Integration of a Canine Agent in a Wireless Sensor Network for Information Gathering in Search and Rescue Missions

J.J. Fernández-Lozano[1], A. Mandow[1], M. Martín-Guzmán[1], J. Martín-Ávila[1], J. Serón[1], J.L. Martínez[1], J.A. Gomez-Ruiz[1], C. Socarras-Bertiz[2], J. Miranda-Páez[3], A. García-Cerezo[1]

[1]Universidad de Málaga, Robotics and Mechatronics Lab, Andalucía Tech, 29071 Málaga, Spain.
[2]Universidad de La Guajira, Riohacha, Colombia.
[3]Universidad de Málaga, Cátedra de Seguridad, Emergencias y Catástrofes, 29071 Málaga, Spain.

Abstract—Search and rescue operations in the context of emergency response to human or natural disasters have the major goal of finding potential victims in the shortest possible time. Multi-agent teams, which can include specialized human respondents, robots and canine units, complement the strengths and weaknesses of each agent, like all-terrain mobility or capability to locate human beings. However, efficient coordination of heterogeneous agents requires specific means to locate the agents, and to provide them with the information they require to complete their mission. The major contribution of this work is an application of Wireless Sensor Networks (WSN) to gather information from a multi-agent team and to make it available to the rest of the agents while keeping coverage. In particular, a canine agent has been equipped with a mobile node installed on a harness, providing information about the dog's location as well as gas levels. The configuration of the mobile node allows for flexible arrangement of the system, being able to integrate static as well as mobile nodes. The gathered information is available at an external database, so that the rest of the agents and the control center can use it in real time. The proposed scheme has been tested in realistic scenarios during search and rescue exercises.

Citation information

J.J. Fernández-Lozano, A. Mandow, M. Martín-Guzmán, J. Martín-Ávila, J. Serón, J.L. Martínez, J.A. Gomez-Ruiz, C. Socarras-Bertiz, J. Miranda-Páez, A. García-Cerezo. "Integration of a Canine Agent in a Wireless Sensor Network for Information Gathering in Search and Rescue Missions". Proceedings of the Conference on Intelligent Robots and Systems, IROS 2018.

Integration of a Canine Agent in a Wireless Sensor Network for Information Gathering in Search and Rescue Missions*

J.J. Fernández-Lozano[1], A. Mandow[1], M. Martín-Guzmán[1], J. Martín-Ávila[1], J. Serón[1], J.L. Martínez[1], J.A. Gomez-Ruiz[1], C. Socarras-Bertiz[2], J. Miranda-Páez[3], A. García-Cerezo[1]

Abstract— **Search and rescue operations in the context of emergency response to human or natural disasters have the major goal of finding potential victims in the shortest possible time. Multi-agent teams, which can include specialized human respondents, robots and canine units, complement the strengths and weaknesses of each agent, like all-terrain mobility or capability to locate human beings. However, efficient coordination of heterogeneous agents requires specific means to locate the agents, and to provide them with the information they require to complete their mission. The major contribution of this work is an application of Wireless Sensor Networks (WSN) to gather information from a multi-agent team and to make it available to the rest of the agents while keeping coverage. In particular, a canine agent has been equipped with a mobile node installed on a harness, providing information about the dog's location as well as gas levels. The configuration of the mobile node allows for flexible arrangement of the system, being able to integrate static as well as mobile nodes. The gathered information is available at an external database, so that the rest of the agents and the control center can use it in real time. The proposed scheme has been tested in realistic scenarios during search and rescue exercises.**

I. Introduction

Wireless sensor networks (WSN) allow for a variety of applications, such as logistics, traceability, urban traffic management or emergency and rescue operations [1]. In particular, the combination of mobile nodes with static sensor networks can be very useful in search and rescue operations [2] [3] [4] [5] [6], as they provide a means to gather and share relevant and up-to-date information about the disaster site from different agents in heterogeneous teams.

