Technology Enhanced Actual Situation Awareness Model for Dog-Handlers Working with Search and Rescue Dogs

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ABSTRACT

Rescue dogs are used in disaster response because of their ability to find victims using their excellent sense of smell, supported by dynamic decision-making skills. Disaster area environment is hazardous for both dogs and dog-handlers. Therefore, new technology is being developed to assist. In this article we argue that if new technologies are developed with the aim of making search and rescue missions in disaster zones safer and more successful, then there is a need to research how such technology can support communication between dog, handler, and incident command; in particular, how is shared situation awareness developed and supported. We present a model that scopes the interactions between human, dog, and technology together with advanced techniques for assessing those interactions through measurement of (shared) situation awareness and understanding. With such a wide range of potential technologies (such as VR, AR, 360-degree online video streaming, gas detecting sensors and special communication vests for dogs) having a clear view of how different parts of a team interact, and how to assess those interactions, is crucial. The use of technology (e.g. AR) is not limited to use in the implementation of search and rescue procedures, but can also be used in testing, and training for, other new technologies.

Keywords

Search and Rescue Dogs (SAR Dogs), Dog-Handlers, Quantitative Analysis of Situation Awareness (QASA), Technology Enhanced Actual Situation Awareness Model for Dog-Handlers working with Search and Rescue Dogs (TEASAM-DH & SAR Dogs)

INTRODUCTION

Every year man-made or natural disasters occur all-over the world. New technologies are constantly developed to improve the safety and effectiveness of first responders, while also saving the lives of victims. New technologies including virtual (and/or augmented) reality, robots and advanced sensors are being tested to replace dogs and humans operating in hostile environments (Sanfilippo & Rañó, 2023). Because dogs have long been established as excellent partners for first responders with the ability to operate autonomously while looking for victims in disaster areas, robots are usually built to mimic dogs' capabilities in the disaster area, such as the ability to move over rough terrain (Bellicoso et al., 2018). At the same time technology enhanced vests are designed to be used with rescue dogs and their handlers (Arnold et al., 2019; Kasnesis et al., 2022). New wearable devices are being developed that allow sensing, geolocation, and monitoring of the state-of-health of the search and rescue (SAR) dog. Such devices also support dog-handler communication, including sending commands to the dog (Contini & Martins, 2024). While such new technology has the potential to be of great benefit, it is important to conduct research to establish whether such benefits include, for example, improved situation awareness (SA) for first responders and incident commanders (Roldán et al., 2017).

Dogs, with roughly 40 times more smell-sensitive receptors than humans (Kumar, 2022), rely heavily on their sense of smell as their primary sense. Currently, no robots or sensors can match a dog's sense of smell. Unlike the human brain, which prioritizes a large visual cortex, the dog's brain is primarily dominated by an olfactory cortex (Correa, 2011). A dog has more than 100 million olfactory receptors in its nose (see Table 1), while humans have only 5 million (Padodara & Jacob, 2014). Dogs (and humans) also have a vomeronasal organ (also called Jacobson's organ) which is located above the palate and behind the upper incisors (Correa, 2011), that is particularly sensitive to pheromones. Dogs' sense of smell has led to them being trained for search and rescue missions (SAR missions), to search for victims in disasters or missing people around the world – and to detect for, amongst other things, narcotics, drugs and contraband agricultural products, homicide victims and forensic materials from corpses.

Table 1. Scent-Detecting Cells in Humans and Dog Breeds
(adopted from Padodara & Jacob, 2014 who reference Stanley and Sarah, 2013)

Species	Number of Scent Receptors
Humans	5 million
Dachshund	125 million
Fox Terrier	147 million
Beagle	225 million
German Shephard	225 million
Bloodhound	300 million

Urban search and rescue (USAR) teams are governed internationally by regulations published by INSARAG (International Search and Rescue Advisory Group). It is mandatory that all rescue teams include technical search units for the search and detection of victims under collapsed structures in earthquakes and other disasters. Currently, there is no more effective and efficient mechanism for searching for victims than trained dogs. These dogs are the main tool of the technical search teams of USAR groups. Given the current effectiveness of dogs within USAR teams, it is essential that any new technologies should be integrated appropriately, and the success of such integration assessed. We propose a model to support the development and integration of the technologies in such a way that the co-operation of dogs and their handlers improves and that, crucially, such improvement is manifest in (and can be assessed by) improved situation awareness.

