Unmanned Ground and Aerial Robots Supporting Mine Action Activities

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> *'Technology developed on the basis of real needs, in a participatory way together with people who exf cost-legged robots, as illustrated pressed these needs, contributes significantly to their human development by enhancing their knowledge and creativity'*
>
> *—E.E. Cepolina (Snail-Aid, Italy)*

Abstract

During the Humanitarian-demining actions, teleoperation of sensors or multi-sensor heads can enhance-detection process by allowing more precise scanning, which is useful for the optimization of the signal processing algorithms. This chapter summarizes the technologies and experiences developed during 16 years through national and/or European-funded projects, illustrated by some contributions of our own laboratory, located at the Royal Military Academy of Brussels, focusing on the detection of unexploded devices and the implementation of mobile robotics systems on minefields.

Keywords: robotics, demining, navigation, sensors, image processing

1. Introduction

The mobile robotics systems are beginning in applications related to - security and the environmental surveillance: prevention of disasters and intervention during disasters with all possible kinds of missions ensuring the security.

The general objective of the International Advanced Robotics Program (IARP) [1] is, as foreseen by its status, 'to encourage development of advanced robotic systems that can dispense with human work for difficult activities in harsh, demanding or dangerous environments, and to contribute to the revitalization and growth of the world'.

Through a first book devoted to the 'Emerging Robotics and Sensors Technologies for Humanitarian Demining and Risky Interventions' [2], the IARP working group HUDEM (Robotics Assistance to Mine-clearing) summarized some important results of R&D activities focusing on the robotics and associates technologies applied to the solution of the Humanitarian demining.

The challenges posed by the use of robotics systems have been examined and partially solved in the FP7-TIRAMISU project. The following chapters focus on the contribution of the Royal Military Academy (RMA) to these challenges.

2. Robotics systems developed at RMA

2.1. 1997–2002

Under the HUDEM'97, project funded by the Belgian Ministry of Defence, with the close cooperation of our partners of the European Network CLAWAR [4], we focused on the design and development of small low-cost-legged robots [10], as illustrated in **Figure 3**.

Wheels have the advantages of engineering simplicity, low friction on a smooth surface and they enable the robot to move at a high speed. Laying down a track for wheels to run on is a way of extending the use of wheels to soft and rough ground. But wheels and tracks have a main weakness. They have poor performance in an unstructured environment when faced with a vertical step or a discontinuous surface. More than half of Earth's land area precludes wheeled and tracked vehicles. In many of these natural terrains, legs are well suited.

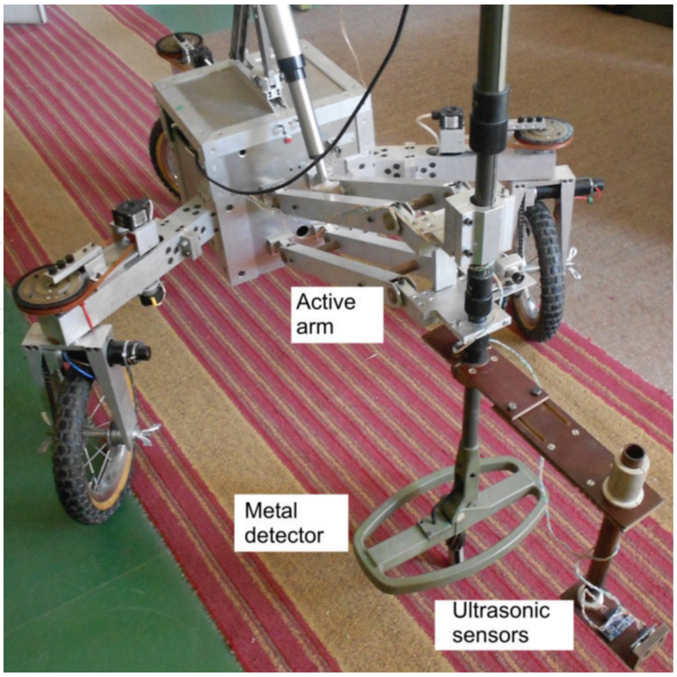


Figure 1. Multi-legged robot, as first prototype (AMRU 5).

