AN EMBEDDED WIRELESS SYSTEM FOR ESTIMATING THE EXPOSITION RISK IN FIRST EMERGENCY MANAGEMENT

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***Abstract:** In this paper we propose the design of a wearable embedded system[1] for wirelessly delimiting an hazardous area during emergency, alerting the rescue operators when entering in it and measuring the consequent exposition time. (The dangerous area is previously identified, e.g., through suitable instrumentation). The suggested approach, which is identically effective in indoor and outdoor environments, significantly extends existing solutions by not requiring any absolute position information for delimiting the hazardous area or fixed infrastructure as requested instead by GPS and UWB solutions. The proposed low-power system can be easily retrieved after use and ready to be deployed in a new environment.*

Index terms: Wireless sensor networks, Relative localisation systems, Civil Protection, Emergency Management.

I. INTRODUCTION

The recent floods across Europe, US and Asia, Tsunami, hazardous materials released following earthquakes, chemical accidents affecting populated areas have shown very complex emergency scenarios characterised by the presence of a time-evolving risk, which may affect the rescue team during intervention. The presence of a residual risk, i.e., a Damocles's sward type of risk insisting on the emergency scene and triggered by the evolution of catastrophic phenomena, can further amplify the risk during operational emergency. The problem of estimating the closeness to hazardous areas and the time spent within it is of particular relevance in emergency and critical situations where the rescue team has to intervene not only in a safe area but also in areas characterised by a real risk (generally increasing while getting closer to the risk source, e.g., think of a chemical risk associated with the presence

[1]Patent # A000983 pending.

of toxic or nuclear substances). As such, it is not only important to define a safety belt but, once the safety belt is violated, alerting the personnel and measuring the history and the time duration spent within such areas to assess, afterward, the exposition risk.

Traditional solutions for delimiting emergency areas generally rely on emergency ribbons. This solution badly scales with the area to be covered: ribbons are not robust and hardly effective in situations where the size of the critical area changes over time; moreover, it is different to evaluate the exposition risk through an automatic mechanism. Reasonable automatic non-invasive solutions for delimiting a safety belt would require a fixed infrastructure to estimate the absolute position of a moving entity (personnel) in indoor situations or satellite-based technologies in outdoor cases. In particular, the literature suggests the use of Global Positioning Systems (also terrestrial, e.g., through UWB [1]), position estimation by means of radio frequency mechanisms [2] [3] or tessellation of the monitored area through passive RFID devices (which contain their spatial coordinates in the tag) [4] [5] [6]. Distance is then evaluated as the difference between the operator and a critical point positions. All these solutions are costly and badly scale with the area to be covered in indoor applications, but are generally effective in outdoor environments where GPS is the most suitable technological solution [7] (provided enough satellite visibility is given). Furthermore, we should observe that setting up a fixed localisation infrastructure in a dangerous area can be time consuming, difficult to be implemented and not risk-free.

The approach suggested in this paper solves problems posed by the existing systems in areas where a GPS solution cannot be applied (e.g., in indoor situations or whenever the GPS signal is either weak or missing). In particular, by relying only on small and portable wireless embedded devices, it neither requires knowledge of absolute information about the environment nor a fixed infrastructure to be deployed in the field.

Here, delimiting a hazardous area can be intended as follows:

1) define the perimeter of the hazardous area;
2) delimit the whole hazard area;
3) introduce different risk levels and, consequently, different risk zones within the hazard area.

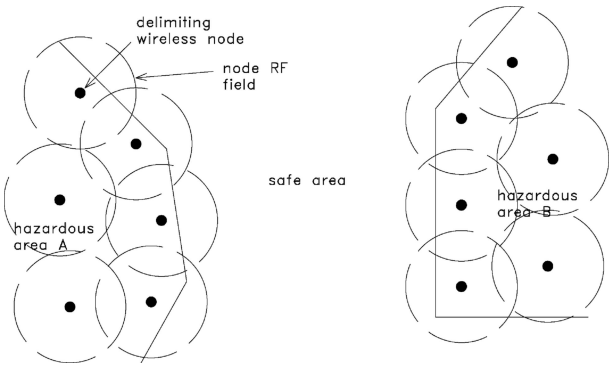


Fig. 1: A possible application scenario

In the first case we aim at providing an alerting mechanism to the operator when leaving the safety belt area and entering the risk one. In the second case we extend the first point by monitoring the presence of the personnel in the whole hazardous area and not solely around its perimeter; once there, we compute the exposition risk in terms of time spent by a member of the emergency personnel within it (e.g., to assess the chemical exposition risk).

Surely, we can identify several security belts around the risk area (third case), each of which possibly characterised by a different risk level; for each belt we evaluate the spatial and temporal presence of a generic entity within the belt during emergency and, if required, sensorial information acquired by the device.

