

# Modular situational awareness for CLAWAR robots

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## Abstract

Field operational results have shown that two of the most important features needed by search and rescue robots and so that to be effectively used in such missions are modularity and situational awareness (SA); both are currently missing. Modular aspects are needed so that different branches of the rescue teams can easily and rapidly re-configure the robots for their own mission goals as well as to expand the use of the robot. The SA is needed as this will significantly improve the quality and effectiveness of the operational time. Field operation studies have shown that more than 50% of the deployment time is spent in the operator trying to identify the state of the robot [1, 2]. This paper focuses on identifying potential issues and inspirations for implementing an adaptive SA module able to cope with the characteristics of the operator as well as the robot and the initiation of a formal methodology for SA assessment. The first results of the authors' research in this area are presented.

**Keywords:** Situational awareness, human-robot interaction, search and rescue robots, semi-autonomous robots, modularity, SAGAT.

## 1 Introduction

The domain of search and rescue operations is an extremely risky, difficult and time constrained one. Mobile robots could be used for search and rescue (SAR) missions in which the risk is too high for a rescuer or to go into inaccessible areas. However, the current developed systems are still

far from being used in real scenarios and their research and development is still an open field. Operational results [3, 1, 2] have identified some fundamental drawbacks in the efficient use of SAR robots. Two of the most important ones are *modularity* and *situational awareness* (SA).

- Modularity is widely accepted as a desirable design concept because of its well known benefits of compatibility, re-usability, local scope of problem resolving, etc. The methodology has been proposed by the EU CLAWAR 1 and 2 Thematic Networks ([www.clawar.com](http://www.clawar.com)). Detailed discussions appear in previous work [4, 5].
- SA of a system in a broad context refers to the ability of determining the status and role of the “system” and its environment with respect to each other, and based on this understanding along with previous understandings and knowledge, make predictions about future actions and events.

This paper focuses on the latter drawback, that of SA, as it was shown that that more than 50% of the mission time is wasted in obtaining this [1, 2]. Related work and the concept of SA as well as methodologies for assessing it are discussed in detail in the rest of the paper.

## 2 Related work

A broad definition to SA of a system is *the ability of determining the status and role of each entity of the holistic system, and based on this understanding along with previous understandings (SA) and knowledge, make predictions about future events and actions.*

A well structured model of SA developed primarily for aircraft navigation and air traffic control operators but generic enough to be applicable to a number of domains is presented in [6]. According to this model, SA consists of three levels, namely perception, comprehension and projection. In the perception level (Level 1), the necessary cues are identified and perceived from the large volume of perceiving data. The comprehension level (Level 2) is concerned with the comprehension of the meaning of the Level 1 data. This is usually achieved through the formation of a mental model of the system, its environment and its current goals. In the projection level (Level 3) the system tries to predict the future status of the Level 2 elements. Based on this decomposition of SA a generic design process has been proposed. It consists of three phases; requirement analysis of the task, design on how the information should be presented in a

meaningful and consistent way and assessment of the system according to the SA. One such assessment method is the Situational Awareness Global Assessment Technique (SAGAT), proved to be successfully used [7] in the area of avionics. In frequent random intervals during the task execution, the task is paused and all display informations are blanked. The user is then asked to answer some questions related to what he/she is currently doing.

To the authors' knowledge there is only one study published which is focused on SA itself for search and rescue robots [3]. It was conducted during an urban search and rescue disaster response drill with teleoperated robots in Miami, US. The methods used included observation and videotaping of five robot operators, encoding their actions and verbal communications with other team members, analysing the data and assessing their SA according to independent raters. The conclusions from this study illustrate the poor SA of the operators as they spent more than half of the operational time trying to build it or maintain it. However, this study is operator-centric, ie the SA of only the operator is under investigation or in our context the holistic system consists of only the human operator. Our case though is both operator-centric as well as robot-centric. Although, the primary requirement is the operator's SA we believe that this cannot be improved without investigating the robot's SA too.

