Exploiting Wireless Localization for Decision Support in Search-And-Rescue Operations

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***Abstract*—This paper introduces "SHARON", an innovative decision support system (*DSS*) that exploits wireless communication and localization technologies for the analysis and the planning of Search-And-Rescue (*SAR*) missions in mountain or rural environments.**

Keywords—wireless localization, distributed sensing, decision support system (DSS), emergency management, search-and-rescue (SAR) mission

I. INTRODUCTION

In recent years, the human activities in rural and mountain environments are increasing worldwide, also due to COVID-19 restrictions. In this scenario, the emergencies related to accidents and to search-and-rescue (*SAR*) of missing persons, are typically coordinated by mountain rescue agencies. In particular, *SAR* is one of the most complex and critical operations due to the high risk, the tight deadline, and the number of involved assets. The common approach is often based on personnel experience and pen-and-paper planning. In fact, the experience of domain experts and operators is particularly relevant for the understanding of environment and weather conditions that influence the target's movements. In this framework, the diffusion of wireless communication and localization technologies, as well as the availability of online data-sources providing accurate description and distributed monitoring of the environment, enable the introduction of decision support systems (*DSS*) that provide situation awareness and support the planning and the coordination of search operations [1].

II. WIRELESS TECHOLOGIES FOR EMERGENCY MANAGEMENT

Situation room operators and managers rely on their training and their long experience for taking decisions. Of course, *DSS*s do not aim to replace operators, but to (*i*) provide updated, reliable, and real-time information, to (*ii*) propose trade-off solutions, and (*iii*) to simulate and explore possible scenarios. In this context, wireless technologies have a crucial role, not only for voice communication but also for sensing, localization, and command and control [2]-[5]. Moreover, in public safety and military applications, the reliability and security of both the infrastructure and the end-user service is a key requirement. While civilian communication infrastructures (e.g., *3G*, *4G*, *5G*) are becoming more and more pervasive, efficient, and reliable, they are still designed as best-effort service. Therefore, *ad-hoc* communication networks, such as the Trunked Radio System (*TRS*) and in general Private Mobile Radio (*PMR*), have been developed and deployed for critical applications. Such wireless technologies are typically characterized by low-capacity, high redundancy, high reliability, and a dedicated narrowband spectrum. One of the most diffused technology, especially in Europe, is the terrestrial trunked radio (*TETRA*), a digital mobile *PMR* system that works on non *3GPP*-standardized bands (i.e., 400 MHz, 800 MHz, 1400 MHz) [6]. *TETRA* provides encrypted communication services including voice, messaging, localization, data services, and over-the-air reconfiguration of mobile terminals. In particular, the real-time localization of vehicles and personnel is the key information to enable situation awareness and to support command and control operations. In outdoor environments, localization is typically provided by global navigation satellite system (*GNSS*) such as the well-known Global Positioning Service (*GPS*) and more recent implementations such as Galileo. It should be noticed that the *GPS* device still requires a communication channel (e.g., provided by *TETRA*) for transmitting the position to the *DSS*. In the last decade, the miniaturization of *GPS* devices has enabled their large diffusion on vehicles, mobile phones, and Unmanned Aerial Vehicles (*UAV*s).

III. METHODOLOGY

The *SAR* mission starts with the missing-person alerting call to the emergency center. After the acquisition of mission parameters, the proposed *DSS* (called "SHARON" - *SearcH And Rescue Operation assistaNt*) aims to support the decision maker [1] by providing the estimation of the search area, of the target's presence probability in such area, and finally to find and select the assets (i.e., men and vehicles) to be involved in the operations on the field. In particular, the *DSS* flow is defined in the following.