Delimitation of a critical area can be accomplished by "tiling" it with a set of spherical neighbourhoods (see figure 1) with neighbours radii that can be automatically adapted according to the local requirements, both to reduce the number of neighbours and provide different spatial resolutions (e.g., adaptation could rely on sensors such as electronic gas sensors or labs on chip). In the following, without loss of generality, we focus on aspects addressing a single belt area; extension to several belt areas is immediate.

In this paper we suggest a solution in which each neighbourhood is assigned to an embedded wireless *slave* unit both defining an electromagnetic neighbourhood and carrying out the information and communication processing. Slave units are deployed to cover the area/perimeter to de delimited and, possibly, mount a sensorial board.

Each entity entering the emergency zone will be in possess of an embedded wireless *master* unit; the unit, by interacting with *slave* ones will identify his/her presence in a critical area

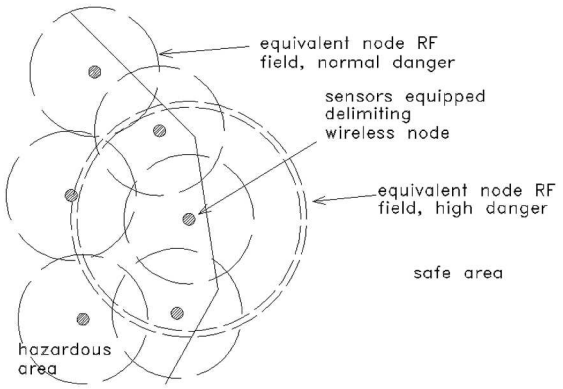


Fig. 2: An application scenario with adaptive zones

and estimate the time exposition to the area as detailed in next sections. Master units can mount sensors to address a specific risk.

Slave and master units define a mobile wireless sensor network with the slave deployed in the emergency area (and generally fixed in position) and masters moving around being worn by the personnel.

The problem of electromagnetically tiling an area and monitoring mobile master units entering in contact with slave ones can be intuitively reduced to the interaction between a single master and a given but, dynamic, number of slave units as presented in Figure 3. Here, we assume that master and slave units are freely moving nodes in an unbound three-dimensional space.

Every time the trajectory of the master unit enters a spherical neighbourhood of the slave one (with a prefixed radius or threshold defining the concept of interaction) we say that the two units interact and we have to measure the interaction time, i.e., the time during which the two entities distance is below a threshold. These issues will be addressed in subsequent sections.

The paper is structured as follows: section II formalises the proximity time estimation problem and provides a high level overview of the suggested algorithm. Section III addresses the case where only one master unit is present and several slave units interact with it without interference. The extension to multi master-multi slave units, i.e., the case where personnel is working close in an area, is addressed in section IV. Section V suggests an algorithm,

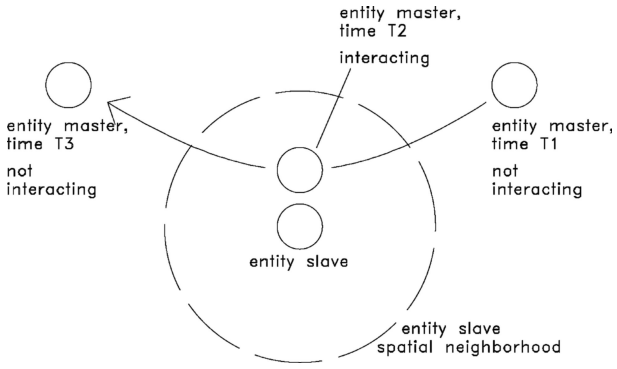


Fig. 3: Overview of the problem.

based on fuzzy logic, to group more than one wireless device to form a 'wireless safety belt'. Finally, section VI provides some experimental results.

II. APPLICATION REQUIREMENTS AND OPERATIONAL ALGORITHMS FOR MASTER AND SLAVE UNITS

The operational and critical nature of the emergency phase requires the system to be fully automatic with master and slave units easily wearable and deployable.

In particular, the main task of a slave unit is to define the concept of interaction neighbourhood and, de facto, acts as an active radiofrequency identification device (RFId). Differently, masters scan their neighbourhoods searching for slave units, negotiate the use of the shared radio channel and control the radiofrequency RF- power for radio transmission purposes. More in detail, a master sends an interrogation radio signal at a given RF power (which creates a spherical electromagnetic field around the master) to investigate its neighbourhood searching for slave units. Once slave units are detected, they are properly tracked; when a slave exists the neighbourhood, the master stores the history of contacts (event) in its non volatile memory (information which can be subsequently downloaded for a subsequent post processing phase).

