An agent-based system for maritime search and rescue operations

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***Abstract*—Maritime search and rescue operations are critical missions involving personnel, boats, helicopter, aircrafts in a struggle against time often worsened by adversary sea and weather conditions. In such a context, telecommunication and information systems may play a crucial role sometimes concurring to successfully accomplish the mission. In this paper we present an application able to localize the vessel who has launched a rescue request and to plan the most effective path for rescue assets. The application has been realised as a distributed and open multi-agent system deployed on rescue vehicles as well as on a land maritime stations of the Italian Coast Guard. The system is going to be tested in real scenarios by the Coast Guard.**

I. Introduction

Coast Guards of all around the world are responsible for monitoring safety at sea and operate all the search and rescue (SAR) operations when someone is in danger. Search and rescue operations usually originates from an explicit request for rescue. Then a preliminary localization of the calling ship is conducted with results that strongly depend on the safety equipment available on-board. A search plan is built based upon this position to cover an area that has to take into account the position changes due to natural derive of objects in the sea and the type and number of the units involved in search operations. After the first eye contact, a physical approach to the ship signs the starting point of the final rescue phase. Time plays a primary role all along the previous phases. Every sailor knows the "golden day" rule stating that only within the first 24 hours from the rescue request there are good chances of successfully accomplish the rescue. This is mainly based on three factors: 1. Injured man condition may require urgent medical assistance. 2. Damaged ship stays a short time at the sea surface level before getting completely underwater. 3. Men in water are difficult to sight and they have a short survival time because of the need for drinking water or due to prohibitive temperature conditions.

Passenger ships and big cargo ships are equipped with digital localization and transmission systems like the Global Maritime Distress and Safety System (GMDSS, *see* [11]), the satellite Emergency Position Indicating Radio Beacons (EPIRBs), the Search And Rescue Transponders (SARTs) and a radio station for long distance radio communications, that allow route monitoring by Coast Guard and instantaneous localization in case of rescue request. The International Convention for the Safety of Life at Sea (SOLAS, *see* [10]), in force in almost every worldwide sea since 1974, requires such kind of devices aboard on big ships. These are called "compulsory ships" because they are required or compelled by treaty or statute to be equipped with specified telecommunications equipment.

What about smaller ships? Smaller ships used for recreation (e.g., sailing, diving, sport fishing, fishing, water skiing) are not always required to have radio stations installed but they may be so equipped by a choice. These ships are known as "voluntary ships" because they are not required by law to carry a radio but voluntarily fit some of the equipments used by compulsory ships. Ship stations may communicate with other ship stations or coast stations primarily for safety, and secondarily for navigation and operational efficiency. They may or may not have a radio-positioning system, like the Long Range Navigation (LORAN) or the Global Positioning System (GPS), depending on the distance from the coast they are authorized to navigate. Some ships or vessels have a radio station including a radio transmitter working on the VHF marine band, a Digital Selective Calling (DSC, *see* [12]) device, usually embedded in the radio transmitter, and a GPS attached to the DSC. When this system is correctly set, it is able to easily send a semi automatic distress digital communication with the vessel position if data is available.

Many other ships, probably the major part of the recreation ships that sail between 6 and 50 marine miles far away from the coast, have just a voice marine VHF radio transmitter. In this case a rescue request has to be done via voice on the emergency channel by a human operator that has to communicate his own position at the best of her/his knowledge. This process is prone to a lot of errors, like: an erroneous knowledge of the position itself, a misunderstanding of the message over the voice channel because of a low quality of the radio communication, etc. Clearly, it takes much more time with respect to an automatic system, in the order of minutes at least, and requires the presence of an operator at the on-board radio station. Obviously, while the operator is using the radio (s)he cannot give her/his help to other people or, worst, (s)he may not have enough time to communicate his position because (s)he has to leave the ship, for instance in case of fire or sinking.

Once that Coast Guard has received a rescue request and knows the source position, it usually follows the International Aeronautical and Maritime Search and Rescue (IAMSAR, *see* [1]) guide lines to plan the search activity and to coordinate all the sea and air search units until the rescue is achieved. In the planning phase it has to determine an area where to limit the search operation and it has to determine the search path of each single unit involved in the activity. Based on many parameters, like elapsed time, weather conditions, kind of search unit (helicopter, ship) and other, it is needed to calculate the shortest way to scour all the search area. This preparation work usually requires precious minutes.

The coordination work then has to assure the search operation is performed as defined in the search plan. How much time the search will require and its final outcome are uncertain variables.

In this scenario, what is possible to do is acting on the timeliness and the accuracy of the overall system to better take advantage of the first moments, when rescue expectation is still high. This paper proposes a system based on sophisticated radio-communication devices and an agent-based software to cope with all of these problems. The solution includes an automatic localization system of the radio signals on the emergency channel, an aiding system for the search area and search paths calculation and a coordination console that assists the Coast Guard operator during SAR phases by visualizing search paths and the last known position of the vessel in distress.

This system is the results of a joint effort of two institutes of the National Research Council (IAMC and ICAR) and of the Italian Coast Guard who participated in the project with personnel from the Mazara del Vallo station. The project itself has been funded by the Sicily Region Government.

The paper is organised as follows: the next section presents some details about the problem of localising the vessel who is in danger and about the search and rescue planning issues. Section three discusses the proposed solution (in both its hardware and software aspects), section four discusses the obtained results and finally some conclusions are drawn in the last section.