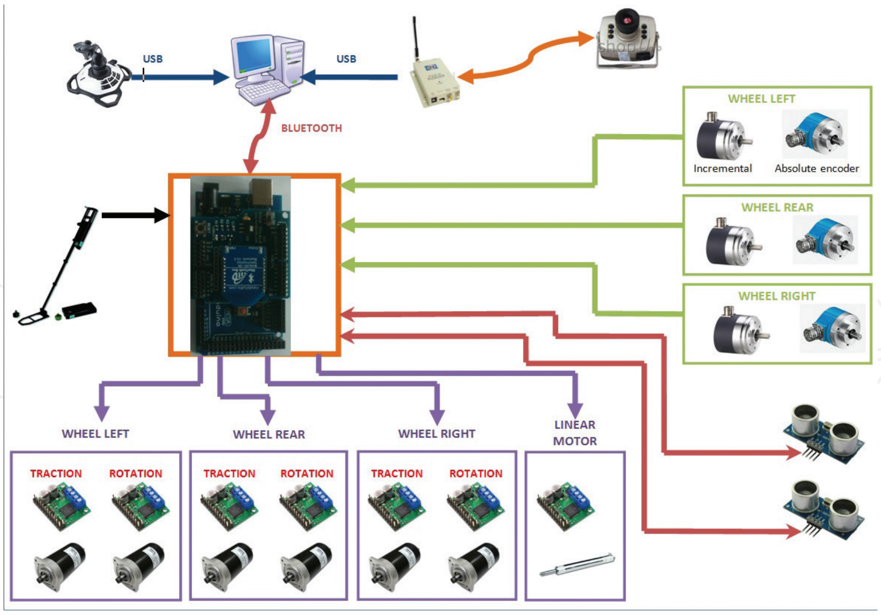


Figure 2. The three-wheeled TRIDEM robot.

Some reasons explain the choice of walking robots [6, 7, 8, 9]:

The last six-legged robot we designed [5] could be equipped with a chemical sensor and followed up with a series of electro-pneumatic platforms, among which a sliding robot could be equipped with several tools.

Several partners of the IARP and CLAWAR Working Groups HUDEM developed similar concepts, but no one could satisfy the basic requirements of cost-effectiveness. The control of such machines is not obvious (**Figure 1**).

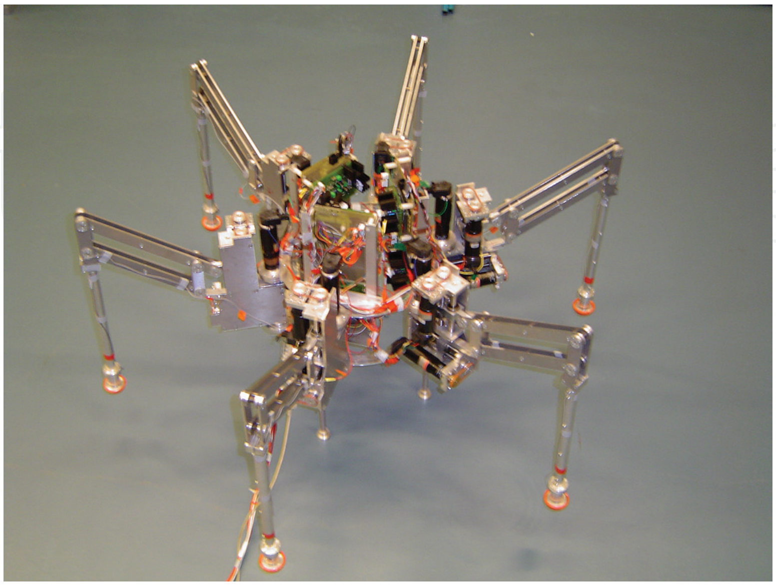


Figure 3. Robot control hardware.