A. Define Mission Parameters

In the first phase, the system acquires some basic information about the target. Such information are usually

This work benefited from the networking activities carried out within the Project "CYBER-PHYSICAL ELECTROMAGNETIC VISION: Context-Aware Electromagnetic Sensing and Smart Reaction (EMvisioning)" (Grant no. 2017HZJXSZ) funded by the Italian Ministry of Education, University, and Research within the PRIN2017 Program (CUP: E64I19002530001), the Project "SMARTOUR - Piattaforma Intelligente per il Turismo" (Grant no. SCN_00166) funded by the Italian Ministry of Education, University, and Research within the Program "Smart cities and communities and Social Innovation" (CUP: E44G14000040008), the Project "SPEED" (Grant No. 6721001) funded by the National Natural Science Foundation of China, and the Project "MITIGO Mitigazione dei rischi naturali per la sicurezza e la mobilita' nelle aree montane del Mezzogiorno" (Grant no. ARS01_00964) funded by the Italian Ministry of Education, University, and Research within the Program "Progetti di Ricerca Industriale e Sviluppo Sperimentale nelle 12 aree di specializzazione individuate dal PNR 2015-2020", Specialization Area "Smart Secure & Inclusive Communities".

provided during the alert call:

- The last seen position (*LSP*) and time;
- The name, age, gender, and physical conditions;
- Optional information regarding target's profile and interest (e.g., target is mushroom finder or climber).

B. Estimation of Search Area

The first key information required for planning the *SAR* mission is to estimate the size and the shape of the search area. The proposed approach assumes the worst scenario in which the missing person behaves as a fugitive, meaning that the target moves from the *LSP* towards an unknown direction at the maximum speed. In order to estimate the search area, the system can simulate the possible paths of the target far away the *LSP* and stop after a given time (i.e., elapsed from last seen time) obtaining the maximum reachable perimeter. In Fig. 1, the *LSP* and the estimated search area are shown. In particular, the environment is represented by a hexagonal mesh in which the target can move from the center of cell to another neighbor cell with a given velocity. The paths simulation can be formulated as graph-exploration problem [7] and techniques such as the Dijkstra's algorithm are suitable for estimating the paths leading to the maximum distance. In this framework, the key variable is the time estimated to move from a cell to another, it can be directly obtained from the estimated target's velocity as the hexagonal cell has a fixed size (e.g., 50 [m]). The proposed *DSS* exploits the simplified model described in [8] that takes into account (*i*) the target's information including age, gender, physical conditions; (*ii*) the morphological characteristics of the environment: the slope towards the neighbor cell, the elevation, the terrain roughness, and the vegetation type. In addition, (*iii*) the weather conditions, as well as the presence of tracks and rivers, are considered.

C. Estimation of Target's Presence Probability

Once the search area has been defined, it is of interest for the mission planning to estimate the distribution of target's presence probability [1]. Towards this end, the proposed system exploits a set of probability models that have been defined on the basis of historical *SAR* missions analysis [9][10] and lost person behaviors [11]. Some presence probability models are:

a) *Ring Model:* Assumes that the target is not escaping. The probability decreases as the distance *LSP* increases. Therefore, the target can be found with higher probability nearby the *LSP*;

b) *Track Offset Model:* Assumes that the target walks on tracks or roads. The probability is lower far from tracks;

c) *Elevation Model:* Assumes that the target moves in an area having a similar elevation. The zones at higher or lower elevation of *LSP* have a lower probability;

d) *Watershed Model:* Assumes that the target moves within the same watershed, that has strong relationship with terrain morphology and vegetation. The probability decreases at each change of watershed;

e) *Angular Dispersion Model:* Assumes that the target moves from *LSP* to a known destination. The probability is higher in the circular sector towards the line of sight (*LOS*) direction and it decreases as the subtended angle increases. Therefore, the minimum

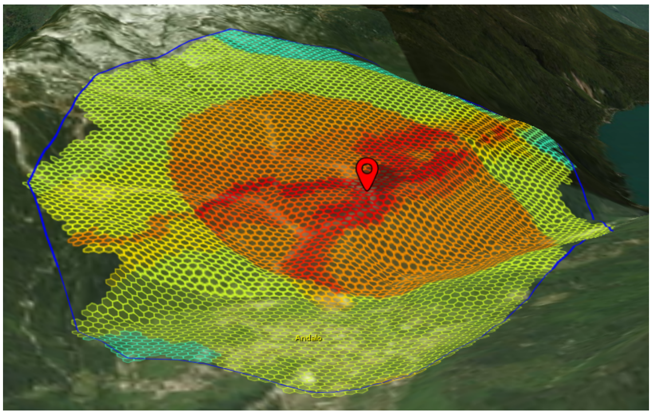


Fig. 1. An example of the estimated search area delimited in blue and the colormap showing the target presence probability estimation for each pixel. The red marker indicates the last seen position of the target (*LSP*).