II. The Problem

This section discusses some details about the problem faced in this project that mainly may be divided in two sub-problems: localization of the vessel who sent a distress signal and the search and rescue operations planning and coordination.

A. Localization

Localization is a very important activity in marine search and rescue operations. The time spent to localize a vessel plays a fundamental role in life saving. The less the time to discovery a vessel position, the more is the probability of saving human beings. Traditional techniques are based on radio communications between the boat in distress and the rescue service. When an accident occurs, many factors such as environment conditions, distance, stress could make hard the communication and delay the rescue operation startup. So far, it's clear that a fast and reliable communication between actors can be the difference in life saving.

While human beings need some time to communicate the vessel position by using the radio, an intelligent system could detect and localize the vessel in the sea by monitoring the radio channel activity. Radio communications often occur during rescue requests so that an intelligent observer which looks from different locations could localize the vessel by signal direction detection.

To this aim a radio direction finder (RDF), that is a device for finding the direction of an incoming radio signal, may be an useful tool. The Radio Direction Finder checks the signal strength of a directional antenna pointing in different directions. While old devices used a simple rotating antenna linked to a degree indicator, new devices use a dipole antenna to detect the signal. In the past the RDF was used during the war to detect and identify secret transmitters in large region. The same idea can be applied to the different scenario of marine search and rescue. A group of RDFs controlled by an intelligent system can detect a distress signal and localize the source before that a communication between human beings even starts.

The system we developed, is also able to track vessel movements after its first identification (tracking feature). This feature can be very useful during long rescue operations to update the vessel position. The automatic localization has the advantage of scalability: human communication requires many radio listening points across the coast with many employees but a network of intelligent detectors can be installed over a long coast (like the Italian one) and it requires a minimal number of human operators. The detection range can be increased by the installation of new units along the coast.

The intelligent system is composed by a society of intelligent agents which collaborate in monitoring radio frequencies, in matching the detections, in notifying every rescue request to the rescue service operator. The system normally listens to the maritime radio emergency channels and whenever a signal is detected, a search of possible matches is looked for. When a match is found, the agents notify the discovery to other agents responsible for other system behaviors (for instance rescue plan definition) and to the Coast Guard personnel. Of course, the rescue operator is free to verify the alarm by using other communications or to monitor the radio signal as long as (s)he wants.

The localization is possible due to at least two radio signal detections by two of the several stations deployed along the sea coast. When the source of the signal (the vessel) and the two detection stations are not aligned, a geometric triangulation gives the vessel position. The triangulation is computed between the direction vectors detected by the two stations. Of course, two vectors are necessary and sufficient but other ones may be used to improve the precision of the localization. Precision is in fact limited by the small error on the identification of the observed signal direction. The degree error becomes an estimated position error that is proportional to the distance between the source and the detection stations.

In Figure 1 we show the most simple search and rescue scenario where a vessel in troubles sends a distress signal that is in turn detected by a couple of coast stations. After the detections, the intelligent agents share that information and localize the source of the signal. In figure 1 we show the two vectors and the two angles used for triangulation.

In the system there are two different kinds of stations: detection stations are unmanned and the only host hardware and software devoted to receive the distress signal and identify its direction. Control stations are manned and they host a complete hardware-software system thus including the capability of receiving information from detection stations, performing triangulation and supporting SAR operations as described in the next subsection. Usually there is one control station responsible for each sea area according to Coast Guard procedures.

Each detection station sends the following data to the control station:

- the radio channel of the signals obtained from detection finder
- the direction of the signal
- the position of the station
- the time of detection

The position and the time of detections are very useful to match detections from several stations. Of course, two detections of the same signal have a very similar detection time.

The detections should be stored in an archive to solve problems about communication delays. In order to match a signal, the system searches a very similar detection from another station occurred in a fixed time window; the match with highest score is selected and used to compute the triangulation. The use of an archive is very important to trace each event collected by the system.

So far, the computed localizations are sent to a GUI-GIS platform which shows a map to support the rescue operators in organizing the rescue operation and in managing it. The operator can update the data about any vessel shown by the GUI and could start tracking or could cancel an alarm detection.

