HEXAPOD ROBOT FOR HUMANITARIAN DEMINING

**Héctor Montes[1, 2], Lisbeth Mena[1], Roemi Fernández[1], Javier Sarria[1],
Pablo González de Santos[1], Manuel Armada[1]**

[1] *Centre for Automation and Robotics CSIC-UPM. Ctra. Campo Real Km 0,200 La Poveda, Arganda del Rey, 28500 Madrid, Spain. E-mails: hector.montes@car.upm-csic.es, lis_sio@yahoo.es, {roemi.fernandez, javier.sarrria, manuel.armada}@car.upm-csic.es*

[2] *Faculty of Electrical Engineering, Technological University of Panama, Panama City, Panama.*

Abstract

This paper presents the main characteristics of a hexapod robot designed and manufactured by the Centre for Automation and Robotics (CAR) CSIC-UPM, Spain. The main objective of this hexapod walking robot is carry out tasks for localisation of anti-personnel mines, using a scanning manipulator on-board with a metal detector installed on the tool centre point.

Previous works done by other hexapod robot, SILO6 (also designed and manufactured by CAR, CSIC-UPM), are considered in this paper. The SILO6 robot of DYLEMA project has been designed specifically in order to carry out humanitarian demining tasks, and it has been tested with excellent results.

The energy consumption of the hexapod robot which is described in this article is relatively low because its legs are gravitationally decoupled. Besides, it can support high payload up to about 300 kg. Finally, is introduced the concept of the hexapod robot reconfigured.

1 Introduction

Currently, detection and removal of landmines fields is a serious problem with remarkable political, social and economic dimensions. There is a clear interest in the international scientific community to solve this problem, which is addressed from different perspectives and with different methodologies. Detection and removal of infested fields with landmines of these explosive artefacts is recognized as a worldwide problem [1]. Peace agreements may be signed, and hostilities may cease, but this kind of explosives is an enduring legacy of conflict. These explosive devices can remain active for several years, they do not discriminate between military and civilian people, killing or injuring indiscriminately to soldiers as civilians, including children and humanitarian workers [2].

It is estimated that there are 110 million landmines in the ground right now, and more than 160 million are in stockpiles waiting to be planted or destroyed [3]. One solution to this problem, although perhaps not the fastest, could be the application of fully automatic systems to detect and remove the landmines. However, regardless of the latest advances in this field, this solution still seems far from possible.

Firstly, efficient sensors, detectors and positioning systems for detecting, locating, and to identify landmines are required. Second, the development of appropriate vehicles is very important to take on board these sensors and move them on infested fields of mines and, in this way, put off to human operator of a direct risk. Since the fully automatic systems for the humanitarian demining application are very complex and difficult to obtain, an intermediate solution may be the use of teleoperation and the human-robot collaboration within the control loop.

Many types of vehicles that can take on board sensors on a mine-infested area; e.g., wheeled vehicles, tracked vehicles and even legged robots; can carry out demining tasks efficiently and safely. Wheeled robots are the simplest and least costly [4-7]; tracked robots have excellent ability to travel on almost any terrain [1, 8, 9]; legged robots have a very interesting potential for this activity [10-15].

The idea of using legged robots for humanitarian demining has been developed, at least, in the last 15 years, and several prototypes of these robots have been tested experimentally. Some examples of these robotics platforms are TITAN VIII [12], AMRU-2 [11], RIMHO2 [10], COMET series [14]. These walking robots are based on configurations of legs insect type. But have been developed other configurations of walking robots for demining, such as sliding frame systems [11, 16]. The need to development walking robots to operate in certain situations where other humanitarian demining systems using wheels or tracks cannot operate properly or have low yield, has been investigated by several research centres (Roya Military Academy (RMA), Free University of Brussels, Chiba University, Tokyo Institute of Technology, The Spanish National Research Council (CSIC)).