2.2. 2002–2006

From the previous experience and the cost-effectiveness requirements, it quickly appeared that a basic constraint on the design of a robot was the modularity and the conviviality of the human-machine interface (HMI) in order to ease the interpretation of the operator.

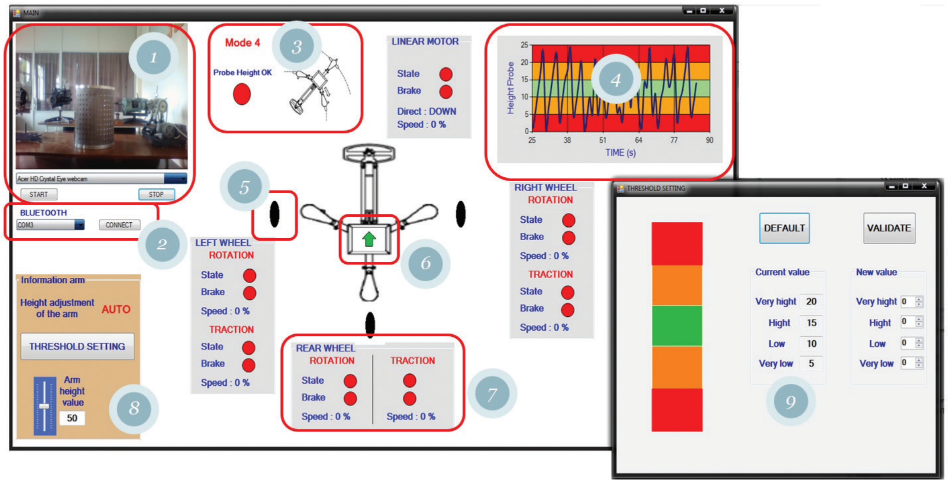
Our next design focused on a three-wheeled lightweight teleoperated platform (TRIDEM) that was refined under the project FP7-TIRAMISU [11, 14,] (**Figure 2**).

The last prototype of TRIDEM is controlled by a wireless joystick. An overall view of the robot control hardware is shown in **Figure 3**. A microcontroller placed on the robot is responsible for the robot control. The joystick is connected to a computer, via a USB port. The commands of the human operator are sent to the robot through this joystick and wireless connection between computer and microcontroller. Information concerning robot movements, the presence of an obstacle, the presence of a mine, and so on, are sent from the microcontroller to the computer. All these parameters may be visualized by a human operator, thanks to a graphical user interface (see **Figure 4**). A wireless video camera, mounted on the robot arm, sends images to the same graphical interface, so that a human operator is informed about the work environment of the robot.

In most robotic applications, in Humanitarian demining in particular, the robot has to be operated by an inexperienced user. Therefore, a simple and intuitive interface is required especially when the robot has many motors and degrees of freedom. We developed such an interface for TRIDEM (**Figures 3** and **4**).

2.3. 2006–2010

Although multi-legged or similar multi-wheeled robots offer promising solutions and despite the current maturity of such platforms, the preference was given to the conversion of existing commercial platforms. Exchange of information was then pursued through the organization of annual IARP workshops, some of them located in countries confronted with mined areas:



Acer HD Crystal Eye webcam

COM3

Mode 4

Probe Height OK

Direct : DOWN

Speed : 0 %

Height adjustment of the arm AUTO

Arm height value 50

Current value

Very hight 20

Hight 15

Low 10

Very low 5

New value

Very hight 0

Hight 0

Low 0

Very low 0

Figure 4. Graphical user interface (HMI).

Kosovo, Egypt, Tunisia, Croatia or in countries pursuing national funded R&D related to the Humanitarian demining: Austria, Japan and Belgium (**Figure 5**).

At the RMA, we then focused on the adaptation of two commercial platforms: the ROBOSOFT, renamed ROBUDEM, laterally equipped with a three-dimensional (3D) scanning carrier of a VALLON metal detector (**Figure 5**) and progressively adapted for an autonomous behaviour-based navigation control [12], finally tested in the context of the FP6 project VIEW-FINDER focusing on the Robotics assistance of security services.