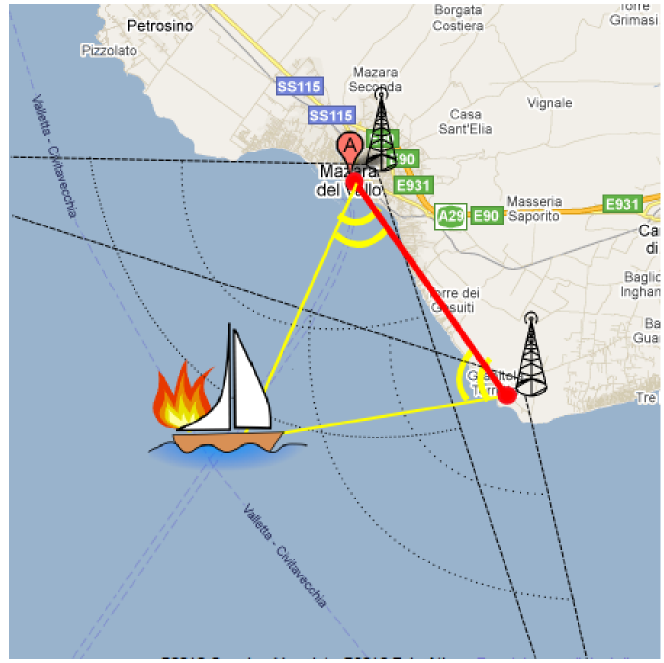


Fig. 1. A simple scenario with two stations detecting an emergency call

B. Search and Rescue

Search and rescue Operations (SAROPs) in maritime environment are regulated by a series of procedures defined and approved at the worldwide level. These procedures are reported in the IAMSAR (International Aeronautical and Maritime Search and Rescue) Manual Volume II. In Italy, SAROPs in maritime environment are entrusted to the Corpo delle Capitanerie di Porto Guardia Costiera (Coast Guard), which uses an articulated organizational network sometimes involving other national forces to accomplish these operations. Our scope is to provide this organization with a computer aided system that covers all the procedures involved in maritime SAROPs and that is compliant to the guidelines provided by the IAMSAR manual extended and optimized with the natural benefits a computer system can give. The procedures involved in SAROPs can be grouped in two principal phases:

- Determining datum
- Define search action plan

Datum in SAR is defined as a geographic point, line, or area used as a reference in search planning. Scope of the first phase is to determinate the datum starting from information like last known position, time of distress, a series of environmental information like wind, water current, leeway and other inputs that combined are able to give the effect of the drift on the search objects. In this phase the use of a computer system enables the remote acquisition and management of a large amount of data and a fast computation on it, with a very important time-saving that is a critical point in SAROPs.

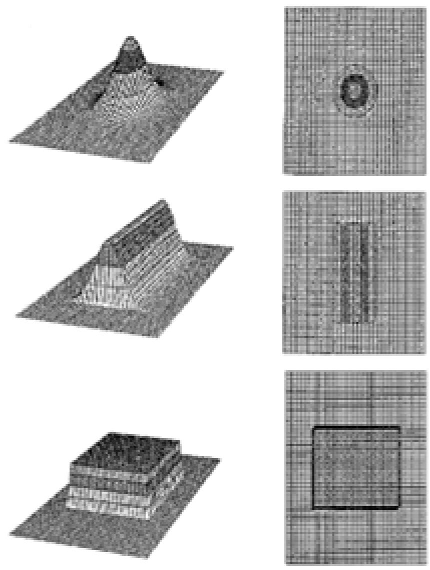
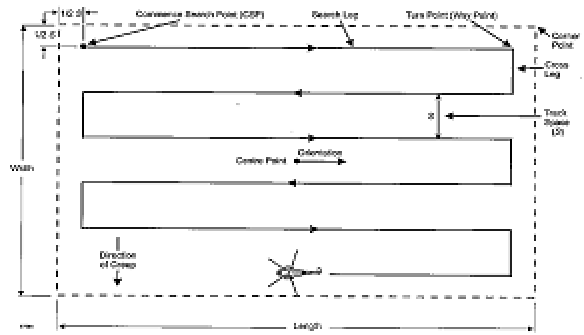
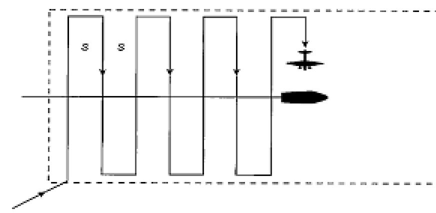


Fig. 2. Probability density for point, line and area datum (from IAMSAR manual, vol. II)



(a) Parallel sweep search (PS).



(b) Creeping line searh, co-ordinated (CSC).

Fig. 3. Two examples of possible search paths (from IAMSAR manual, vol. II)

Once the datum has been determined, the second phase is to define the optimal search area where the available search effort should be deployed. The search planner involved in this phase must define the optimal search area starting from the previously calculated datum and from some statistical considerations based on probability distributions. The IAMSAR manual only considers two types of probability distributions: standard normal distribution and uniform distribution, respectively used for datum points and lines or for areas datum. The first consists in a Gaussian distribution with the highest probability density near the datum and a decreasing probability density as the distance from the datum increases.The second consists in an area assumed to be evenly distributed unless there is specific information which favourishes some parts over others. Figure 2 is taken from IAMSAR Manual and it shows respectively the probability density for point, line and area datum.

Based on these distributions, the manual provides a set of probability maps of grid type where every cell has a prefixed value of probability of containment of the search object. The search planner must chooses one of these maps and overlay it over the chart centered in the estimated datum position. In this way (s)he obtains the area which contains the search object and the probability of containment distribution in that area. After that, the search planner evaluates the environmental search conditions, (s)he splits the search area in sub-areas and assigns them to search facilities chosen for the operations between all available ones. Such search rescue units (SRUs) will cover the assigned area with a prefixed navigational path chosen by the search planner from a set defined in the manual. Figures 3(a) and 3(b) are taken from IAMSAR Manual and show two examples of possible search paths.

The step illustrated in 3(b) may seem simple for the search planner, but it requires a relevant experience because of the presence of a limited set of very generic choices for covering every specific scenario. We think that, thanks to the use of a computer system, there is a lot of optimization margin in this phase and our system has been designed to support enhanced statistical elaboration techniques like the Monte Carlo Simulation (*see* [6]) to determine the search area instead of the prefixed probability maps suggested by the IAMSAR. Moreover optimization of search paths for the navigation of the SRUs is supported by a similar analysis. The Requirement Analysis phase of the project was done with the support of a domain specialist working with the Coast Guard and considering the list of "Functional Characteristics to Consider with the Computer-based Search Planning Aids" provided by the IAMSAR Manual.