We use a definition of situation awareness (SA) first proposed by Endsley (1995), that SA is the: "perception of the elements in the environment within a volume of time and space, comprehension of their meaning, and the projection of their status in the near future". In the event of a disaster, SAR dogs and their handlers (as well other first responders, inhabitants, and victims) need to quickly be aware of elements of the disaster such as the location (GPS coordinates) of SMS-warnings, sirens, drones, collapsed buildings, safe areas etc. Individuals and teams within the disaster zone then need to be able to integrate the available information to comprehend the situation and, at highest level of SA, to predict the most effective and safe activity in that situation. While technology has the potential to enhance SA at all levels and for all involved, it is crucial not to assume that the mere adoption of new technological tools will automatically bolster SA; thorough research is necessary. Additionally, it is important to emphasize that the implementation of any new technology requires the adjustment of standard operational procedures, and the training of both dog-handlers and dogs, to effectively integrate those new technologies.

MEASURING SITUATION AWARNESS

While the general concept of SA has become well established and researched in a number of domains, the use of simulation-based training scenarios as a method to improve SA has been the subject of relatively little research (Polikarpus et al., 2019, 2022). Nevertheless, Model-based Design is suggested for complex systems when real-time simulation are needed (Bélanger et al., 2010) and a Venn diagram is the world's most recognizable graphic approach to visualize and learn from similarity and matches (Koll et al., 2023). We combined our practical experiences of training SAR dogs and dog handlers using technology to measure SA into Technology Enhanced Actual Situation Awareness Model for Dog-Handlers presented as a Vienn-diagram below in the paper.

Endsley (Endsley, 2021) reviewed a number of methods for measuring SA one of which, Quantitative Analysis of Situation Awareness (QASA – although the attribution in Endsley's paper is incorrect) has the unique feature of being able to measure *negative* SA – indicating not only that somebody has no awareness of the situation, but that they also misunderstand it. In disaster situations, under heavy stress, such misunderstanding could easily happen to the extent that the dog-handler does not understand that his/her dog is threatened by the hazard from environment.

QASA measures both actual situation awareness (ASA) and actual situation understanding (ASU). See Table 2 for an overview of abbreviations and descriptions. ASA and ASU are rather novel terms used in recent projects, such as the FireFront project (Thoelen et al., 2020), compared to Endsley`s well cited SA definition. ASA refers to an awareness of the 'ground truth'. That is, the situation as it objectively really is. Good SA is, arguably, a necessary, but not sufficient, criterion for effective performance. An individual (or team) needs to not only be aware of the situation, but they also need to understand it - ASU.

QASA also measures *perceived* SA (PSA) and perceived SU (PSU). PSA/U refers to how good an individual *believes* their awareness/understanding of the situation to be. It is not guaranteed that ASA/U and PSA/U will necessarily match, and the cause of some catastrophic accidents can be traced back to a mismatch of ASA/U and PSA/U. It is therefore desirable to assess not only ASA and ASU, but also PSA and PSU. Good ASA can tell you that the technology is doing its job in delivering the necessary information, ASU can tell you whether the information is presented in such a way that the end user can understand it. PSA/U can tell you whether the individual has an *awareness* of their own performance level. Given the range and sophistication of the technique, we therefore propose the use of QASA (Edgar et al., 2018) to measure aspects of SA and SU while using The Collaborative Authoring Process Model for Virtual Simulations (CAPM) (Polikarpus et al., 2022) to assess the impact of new technologies on SA and SU, as shared across teams.