The geometry of the RF neighbourhood strongly depends on the antenna designed for master and slave units. For simplify the problem, we consider ideal isotropic antennas for which we have a straight relationship between the power density S_A of an electromagnetic wave at some point A in space, and the power density S_B at some point B at distance r. In

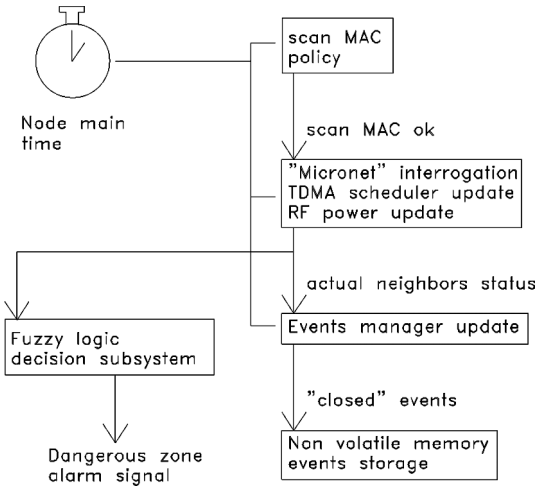


Fig. 4: A high level representation of the master's algorithm

particular, by referring to [8] we have that

$$\frac{S_B}{S_A} \propto \frac{1}{r^k} \tag{1}$$

where

$$k \geq 2 \tag{2}$$

This classic simple radio model (also called "free space model") [9] [10], can be impaired by reflection phenomena in indoor environments [11] and by antennas non idealities, which reduce the isotropy of the electromagnetic field (as a consequence, a spherical neighbourhood cannot be granted).

An Ultra Wide Band solution would provide more robust and accurate estimates of the distance between two RF units but it requires high power consumption and system complexity; moreover we didn't find any embedded UWB transceiver able to measure distances integrable in a small wearable equipment.

To deal with antenna non-idealities and electromagnetic wave reflections and refractions (which affect the quality of the electromagnetic field by disrupting the spherical neighbourhood) a control of the master-slave interaction is needed; the high level structure of the algorithm in execution on the master is given in figure 4.

More in detail, the node main time is based on a real time clock which, periodically

(e.g., each 1s), sends an interrupt activation signal enabling the interrogation procedure. As a result, by sending a RF signal at a given RF power and waiting for a -possible- slave response, the master looks for the presence of slaves in the neighbourhood. The “scan MAC policy”) supersedes the negotiation of the radio channel between multiple masters whenever more than one share the same spatial neighbourhood (we could not identify in the literature for such unconnected ad-hoc network, a MAC layer fully satisfying our requests in terms of time coherence and energy saving). The “MicroNet” module performs the radio interrogation with our ad-hoc CSMA/CA -TDMA hybrid protocol. The outcome of this phase is a list of slaves present within the interaction neighbourhood.

Then, an inference system based on fuzzy logic evaluates whether the master units belong to one or more dangerous area or not and, in case of a positive answer, it generates an alarm message for the person wearing the master unit.

Afterwards, the module “Events manager update” updates the information of the slaves present in the list: when a master moves outside the neighbourhood the interaction with the specific slave terminates and the information associated with the contact need to be stored in the non volatile memory of the master unit for later use.

On the other hand, the task to be carried out by slave units is simpler: when slaves receive an interrogation message they respond with a presence confirmation reply message. Reply messages’ broadcast time and power are set according to master’s directives transmitted in the interrogation message. Finally, battery status is included in the slaves’ messages allowing the querying master to store energy status of the responding tags in his event logs. This information could be important to subsequent off line data analysis.

III. THE SINGLE MASTER CASE

The single master case is the simplest operative situation where a single person wears a master and several slave units interact with it. The case is characterized by a sparse connectiviy network presents a sparse connectivity (i.e. the personnel moves far apart each other). In this simple case the master does not need to negotiate the radio channel and the MAC block of fig.4 is not activated.

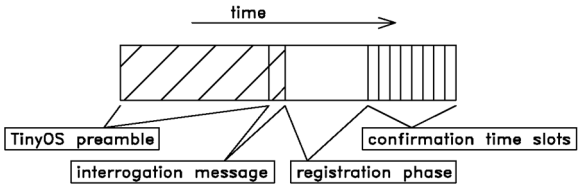


Fig. 5: The interrogation message frame. The filled part is the transmitting one whereas the other is the receiving one.

A. The interrogation protocol ("MicroNet" interrogation)

The goal of the interrogation phase is to provide the list of slaves present in a specific instant of time in the master's spatial neighborhood. Since master units are highly mobile (and hence the local topology of the master is subject to significant variations) some care must be taken to control the radio communication. In particular, during transmission we have to address the hidden radio problem where two or more units require transmittal information to a common node but cannot communicate between them. A Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol was here considered which introduces an acknowledgment mechanism to grant packet delivery [14] [15]. Unfortunately, CSMA/CA requires repetition of transmission packets upon failure which does not only imply time accuracy loss but unnecessary power consumption.