III. The Proposed Solution

In order of improve the time response of SAR operations following a distress request, we propose an integrated aiding system that is able to localize and visualize the requesting vessel position, it is able to estimate and visualize the search plan for the search operators and the operation coordinator and to allow to visually follow all the SAR operations. The proposed solution uses multiple detection stations equipped with a RDF to simultaneously acquire the direction of the distress radio request and then to estimate the source signal position by triangulation. The solution also includes some visualization features by which operators are provided with a Geographic(al) Information System (GIS) interface that graphically shows the searched vessel estimated position, the position of the search units and the search plan information.

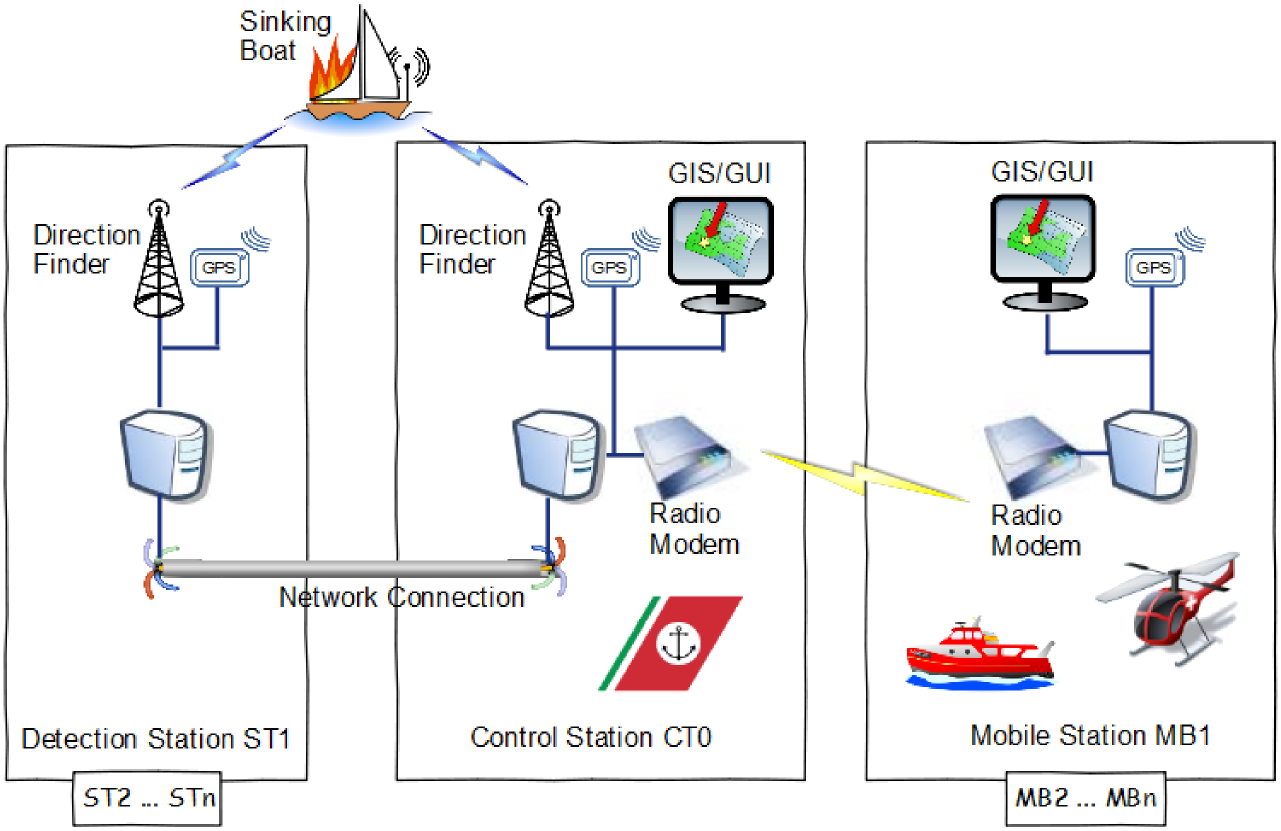


Fig. 4. Architecture of the system.

The same interface allows to interact with the system for configuration and control purpose.

In the next subsections the details of the developed solution will be presented starting by the analysis of the hardware components and then considering the software part.

A. System Devices and Technologies

The engineering of a distributed system as a solution to the above problem involves the design of hardware and software architectures. The hardware architecture will comprise all the needed devices to work in marine radio environment both for detection and communication. The hardware architecture of the system is shown in figure 4. The main components are:

- Detection Finder: listens to a fixed radio frequency to identify a source of a radio signal in any directions
- Global Positioning System: reads from satellites the position of itself and the current time
- Computer: hosts a component of the intelligent system which manages the devices used to localize the source of a radio signal
- Network Device: is used fro communication between stations. For mobile station a marine radio-modem is used while a router or switch is used to connect several network segments in the coast.

While the communication among coast stations is always wired, the communications among mobile units and coast stations are based on a wireless connection. The radio-modem used in the last cases operates on the radio marine frequency to send data at the fastest possible speed. Of course, the connection speed is affected by other communications but more significantly by the distance between communication points. The location of the stations is needed to compute the triangulation of detected signals. Therefore a Global Positioning System (GPS) is installed in every detection station. The GPS is connected to the computer which hosts the intelligent agents so that they can read the station coordinates and send them data about the radio signal.