Canine units are already an essential part of the Search and Rescue (SAR) teams, and can actually be considered part of a biological search and rescue robot system [7]. Consequently, there is a growing research interest in technologies that enhance the possibilities of communication between dog and human teams in SAR [8]. In this sense, wireless inertial units can be used to provide more information to the trainer [9]. Tracking through Global Positioning Systems (GPS) and the measurement of the temperature has served for the study of the efficiency of SAR dogs [10]. Besides, the development of interfaces through voice and vibration allow maintaining a greater distance between the dog and the trainer [11].

Furthermore, canine units can locate victims in areas that are difficult to access for the human rescue teams. Thus, it has been proposed that dogs serve for the deployment of robots in catastrophe scenarios [12]. In addition, dogs can be used to obtain maps of the area of interest, even if harness-mounted cameras offer some difficulties due to abrupt posture changes [13]. The devices and interfaces for canine agents have distinctive design requirements [14].

Robots have been considered as useful agents in search and rescue operations, and several authors have studied robot integration in WSN within this context [15]. However, integration of canine agents has received comparatively little attention. The high mobility of rescue dogs can make it difficult to ensure coverage, or can reduce operating lifetime of devices due to energy consumption. A WSN including rescue dogs must consider these features in its design. Hybrid Wireless Sensor Networks (H-WSN), where both static and mobile sensors are deployed, have coverage as a major concern [16]. Considering a hierarchical architecture in mobile wireless sensor nodes can improve overall performance, reducing energy consumption and delays, and enhancing reliability of data transmission and the connectivity of the network [17]. The use of a mobile sink (MS) allows for a longer lifetime of the sensor nodes on the working dog's harness, since multihop data collection is avoided [18]. While WSN technology has been proposed for application in natural disasters, its real use addresses several challenges in this scenario, like transmission reliability, handling of heterogeneous data and energy consumption [19].

This article proposes the integration of a sensorized SAR dog with a WSN for victim location (see Figure 1). A sensorized harness has been developed to obtain wireless information about both the GPS position of the dog and a set of environmental variables. These data are sent to a mobile sink and synchronized with an external database, available to the rest of the participants in the SAR operation. During the mission, a tele-operated UAV with an onboard camera followed of the trajectory of the dog, helping to modify the position of the mobile sink to keep communication with the sensorized harness. Additional information for off-line analysis was also obtained. A series of realistic experiments have been carried out to test the system. The paper discusses lessons learned from their experience.

* This work was partially funded by the Spanish project DPI2015-65186-R. The publication has received support from Universidad de Málaga, Campus de Excelencia Andalucía Tech.

[1]Universidad de Málaga, Robotics and Mechatronics Lab, Andalucía Tech, 29071 Málaga, Spain. jfl@uma.es

[2]Universidad de La Guajira, Riohacha, Colombia. csocarras@uniguajira.edu.co

[3]Universidad de Málaga, Ctedra de Seguridad, Emergencias y Catstrofes, 29071 Málaga, Spain. jmpaez@uma.es

Fig. 1. The search team is composed by the dog, the trainer and the UAV.

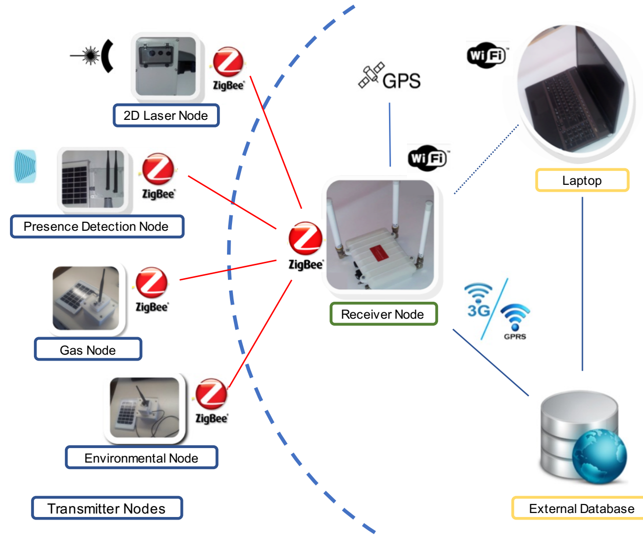

Fig. 2. Static WSN system architecture.