To solve the problem we opted for an ad-hoc Time Division Multiple Access (TDMA) protocol, with the master unit controlling both protocol and slaves. Figure 5 shows the implemented interrogation message's frame as broadcast by masters.

First a preamble is broadcast by the master. This is used to synchronize receivers' transceivers. Then the interrogation message follows. At the end of the interrogation message the transceiver is switched to the receiving mode and the master waits for slaves' answers. Since master units handle the TDMA protocol, they control time slots allocation and inform the slaves about the allotted time for response. Whenever a slave receives the interrogation message it provides its identification number in the assigned time slot. If the slave is new it has first to register by transmitting a registration message in the registration time slot (registration phase in the figure). Registration enables the master to register the slave by updating the slave list and allocate a time slot to it (in the next neighbourhood scan the slave will be able to respond

once interrogated).

In the registration phase the communication stack is CSMA whereas, upon registration, a slave responds in the allotted time hence using a TDMA communication stack. As such, the hidden radio problem has been confined only to the registration phase which, for effectiveness of the protocol, should be a rare event (false positive and negative events are managed by the regularisation filter, as shown in the subsequent subsection).

Whenever the master identifies that a slave has moved outside its spatial neighborhood, the associated time slot will be freed and information associated with the proximity time event (e.g., start and time) is stored in the non volatile memory of the master unit.

B. The regularisation filter

The described interrogation mechanism suffers from the strong non ideal nature of the electromagnetic field. As a consequence, we would generate many short contacts and unnecessary registration events which, in turn, will affect the MicroNet protocol efficacy, memory usage and power consumption. Moreover this non-ideality heavily degrades the accuracy of master and slaves distance extimate and the time measurement.

A simple regularisation filter was introduced for reconstructing the events by filtering missing contacts due to communication problems. The regularisation algorithm is given in equation (3).

$$T_{e,\tau_2} = \begin{cases} 0 & \text{if} \quad \text{new event} \\ T_{e,\tau_1} + \Delta t_{\tau_2,\tau_1} & \text{if} \quad \Delta t_{\tau_2,\tau_1} \leq T_f \\ & \quad \text{(event confirmation)} \\ T_{e,\tau_1} & \text{if} \quad \Delta t_{\tau_n,\tau_1} > T_f \\ & \quad \text{(event termination)} \end{cases} \tag{3}$$

where T_e is the time duration of an active event (the time elapsed since a slave registration and the associated event generation), τ_1 and τ_2 refer to two scanning events performed by the master, with $\tau_2 > \tau_1$ (both time instants reporting a presence of the slave). τ_n refers to a scanning event successive to τ_1 for which no presence of slaves has been detected, $\Delta t_{\tau_2,\tau_1}$ is

the time elapsed between the radio scan performed at τ_1 and the one performed at τ_2, $\Delta t_{\tau_n,\tau_1}$ is the time elapsed between the interrogation performed at τ_1 and the one performed at τ_n and, finally, T_f is a preset filter constant. The suggested filter is executed in correspondence with each active event, in the interrogating phase. For all active events two conditions occur: the time elapsed since the last contact is either below T_f (event confirmation condition in (3)) or above it (event termination condition in (3)). In the first case the time duration of the event is updated by summing the time elapsed since the last contact (and the event is labelled as being valid), in the second case the event is considered over and the slave is labelled as being outside the master's neighbourhood. When the slave exits the master's neighbourhood the associated event terminates and all contact information is stored in the non volatile memory.

C. The radio power control algorithm

In order to give the maximum amount of information to the inference subsystem, reduce power consumption and cross-interference, we implemented an algorithm adjusting the communication power to its minimum value, yet granting communication between master and slave. If we consider that the interrogation signal is common to all slaves whereas the response signal belongs only to a specific one, it turns out that it is simpler to adjust the slave's answering signal than the master's interrogation one. To accomplish this task, the interrogation signal carries also the transmission power for each master registered in the "MicroNet" protocol. As such, a registered slave always knows the power level to be used for responding to a master, hence enabling the master to perform the power control algorithm for each registered slave.

The power control algorithm is a tracking algorithm that aims at establishing the minimum RF power requested to maintain each slave's contact; the algorithm is given in (4).

$$x_{c,t+1} = \begin{cases} x_{c,init} & \text{if} \quad \text{new contact} \\ x_{c,t} & \text{if} \quad x = x_{min} \text{ and contact at } t \\ x_{c,t} & \text{if} \quad x = x_{max} \text{ and not contact at } t \\ x_{c,t} + 1 & \text{if} \quad x > x_{min} \text{ and not contact at } t \\ x_{c,t} - 1 & \text{if} \quad x > x_{min} \text{ and contact at } t \end{cases} \tag{4}$$

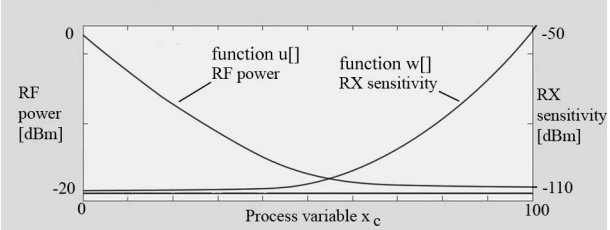


Fig. 6: The function u and w.