A detailed study of the state-of-the-art has been entrusted to Daniela Doroftei [13].

An optimal combination of sensors (location of the robot, detection of explosives and vision sensory package) was analysed and tested under the project FP7-TIRAMISU. A partial combination has been developed at the RMA, focused on the use of a limited number of sensors: a behaviour-based architecture for mine detection (project RSTD MB07 [13]) and a behaviour-based navigation for search and inspection interventions (project VIEW-Finder [15]). **Figure 6** summarizes the control architecture.

2.4. 2011–2015

Under the FP7-TIRAMISU project [20], another commercial mobile robotic platform (the tEO-Dor) was used for the integration with a metal detector array developed by VALLON (the MCMD) (**Figure 7**).

An important drawback of the standard EOD tEODor platform is that it did not feature any autonomous capabilities. To overcome such a constraint, the platform was upgraded by RMA

Figure 5. The ROBUDEM.

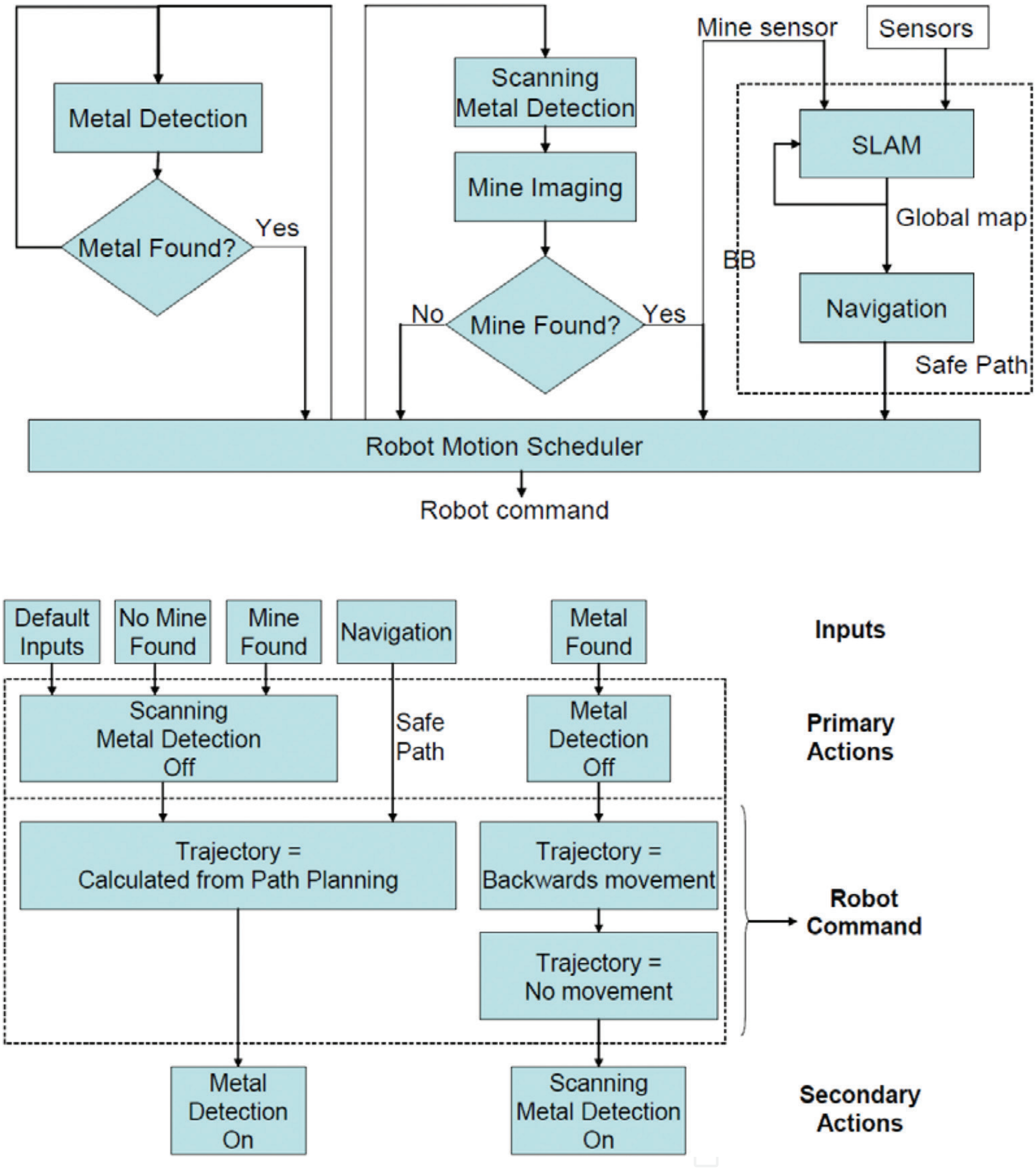


Figure 6. General control architecture of the ROBUDEM.

with necessary electronics, sensors, computing power, motor control units and power sources in order to be able to execute remote-controlled and semi-autonomous tasks [18].

A geo-positioning and communication device, the TCP box developed by DIALOGIS/ PROTIME, partners of TIRAMISU, was integrated with the system for geo-referencing the data.

The validation tests of the system were conducted on a dummy minefield at the SEDEE-DOVO (Demining Service of the Belgian Defence) and led to the desired Technical Readiness Level 7.

Figure 7. The teoDOR equipped with the MCMD and a TCP box positioning system.

Furthermore, a similar platform was adapted under the FP7-ICARUS project (2012–2016—Robotics Assistance for Search and Rescue Operations), including vision capabilities enabling an assessment of terrain traversability and thereby allowing a semi-autonomous navigation facing the traversability issues [16, 17, 19, 21].

