Robot-Dog – Human Interaction in Urban Search and Rescue Scenarios

Improving the Efficiency of Rescue Teams in Hazardous Environments

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Keywords: Robot-Dog – Human Interaction, Autonomous Robot, Cognitive Systems, Improving Efficiency of Search and Rescue Teams, Trained Dogs.

Abstract: After a natural urban disaster the interior of the rubble is often where the majority of victims are located. Mortality rates increases and peaks after 48 hours, so it is of major importance to have fast and effective search and rescue teams. Nowadays, the rescue and exploration teams normally use dogs as a companion to find victims. Trained dogs are very helpful in these situations since their high mobility, speed and detection capacity. However they need constant instructions and supervision, they can be in danger in some situations and they are not able to collect precise data from the environment. Instead of trying to build competing devices, the COMPANIONS project looks at cooperation between natural and artificial creatures and in particular robots and dogs. This is rather new ground for research, where all the dog shortcomings can be complemented with autonomous robots with cognitive abilities able to cooperate with dogs and humans in search and rescue environments. The aim of the project is to analyse how a team of agents (robots-dogs-humans in this case) can cooperate and interact during search and rescue. Research will be towards a new rescue scenario composed that will allow: (i) to empower the best characteristics of all the involved agents and to minimize the worst ones; (ii) provide the fundamental tools for enabling these three agents to work in a cooperative and efficient way in rescue missions; and (iii) and to lengthen the human-dog link by allowing the exploration combining mobile robots and trained dogs with more distant and safer human intervention in the dangerous rescue scenes. The main challenge will be the dog-robot interaction: to give visual cognitive and reasoning abilities to the robot in order to let him autonomously interact and cooperate with the dog according its behaviour and the environment conditions; and to specifically train a dog to correctly accept and interact the robot (in charge of an expert dog training company).

1 INTRODUCTION

After a tsunami, and earthquake, or any big World urban disaster only a small fraction of victims may actually survive. The majority of survivors (80%) are surface victims and only 20% of them come from interior of the rubble. The interior is often where the majority of victims are located and mortality rates increases and peaks after 48 hours, meaning that survivors who are not extricated in this first period of time are unlikely to survive beyond a few weeks in the hospital.

Nowadays the rescue and exploration teams normally use dogs as a companion mainly to find hidden injured persons or victims. Trained dogs are very helpful in these situations because of their high mobility, speed and detection capacity. However they need constant directions and supervision provided by the rescue team members, they can be in danger in some situations (e.g. if there are high levels of undetected lethal gases) and they are not able to collect precise data from the environment. All these shortcomings can be complemented with autonomous (or semi-autonomous) robots with cognitive abilities able to work in dynamic, non-deterministic rescue and exploration environments. Robots have a high sensorial capacity, can collect and interpret very precise data and can operate in hazardous zones in an autonomous way.

We propose a new rescue approach composed by a robot-dog-human team that will allow: (i) to maximize the favourable characteristics of all the

Bosch A., Cufi X., Ll. De la Rosa J. and Figueras A..
Robot-Dog – Human Interaction in Urban Search and Rescue Scenarios - Improving the Efficiency of Rescue Teams in Hazardous Environments.
DOI: 10.5220/0004117403660371
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2012), pages 366-371
ISBN: 978-989-8565-22-8

involved agents in the triangle formed by humans, dogs and robots, and to minimize the adverse ones; (ii) provide the basics of these three agents to work in a cooperative and efficient way in rescue missions; and (iii) and to enlarge the human-dog link by allowing the exploration using mobile robots, Canine Augmentative Technology (CAT) systems and trained dogs limiting the human supervision. Moreover there might be some daily situations where not all the three agents are needed so the three agents and the system developed should be able to work independently.

The human-dog and the human-robot links have been studied for years and are well documented in the literature. However, and to our knowledge, it is the first time that it is attempted to study the interaction and cooperation between robot-dog through an autonomous robot with cognitive capabilities.

1.1 Improving the Performance of Heterogeneous Search and Rescue Teams

The goal of the project is to improve the performance of trained Urban Search and Rescue (USAR) canine teams. Note that the goal is to improve the performance of the team as a whole. This means that the performance of the humans must be improved as the dog actually does very well on their own. A dog moves through the rubble, detects people and indicates where they are. Problems occur when the handler cannot go where it goes and therefore does not experience what the dog experiences. This is where the cooperation with rescue robots can be very helpful. The cooperation and interaction of dogs-robots-humans in a USAR scenario will have several advantages:

- A camera is normally used over the dog to allow the human team to see what the dog is looking at; however a camera over the robot could bring new functionalities. It will allow the human team (i) to see what the dog is doing, (ii) to have more control over the whole rescue scene, (iii) to interact with the dog if he/her gets distracted or needs more directions, and (iv) to interact with the victim.
- The visual information fused with the sensor data interpretation will allow building a much more precise situational awareness map.
- Mobility of dogs surpasses any robot mobility (on rubble etc.) however a dog can work for a very small period of time while a robot could remain at the scene considerably longer.
- The space over the dog is limited and they might be heavy sensors. A robot could bring to the team multiple sensors that enhance the search of the dog.

