING approach flips over it: while moving into the environment, a user equipped with a RFID reader is able to retrieve information from pre-installed tags. Tags embed an internal memory and are able to collect useful information about the environment. A user equipped with a RFID reader and close enough to a tag can easily retrieve and display the information on the mobile unit. Specific attention has been paid in the design of the whole RISING system. The SD is indeed lightweight and the component are placed so to avoid hindrances and overlap with the rescuer equipment. For example, the reader is placed on the chest to enhance the communication between the reader and the tags, located in the emergency lamps. Concerning the PTs-SPATs, they are implemented to reduce deployment and maintenance costs. As the usability, also the realization and implementation costs of the solution were thoroughly evaluated. In order to gain a consumer distribution into public and private buildings, the start-up investment as well as the maintenance cost of the solution should be limited. To this end, RFID technology fits to achieve these requirements due to their robustness and low cost. Several reasons underpin this design option, since emergency resources are usually located close to potential POIs: it helps reducing the PTs/SPATs installation overhead, it guarantees area coverage, and it potentially provides for power supply.

4. The RISING SAS

The RISING SAS improves the situational awareness by providing to the rescuers the information selected during the survey (e.g., nature of the POIs, location, etc.). This information are encoded using a protocol developed in the project and tailored on the Omni-ID passive UHF RFID tags by CAEN, equipped a 28-words user memory. Two different set of data are considered: *General*, and *POIs*.

Concerning the *General* data, the RISING protocol defines:

- *Tag ID*: unique code to identify the tag;
- *Tag absolute position*: it is expressed in Cartesian coordinates with respect to an absolute reference frame attached to the environment;
- *Date* and *userID* for data initialization, updating and inspection;

Concerning the *POI* message, descriptors, composed by few bits, encode the kind of POI and the relative position with respect to the absolute tag location. The used descriptors are:

- *Category*: specifies the category of the POI (i.e., hazard, resource, facility, etc.);
- *Type*: defines the type of the POI, related to its category. For example, for the category *Fire Hazard*, the type specify the *Fire Hazard*, e.g., oxygen fire hazard, methane fire hazard, etc.;
- *Sub-Type*: defines the type of the POI (if necessary);
- *Value*: defines the range of the POI (if available), relating to its category, type and sub-type (when available).
- *Localization*: indicates the relative position of the POI with respect to the tag absolute pose within the environment. This information is presented in a qualitative way, as *near* (less than 8 m), *far* (8-16 m), and *far away* (16-25 m) with respect to the tag. The relative direction is also encoded (i.e., *left/right/front/rear*).

A Graphical User Interface (GUI) has been developed to show the information retrieved from the tag according with the requirements from the survey. The GUI is displayed on the smart device and a mock-up is shown in Figure 1. To improve its usability, the GUI is theoretically divided in two parts: a central box and the corners. In the central box, the relative user/items positions are represented. Each resource/hazard is represented by an icon with a short description: the position of the icon with respect to the blue circle (i.e., the current user pose) is set according with the data retrieved from the tag. Two black boxes identify the above mentioned ranges. The corners of the GUI are used to identify the last detected tag (bottom-right corner), to manually update the information in the GUI (bottom-left corner) and to show the tag-reader connection status (top-left corner). It is worth noticing that a haptic feedback is triggered on a tag reading. When the signal is perceived, the rescuer stops to retrieve data from a tag optimizing communication's link. Field tests performed in real operating conditions show that, standing in a range of max 2.5 m from the tag, the information stored in the tag are downloaded and displayed in less than 3 s.

The real feasibility of the RISING solution tightly depends on the compliance between the data stored in tags and the actual state of the environment. Due to the relevance of this topic, specific maintenance procedures will also be defined in the project to satisfy the above-mentioned constraints. To this end, the RISING project supports the activities of building maintenance workers. These activities include data updating, plants preservation, trials, refuelling, etc. The frequency of the data update is also included in the maintenance policy: data controlled long time ago are not useful and turn out to be dangerous in an emergency. Thus, the maintenance policies will include the timeline and the methodologies to perform controls.

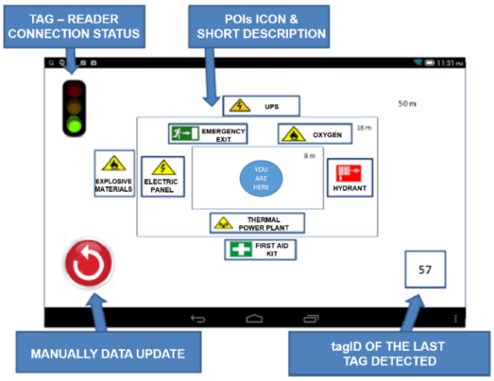

Figure 1: The mock-up of the RISING mobile application.