3. Remotely piloted aircraft system (RPAS) deployment for mine action

The deployment of the remotely piloted aircraft system (RPAS) was extensively used within the TIRAMISU project [20] for the support of different scenarios (**Figure 8**).

Figure 8. Overview of the complete RPAS.

Over the 3 years (2012–2015), the RPAS was deployed in test areas as well as in real missions. The next sections shortly introduce some of the missions done with the RPAS.

4. RPAS survey of honeybees

Survey of honeybees with an RPAS was a cooperation we did in 2014 together with the Croatian partners CTRO and the University of Zagreb within the TIRAMISU project. We used the RPAS in order to make the survey of honeybees by monitoring their activities and to analyse their ability to detect buried mines. The initial first proposal was prepared by Milan Bajic (CTRO) and Haris Balta (RMA) and field mission was done in the period of end of July beginning of August 2014 at the CTRO test centre in Cerovac, Croatia.

The scenario was that the conditioned (trained) honeybees fly over the area where landmines (real, with explosives, not the dummy landmines) were placed, or over area where remains of the explosive exist after the use of mechanical machines. The images shot from a RPAS (hovering or flying very slow) provided a time sequence of images of one area. Processing and analysis of time sequence enables assessment of bee's density in space and time.

Therefore, we used the RPAS in hover-mode-flying altitude around 25 m with the high-resolution digital camera and collecting sequences of 60–85 images per each section of the minefield. Collected images were processed and analysed offline by CTRO and the University of Zagre.