### **3 Methods**

The long term main objectives are to improve the SA of the holistic system and to reduce the time spent during an operation on determining this. The design process is inspired by Endsley's SA decomposition into three levels [6], the perception level, the comprehension level and the prediction level. For that to be realised we should firstly identify the mission goals and develop mental models for the operator(s), the robot(s) and the environment if appropriate. The high level mission goals are searching, identification of victims or clues leading to victims and safety of the system. Searching is primarily concerned with navigation of the robot in a confined area and consists of elements such as obstacle avoidance, localisation and mapping and percentage of area covered. Identification of victims includes determining if they are alive, their position and the route leading to them. Safety includes avoidance of hazards that can damage the robot as well as avoidance of triggering a further disaster. Mental

models realising the mission goals should be developed for the operator and the robot. It is expected that these mental models should be different from each other as the perception and comprehension levels for each entity are very different. The operator primarily relies on visual information from the camera to build a SA while for the robot this is a very difficult process. On the other hand the rest of the robot sensors can give it a SA which the operator may not be able to build. For example, a robot can perceive a potential hazard in front of it, such as a gap, which is out of the field of view of the camera and hence undetectable to the user.

In a sense there are individual SA for each of the entities. However, these are only parts of the overall picture. By communicating with each other they build the overall SA of the system. This raises two questions. *How* they are presented and *when*. The answers to these questions depend on the mental models of the entities.

In our case we are looking at the SA of the holistic system (operator, robot and environment). However, in these early experiments we are focusing on the operator's SA; more precisely we are investigating the:

- The quality of the SA of the operators.
- The efficiency of the operators when presented with unprocessed data.

The variables under investigation in the experiments are the time needed for an operator to cover a specified area, errors determined by independent observations in the operator's actions due to incomplete SA, analysing the statements of the operator during the trial and afterwards, analysing the operator's SA during the operation.

The analysis of these variables will provide a first indication for the above benchmarks to help us better understand how to design and implement the mental models of the entities, how to design and implement the presentation level, how to improve the current system and how to formulate the unprocessed data to meaningful information.

At these first stages the experiments are carried out on a simulator, and these are presented in this paper. The material is described in more detail in Section 4. An experimental trial consists of an initial briefing explaining the environment, the mission goals, the robot and its capabilities, the control interface and its capabilities and the procedure of the SAGAT method. The operators are videotaped and are informed that if they want to they can think loud, although they are not encouraged any further as this may distract them from the mission. After the mission is over the operators are asked to write down what according to their opinions might be helpful in improving their performance. This with conjunction

of the videotapes can provide some suggestions for further work, but by no means is it used as a metric as they are only subjective opinions.

The possible major goals which an operator can have in mind are searching an area, identifying a victim and evaluating his/her condition, rescuing a victim, concerns about the safety of the robot and the victims and returning to base (exit point).

Due to the robot setup and the missions goals, only searching, identification and return to base are realistic and these are the ones under investigation. For each one of them there is a set of questions. The questions regarding the searching of an area can be grouped in the analysis into localisation awareness (position and trajectory evaluation), time awareness (estimated time elapsed or estimated time needed to complete the mission), coverage awareness (how much area has been covered or can be covered in the remaining time), spatial awareness (if there are any obstacles), cue awareness (finding survivors).

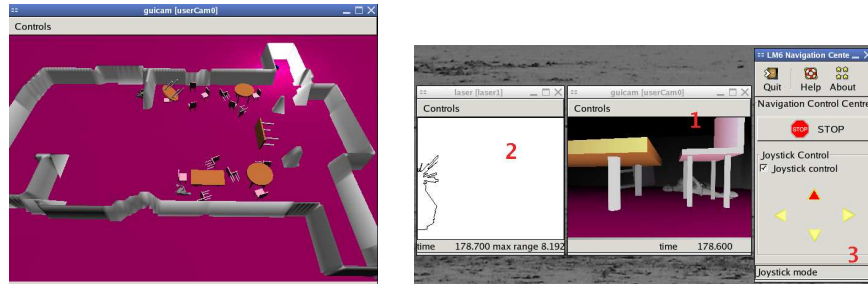
The identification of a victim goal can be analysed into victim recognition awareness (that a cue signify a victim), localisation awareness (position of the victim), and status awareness (health condition).