II. Sensor Network Architecture for Canine Search Information System

A. Architecture Overview

The system is based on a WSN, with smart sensor nodes mounting several types of sensors: ultra-sound presence detection, 2D laser range, noise, temperature, dust or gas emissions (see Fig. 2).

The WSN has a modular architecture so that the topology can be reconfigured for a different number of transmitter nodes, as well as a different number or types of sensors within the nodes. Additionally, a receiver node is responsible for setting up and managing the network. After setup, the transmitter nodes perform data acquisition and processing. The receiver node keeps an updated internal database of gathered data that is synchronized with an external server. The information in the server's database is presented through a graphical user interface (GUI) [20].

The proposed system has been developed on the basis of the hardware components by Libelium [21]. All transmitter nodes are built upon the same basic hardware module, called Waspmote V. 1.2, plus a communications module (XBee Pro S2 from Digi). The receiver node is based on a multi-protocol router named Meshlium, also from Libelium, configured to work with ZigBee, WiFi, Bluetooth and 3G/GPRS protocols, and including a GPS. The ZigBee protocol (2.4 GHz) has been selected to link the transmitter nodes with the receiver node. This protocol is appropriate for the first response information system because it can transmit small information packages with low energy consumption and ranges of over 700 meters (depending on visibility conditions) and it allows a simple and fast network setup [22].

The modularity of the system allows its adaptation to the needs of the use case. For instance, a deployment for emergency response can include nodes to gather information about temperature, noise or gas emissions. All transmitter nodes are encapsulated in IP 67 boxes, allowing deployment outdoors in any weather condition. A solar kit can be installed to provide autonomy from the electric power grid. With this architecture, the WSN can provide information on a given area of interest thanks to its easy and fast deployment. But once the nodes have been deployed, they are static, and obtaining additional information requires new nodes to be installed. Some use cases, like emergency response, require also information on a wide area in tasks like exploration or victim search [23]. Those needs have driven the development of a mobile node.

B. Mobile (Canine) node Implementation

A mobile node has been designed to be moved around an area of interest, providing information without the need of a deployment of additional nodes. It can be carried by a vehicle, or by a rescue dog as in this use case. The mobile node includes one or several transmitter nodes. But since the communication between the transmitter nodes and the receiver nodes is provided by the ZigBee protocol, and its range depends on the obstacles between emitter and receiver, an additional receiver node has to be included, acting as a mobile sink. This node gathers the information from the transmitter nodes, and synchronizes it with the database in the external server via 3G. It must be noticed that, since communication between all the nodes is wireless, the nodes can be physically separated. The presence of this receiver node turns it into a mobile sub-network rather than a mobile node. However, the interaction with the WSN makes it closer to a multi-sensor node. Initially, all the transmitter nodes acquire and process data from the environment. These data are sent to the receiver node, where they are collected. Then, two strategies are possible. First, only when data from all the transmitter nodes have been received, the full set is sent to the database at the external server in an extended frame with fields for all present sensors. The information is then seen as provided by a single, multi-sensor node, but in this case, the dynamics of the mobile node is dictated by that

Fig. 3. Search and rescue dog equipped with the sensorized harness.