The algorithm updates a status variable x_c (one for each registered slave) at each neighbor's interrogation according to the presence of the slave in the previous interrogation. The actual communication power $P_{c,t}$ is a monotonically increasing function of $x_{c,t}$. To gather a better accuracy in distance measurement, especially in close proximity situations, we also opted for changing the master receiver sensitivity so that the actual sensitivity $\sigma_{c,t}$ is function of the process variable x_c. Thus, during a contact, the actual transmission power and receiver sensitivity are updated as:

$$\begin{aligned} P_{c,t} &= u[x_{c,t}] \\ \sigma_{c,t} &= w[x_{c,t}] \end{aligned} \tag{5}$$

The functions here adopted are depicted in figure 6. With this tracking technique, each slave in contact with a master is characterized by a dynamically updated variable $x_{c,t}$ that set radio communication physical parameters P and σ, and, in turn, modifies the maximum distance of communication between master and slave, according to (1).

From (1) we see that value $x_{c,t}$ is related to the distance between master and slave and, from figure 6, we have that the larger the distance between master and a slave the smaller the value of its process variable.

IV. EXTENSION TO THE MULTI-MASTER CASE

The previous section has presented the core of the algorithm. Now, we have to extend it to cover the multi-master case, i.e., the case where several masters are present in the same area and entirely or partly interrogate the same neighbourhood.

A. The scan MAC policy.

Whenever two or more master interrogation regions overlap a channel sharing problem arise. A MAC control algorithm must hence be implemented to arbitrate the radio channel use. The suggested MAC policy can be summarised in two steps:

1) Before the beginning of the interrogation sequence, a handshake message is transmitted.
2) If a handshake message is received, every transmission is interdicted for a time equal to the interrogation cycle time length (which is fixed).

This handshaking mechanism promotes only one master at time to perform the neighbour's interrogation while silencing all others. Since the master in possess of the channel is the one broadcasting the handshake signal and the masters' main node timers start the interrogation sequence at the same fixed time for all masters, this algorithm always promotes the same master. To enable all masters to perform the interrogation sequence, an auto-penalisation mechanism has been introduced where the masters' interrogation sequences are delayed with respect to the main timer's scan signals. The discrepancy between the timer scan signals and the actual scan sequence does not affect the time measurement accuracy because the penalisation delay is always smaller than the time interval between two neighbours' scans.

The suggested equation ruling the penalisation delay T_d is given in (6):

$$T_{d,t+1} = \begin{cases} T_{d,t} & \text{if channel lost} \\ T_{d,t} + T_p & \text{if } T_{d,t} + T_p < T_{scan} \\ & \text{and channel won} \\ 0 & \text{if } T_{d,t} + T_p \geq T_{scan} \\ & \text{and channel won} \end{cases} \tag{6}$$

where

$$T_p \sim U[0, T_{scan}] \tag{7}$$

The penalisation delay is kept fixed if the master does not win the channel usage (i.e. if its communication is inhibited by a received handshake message when a interrogation message should be broadcast) while it is increased when the master wins the channel and performs

an interrogation. The delay is increased by a random variable of uniform distribution in the $[0, T_{scan}]$ interval, T_{scan} being the main node timer interval between two consecutive interrogations. The delay cannot become larger than T_{scan} in order to maintain time correlation between actual interrogation and events.

B. Radio power co-reduction algorithm

If the system is employed only for measuring proximity time (for example in the patient care measurement example presented in section VI), the situation involving more than one master in the same spatial region needs a deeper analysis. When the master interrogation areas heavily overlap, the overall problem of measuring the proximity time becomes meaningless since it is not possible to distinguish the master scan boundaries. To deal with this fact, a radio power co-reduction algorithm has been included in the handshaking mechanism. This algorithm reduces the communication power of the interrogation messages to increase the boundary separation among masters. The algorithm activates whenever a master realizes the presence of other masters in its neighbourhood. The co-reduction algorithm operates as follows:

1) When a master realizes to be in a multi-master condition it generates a requested maximum value for the communication power, which is broadcast in its handshake message.
2) When a master receives a handshake message it enters a multi-master condition and, consequently, lowers its power transmission according with the information present in the handshake message.
3) The power reduces to its minimum value.
4) When a master does not receive a handshake message for a preset amount of time, it disengages the multi-master condition and raises the transmitting power to a normal value.