5. RPAS use for hazardous suspected area

In 2015, we prepared a campaign for operational validation of RPAS [3, 22–24]. This work was conducted together with CTRO and ULB, Belgium, and partially with the support of the University of Zagreb. We used the RPAS in order to perform oblique flights and near infrared

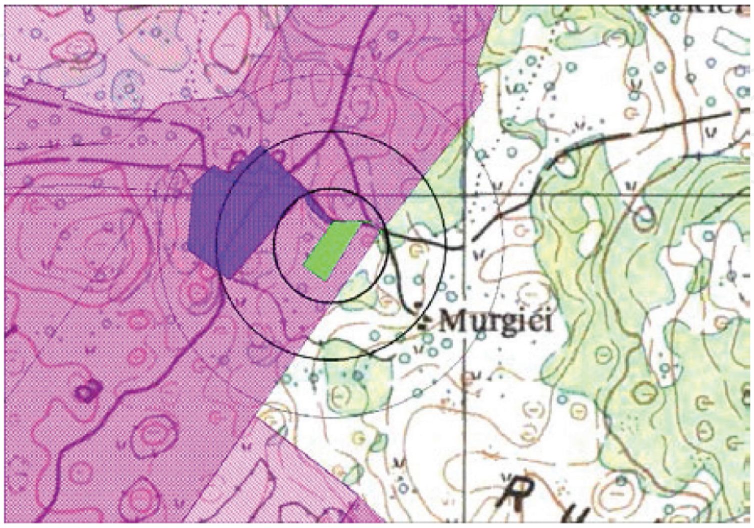


Figure 9. HSA operational area Murgici, Croatia.

(NIR)-mapping flights of the suspected hazardous area (SHA) and the minefields. The initial first proposal was prepared by Milan Bajic (CTRO) and Haris Balta (RMA) and A field mission was done in April 2015 in the Region Murgici, Croatia (44°38'53.28″ N 15°28'10.55″ E.). **Figure 9** shows the SHA (cross-hatched in pink colour).

6. Oblique survey of the indicators of mine presence

Some of the existing tools for the detection of mine presence indicators are limited by nadir images shooting. On the plane terrain, it is acceptable, but on hilly terrain or in mountains this is very limiting. When the RPAS is used on terrains where objects of interest (indicators of mine presence) exist, the oblique images can provide very valuable data of the mine-suspected area. We used the RPAS on our second mission and collected data for these activities (**Figure 10**).

General overview flight above the SHA. Flying altitude is around 120 m. Detection of a possible anomaly is shown in **Figure 11**.

Vertical inspection flight above the anomaly is to confirm it as shown in **Figure 12**.

Figure 10. Sequence of NiR images over the SHA.

Figure 11. Flight above the SHA with a recognition of an anomaly.

Figure 12. Vertical flight above the anomaly with zoom.

7. RPAS deployment in post-flood mine action with TIRAMISU end-user Bosnia and Herzegovina Mine Action Centre (BHMAC), 2014

RPAS was deployed in post-flood mine action activities in Bosnia and Herzegovina in the period of May to June 2014 [3]. We used the RPAS to assist the team from the Bosnia and Herzegovina Mine Action Centre (BHMAC) in detecting the locations of Explosive Remnants of War (ERWs) and performing damage assessment, mapping and aerial inspection. The ERWs were displaced as a result of landslides caused by the floods.

Detected mine, re-located due to the landslides, is shown in **Figure 13**.

Figure 13. Detected mine in the region: Sarajevo-Vogosca, Bosnia and Herzegovina, 4 June 2014.