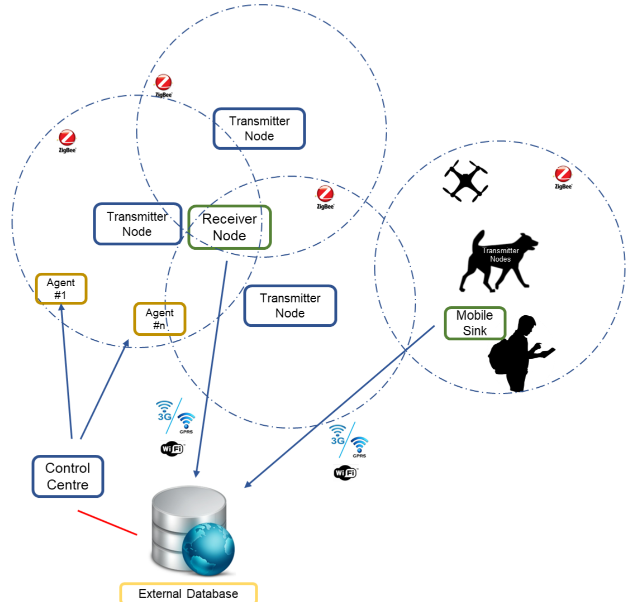

Fig. 4. Mobile node integrated with the static WSN.

of the slowest transmitter node. A second option is to send data from the transmitter nodes as soon as they arrive to the receiver node, using regular frames, and synchronizing with the external database. The receiver node acts as a gateway, ensuring that information is available as soon as possible. In any case, the information is compatible with the deployment of conventional, static, transmitter nodes.

The nodes are installed on a special harness developed for this application (see Fig. 3). It includes two compartments, one at each side, whose weight has been balanced to be comfortable for the dog. Each compartment contains an independent node which performs measurements, processing and transmission of the resulting information. In particular, the nodes included in this implementation are:

- Gas node. It is composed of several gas sensors: O_2 (SK-25, from Figaro), O_3 (MICS-2610, from E2V), CO_2 (TGS 4161, from Figaro), CO (TGS 2442, from Figaro), NH_3 (TGS 2444, from Figaro), VOC (TGS 2600, from Figaro). Additional sensors include humidity (J808H5V5, from JIN ZON ENTREPRISE CO.), atmospheric pressure (MPX4115A, from Motorola) and temperature (MCP9700/9701, from Microchip).
- GPS node. It includes a Jupiter N3 GPS module from Telit.

In this case, the receiver node was not carried by the dog, but included in the operator's control station. The complete system is then a H-WSN, where both static and mobile sensors are deployed. The inclusion of a receiver node in the control station serves as a mobile sink, solving the problem of coverage [16]. Since the operator receives the position of the canine agent as well as live video streaming via an UAV, he can correct his position so that coverage is guaranteed. The use of a mobile sink allows also for a longer lifetime of the sensor nodes on the working dog's harness, since multihop data collection is avoided [18] (see Fig. 4).

Fig. 5. Control station GUI offering gathered data on a map.

C. *Control Station*

A control station has been developed to present the relevant information to a human operator. A GUI has been designed to show the information gathered by the mobile node, superposed to a map of the area (see Fig. 5). Additionally, a UAV is controlled by the operator, tracking the dog and streaming live video to the control center. The control station is carried by the operator in a small backpack, including the receiver node. The communication with the transmitter nodes is based on ZigBee, providing a reach between 0.5 km and 7 km (depending on visibility). Since the operator receives the GPS coordinates of the canine agent, he can modify his position so that the communication between the mobile node and the receiver node is not interrupted. The live video streaming provides redundant information to keep communication alive between the mobile node and the receiver node. A general diagram of the system is shown in Fig. 6.

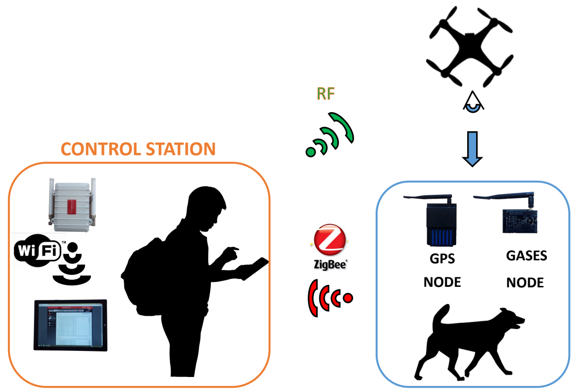

Fig. 6. WSN system architecture for the experiments, where the dog carries two sensor nodes.