In other words, the algorithm decreases the communication power between master nodes whenever two or more masters are co-present. Obviously, the power profiles of fig. 6 are modified to respect the mutual maximum condition, i.e., the transmitting power pattern is

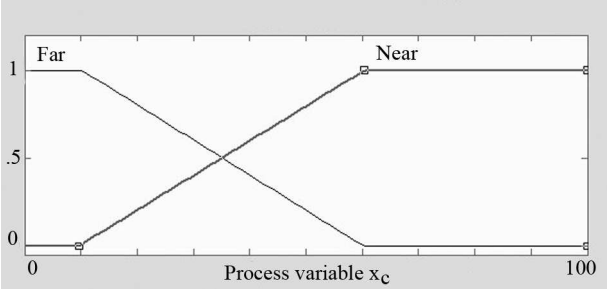


Fig. 7: Membership functions modeling the concept of proximity on the process variable x_c.

truncated to its maximum value.

In this condition the power patterns of the interrogation procedure change and the MAC policy enhances the frequency of the spatial interrogation. To simplify the post processing of data collected, acquired events in a single master situation are kept separate from those events acquired in a multi master situation.

V. THE FUZZY LOGIC INFERENCE SUBSYSTEM

As mentioned in section III-B, the real electromagnetic field might be far from been spherical with the consequence that slaves can provide a bad coverage of the environment and master might not communicated with them even when they should (false negative). To deal with this issue, we opted for a fuzzy inference system to decide whether a master belongs to a particular safety belt or not. The fuzzy inference system receives the process variables x_c and the identity of each present slave and classifies the masters status as being in or not in the hazard area.

In other words, fuzzy rules have been used to provide the concept of proximity with the process variables x_c of each slave as shown in figure 7.

For example, by referring to figure 8, where four slaves are grouped into 2 groups to differentiate 2 areas, the fuzzy logic inference system can be written as:

```
If (slave10 is Near) and (slave11 is Near) and
(slave20 is Far) and (slave21 is Far) then
(master is Zone1) (1)
If (slave10 is Near) and (slave11 is Far) and
(slave20 is Far) and (slave21 is Far) then
(master is Zone1) (0.9)
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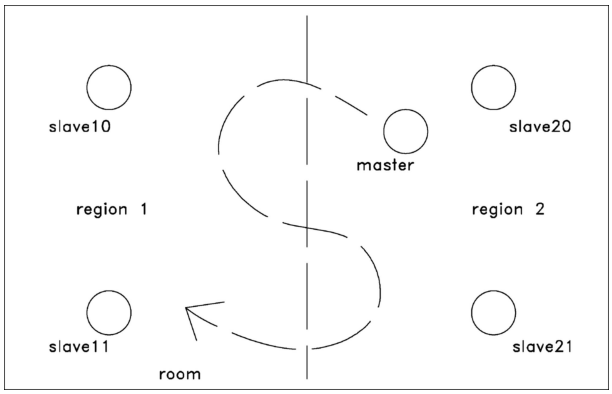


Fig. 8: A simple scenario with 2 groups of 2 slave units delimiting 2 areas.