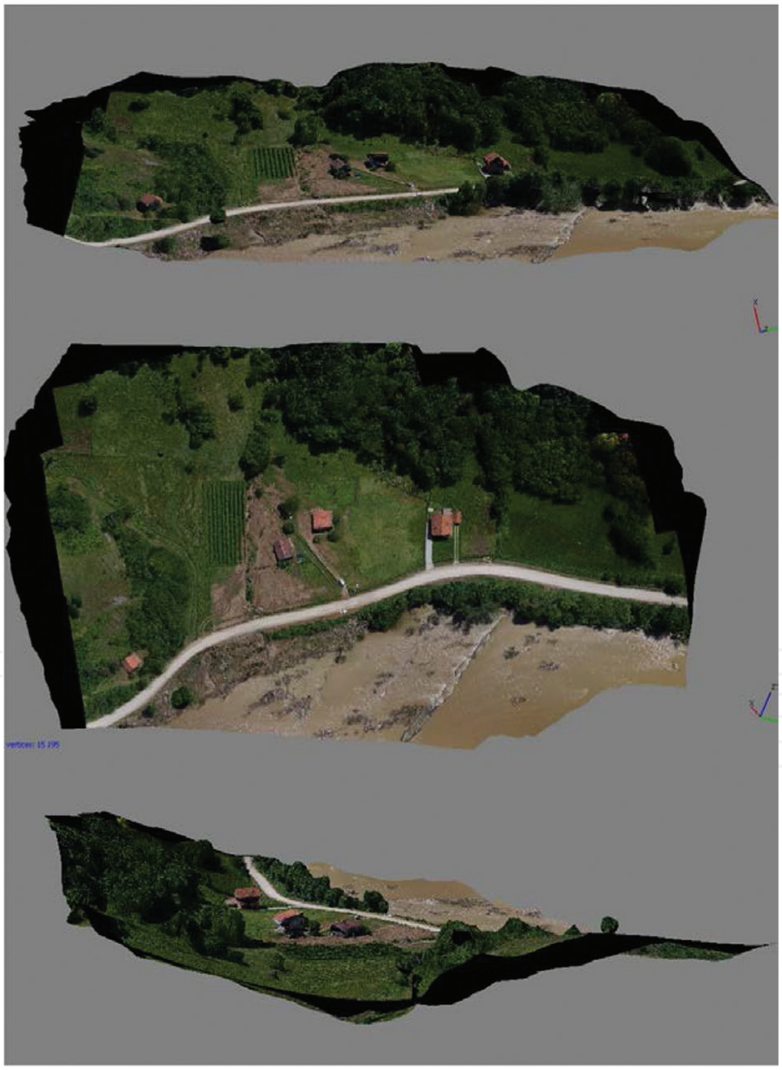


Figure 14. Sequence of oblique images around the SHA.

First post-processed results of the regions Zavidovici- Dolac and Olovo, in central Bosnia and Herzegovina, with geo-referenced aerial images, were produced (as shown in **Figure 14**). The RPAS was used for providing 3D-maps, orthophotos and digital terrain models of the environment to analyse the effects of the landslides on mines and ERW. This result has been used by Bosnia and Herzegovina Mine Action Centre (BHMAC) for the localization of displaced ERW, damage assessment and documentation purposes.

8. Conclusions

The development of a Robotics System for demining operations has to take several constraints into account: a high level of protection against the environmental conditions (dust, humidity, temperature, etc.), protection and resistance against vibration, mechanical shocks and instability factors, a sufficient autonomy and reliable communications between the mobile platform and the operator.

In this chapter, some of the most relevant aspects of both technical and environmental aspects have been underlined. Other robotics systems have been co-developed with the partners of the FP7-TIRAMISU project. We invite the reader to consult [20].

Acknowledgements

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References

[1] IARP. www.iarp-robotics.org *(accessed on 2016-06-21).*

[2] Baudoin Y., Habib M.K. Using Robots in Hazardous Environments. Landmine detection, demining and other applications. Woodhead Publishing in Mechanical Engineering, 2011. ISBN 978-1-84569-786-0

[3] Haris B., Geert De C., Yvan B., Daniela D. UAS deployment and data processing during the Balkans flooding with the support to Mine Action"8th International Advanced Robotics Programme (IARP) Workshop on Robotics for Risky Environment (RISE), 28-29 January 2015, Lisbon, Portugal.

[4] CLAWAR. www.clawar.org *(accessed on 2016-06-22).* Clawar Task 9 report, 1999.

[5] Habumureyi, J.C. Adaptive neuro-fuzzy control for a walking robot with 6 pantograph-based legs. PhD Thesis, Free University of Brussels, 2004.

[6] Gonzalez de Santos P., Garcia E., Estremera J., Armada M.A. SILO-6: design and configuration of a legged robot for humanitarian demining. International Symposium Clawar, Brussels, 1998.