III. Experiments

A. Exploration Exercise

Several experiments have been carried out to test the proposed system. The goal was to verify the mobile node as well as its integration with the complete information system. The mobile node was configured including a Gas node and a GPS node on the harness. A static network was deployed in the vicinities including Gas nodes and Environmental nodes [20], as well as a receiver node. The task was to explore an area outside of the reach of this receiver node, and gather field information. In particular, parameters measured by the Gas node were the following:

- TCA: temperature (C)
- HUMA: relative humidity (%)
- PA: absolute pressure (kPa)
- O2: oxigen concentration o (p.p.m)
- CO: carbon monoxide concentration (p.p.m.)
- CO2: carbon dioxide concentration (p.p.m.)
- NH3: nitrate concentration (p.p.m.)
- AP2: volatile concentration (p.p.m.)

These data were to be synchronized with the External Database, and shown in the GUI. A system operator was carrying the backpack with the control station.

The experiments were carried out in a test area in the University of Malaga, devoted to mobile robotics and search and rescue exercises. A search and rescue dog was equipped with harness, and sent by its trainer to explore the area, in a series of short routes. The routes were confined to the experimental area, but defined by the dog trainer according to a regular exploration pattern. Data from the gas sensors and from the GPS were gathered, and shown to the operator in the GUI (see Fig. 7). An option in the GUI allows for presenting details on the gas data (see Fig. 8). The position and gas data were also available for other operators, through the integration with the External Database. The system performed according to the expectations. The dog could move easily despite the harness.

B. Search and Rescue Exercise

A realistic experiment was set up to test the performance of the system in a practical use case. The mission consisted in the search for a survivor in the surrounding area of an accident. A person acting as the victim was hidden out-of-sight on the floor under a vegetation area. In this case the zone was within a larger exercise area, in order to provide longer distances for the exploration and for the communications. The terrain presented harsh conditions for the search and rescue dog (including thorny vegetation and sharp stones). The dog was equipped with the harness including the same Sensor nodes as in the previous series of experiments. The operator carried the control-station backpack, but in this case he also tele-operated an octocopter UAV and supervised the mission from the start area. This way, he was ready to modify his position according to the movements of the rescue dog, so that communication with the receiver node in the control-station was possible all the time.

As in the previous series, data from the rescue dog was gathered and presented to the operator. The size of the exercise area required some displacements of the operator to guarantee the connection between the mobile node and the control-station. He was helped by the availability of the live video stream from the UAV. The search start was signaled by the dog trainer, and consisted of several exploration routes around likely areas. The dog trainer decided according to his regular criteria how to perform the search. The victim was found after the dog had explored several of these routes.

The search could be successfully performed by the dog, despite the difficult terrain. Data from the mobile node was received and shown in the control-station, and stored in the External Database. The availability of data allows for off-line analysis of the rescue task. For instance, the search activity of the dog can be estimated from the GPS data. The graph in Fig. 9 provides the average velocity of the dog between consecutive GPS readings. According to these data, the victim was found in $7.37\,\mathrm{min}$ with a dog trajectory of $189\,\mathrm{m}$ from the start signaled by the dog trainer for this route. A 3D terrain model has been obtained off-line by using aerial photogrammetry techniques with images taken by the UAV during the mission, as seen in Fig 10. This model can be used to analyze the task, or to plan new searches if the victim is not found.

C. Lessons Learned

The major lessons learned from this series of experiments are the following:

- It would be desirable to reduce the work load of the control station operator. In the Search and Rescue experiment, most of the operator attention was grabbed by UAV tele-operation. Autonomous UAV for dog tracking would allow that the operator could be more concentrated on victim search details.
- The fast pace of the rescue dog can make it difficult for the control-station operator to move accordingly and keep communication between the mobile node and the receiver node at the control-station. An autonomous

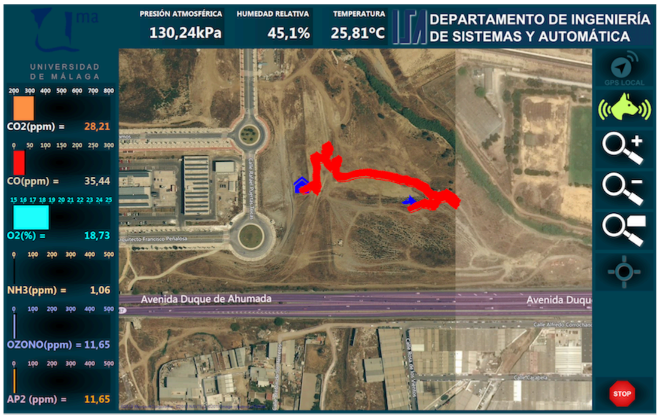

Fig. 7. GUI at the control station, showing the route of one of the experiments.