Table 2. Overview of abbreviations and descriptions

Abbreviations	Description	Reference
SA	Situation Awareness	Endsely, 1995
SU	Situation Understanding	Thoelen et al., 2020
PSA	Perceived Situation Awareness	Edgar et al., 2018
ASA	Actual Situation Awareness	Thoelen et al., 2020
ASU	Actual Situation Understanding	Thoelen et al., 2020
PSU	Perceived Situation Understanding	Thoelen et al., 2020
QASA	Quantitative Analysis of Situation Awareness	Edgar et al., 2018

MEASURING DOG-HANDLER COMMUNICATION AND DOG SITUATION AWARENESS

Dogs have been a part of human society for longer than any other domestic species (Benz-Schwarzburg et al., 2020), and they have a certain level of SA/U, although it may not be as sophisticated as that of humans. As discussed, SA/U involves understanding and interpreting what is happening in the environment, and dogs exhibit this ability in various ways. Research has shown that dogs are capable of assessing their surroundings, using their senses (including sight, hearing, and smell) to recognize familiar people and objects, and responding to changes in their environment (Benz-Schwarzburg et al., 2020).

The real bond between humans and dogs is marked by cohabitation in the same living space (Kuhne, 2016). Research has suggested that canine domestication has uniquely endowed dogs with two essential abilities for cooperative dog-human problem-solving: social tolerance and social attentiveness. These capabilities enable dogs to adapt their behavior to that of their human partners (Ostojić & Clayton, 2014). Collaboration necessitates such partners dedicating ample attention to one another to adapt or coordinate their actions. Additionally, social learning involves focusing on a demonstrator's actions and the context in which that action occurs (Huber et al., 2009).

In the case of human-dog interactions, the level of attentiveness is significantly influenced by the relationship between the dog and the human (Horn et al., 2013). Dogs have proven successful in several tasks that are thought to require high attention towards humans, as demonstrated by experiments on social learning, social reflecting, communication, responding to unequal rewards, and cooperation (Benz-Schwarzburg et al., 2020). Based on these processes, dogs make informed decisions about proper behavior (Huber, 2016). Studies have investigated the effects of training methods on the performance of working dogs e.g.(Alexander et al., 2011) while others have emphasized the role of the dog-handler relationship e.g. (Lefebvre et al., 2007). In their study, Lefebvre et al. (2007) noted that working dogs residing in their handler's household, and participating in sporting activities together, exhibited increased sociability, obedience, and efficiency. The bond between humans and canines was found to have a positive impact on the dog's focus on its handler, leading to improved communication and, in turn, heightened performance among working dogs. Figure 1. shows a SAR dog, alert and focused on its handler, patiently awaiting instructions. Further, Szetei et al., (2003) found that in their study that, when locating a hidden object, SAR dogs may favor human communicative signals, such as pointing, over olfactory information.

Figure 1. SAR dog waiting for instructions (Private photo Kristine Steen-Tveit)

While searching for possible victims the tasks of the dog could be described in the following steps:

1. **Searching** for scents in the area of interest;
2. **Detecting** the location of the first relevant odor particles in an area;
3. **Locating** the origin of the desired odor, or the place with the highest concentration of odor particles;
4. **Manifestating** the appropriate behaviour - the dog decides the area on which it will focus its attention and then manifests the appropriate behavior to demand the handler's attention.

The first three steps could be seen as closely related to situation awareness levels: the dog collects the (sensory) information from the area, comprehends the meaning (picking out the appropriate odour to indicate a person in distress), and then makes the correct response in summoning the handler.

In step four, fixation or manifestation, barking is the most used alerting behavior for dogs in disaster areas. Currently, the barking alert is essential in the process of searching for victims in collapsed structures, as there is no technological tool that is sufficiently precise and safe to replace the barking alert. When the dog finds the person, s/he must indicate the position of the victim to the handler either by remaining in the immediate vicinity of the person and barking until the handler arrives – or use his/her teeth to acquire the "bringsel" hanging from his/her collar. The dog then returns to the handler carrying the “bringsel” in the mouth (see Figure 2) (Hiljanen & Nordin, 2012) and, on receiving a specific command, will show the handler the location of the victim.

Figure 2. Dog with bringsel (Private photo: Kristine Steen-Tveit)

With the addition of GPS technology, however, the dog could “mark the victim” by sitting or lying down and, if the GPS indicates that the dog stays in position for more than 5 seconds, a signal would be sent to the dog-handler.

Another way in which technology could be utilized would be to develop technology that detects the dog’s activity and barking in real-time, and alerts the dog handler that the dog has found a victim, and where the dog (and victim) is located (Kasnesis et al., 2022).