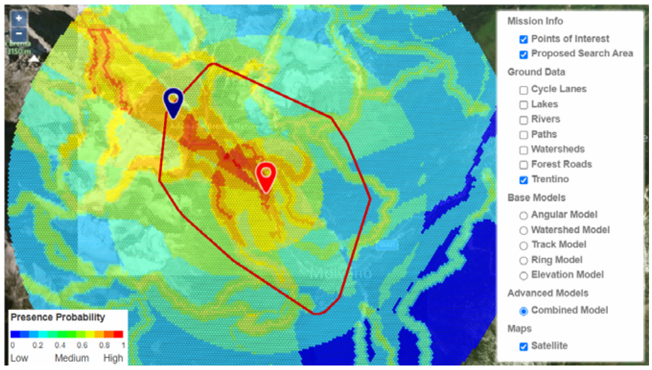
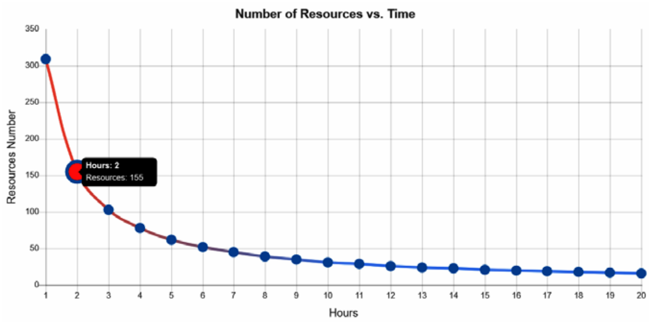
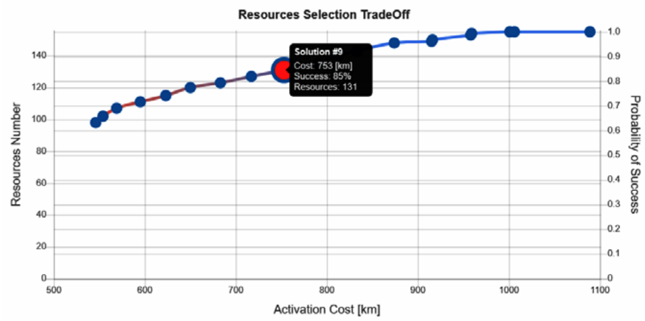


Fig. 2. The *DSS* web interface showing target's presence probability combined model. On the right panel, the user can inspect the output of each probability model as well as the environmental information layers.



(*a*)



(*b*)

Fig. 3. The two trade-off decisions for planning the *SAR* mission: (*a*) shows how many men/resources shall be involved in the search, in function of target mission time. Once the target mission time is selected (i.e., 2 hours), the SHARON *DSS* evaluates the best solution set fullfilling the criteria, such solutions are reported in (*b*) as the relationship betweem the number of involved resources and the mission activation cost (i.e., travels length).

probability is at the opposite direction with respect to the destination.

The output of each model is made available to the decision maker (Fig. 2), moreover SHARON provides a unified model computed as the weighed sum of available models. In particular, the weight of each model is pre-assigned as based on target's profile [12] and then confirmed by the user. The current strategy exploits a look-up table that has been defined with the support of domain experts. For example, a target that was going to search for mushrooms typically stay away from tracks, while elderly or impaired people most probably stay quite close to the *LSP* and moves on tracks within a similar elevation.