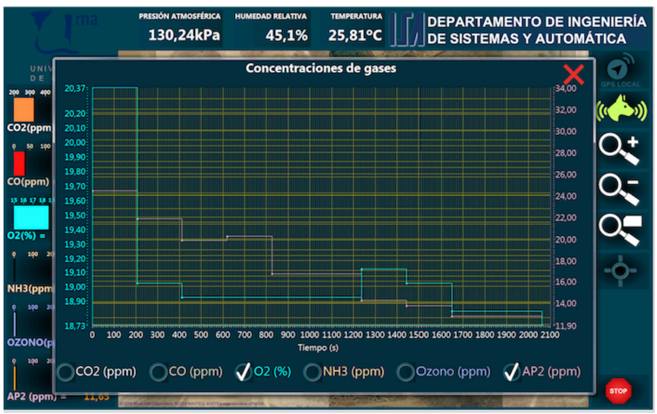

Fig. 8. GUI showing gas readings in one of the experiments.

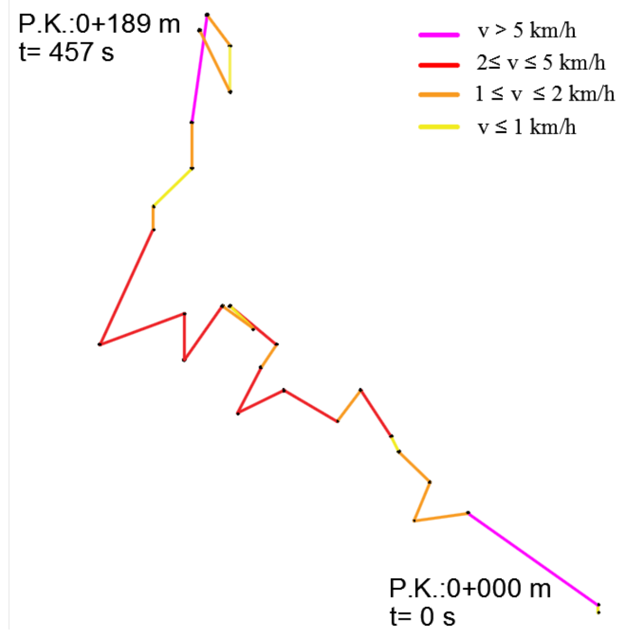

Fig. 9. Average speeds of the dog between GPS readings, which are indicated as dots on the ground plane.

system carrying the receiver node can be more effective and reduce the operator's workload.

- The information produced by the proposed system seems promising for identification of SAR dog behavior and performance assessment. This could have potential applications in the training phases.
- In the experiments, there was no direct communication between the dog trainer and the control station operator. A communication link between them could be useful as they actually had different and complementary perceptions of the victim search.

IV. Conclusions

The paper has presented the integration of a canine agent in a wireless sensor network (WSN) for Search and Rescue missions. A mobile node architecture has been developed to be integrated in a WSN. This architecture includes a mobile sink to improve coverage, reduce energy consumption of the sensor nodes and enhance network lifetime. The resulting system is a hybrid WSN (H-WSN). A special harness has been developed that includes intelligent sensors for gas detection and a Global Positioning System (GPS). Thus, both the environmental conditions and the dog position can be monitored. Besides, a tele-operated UAV is used to supervise the mission from a control station. The availability of data from the mobile node and from the UAV allows for off-line analysis of search and rescue operations. The system has been tested in a series of realistic experiments in collaboration with search and rescue professionals, with good results.