Given that there is an appropriate behaviour for the dog at any particular point in the search process, we could measure dog and dog-handler ASA and ASU by measuring the dogs’ actual behavior against the optimum behavior (considered further below). More conventional measures could be used to measure handler ASA and ASU.

The dog handler stops a dog working via voice or whistle (vile) command, but this means that means that the dog must stay within earshot of the handler. Some GPS collars now have the capability to emit a sound or vibration initiated from the handler's GPS device, and which the dogs can be trained to interpret as a "find owner" signal. Currently, however, all the devices developed to locate dogs during a search are not viable to locate dogs during their work under rubble, since the devices lack reliability and safety. Research shows that if dog is more than 60 meters from handler the contact breaks (Contini & Martins, 2024). Therefore, still now if the dog locates a victim out of sight of the handler (under debris or in a hidden place), the only way to signal the discovery to the handler is by means of an audible signal (barking) or by means of a dog body signal (remaining in position such as sitting or lying or taking bringsel into mouth). If these dogs’ signals could be interpreted by a technical tool that then sends a warning signal to the dog-handler, it has a potential to speed up the search and rescue process and improve dog-handler ASA. For safety purposes, such technology need not be mounted on the dog. The dogs’ behaviours could be monitored remotely by networked drones or robots, potentially vastly increasing the ‘area coverage’ for any one handler and dog. In terms of SA, the 'perception' aspect of the handler is greatly increased.

If technology is to be successfully used with SAR dogs, then another crucial area of research is to study how dogs interact with that technology. The authors have noticed, for example, that dogs, without any training to interact with technology, will ignore everything on a television show - except animal shows. Such shows appear to draw the dog's attention and lead to the dog approaching the TV (see Figure 3). There is research that explores the ability of canines to interact with touchscreen interfaces in order to improve service dogs' communication with their handlers (Zeagler, Zuerndorfer, et al., 2016). Animal-computer interaction research has enhanced the creation of computer-aided systems that allow handlers and dogs to work together better while conducting SAR tasks (Zeagler, Byrne, et al., 2016).

Figure 3. Dog watching animal shows on TV (Private photo: Stella Polikarpus)

Extending the idea (discussed above) of using technology to simply detect a dog barking, there is research on using artificial intelligent (AI) to convert dog barks into English (Adamson, 2018) or to allow the dog to send signals using a worn vest in emergency situations (Kasnesis et al., 2022; Zeagler, Byrne, et al., 2016). Dogs have been trained to alert another human to a problem using a vest that includes a handy mechanical lever which, when pulled by the dog, plays an audio message such as: "My handler needs you to come with me!" (National Geographic Kids). AI can also be used to assess the behavior of dogs in a particular situation (Farhat et al., 2023) which, when compared with identified optimal behavior would provide a semi-automated, and real time, measure of ASA and ASU.

MEASURING THE ACTUAL SA OF HUMANS AND DOGS WITH THE HELP OF TECHNOLOGY

Technology mediated systems lend themselves well to knowledge-based measures of SA as there is often a clear, and recorded, path of information flow around members of the team (including IT systems). One such knowledge-based technique, as discussed above, is QASA (Edgar et al., 2018) that has been successfully used to assess ASA, PSA, ASU, and PSU in simulated safety critical situations (See table 2 for a reminder of descriptions). QASA is based on probing team members SA/SU (and this could include IT systems) using true/false (T/F) statements drawn from the situation, combined with an underlying analysis based around signal detection theory (SDT). While this approach works well for human and (potentially) IT elements of a team, the training overhead in getting dogs to respond to T/F probes is likely to be extreme. There are, however, performance-based measures of SA e.g. (Burge & Chaparro, 2012) or (Collier & Follesoe, 1995) that are also based around signal detection theory and so would dovetail well with QASA. These measures compare actual performance with optimum performance and could (in theory!) be readily adapted to assessing the performance of dogs (and hence their underlying SA/SU) in a safety critical context such as SAR.