5. The RISING IPS

In the last decade, the indoor localization problem has been largely addressed due to the unavailability of an industrial solution, like the Global Navigation Satellite System for outdoor. Most of the approaches proposed in the literature are based on infrastructure deployed in the environment and customized mobile units based on different technologies (e.g., Wi-Fi, ZigBee, RFID, ultra wide band, Bluetooth, Pseudolite and 2G/3G/4G mobile communication systems, etc.). Those solutions fail in emergency situation because of the harsh operating conditions. To this end, in the RISING project, both proprioceptive sensors and passive infrastructure are adopted. Specifically, an IMU is used to form a rough estimate of the rescuer position. The main drawback of this sensors is represented by the drift that increases the estimate errors. In the RISING IPS, these errors are bounded by the location information retrieved by the RFID tags that are used to reset the estimate. The RISING IPS is, therefore, a hybrid approach: it is worth mentioning that RFID tags represent a passive infrastructure, since there is no need of external power supply.

The RISING IPS is a recursive algorithm that can be divided in three steps. In the first step, data coming from accelerometers and gyroscope are used to evaluate the human activity. Since the proposed application only considers planar environments, the user activity detects staying still and walking. The pattern recognition is implemented by a decision tree. A time window is applied to select samples: the covariance of collected measurements is computed and compared with a fixed threshold to detect the human activity. In the second step, the displacement and the heading of the rescuer is computed according to the classified activity. Specifically, the displacement is set to 0 when the rescuer is still, while is computed as in De Cillis et al. (2014) when moving. The third step is executed only when a tag is detected. Once the position of the tag is retrieved, the current position of the rescuer is updated according to the rules proposed in De Cillis et al. (2016). When 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 lobe and the reader is able to detect the tag, the user’s position is updated to the centre of mass of the lobe. Clearly, multiple tags detection allows a more accurate estimation of the user position. Since no ranging technique is adopted, only the position of the rescuer is corrected, due to observability issues.

It is worth noticing that the proposed PDR tracks the rescuer from a known starting position: therefore, it is supposed that the position and the heading of the rescuer at the beginning of the mission is known with respect to the absolute reference frame used by the tag. The heading of the rescuer can be easily updated by exploiting the position of the IMU. In the RISING paradigm, indeed, the IMU is placed at pelvis level and fixed to the rescuer belt: the body reference frame has x, y and z-axes pointing to the left (medio-lateral), forward (antero-posterior), and upward (vertical) direction, respectively. The heading is updated by computing the rotation along the vertical axis of the body frame.

6. Conclusions

In emergencies, the crisis management concerns the gain of the control of the situation. Especially on the field, an effective emergency management strictly relies on situational awareness. Through the consciousness about potential local items and their position, decisions can become pro-active rather than reactive and the crisis management team can better manage the activities. Nevertheless, the gap between the information collected by the emergency manager and those effectively required or available to on field operators heavily limits the current level of situational awareness. To partially fill this gap, the RISING solution takes advantages from smart environments, where RFID tags are embedded in emergency signs/lamps. These tags are able to provide useful information about resources/hazards in the surrounding in real time and, together with inertial measurements, room-level accuracy for localization. In such context, the integration of the RFID system within pre-installed devices and its synergic integration with professionals' equipment enable rescuers to assess risks in real time, paving the way to new dynamic risk management procedures in emergencies. This requirement becomes crucial in typical Seveso sites (refineries, petrochemical parks, etc.), where internal firefighters squads could benefit from the RISING system. Industrial facilities, compared with civil facilities where RISING has been tested, are unobstructed, thus wireless communication may be exploited to allow interactions between rescuers and the emergency commander. The cost of the proposed system is affordable and investment return is expected as increasing safety. At Seveso plants, the system may be also used to improve inspection and maintenance of the safety systems in any area of the complex, as well as to simulate different situations in emergency exercise.

Acknowledgments

This project is partially supported by the ERA-NET SAF€RA project, the Italian National Institute for Insurance against Accidents at Work (INAIL) and the Basque Institute for Occupational Health and Safety (OSALAN). This publication only reflects the views of the authors; funding Institutes cannot be held responsible for any use of the information contained therein.

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