SILO6 robot (DYLEMA project) [13, 15] has been designed by CSIC specifically in order to carry out humanitarian demining tasks, and it has been tested with excellent results. DYLEMA's project has been aimed at developing walking robots that integrate relevant technologies in locomotion, manipulation and sensors for humanitarian demining [17-19]. The main characteristics of this robot are considered in this paper.

In this work the main characteristics of a hexapod robot designed and manufactured by the Centre for Automation and Robotics (CAR) CSIC-UPM are presented. The main objective of this hexapod walking robot is carry out tasks for localisation of antipersonnel mines, taking on board a manipulator arm with a metal detector installed on it. Primarily, in Section 2 a brief summary of the main characteristics of SILO6 is presented. Afterwards, Section 3 details the mechanical design and system architecture of the hexapod robot, which is the objective of this work. Finally some future modifications in the hexapod robot and conclusions are given in Section 4.

2 The SILO6 walking robot

SILO 6 is an autonomous walking robot with six legs carrying a scanning manipulator with a metal detector installed on the tool centre point and a set of infrared sensors assembled around on it [17-19]. The infrared sensors are used for tracking the ground level and to detect any obstacle to height of the sensor head [20]. Figure 1 shows the SILO6 robot with the manipulator arm, metal detector and infrared sensors, and GPS.

The main objective of the SILO6 robot is to server as mobile platform to carry on board sensors to a mine-infested area in order to realize demining tasks. Consequently, the robot must be large enough to contain and load its subsystems, which are on board computer, electronic cards, drivers, DC motors, GPS, manipulator arm, batteries and other. However, it should be considered the body dimensions and the mass of the robot with regard to the mass, position, the movement, and the time of use the scanning manipulator. Table 1 shows the main features of SILO6.

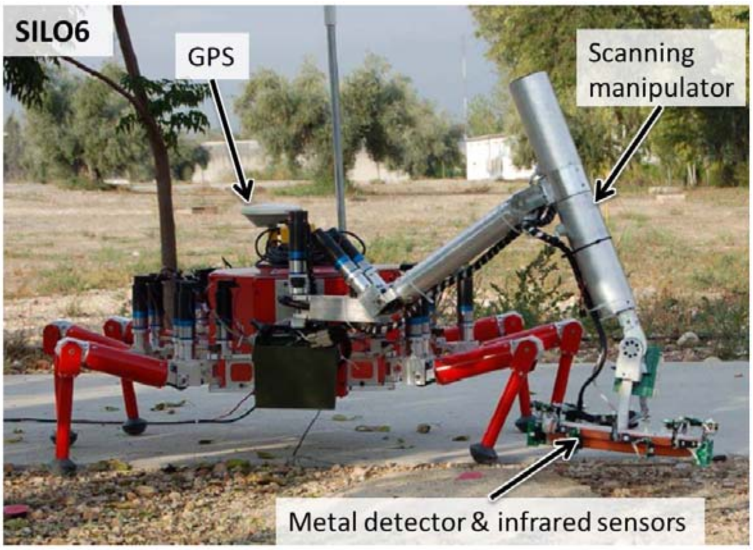


Figure 1. SILO6 carrying a scanning manipulator, a metal detector head and infrared sensors, and GPS.

Table 1. Main features of the SILO6 walking robot.

Body dimensions (mm)				Mass (kg)
Length	Width front/rear	Width middle	Height	
880	200	450	260	44.34

In general, the scanning manipulator has 5 rotational joints in elbow-up configuration, providing sufficient mobility and reducing possible undesirable contacts with other parts of the robot or objects in its environment. Together with the walking robot, the scanning manipulator orients toward the ground the metal detector coupled at its end. This manipulator is also actuated by DC motors. Figure 2 shows the scanning manipulator with metal detector head and infrared sensors. Table 2 shows the main mechanical characteristics of the scanning manipulator.