```
...
If (slave10 is Far) and (slave11 is Far) and
(slave20 is Near) and (slave21 is Near) then
(master is Zone2) (1)
If (slave10 is Far) and (slave11 is Far) and
(slave20 is Near) and (slave21 is Far) then
(master is Zone2) (0.9)
...
If (slave10 is Far) and (slave11 is Far) and
(slave20 is Far) and (slave21 is Far) then
(master is Free) (0.2)
...
If (slave10 is Near) and (slave11 is Near) and
(slave20 is Near) and (slave21 is Near) then
(master is Dubt) (0.7)
If (slave10 is Near) and (slave11 is Far) and
(slave20 is Near) and (slave21 is Far) then
(master is Dubt) (0.6)
...
```

At the end of the fuzzy rule evaluation process, a fuzzy variable containing the status of the master is computed while a singleton-based defuzzyfication rule provides the final status of the master.

Figure 9 presents a possible defuzzification rule for the previous example. The actual shape of slave membership functions as well as the rules weights have been experimentally determined to grant the best accuracy in recognition.

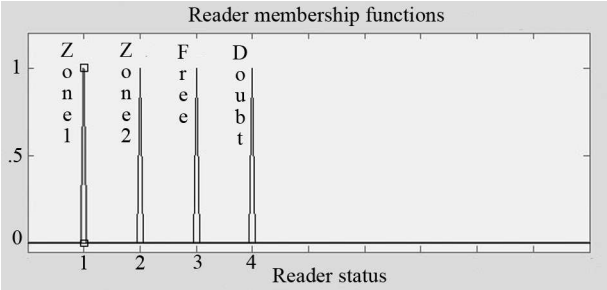


Fig. 9: A possible singleton based defuzzification rule for the given example.

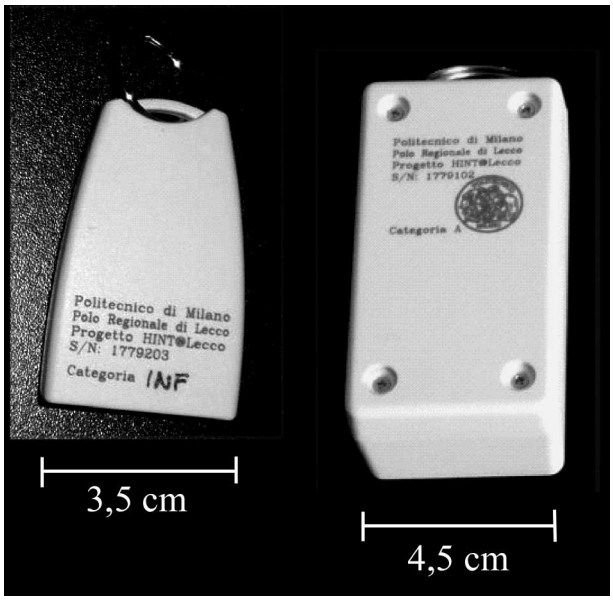


Fig. 10: A picture of the devices employed in experimental phases, left a slave unit, right a master one.

VI. EXPERIMENTAL RESULTS

The designed master and slaves units are depicted in figure 10.

A. An indoor multi slaves localization experiment

The experiment refers to the indoor multi slave localization experiment depicted in figure 11 (a two zone indoor localization system deployed in a room). Six slaves are present, grouped into two sets to generate two safety belts in the room (slaves A1 to A3 identify zone A whereas slaves B1 to B3 identify zone B); the safety belts cover the whole environment. The master performs the radio tracking algorithm and sends process variables $x_{c,t}$ to a base station where the fuzzy logic inference subsystem is executed. By moving the master inside the room we can assess the recognition ability of safety belt.

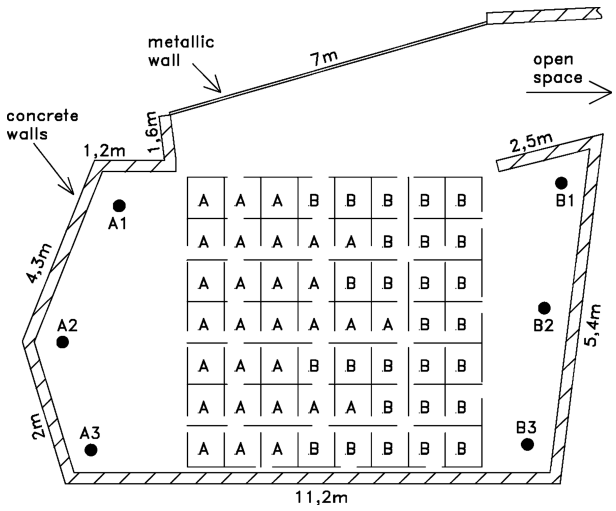


Fig. 11: Zone recornition results in the experiment room.

The figure shows that the system was actually able to differentiate the two zones within the environment (characterized by the presence of strong EM reflections). Figure 12 is a detailed version of 11. We note that the border between zone A and B is not symmetrical with respect to the center of the room, probably due to electromagnetic reflection phenomena in the room. The presence of the status “doubt” is evident in the lower part of the zone (gray squares). As discussed in the article, zone boundaries are reconfigurable by adjusting nodes RF power or fuzzy member functions. Here we adjusted the membership functions of zone B to be more permissive to the “near” concept, basically translating the ramps of figure 7 to lower values. Figure 13 displays the same experiment with these new membership functions. Zones are more well balanced with a correct association of the “doubt” position in the middle. The effect of this change, as well as the easiness of zone reconfiguration manifested by this system, is demonstrated.

B. A patient care measurement application in hospitals

The experiment was selected for its highly expressivity, also in terms of complexity interaction among people and fixed entities. Here we are assuming a contamination risk for the rescue team and we wish to evaluate their complexity in terms of assistance needs; in turn we could easily use the same model to estimate the time interaction among the rescue personnel (master units) and contamined people (slave units) following a NaTech risk. The

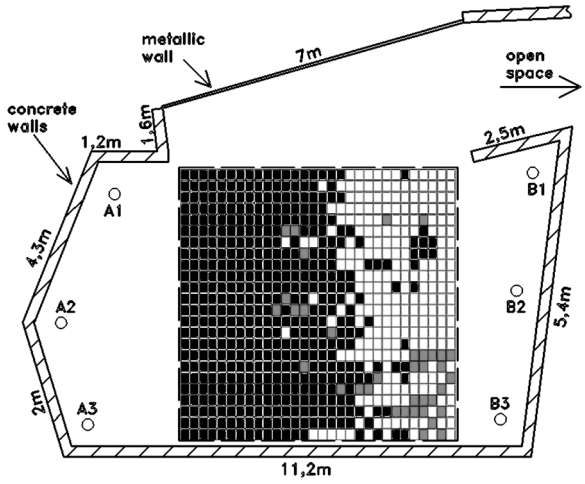