Lastly, the return to base goal is concerned with localisation awareness (position of the robot and planned trajectory to exit point evaluation), distance and time awareness (time needed to reach the base).

Some of these can be measured independently from the rest, for example spatial awareness in searching goal, while some are affected by the others. For example the (victim) localisation awareness in identification is affected by the (robot) localisation awareness of searching. Furthermore, some of them are used using averaging of all questions falling into the particular subcategory and some are measured in a Delphi evaluation where an expert is assessing them. The same procedure applies for the questions themselves. The overall operator awareness cannot be directly assessed as a sum of the different types of sub-awareness. This is wrong and deceptive because these types and their questions are not all necessarily measured using the same metrics. So each one had to be analysed individually.

## 4 Materials

Experiments were carried out in simulation, using the Player/Gazebo package as it provides a powerful 3D robot-environment simulator [8, 9]. The environment was the entrance hall of the School of Mechanical



**Fig. 1.** The virtual environment and the control interface

Engineering building at the University of Leeds. This was chosen as it provides a realistic office environment where a disaster can occur and can be modified according to the experiments requirements to match real world characteristics. During the first stages no ambient intelligence is assumed. A picture of the virtual environment lighted so that it is visible is shown in **Fig. 1**. In the experiments the range of view of the operator is about 4–5 meters. In the arena there are 2 victims both alive, but with one of them lying on the floor being unconscious. The simulated robot is an Activmedia Pioneer 2DX which moves forward, backward, turn on spot right and left with a constant speed of 0.2 m/sec. It carries a camera and a SICK LMS200 laser range finder. These characteristics were simulated because the load of the simulated robot is close to the “teleoperated camera on wheels” [1] used in the World Trade Centre robot SAR operations, with the significant difference that there the operators had no clue of the searched area and a map was also not available. **Fig. 1** shows the camera window with the timer (1), the range finder display (2) and the control interface (3). A simple paper drawing of the area served as a map to the user.

## 5 Results

A sample of 19 trials have been conducted. A trial consists of the actual simulation time and the SAGAT questions sessions time. **Table 1** shows the mean times for the overall trials, the simulator runs and the SAGAT stops. It is worth noting that the SAGAT stops, in which between 5 and 8 questions were asked, occupied approximately one third of the total time and it was found not to distract the operators, which is one of the

**Table 1.** Mean durations of the trials, simulator runs and the SAGAT stops

	<b>Mean</b>		<b>Mean</b>
Experiment	33:01 mins	Simulator	20:45
Successful runs	19:59 mins	SAGAT Stops	3 stops
SAGAT total	10:34 mins	SAGAT each	3:16

primary requirements for the success of the SAGAT method. As expected since most of the operational time is spent on searching, 52% of the stops involved questions regarding searching and navigating the area. 28% of the stops involved questions regarding the identification of a victim, 16% involved the return to base goal. The rest 4% were irrelevant.

The results have to be analysed individually according to the three goals under investigation. The quality of SA when the searching for victims goal is active is measured according to localisation, time, coverage, spatial and cue awareness.

Localisation awareness is assessed primarily with the accuracy of the position and the trajectory the robot has followed so far to the true ones using a 0–1 scale, with 1 being same as the true ones. The corresponding values for position and trajectory accuracy were 0.57 and 0.62. The spatial distribution was wide which means that when the operators were lost their approximations were far from the real ones. This was also the main reason for 75% of mission failures. Another factor that can influence the localisation awareness of the operator is the physical landmarks used. In twelve people that they were asked to identify their physical landmarks 3 of them used fixed landmarks such as the walls of the room, 5 used objects of the environment such as chairs and tables, while 4 used both types.

The time awareness was assessed by comparing the estimate time given from the operator to complete the mission with the actual time needed for finish. In 7% of the cases the operator could not even estimate the approximate time, 39% of the replies were significant underestimates, 26% were quite close to the real time and 28% of the cases were significant overestimates. The reasons for this low time awareness were poor localisation awareness and inadequate perception and comprehension of the existing data. For example in some cases the user only realised very late that he/she was running out of time.