To the knowledge of the authors, no similar experience has been reported. One major conclusion of the experiment is that the dog behavior has not been affected by wearing the harness or by the presence of the UAV. Thus, the combination of SAR dogs with sensorized harnesses and UAVs seems a promising research area with potential benefits for emergency response efficiency.

To be fully operational, the system will require future developments in UAV autonomy and communications between team members.

Acknowledgments

The authors want to thank the collaboration of Juan Manuel García Hernández, from *Grupo Especial Intervención en Montaña*, Ávila (Spain), during the experiments.

References

[1] A. S. Tonneau, N. Mitton, and J. Vandaele, "A survey on (mobile) wireless sensor network experimentation testbeds," in *2014 IEEE International Conference on Distributed Computing in Sensor Systems*, May 2014, pp. 263–268.

[2] G. Kantor, S. Singh, R. Peterson, D. Rus, A. Das, V. Kumar, G. Pereira, and J. Spletzer, "Distributed search and rescue with robot and sensor teams," *Springer Tracts in Advanced Robotics*, vol. 24, pp. 529–538, 2006.

[3] A. Ko, H. Y. K. Lau, and R. P. S. Sham, "Application of distributed wireless sensor network on humanitarian search and rescue systems," in *International Conference on Future Generation Communication and Networking*, vol. 2, 2008, pp. 328–333.

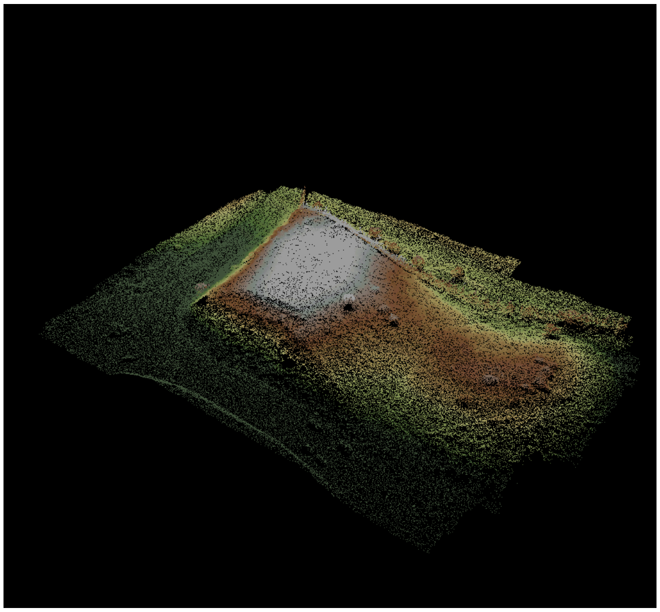

Fig. 10. 3D terrain map of the area explored by the dog computed from the UAV images.

[4] G. M. Hoffmann and C. J. Tomlin, “Mobile sensor network control using mutual information methods and particle filters,” *IEEE Transactions on Automatic Control*, vol. 55, no. 1, pp. 32–47, 2010.

[5] J. D. Freeman, V. Omanan, and M. V. Ramesh, “Wireless integrated robots for effective search and guidance of rescue teams,” in *IEEE and IFIP International Conference on Wireless and Optical Communications Networks*, 2011.

[6] S. S. Anjum, R. M. Noor, and M. H. Anisi, “Review on manet based communication for search and rescue operations,” *Wireless Personal Communications*, vol. 94, no. 1, pp. 31–52, 2017.

[7] F. Zhang, J. Xu, and G. Zheng, “The development and application of biological search and rescue robots system,” in *International Forum on Strategic Technology*, 2016, pp. 516–520.

[8] A. Bozkurt, D. L. Roberts, B. L. Sherman, R. Brugarolas, S. Mealin, J. Majikes, P. Yang, and R. Loftin, “Toward cyber-enhanced working dogs for search and rescue,” *IEEE Intelligent Systems*, vol. 29, no. 6, pp. 32–39, 2015.