Communications in this project are affected by the limits deriving from the use of marine radio systems famong coast stations and rescue boats. We decided to adopt a classical TCP/IP connection by Point-To-Point-Protocol (PPP) over radio-modems. The TCP protocol permits an easy communication among the agent platforms due to digital bridge created by PPP over a radio communication. Indeed, the stations on the coast are connected by an Intranet or Internet connection so that no communication problems should occur.

The used direction finders are the RT-300 made by Rho-Theta. They can receive radio signals on the marine VHF

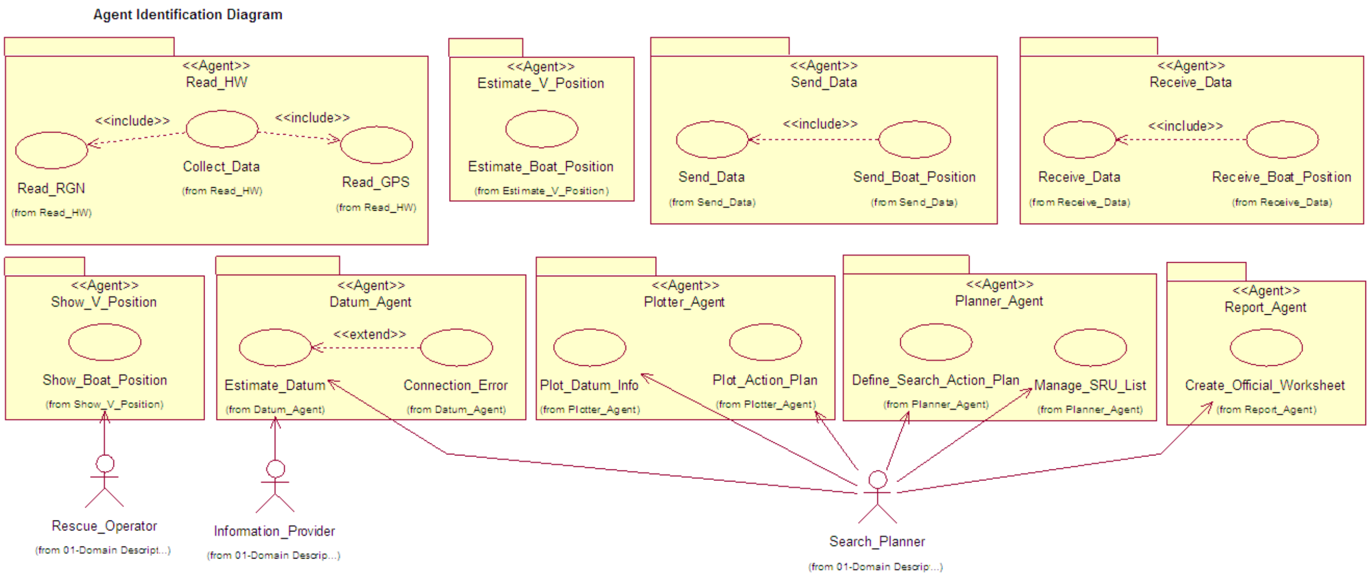


Fig. 5. Agent Identification Diagram of the designed system

band and they export the signal detections using the National Marine Electronics Association (NMEA) 0183 [2] compliant communications. Also the selected GPS receivers are NMEA compliant. They are marine GPS devices with 12 parallel receiving channels. The used radio modems are the Tait radio modems. They have a transmission power of 5W on the marine VHF band that allow communication boat-coast up to about 15 miles (radio horizon distance). For the on-board stations we used Panel PCs because of their water and solicitation resistance and the easy to use their touch-screen based interface. Other devices are standard office equipments as PCs and network devices.

To the software design and implementation we devoted the next two subsections.

B. The Multi Agent System

The software solution has been designed by using the PASSI design process (*see* [3]) and its evolution PASSI2 (*see* [4]). The multi-agent system has been implemented by using the JADE agent framework (*see* [8] and [9]) in Java language (*see* [7]).

Figure 5 shows the PASSI Agent Identification Diagram of the designed system. This diagram depicts agents in form of packages and their functionalities are reported as use cases.

The most important agents identified in the design process are:

- *Read_HW*: the agent collects data from a detection finder and GPS device connected to the station. The data read from devices is NMEA coded and each uses a different subset of the protocol. The devices are connected through a serial link to the computer that hosts the agent platform node. The serial line is used to query the device and to read the response. The agent collects the data and sends them to the agent 'Send_Data' (see below).
- *Send_Data*: this agent is designed to solve a project risk: the radio communication channel in some cases is not as fast as a wired one so a communication point which serialize data in very efficient way must be defined. This agent is needed because the slow communication channel should be used as little as possible. A message must be sent only to the agent that will use it. These problems are very important when the number of installed detection stations is high.
- *Receive_Data*: this agent is the receiving agent which is coupled with the agent 'Send_Data' described above.
- *Estimate_V_Position*: this agent collects the detected signals, stores them and finds any match inside to estimate the source of the radio signal. Of course the source of the signal is the position of the boat distress. The data is stored in a relational database system with logs of any event of the system.The search of the matches is implemented by a JADE cyclic behaviour which verifies any detection not marked and searches a compatible signal in different detection stations. Two signals are compatible if the radio channel is the same and the detection time is quite 'near'. When a match is found the agent searches another compatible match to verify if the estimated position is about a movement of the distress boat. The latter feature is the boat tracking one. So the agent understands if the estimated position is about a new detection or about a movement of a known boat.
- *Show_V_Position*: this agent is the nearest to the human user. The agent has a GUI with a GIS support to show the state of the system to the operator and to interact with her/him. The GUI shows a sea and coast map with the estimated position of the active boat distress. The agent collects the estimated position produced by the above