Fig. 12: Fine zone recornition results in the experiment room, fuzzy inference subsystem 1.

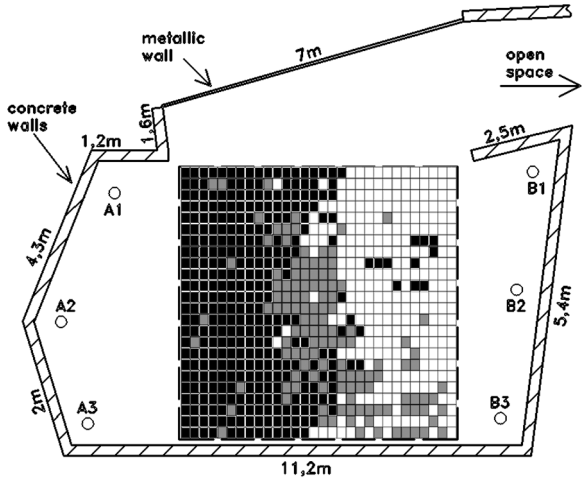


Fig. 13: Fine zone recornition results in the experiment room, fuzzy inference subsystem 2.

25 days non-stop campaign required data download and battery replacements once a week; masters where caregivers and slaves patients and fixed infrastructure of a rehabilitation clinic. At the end of the acquisition campaign the masters registered more than 50000 events.

Figure 14 presents a plot of the interaction among nurse-masters and patient-slaves measured by a patient's master during two hours of the measuring campaign. The time resolution of the measure has been set to half a minute. Contacts are represented with a rectangle whose base starts from the beginning of the contact (the tag's registration) and ends with the contact's end (end of event). The height of the rectangle are proportional to the value of μ_{a_c} of the contact, μ_{a_c} being the inverse of the mean value of the process variable x_c evaluated during

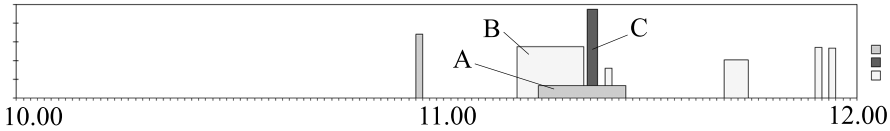


Fig. 14: History of contacts of a patient from 10.00 am to 12.00 am. The abscissa represents time, the ordinate the value μ_{a_c} of the contacts. Different grey shades represent three different tags.

the contact time length.

In the figure we can distinguish three types of contacts (according to what stated in III-C). In particular, event A has a very low value of μ_{a_c} and is quite long, so we can safely assume that it is a good contact with a small master to slave distance. Contact C has a high value of μ_{a_c} and, as such, the slave has been quite far from the master during the event. Contact B is somehow in a middle position between A and C. In this first experimental phase we assumed all contacts to be good contacts, regardless of values provided by μ_{a_c}

Table I shows the final results of the experimentation. The 15 slaves have been divided into categories: hygiene facility, drugs facility, table facility, nurses and OTA (auxiliary personnel).

TABLE I: Experiment final results: complexity estimate of 5 patients. Contacts' time length is in minutes.

patient no.	hygiene facility	drug facility	nurses	OTA	table facility	total
patient 1	619	85	1919	3142	1917	7682
patient 2	664	181	1579	2183	1183	5790
patient 3	5331	61	3647	6184	3739	18962
patient 4	458	74	2648	2720	4276	10176
patient 5	112	122	1790	1627	71	3722

We note, for instance, that patient 3 is particularly complex it terms of care giving needs once compared to the others while patient 2 requires a more complex drugs providing phase (i.e., doctors and nurse require long time to provide drugs to the patient). Finally, patient 5 is surely the less critical one on all aspects since the care-giving time as estimated by the proximity estimation time algorithm is smaller than the others. It is interesting to compare two patients, e.g., 1 and 5 on the hygiene facility time. Here we measure the time the patient needs to be cleaned (a tag is on the clean trolley) by nursery. We see that patient 5 requires one fifth of the time needed by patient 2.

VII. CONCLUSIONS

A solution for delimiting hazardous areas -hence alerting operators when crossing safety belts generated around the hazard- as well as estimating the exposition time to the risk has been suggested which does not require any fixed infrastructure. Once formalized, the problem can be solved with a mobile wireless network composed of master and slave units with suitably protocols developed to control the radio channel. The effectiveness of the algorithm, suitably implemented on a dedicated network, was shown. Master and slaves units have been implemented as embedded wireless systems.

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