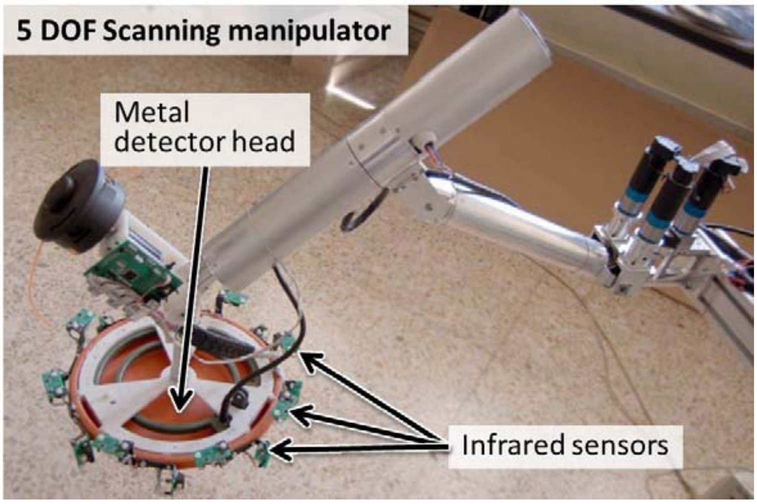


Figure 2. The scanning manipulator with metal detector head and infrared sensors.

Table 2. Main mechanical characteristics of the scanning manipulator.

Degree of freedom	5
Stability	High
Mass	7.1 kg
Maximum range	942 mm
Power supply	16-30 VDC, Typ. 24 VDC

As has been mentioned previously, the SILO6 robot has been tested with excellent results in demining tasks [13, 15]. However, over time, some deformations in joints, specifically, in the gears have appeared. This is due to the momentum caused by the manipulator arm together with the uneven terrain where the robot has walked. It is for this reason that CSIC team is reconfiguring other hexapod robot in order to carry out humanitarian demining tasks. This hexapod robot is larger than the SILO6 robot and can carry on board much bigger payload capacity. The main characteristics of this hexapod robot will be presented in the next section.

3 Description of the hexapod robot

The new configuration of the hexapod walking robot is carrying out tasks of humanitarian demining according to the requirements established in TIRAMISU Project[*]. This legged robot will carry on-board the scanning manipulator described in Section 2, several sensors to help the scanning tasks, the industrial computer, electronics, control/power cards, batteries, and other devices and accessories.