[7] Berns K., Kepplin V. Lauron-II a general purpose walking machine for rough terrain', International Symposium Hudem'97, Royal Military Academy, Brussels, June 1999.

[8] Nonami K. Development of autonomous mine detection six-legged walking robot for Humanitarian demining, 5th IARP Workshop, Tokyo, Japan, June 2005.

[9] Randall M.J., Pipe A.G. An intelligent control architecture and its application to walking robots. Proceedings of International Workshop on Advanced Robotics and Intelligent Machines, Salford, UK, 1997, ISSN 1363-2698.

[10] Baudoin Y., Dorofteï I. Hierarchical control of a Hexapod walking robot. International Journal of Robotica & Management 14-1, 2009, ISSN 1453-2069.

[11] Doroftei I., Baudoin Y. Using mobile robots for a clean and safe environment-a difficult challenge, in Proceedings of 2012 International Conference and Exposition on Electrical and Power Engineering (EPE), Iasi, Romania, 2012, pp. 41-46.

[12] De Cubber G., Berrabah, S.A., Doroftei D., Baudoin Y., Sahli H. Combining dense structure from motion and visual SLAM in a behavior-based robot control architecture. International Journal of Advanced Robotics Systems, vol. 7, issue 1, 2010.

[13] Doroftei D. Behavior based navigation techniques. Internal report MoD Study MB07, October 2006 (http://mecatron.rma.ac.be/Research/Behavior-based_Robot_Control.html).

[14] Doroftei D., Baudoin Y. Development of a semi-autonomous demining vehicle. Proceedings of the 7th IARP WS HUDEM'2008, The American University in Cairo (AUC), Cairo, Egypt, 28-30 March 2008.

[15] De Cubber G., Dorofeti D., Marton G. Development of a visually guided mobile robot for environmental observation as an aid for outdoor crisis management operations, Proceedings of the IARP Workshop on Environmental Maintenance & Protection, July 22-23, 2008, Baden-Baden, Germany.

[16] De Cubber G., Doroftei D. Human victim detection and stereo-based terrain traversability analysis for behavior-based robot navigation, handbook using robots in hazardous environments. Landmine detection, demining and other applications. Woodhead Publishing in Mechanical Engineering, 2011, pp. 476-496. ISBN 978-1-84569-786-0.

[17] De Cubber G. Variational methods for dense depth reconstruction from monocular and binocular video sequences, PhD Thesis. VUB-RMA, 2010 (http://mecatron.rma.ac.be/Publications.html).

[18] Balta H., Wolfmayr H., Braunstein J., Baudoin Y. Integrated Mobile Robot System for Landmine Detection. Proceeding of 12th IARP WS HUDEM 2014, Zadar, 25 April 2014 (http://mecatron.rma.ac.be/pub/2014/IARP-6-BALTA.pdf).

[19] De Cubber G., Balta H. Terrain traversability analysis using full-scale 3D processing. in Proceeding of 8th IARP Workshop on Robotics for Risky Environments, Lisbon, January 28, 2015.

[20] www.fp7-tiramisu.eu (accessed on 2016-06-17).

[21] www.fp7-icarus.eu (2016).

[22] De Cubber G., Balta H., Doroftei D., Baudoin Y., 2014. UAS deployment and data processing during the Balkans flooding. 12th IEEE International Symposium on Safety, Security, and Rescue Robotics 27-30 Oktobar 2014, Hokkaido, Japan.

[23] Mechanical Demining Equipment Catalogue 2010, GICHD, Geneva, January 2010. ISBN 2-940369-33-X, http://www.gichd.org/fileadmin/GICHD-resources/rec-documents/MDE-Catalogue-2010.pdf, accessed on 2016-06-16

[24] A Study of Mechanical Application in Demining, GICHD, Geneva, May 2004. ISBN 2-88487-023-7, http://www.gichd.org/fileadmin/GICHD-resources/rec-documents/Mechanical_study_complete.pdf, accessed on 2016-06-16.