D. Selection and Dispatchment of Rescue Teams

Based on the search area estimated in the previous phases, the next step consists in the selection and the dispatch of assets to be involved in the operation on the field. Towards this end, the decision maker deals with two major questions (*a*) and (*b*). The first one is:

a) *How many men do we need to search the area? How much time will be required?*

In other words, the decision maker needs to evaluate the trade-off between the duration T [s] required to search the area A [m^2] and the number of rescuers N that are involved. Assuming that the search operations follows the standard *rake* scheme, in which men move together in a row at the same speed v [m/s] and along parallel columns at fixed distance $2W$ [m], the relationship can be defined as follows

$$\Phi(T,N)=\frac{(W\times v)\times T}{A}N \quad (1)$$

where $\Phi(T,N)$ is the ratio of area covered by rescuers. The optimum is to have N large enough to cover the whole area in the given time, leading to $\Phi(T,N)=1$. The *DSS* plots this function [Fig. 3(*a*)] and the decision maker can pick one of the possible trade-off solutions. It should be noticed that the number of needed resources is typically much larger with respect to available resources (i.e., men ready on the field).

b) *Do we have at disposal such number of men? Where can we gather them? How many men should we ask to each organization / barrack? What is the estimated time of arrival and the operation cost?*

Such a scenario and related questions are typical of the fleet management problem [13][14]: there are different organizations, such as Civil Defense agencies, having barracks, vehicles, and men with different skills and equipment distributed in the territory. In fact, during critical emergency missions, such as *SAR*, a large set of organizations can be involved. In this framework, we assume to know the location of barracks, information and real-time location of vehicles, the affiliation of men (i.e., their reference barrack and vehicles). Fortunately, such requirements are fulfilled in many real-world scenarios by means of modern telecommunication systems. In particular, to answer to the questions we would need to evaluate all possible solutions, where a solution defines how many men to be gathered from each barrack among the available ones. It is worth noticing that the total number of men that a solution provides might not be exactly equal to N (i.e., the optimum) as such quantity might not be available. According to the context at hand, the quality – fitness of a solution is determined by the following contradictory criteria:

- Reach the target number of men N required to complete the mission in the given time T (i.e., time is considered as a dominating variable);
- Minimize the estimated time of arrival to bring men at the base camp (e.g., set nearby *LSP*), as it is important to start the mission as soon as possible;
- Minimize the on-road distance of men transportations (i.e., assumed as the operation cost);
- Maximize the men's transportation efficiency for road vehicles (e.g., a normal vehicle can hold four places, selecting one more man requires another vehicle);
- Do not leave barracks empty (i.e., take all men) as a local emergency might occur in the near future.

The problem at hand can be recast as an inverse problem that can be solved by means of multi-objective evolutionary optimization [15] as addressed in [16]-[18]. The proposed approach leads two key advantages: (*i*) computational efficiency, as only a small part of all possible combinations are evaluated (i.e., leading to a sub-optimal solution set), moreover (*ii*) the output consist in the solutions on the approximated Pareto front (i.e., non-dominated solution set). Finally, (*iii*) there is no need to aggregate heterogeneous criteria within a single mathematical function (e.g., using a weighted sum). In fact, each criterion can be mapped to one different objective to be considered by the optimization process, in which each objective is defined by its own mathematical function with a given scale. The *DSS* shows the output solution set in function of the total number of men and with respect to the mission cost [Fig. 3(*b*)]. Therefore, the decision maker can explore solutions detail and make the final choice.

IV. Experimental Validation

The SHARON *DSS* has been implemented in Java as an interactive Web application that exploits Geographical Information System (*GIS*) technologies to embed and process the spatial information of the environment [19]. A database containing required information (e.g., barracks location, ground elevations and slopes, tracks, rivers, weather conditions) of Autonomous Province of Trento, Italy, has been setup. Moreover, the local Civil Defence fleet and personnel are equipped with thousands of *TETRA* terminals providing real-time localization. SHARON is currently under experimental validation with the support of the regional mountain rescue agency "Soccorso Alpino Speleologico Trentino" [20].

V. Conclusion

In this paper, a new *DSS* for the management of search and rescue operations has been introduced. The proposed SHARON system [20] is based on real-time wireless communication and localization technologies for supporting decision makers in the analysis and planning phases. The next activities will be aimed to extend the *DSS* support to the search units' coordination and to support real-time updates of simulations and outputs by exploiting information acquired by the wireless localization of men during the search on the field.

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