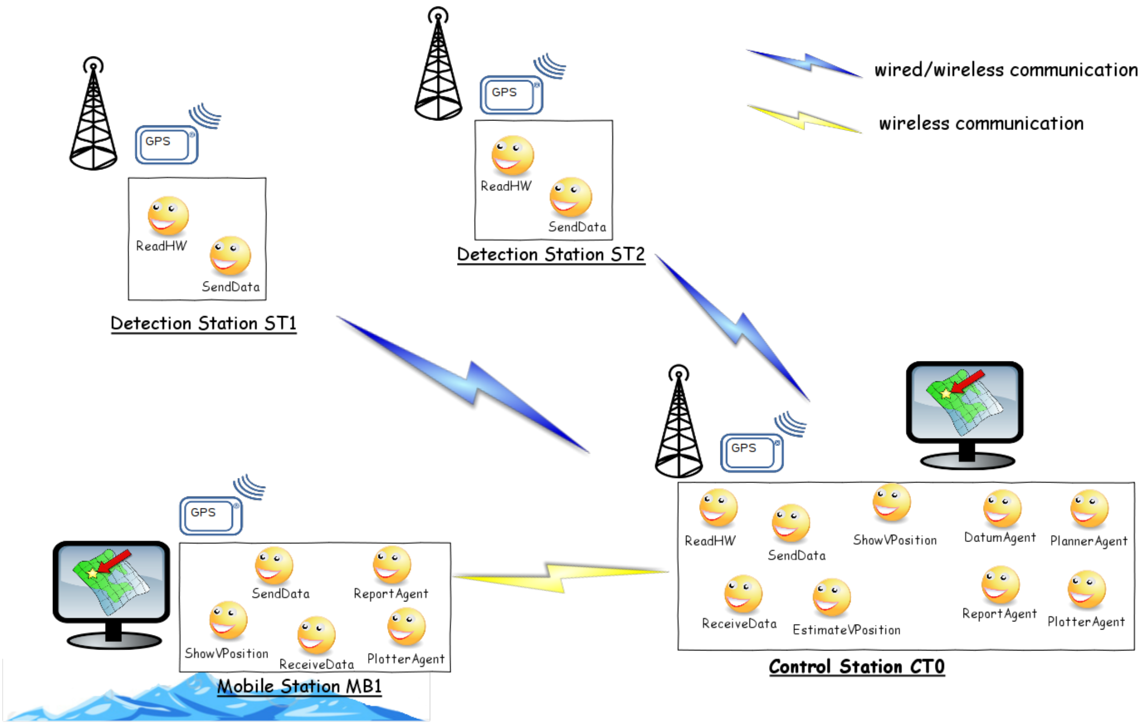


Fig. 6. A deployment of the agents in the system: each node is a JADE container connected to the *Main Container - Control Station CT0*

mentioned agent 'Estimate_V_Position' and permits to users to execute some operations as alarm validation and tracking.

- *Datum_Agent*: This agent is responsible for determining the datum for the search targets. It receives the estimated incident position (or last known position) from the agent Send_Data and starting from this information and other inputs about the scenario coming from Search_Planner and Information_Provider actors, it computes the drift forces by which the searched objects are affected. In this way the agent can provide to the Search_Planner an estimated datum of the search objects after the amount of time from time of distress to the commence search point. Main abilities of this agent are the acquisition of external information, management of points in WGS84 coordinates and vector calculus.
- *Planner_Agent*: This agent is responsible for providing a search action plan for the search objects starting from the datum estimated by the Datum_Agent. Once the datum is received, it defines the search area based on the facilities employed, environmental search conditions and probability calculation based on Monte Carlo Simulation. After that, it considers the area with the maximum probability of containment of the search objects that can be covered by the employed facilities and splits it in sub-areas to assign each of them to a SRU (Search and Rescue Unit). The agent is also responsible for determining the best coverage path for every SRU so to maximize the probability of success with the maximum search effort available. Another functionality provided by this agent is the management of the list of facilities available for the Cost Guard, with insert, update and remove functions of the facility. Main abilities of this agent are statistical and operational research computation, respectively for Monte Carlo Simulation and best coverage path algorithm.
- *Plotter_Agent*: This agent is responsible to plot the information relative to the datum and search action plan previously calculated by the relative agents. It makes use of an open source GIS library (OpenMap) **??** to overlay the relevant operation results on nautical charts in WGS84 coordinates.
- *Report_Agent*: This agent is responsible for producing the official papery worksheets defined in the IAMSAR manual. After a SAR mission is completed, and all data relative to the mission is known, it produces several PDF files that represent the previously cited documents.