[9] R. Brugarolas, D. Roberts, B. Sherman, and A. Bozkurt, “Posture estimation for a canine machine interface based training system,” in *Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, San Diego, USA, 2012, pp. 4489–4492.

[10] I. Greatbatch, R. J. Gosling, and S. Allen, “Quantifying search dog effectiveness in a terrestrial search and rescue environment,” *Wilderness and Environmental Medicine, doi: 10.1016/j.wem.2015.02.009*, 2015.

[11] W. R. Britt, J. Miller, P. Waggoner, D. M. Bevly, and J. A. Hamilton Jr., “An embedded system for real-time navigation and remote command of a trained canine,” *Personal and Ubiquitous Computing*, vol. 15, no. 1, pp. 61–74, 2011.

[12] M. Gerdzhev, J. Tran, A. Ferworn, and D. Ostrom, “Dex - a design for canine-delivered marsupial robot,” in *IEEE International Workshop on Safety, Security, and Rescue Robotics*, Bremen, Germany, 2010.

[13] J. Tran, A. Ufkes, A. Ferworn, and M. Fiala, “3D disaster scene reconstruction using a canine-mounted RGB-D sensor,” in *International Conference on Computer and Robot Vision*, Regina, Canada, 2013, pp. 23–28.

[14] J. J. Majikes, S. Mealin, Rita, Brugarolas, K. Walker, S. Yuschak, B. Sherman, A. Bozkurt, and D. L. Roberts, “Smart connected canines: IoT design considerations for the lab, home, and mission-critical environments,” in *IEEE Sarnoff Symposium*, 2016, pp. 118–123.

[15] G. Tuna, V. C. Gungor, and K. Gulez, “An autonomous wireless sensor network deployment system using mobile robots for human existence detection in case of disasters,” *Ad Hoc Networks*, vol. 13, pp. 54 – 68, 2014.

[16] S. M. Mohamed, H. S. Hamza, and I. A. Saroit, “Coverage in mobile wireless sensor networks (m-wsn): A survey,” *Computer Communications*, vol. 110, pp. 133 – 150, 2017. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0140366417307235

[17] X. Chen and P. Yu, “Research on hierarchical mobile wireless sensor network architecture with mobile sensor nodes,” in *2010 3rd International Conference on Biomedical Engineering and Informatics*, vol. 7, Oct 2010, pp. 2863–2867.

[18] A. Kaswan, K. Nitesh, and P. K. Jana, “Energy efficient path selection for mobile sink and data gathering in wireless sensor networks,” *AEU - International Journal of Electronics and Communications*, vol. 73, pp. 110 – 118, 2017. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1434841116314170

[19] D. Chen, Z. Liu, L. Wang, M. Dou, J. Chen, and H. Li, “Natural disaster monitoring with wireless sensor networks: A case study of data-intensive applications upon low-cost scalable systems,” *Mobile Networks and Applications*, vol. 18, no. 5, pp. 651–663, Oct 2013. [Online]. Available: https://doi.org/10.1007/s11036-013-0456-9

[20] J. Fernández-Lozano, M. Martín-Guzmán, J. Martín-Ávila, and A. García-Cerezo, “A wireless sensor network for urban traffic characterization and trend monitoring,” *Sensors*, vol. 15, no. 10, pp. 26 143–26 169, 2015.

[21] Libelium, *Homepage*, 2018 (accessed February, 2018). [Online]. Available: http://www.libelium.com

[22] S. Tateno and Y. Okamoto, “Remote monitoring system for rescue operations with wireless sensor network,” in *International Conference on Control, Automation and Systems*, Kintex, Korea, 2014, pp. 551–555.

[23] J. J. Fernández-Lozano, J. A. Gomez-Ruiz, M. Martín-Guzmán, J. Martín-Ávila, S.-B. Carlos, and A. García-Cerezo, “Wireless sensor networks for urban information systems: Preliminary results of integration of an electric vehicle as a mobile node,” *Advances in Intelligent Systems and Computing*, vol. 694, pp. 190–199, 2018.