If methods of assessing SA/U in a team can be developed then those methods could be used to assess the effect of introducing technologies such as smart phones, GPS positioning, 360^{o} camera streaming, advanced sensors, robots or drones, dog vests, artificial intelligent, machine learning, augmented reality, local data networks, radios, and much more. As the interactions of dogs and handlers are increasingly mediated by technology, the effectiveness of that technology can be assessed by measuring SA/U. Different technologies may impact different aspects of SA. For example, improved communication systems (between, dog, handler, and incident command) (Arnold et al., 2019) may improve SA. The use of VR and AR (for example by handler) for data fusion and presentation could potentially increase SU. Assessing such effects is vital. One thing that additional technology almost always brings is additional information (e.g. 360^{o} camera streaming is proposed instead of images processing (Arnold et al., 2019)). This could be an excellent support for SA (and SU) or it could overload the individual causing a loss of SA/U (a handler too busy trying to understand the camera output and missing a signal from the dog, for example). More is not always better.

The use of dogs in disaster areas raises traditional questions of ethics, such as whether dogs should be used in hazardous areas involving gas leaks, bombed buildings etc. Introducing technology, however, raises a whole new range of issues around such things as data protection, data transfer, and other cyber security issues. It is therefore necessary to scope the SAR task in terms of the elements (human, dog, technology) and the interactions between them. It would be helpful to have a simple model for crisis management research that embodies the areas of overlap between elements of a system and the different facets of SA (and SU) that are generated by those overlaps. Such a model allows the assessment of new technologies to be targeted and interpreted as a part of the 'big picture. In Figure 4. we propose a Technology Enhanced Actual Situation Awareness Model for Dog-Handlers working with SAR Dogs. For simplicity, at this stage, we have only scoped for SA (not SU, although the regions would be similar).

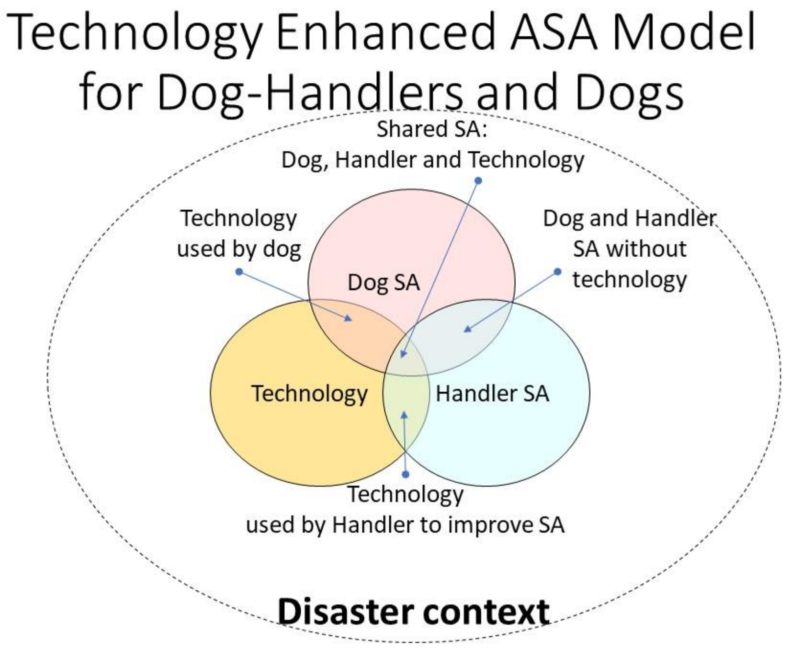

Figure 4. Technology Enhanced Actual Situation Awareness Model for Dog-Handlers working with Search and Rescue Dogs

In the model (Figure 4.) seven different areas can be identified; three discrete areas and four overlapping. The first discrete area is the dog with its unique set of characteristics, experiences and training that help it to make dynamic decisions in specific context. The second is the dog-handler who has same factors influencing his/her decision-making as dog but with additional factors and possibilities to gain situation awareness from command center. The third is the technology like 360-degree video streaming, GPS, communication, and observation technology as well as AI. Each element will develop its own awareness (SA) of the situation. For example, technology can have false positive alert in image recognition (Arnold et al., 2019). There are then three dual overlaps. The first dual overlap is the dog and handler, here belongs behaviours dog and handler use to communicate with each other, and standard operation procedures based on what dogs are certified. The second the dog and technology where most used have been vests with different technologies attached to it (GPS positioning, sensors, communication tools) but also dogs might learn to use specific technology themselves to communicate like touchscreens (Zeagler, Zuerndorfer, et al., 2016). The third component is the handler and technology, and dog handlers should be able to use all technological tools and information systems needed to gain "big picture" and follow standard operational procedures.