The participating actors of the system are:

- *Rescue_Operator*: he is the actor that interacts with the localization subsystem. Any position about source of signal on emergency channels is notified to this actor which tries to communicate with that source for understanding what is going on.
- *Search_Planner*: Actor that represents the SAR mission coordinator (SMC) of the Coast Guard. (S)He interacts with the system typing the scenario information of the system and receiving the output results.
- *Information_Provider*: Actor that represents any external information provider useful for the scenario definition

and elaboration, like Web Services for weather condition, time-zone calculation, daylight/sunrise calculation, and so on.

The system is fully implemented in Jade. Some little parts are native libraries used to read and write through the serial ports. The object-oriented persistence is implemented by use of the framework Hibernate. The persistence framework permits to be independent from databases: the first implementation uses an installation of Apache Derby but future development is possible on more performant databases as MySQL or PostgreSQL.

The deployment of the agents is shown in figure 6. We can see that a mobile station has only agents useful to receive and show the active detections and to send requests about validation and tracking to nodes that perform the estimate of vessel position. A detection station in the coast may have or not the GIS platform that shows a map with detections. In every way an agent 'Show_V_Position' can be deployed in the node to add visualization features. This feature is an advantage of the agent-platform over service-oriented architectures because an agent can be created and can easily migrate to any node connected to the main container.

The mobile station receives the updated state of detections so that rescue operation will be more efficient. The operator on the rescue boat doesn't need to retrieve information about boat distress from main rescue station because the system does it for him.

C. User interfaces

The system is provided with a graphical user interface developed using Java Swing library. The main interface screen reports GIS data visualization. This is based on the open source GIS platform "OpenMap" that allows to easily visualize geographical coordinates for points, shapes or lines on a geographic map.

An example of such interface is reported in Figure 7. Here a "Sinking Boat" is shown by a red blinking point and a boat name. This name is initialized by the system with the Maritime Mobile Service Identity (MMSI) when the distress request is sent by a DSC/VHF or it is assigned by the system in case of voice communication, but the operator can modify it for a more friendly mnemonic name. Blue icons refer to search units. The shadowed area is referring to the boat datum, i.e. the search area. Other boats are represented by white icons. More information could be recalled on this page by the operator.

System SAR functionalities are grouped in three different tab-forms respectively for the estimate datum, search action plan and plot activities. This GUI was designed according to the guidelines of the domain specialist working with the Coast Guard. This collaboration reflects the choice to produce large forms with great vertical grow that contain the greatest information as possible, so to reduce input typing of information and different screen navigation, with consequently time-saving for the SMC. Figure 8 shows a fragment of the Estimate Datum tab where the user can input information about wind and water current and obtain the results both in textual and graphical representation.

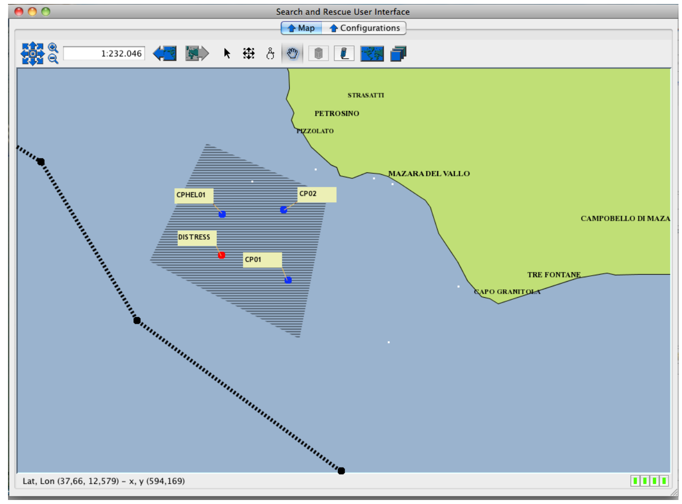


Fig. 7. A screenshot of the GIS interface.

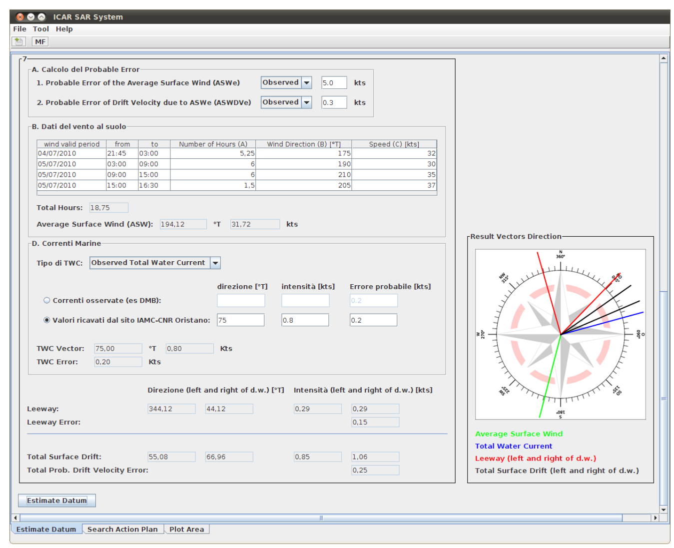


Fig. 8. A screenshot of the Estimate Datum form.

IV. Discussion

The problem we are studying is in our opinion a good example of ideal application context for multi-agent systems. This is due to the some specific requirements it has to fulfill: autonomy of components, scalability, distribution and openness.