There are several works that showed that dogs are not indifferent to robots (Lawson, 2005), so with the proper training of dogs together with the right motivation trough rewards, a successful interaction and cooperation with robots is possible in the opinion of the experts in Dog training (f.i. K9Dogs Europe).

Concretely three agents are considered (i) a robot called Link robot from now on; (ii) a trained dog; and (iii) a human team. Brief descriptions of the agents involved in the team and how they will cooperate are as explained in section 2.

1.2 Specific Objectives

Dog Training and Interaction. Select and train a dog for rescue situations. Train the dog for its interaction with the robot(s). Study the best way for a successful robot-dog communication. Build some mock-ups for the Link robot so the training team can analyse different solutions and configurations and the dog can get used to it.

Agents Sensorization for the New Rescue Scenario. Improve the limitations of the actual Canine Augmentative Technology (CAT) systems by studying a better distribution of sensors over the dog. Investigate the best way to sensorize all agents, dog and robot(s), and combine their sensors.

Give Visual Cognitive Capabilities to the Link Robot. Localize and track the dog and recognize its poses and actions. Dogs communicate through innate responses and through learned signals. Much can be learned about a dog's state simply by observing its body position and activity. Dogs have a complex set of behaviours related to their social position relative to other dogs and their physical, as well as mental states. However, dogs can also learn to communicate through barking and pose which makes them ideal for USAR work as they can roughly "tell" the handler what is going on when they find something. Moreover the visual scene interpretation could be used to build a situational awareness map for the human team.

Build a Collaborative Map of the Environment. Use different sensors (visual data, IR information, sensor information) from the CAT System, and Link robot to build a multi-layer map useful to have complete information of the environment from different sources. Give visual reasoning abilities for a better understanding of the environment.

Give Autonomous Capabilities to the Link Robot. Use ontologies, previous experiences and the actual situation to give autonomy and decision making to the Link robot. Design and develop cooperative navigation and decision making according to the information of all the agents (Link robot, dog and humans).

Extend the Human-dog link by using the Link Robot. Provide the communication tools and interfaces so that the human team can control the scene through the devices mounted over the robot(s) and over the dog.

To Improve Performance, Safety and Efficiency in Rescue Situations. The cooperation of the three agents will improve on (i) performance, each agent will use its best abilities in rescue situations; (ii) safety, the robots will be equipped with dedicated sensors to capture the rescue environment and alert the dog and the humans in case of danger; (iii) efficiency, the human team will be able to supervise at the distance, having a global idea of the situation so allowing them to act more efficiently.

For the moment the objectives are limited to the interaction of one dog with one Link robot and one handler. The cognitive issues for handling crew of several dogs, several Link robots, and several handlers in complex rescue scenarios are out of the scope of this initial proposal and are part of the roadmap towards a full integration of crew intelligence with dogs and robots presumably affordable from 2020.

2 AGENTS OF THE NEW USAR SCENARIO

2.1 The Link Robot

Vision cameras will be set on it to observe and follow the dog and see what he/she is doing and to give cognitive visual capabilities to the robot (dog poses interpretation visual scene interpretation, etc.). Moreover a laser will be used to point and show to the dog where he/she has to look for (as humans do nowadays) and it will carry a reward for the dog if he/she finds a victim. It will be sensorized with a screen, a camera and audio devices used to communicate the human team with the victim and with the dog, so used to enlarge the link with the human team. It will carry much more sensors to have a more complete map of the environment: vision cameras, IR cameras, 360º cameras for visual mapping; thermal and gases sensors will be put over it so data analysis of them will be used to alert the dog if a dangerous situation is detected (e.g. of presence high level of lethal gases previously undetected by humans). A visual map with the merging and interpretation (high level reasoning) of all the sensor information (vision and data) will be build and send to the human team for their awareness and supervision. This robot will work autonomously in two ways: by following and interacting with the dog and by exploring the scene itself. Moreover humans can remotely control it if necessary.

2.2 Trained Dog

A trained dog will be sensorized with Canine Augmentation Technology (camera, audio and wireless sent to the human team through the Link). It will interact with the Link robot by: following orders given by the human team, by searching where the link robot is pointing, by obtaining a reward, by making certain poses when a situation is done (e.g. find a victim) so the Link robot can understand it. A specific training of the Dog in order to be able the interaction and cooperation with the robots will be absolutely necessary.