These overlaps will mediate the SA of each of the overlapping elements and, one would hope, improve SA rather than impair it. For example, introducing technological communication systems might improve the handler SA (they could receive information from other handlers, the 'big picture' from incident command, and so on). The last area in Figure 4. is a triple overlap between handler, dog, and technology and this is, effectively, where the 'shared SA' of the team (handler, dog, technology) resides. It is, perhaps, in this area where the disaster context specific technologies could have most impact on enhancing the effectiveness and safety of both dogs and handlers.

FROM CURRENT PRACTICES TO FUTURE STRATEGIES: ADVANCING CANINE TRAINING

Regardless of the type of SAR activities, canine training is extensive. Training programs are conducted in many countries worldwide, such as Germany, Japan, Australia, and Norway. Although the training processes in different countries often share similarities, different countries and regions may have specific protocols and standard operational procedures. Standards for the certification of SAR dogs also vary by certifying organization. The

National Association for search and rescue (NASAR) has, however, established voluntary qualification standards for, among other roles, disaster search (Jones et al., 2004).

The overarching goal of all training is to prepare the dogs and their handlers for effective SAR operations in different disaster contexts. The canine training process is a rigorous process that requires dedication, time, and specialized skills and includes obedience training, scent discrimination, search techniques, trailing, and avalanche/disaster training. The foundation of SAR dog training is socialization. Dogs are frequently brought out into public settings to get as accustomed to a wide range of situations and people as possible. Since leash control is crucial in SAR, obedience, and the capacity to obey directed instructions are also crucial. For dogs that are trained to search in both urban and wilderness settings, athleticism and agility are essential. Dogs are taught to move boldly, but cautiously, over surfaces that they would normally avoid. Urban SAR canines train extensively on debris, which might include broken concrete, old cars, uneven terrain, chain link fences, and rebar. Urban search and rescue dogs are required to climb ladders, negotiate tunnels, and rappel with their handler (see photos in Figure 5.). As opposed to patrol dogs, aggression towards humans or other animals is not tolerated in SAR dogs (Jones et al., 2004).

The future of SAR canine training is likely to see a significant integration of technology to enhance the safety of both the dogs and their handlers, as well as to improve SA. Examples can be smart vests for dogs equipped with sensors that can provide real-time data on the dog's position, vital signs, temperature, and overall well-being (Contini & Martins, 2024; Kasnesis et al., 2022). Exploring ways to enhance communication between SAR dogs and their handlers through technology could improve the efficiency and effectiveness of search operations. Integrating technologies into canine training requires a balance between innovation and reliability and a means of assessing whether inclusion of that technology has been beneficial. It has been already observed in the research that new training requirements must be developed to integrate effectively technologies to be used by service dogs (Zeagler, Zuerndorfer, et al., 2016). Additionally, considerations for ethical and humane treatment of the dogs, as well as the need for adaptability in various operational contexts, will be essential in shaping the future of SAR dog training.

Figure 5. Urban SAR dog training. (Private photo: Marita Poulsen)

CONCLUSION

It is important that the context and characteristics of dogs and their handlers are taken into account when new technologies are introduced with the aim of improving ASA and, by extension, dogs and handlers' safety, communication, performance, standard operating procedures, ease of standardization etc. Improved performance of the team means being better able to assist victims in different disaster areas. The proposed Technology Enhanced Actual Situation Awareness Model for Dog-Handlers working with SAR Dogs is provided as a way of scoping out the interactions and issues inherent in any complex team; and a team involving humans, dogs, and new technology, is likely to be complex. The approach in this paper proposes the model as a way of scoping those complex interactions, combined with advanced techniques for measuring SA/U to assess the impact (both good and bad) of such interactions. Such assessment will necessarily involve possibly disparate communities such as technology developers, researchers, and practitioners. The overall aim is, however, to further improve the effectiveness of SAR dogs through the use of technology, and the ISCRAM community has all the competencies needed to achieve this.

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