Coverage awareness is evaluated through how much area has been searched so far. 16 out of the 19 people were asked and most of them more than once. In 19% of the responses the operators did not know how

much area they had covered, 27% of the responses were underestimates of the true searched area, 19% were overestimates and the rest 35% were approximately accurate. In total 65% were incorrect answers which is a very high percentage since the operators still had the paper version map in front of them helping them to calculate their estimate.

Spatial awareness was evaluated through questions about if there are obstacles within 3 metres and within 3–8 meters, which is approximately the range of the laser range finder. For close by obstacles the side which the obstacle lies was also asked. In the range of 0-3 metres 81% of the answers were correct with the rest 19% being wrong. In the range of 3-6 metres the wrong answers are doubled to 38% with 62% correct ones. The main reasons are improper or not at all use of the laser range finder, which can be further explained due to unfamiliarity with the sensor as well as the non user friendliness of the current display. For the range of 3–6 metres another reason that explains the increase of wrong answers is that the operators form zones of interest or priority with the highest being near the robot and slowly decaying the further away something lies. Although, this approach is common and helps in reacting to immediate situations it does not help to plan ahead. About spatial awareness, two operators out of the nineteen expressed ambiguity if they could fit through a gap. According to the evaluator's observations most of the operators had collisions with objects in particular on the sides of the robot. Two of the robot losses occurred due to a collision with an object leaving the robot incapable of moving.

Cue awareness was pretty straightforward as the only source of information for identifying if there is a victim nearby or not was the camera. However, in two different cases the operators missed to see the survivor from a distance of approximately 3 metres.

The goal of identifying a victim or if there is a cue that signifies a victim was also straightforward and simple since the victims were clearly "look like victims" and moreover there was only one sensor, the camera, capable of being used for this goal. For the victim localisation awareness out of the possible 38 victims in the 19 runs, 36 were discovered from which 19 were marked in their true positions. Obviously, victim localisation awareness is directly correlated with robot localisation awareness, and these results are expected to agree with the above ones presented. In the victims health status awareness the results for the lying on the floor unconscious victim are interesting since the expected answer is they cannot tell as their status cannot be evaluated with just a camera. However,

42% expressed an opinion on whether being dead or alive while the rest 58% suggested they need more information to answer.

In the return to base goal the results are also directly correlated to the robot localisation awareness. However, there is no indication of distance measurement and this is reflected on the answers to assessing the distance and time awareness, as 23% had no clue of estimating the distance since they did not know where they were, another 23% underestimated the distance to the exit point, while 38% of the replies were overestimates. Only an 8% was within the 4 metres difference limit. Similar results were obtained for the time awareness since most of the operators did not take into account the speed of the robot.

As presented in the beginning of the section the SAGAT method proved did not interfere with the subjects' awareness when resuming their simulator run. The only drawback was that the operators were helped after the first couple of stops in seeking particular information. However, the not so frequent and unexpected times of stop in conjunction with the randomness of questions was a counterbalance to this.

## 6 Conclusions

In this paper the results of some early experiments regarding the situational awareness (SA) of a teleoperator and its operator were presented. By using a virtual environment and a simulated robot with an overhead camera and laser range finder the operator is asked to search for survivors in an office environment area. This initial robot setup was chosen because this was approximately used in the search and rescue operations in the World Trade Centre. Although our aim is to evaluate the SA of the holistic system in these experiments only the operator's SA is under investigation. For this assessment the SAGAT method was used and proved to be a reliable in our case. The results have shown that there are significant problems in the operators' SA, mainly regarding localisation of the robot, efficiency of the search strategy, interpretation and correlation of the data provided, even in this simple case. These resulted in robot loss in many of our experiments.

Based on the conclusions and the experience gained from these tests we are aiming to improve the human-robot interaction interface and investigate if these additions in one dimension will increase the complexity of the system or can improve the SA and up to what extent. Furthermore, there are a few remarks on the current SAGAT methodology which need

to be improved as well as adapt to the new requirements of the new system. Our intention is to carry out these experiments both in simulation as well as a real robot platform in a more dynamic disaster environment.

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