2.3 Human Team

We will refer to the human team as the team on the command area or control zone. They will have access to the vision cameras (dog, link) to the audio systems (dog, link), all this information will be sent through the Link. It will have access to the map that the Link robot will build using the link robot sensors (visual, thermal and gases) and dog sensors (visual). It will be able to see and speak with the victims trough the Link robot (victims will be able to see and speak with the human team). They will be able to manually operate the Link and to speak and give direction to the Dog through the Link.

Figure 1 shows the base of operations layout defined by the International Search and Rescue Advisory Group (INSARAG) with the new areas and agents that will be introduced in our proposal. INSARAG is a network of disaster-prone and disaster-responding countries and organizations dedicated to urban search and rescue (USAR) and operational field coordination. Of special interest is the Control zone that will be “improved” by giving them more control on the rescue zone and a new area to leave the robots.

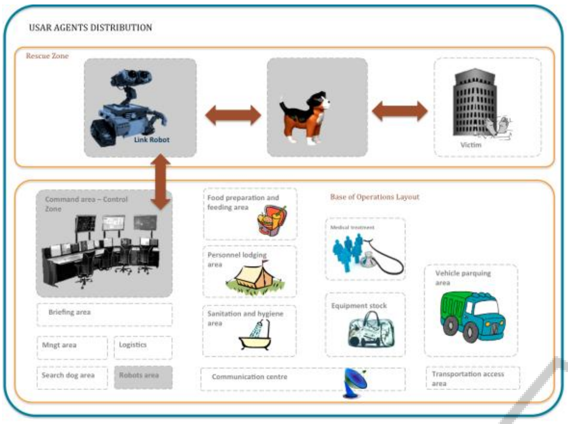

Figure 1: Base of Operations Layout defined in the INSARAG Guidelines. Grey boxes indicate the new areas and agents to be introduced.

3 TESTING SCENARIOS

To better understand the proposed research, we have defined two scenarios, but more could be considered during the development of this research:

Scenario 1 – Dog Searching. Dog and Link are in the rescue zone, where the dog uses its abilities to search victims and the Link follows him/her while capturing data from the environment (visual and sensors) interpreting the data and building a visual map. This map and all the camera images of the dog and the Link are sent to the control zone where are analysed by the human team. The dog finds a victim and acts with the pose of "victim found", so the Link interprets it using its cognitive visual capabilities and rewards the dog. Link turns the screen on so the victim can see and communicate with the human team, and some first aid pack is given to the victim. The human team can also talk to the dog to provide it oral and visual positive feedback. The map is updated with the location of the victim and some data interpretation (e.g. some gases detection and their degree of dangerous). The human team sends further assistance to the victim.

Scenario 2 – Link Guiding. The Link points with a laser where the Dog should go and search and they both go there. The dog finds a void where he/she cannot go in but the presence of a victim is detected, so he acts with the pose "victim in the void". The Link recognizes the poses and alerts the human team. The Link detects some gases that could be dangerous, so updates the map that is sent to the human control. Since gases could be dangerous for the dog, Link robot alerts the dog and they both leave for further exploration. The human team can send assistance to the victim taking into account all the information collected by the system (f.i. presence of dangerous gases).

To achieve the generic intervention scenarios presented above, it is necessary to advance in the state of the art as it is explained in next section.

4 PROGRESS BEYOND THE STATE OF THE ART

In the conventional search and rescue scenarios the search team is composed by humans and trained dogs. Recently, robots that are able to communicate with humans are introduced in these scenarios, however to the best of our knowledge there is still a missing link: the dog-robot interaction, cooperation and communication.

Within this research we propose to advance in the state-of-the-art by providing cognitive abilities to the robots so that they will be able to communicate and cooperate with trained search and rescue dogs in rescue context. Moreover the basis of the dog behaviour for a correct communication with the dog will have to be studied and researched. The new proposed scenarios will have the three agents mentioned above: dog, robot and humans where they cooperate together. We will take into account all of them in this research however special emphasis will be given on the cognitive abilities for the Link robot and the dog training for their cooperation.

This new workflow will require improvements beyond the state-of-the-art on the fields of: dog training, dog-robot interaction, dog sensorization, dog localization and tracking, pose and action recognition, scene understanding and object recognition, data capture form the environment and data fusion, high level reasoning and network communications for sharing data between all the agents. The advances in the technologies mentioned will enable a new research workflow as proposed in Figure 2

There have been other projects related to different aspects of rescue robotics (GUARDIANS, VIEWFINDER, NIFTI) but none of them considers the animal-robot interaction, one of the key objectives of this proposal. Regarding the Animal-Robot Interaction we can find in the literature several papers where a general interaction animal robot has been attempted (Gribovskiy, 2010), (Caprari, 2005), (Nanayakkara, 2008) and there are several things to take into account for a correct interaction between an animal (a dog in our case)