- In the faced scenario specific problems may occur as an obvious consequence of the complexity descending from the distribution of a very large system. Each station should be autonomous and independent from other stations so that a failure in one station does not seriously affect the system functionalities. This fault tolerance is very important in a rescue system because a block of the system may cause an injury for people or things. Each system component should be able to resume its activity after a (system or communication) failure so that the collected data can be analyzed when the fault is resolved. This behavior is a feature that in a service-oriented architecture may create some problems. A service is always called by someone else: a service is a procedure that is executed when it is requested. A service is not autonomous: if it is not called then it doesn't start any action.

- Scalability permits a wide installation to cover large regions as well as a small initial deploy (what we are realizing within this project). The adoption of a MAS easily permits to scale the number of installed stations without any significant change to the system architecture.
- The easiness of agents distribution (together with their autonomous behavior) permits the installation in some of the stations of only a part of the system that is duplicated in some others. Upgrade of existing software components (necessary because of a bug fixing or a new release deploy) may be rapidly thanks to agents' mobility.
- Openess in another issue to be faced. The system is supposed to be in operation for a long period and it should be able to accept new functionalities by dynamically introducing new agents in the society. This is not only supposed to be done by the central authority but any local station should be able to start a local project delivering new agents that should smoothly enter the system. In order to fully support that, we rigorously applied some of the most advanced features of the PASSI process. Agents may depend on other agents for information or services. Such a dependency is never hard coded but it is dynamically realized on the basis of ontological specifications. Each agent registers on the system yellow pages the services and information it is able to provide. Agents in need of such services/information always look for their providers in the yellow pages and then directly contact them. PASSI fully supports that thanks to the specification of service/information exchange in the Domain Ontology Description and the Communication Ontology Diagram. When a new agent enters the community, it can offer new services or depend on existing ones. The system automatically accepts the change and the agents will consider the new service at the same level of the older ones. This will obviously imply an autonomous reorganization of the society behavior towards the achievement of the new goals.

In other words, the nature of the project and the environment where it is executed are good reasons to have a solution based on agent- oriented software. A primary advantage of this solution is the autonomy of the agents and their capacity to work in large cooperating environments. Agents' autonomy also contributes to solve the problem of fault tolerance: everywhen a fault happens the agents which are not involved or damaged continue to collect, send and compute data. Each agent executes a unit of work and, because of its autonomy, it decides any action to be executed on the occurrence of several events. The scalability is another intrinsic aspect obtained by the use of agent technology. The proposed system can grow to meet new requirements about land cover: to cover a new marine area it is just sufficient to install a new detection station manages by a new set of agents which collaborate with the existing agent-society.

V. Conclusions

Maritime search and rescue operations are critical missions involving personnel, boats, helicopters, aircrafts in a struggle against time often worsened by adversary sea and weather conditions. In such a context, telecommunication and information systems may play a crucial role sometimes concurring to successfully accomplish the mission. In this paper we present a complex system designed and developed to cope with these problems in a real application scenario. The hardware part of the system includes radio communication devices, GPS receivers and Radio Direction Finders (RDF). The software part is composed by a multi-agent system with demanding features like high distribution, scalability, openness, fault tolerance and high reliability. The system is to be deployed on rescue vehicles as well as on a land maritime stations of the Italian Coast Guard. The system is going to be tested in real SAR scenarios.

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References

[1] *IAMSAR Manual Volume II :Mission Co-Ordination 2007 Consolidated Edition*, 2007.
[2] *NMEA 0183 Standard*. National Marine Electronics Association, 7 Riggs Ave., Severna Park, MD 21146.
`http://www.nmea.org`
[3] M.Cossentino, *From Requirements to Code with the PASSI Methodology.* In Agent-Oriented Methodologies, B. Henderson-Sellers and P. Giorgini (Editors). Idea Group Inc., Hershey, PA, USA. 2005. 2008.
[4] M. Cossentino, V. Seidita. *PASSI 2 - Going Towards Maturity of the PASSI Process.* ICAR-CNR Technical Report 09-02. December 2009, 2008.
[5] BBN Technologies, *OpenMap: Open System Mapping Technology* (`http://www.openmap.org`), 2005.
[6] Metropolis, N.; Ulam, S., *The Monte Carlo Method*, 1949 - Journal of the American Statistical Association (American Statistical Association) 44 (247): 335341. doi:10.2307/2280232. PMID 18139350.
[7] James Gosling, Bill Joy, Guy Steele and Gilad Bracha. Java TM Language Specification, The 3rd Edition. Addison-Wesley Professional. 2005. ISBN 0321246780.
[8] F. Bellifemine, A. Poggi and G. Rimassa., *Developing multi-agent systems with JADE*, Seventh International Workshop on Agent Theories, Architectures, and Languages (ATAL-2000), Boston, MA, 2000.
[9] Fabio Bellifemine, Agostino Poggi, Giovanni Rimassa, *JADE - A FIPA-compliant agent framework*, Telecom Italia internal technical report. Part of this report has been also published in Proceedings of PAAM'99, London, April 1999, pp.97-108.
[10] *International Conference on Safety of Life at Sea, 1974*. Intergovernmental Maritime Consultative Organization. ISBN 9280110365, 1974.

[11] *Global Maritime Distress and Safety System (GMDSS)* - International Maritime Organization (IMO).
http://www.imo.org/About/mainframe.asp?topic_id=389

[12] *Digital selective-calling system for use in the maritime mobile service*. Recommendation International Telecommunication Union ITU-R M.493-13, techinical specification. 10-2009. http://www.gmdss.com.au/DSC%20tech%20spec.pdf.