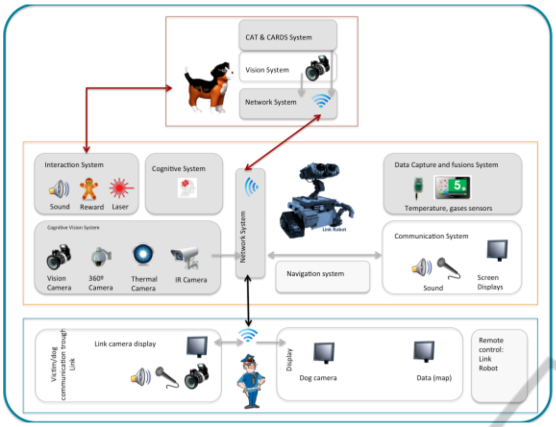

Figure 2: Research areas; Dark grey boxes: strong research; Soft grey boxes: integration; White boxes: sensorization.

and a robot (Kim, 2009):

- The developer should have a full knowledge of animal's behaviours and emotions to make robot understand animal's needs well for natural interaction with the animal.
- Robot should know the state of animal and provide the service to animal by itself, as most of animals do not know how to request a service to robot.
- The animal may have fear of the robot because the robot is a noisy creature, which has never been seen before. The shape and texture of robot need to be familiar with animal to reduce the fear.
- The noise of the robot may astonish animal and it would be a great difficulty for the robot to be familiar with animal.
- As the sudden movement of robot may also scare pet, robot behaviours should be well designed considering the animal ethology.

Moreover in previous cited research works the robots have very few (if any) cognitive ability that gives them the ability to autonomously reason and interact with the animal.

In respect to Dog Sensorization, the Ryerson University team started to develop Canine Augmentation Technology (CAT) (Ferworn, 2008), (Ferworn, 2009). The CAT system currently consists of side-mounted, armoured, low-light cameras with on-dog recording and the potential of real-time transmission of video, audio and telemetry information. The notion of dropping items from USAR dogs was devised by one of the Patent holders of the Ryerson University Canine Remote Deployment System (CRDS)-Kevin Barnum who was a canine handler with the Ontario Provincial Police at the time. The CRDS was modified with a different kind of underdog designed around the idea of a discarding "sabot" that holds a robot against a dog's chest. This system is known as Canine Automatic Robot Deployment System (CARDS) (Tran, 2010). They have demonstrated various robots being deployed including their own Drop and Explore robot (DEX). In addition, CARDS relies on the ability to detect and interpret canine barking in order to drop a robot (the system detects and interprets a dog's barking). Of course CAT and CARDS systems represent a very interesting starting point of our research in this field. Moreover one of the challenges we will face is that the useable space on a dog is limited and variable. As such, some of this research effort will be spent on reconfiguring the CAT and CARDS systems to better distribute sensors between the different involved agents (robots).

It will absolutely necessary to recognize pose and action recognition for the trained dog. We will recognize static poses (such as "sitting down") and dynamic poses (such as "searching"). Assuming the dog is well localized, recognized and tracked we will first distinguish body parts and characterize those using spatio-temporal features and template/shape based features. A discriminative learning classifier will be learned. Moreover since the robot can see the pose from different point of view, 3D models will be learned obtaining just 1 model for each pose or action. 3D spatio-temporal models for pose and action recognition will be studied. The scene context will also be incorporated for a better action recognition and understanding and to help disambiguate similar poses and actions.

Finally a collaborative and enriched 3D map of the environment will be built, benefiting from the information provided by the different image modalities and data sensors.

5 PROJECT STARTING POINT

The starting point of the idea presented in this position paper is the work developed in the framework of the Spanish national project "SAN BERNARDO" funded by the "Ministerio de Educación y Ciencia" that finished on 2010. The aim of the project was to conduct research into control and interactional architectures to carry out robot cooperation tasks, whose purpose was to locate and help people missed in emergency situations. In the first step, these robots were used to locate survivors and transmit their location to rescue services through wireless devices (to locate and communicate with the rescue teams), and to render first aid kits to these survivors. We proposed the research into awareness in robots about their capabilities to perform tasks entrusted to them, in order to ensure good performance and cooperation functionalities in a heterogeneous team of robots. In Figure 3 we show this team of heterogeneous robots previously developed for rescue scenarios. It includes: (i) SmallBot. Its reduced size, small weight and high speed (1m/s) do this robot easily transportable and ideal for the first exploration after a catastrophe. (ii) BigBot with a weight approx. 11kg that allows it to evolve in more difficult lands and to avoid obstacles up to 25cm. (iii) WaterBot is a robot thought to operate in specific complicated lands with puddles.

Figure 3: Heterogeneous Robotic Team (Project SAN BERNARDO). Spanish Research Agency.

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