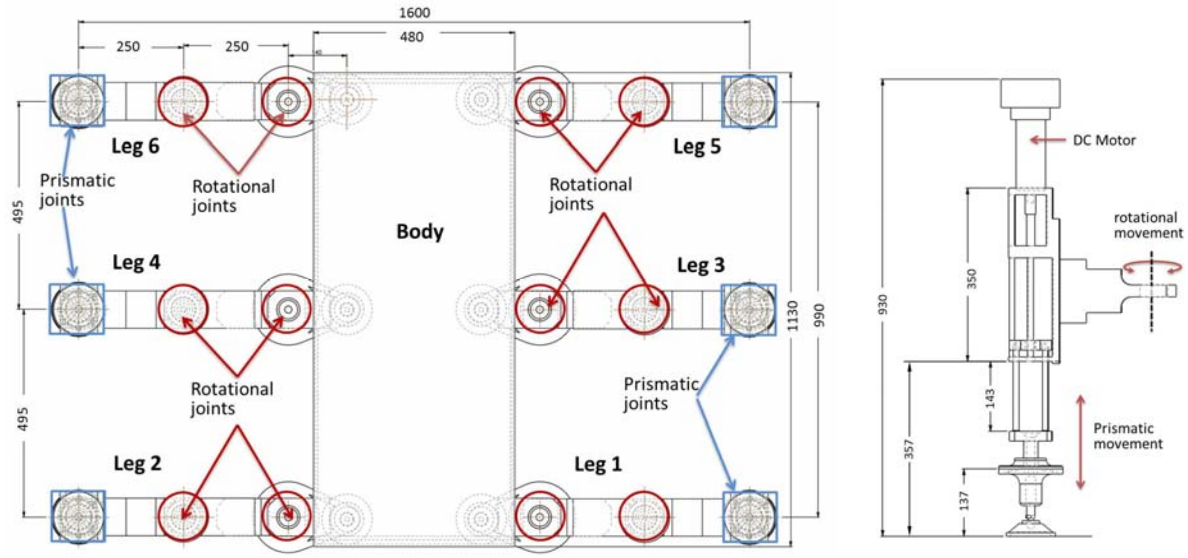
3.1 Mechanical design

Each leg of the hexapod robot has a SCARA configuration (RRP). This configuration decouples gravitationally the movement of the body robot (obviously, when it is walking on surfaces without slope). For this reason, this hexapod robot has an energetic autonomy relatively high, besides it can carry high a payload according to its size. This hexapod robot can handle masses of up to 300 kg. Consequently, the manipulator arm with metal detector and other sensors and devices installed on-board of this hexapod robot shall not comprise a significant load to the robot. Figure 3 shows the mechanical configuration of the hexapod robot. Table 3 shows the main characteristics of the hexapod walking robot platform.

The main robot gait is performed by means of an alternating tripod gait. The hexapod has three feet in contact with the ground all times, while the other legs are in transfer phase. In this gait two non-adjacent legs of one side and the central leg of the opposite side of the robot support the robotic platform, with high stability, while the other tripod are in transfer. Other gaits are also considered to be implemented on the hexapod robot. Figure 4 shows the hexapod robot in CAR lab.

---

[*] http://www.fp7-tiramisu.eu/



(a) **(b)**

Figure 3. Mechanical configuration of the hexapod robot. (a) Top view of the robot; (b) Frontal view of the leg.

Table 3. Main mechanical characteristics of the hexapod walking robot.

Degrees of freedom		18
Stability		High
Robot mass		250 kg
Payload capacity		Up to 300 kg
Obstacle height to surpass		Up to 200 mm
Power supply		16-30 VDC, Typ. 24 VDC
Body size	Length	1130 mm
	Width	480 mm
Robot size	Max length	1130 mm
	Max width	1700 mm

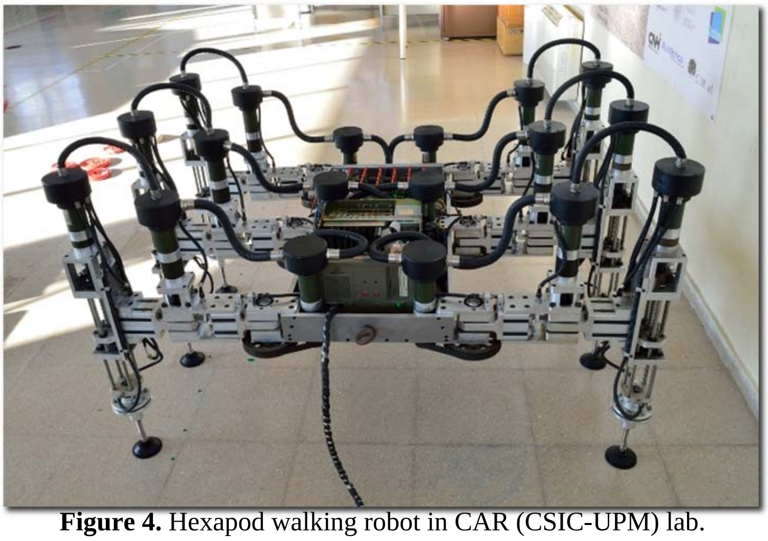


Figure 4. Hexapod walking robot in CAR (CSIC-UPM) lab.

3.2 System architecture

Currently, the system architecture of the hexapod robot consist of an on-board computer, control cards, data acquisition boards, power cards, signals conditioner cards, positioning sensors, DC motors, other accessories. This control architecture provides a reliable starting point for developing several control strategies in order to carry out humanitarian demining tasks. Figure 5 shows the most important subsystems that comprise the control architecture assembled in the hexapod robot.

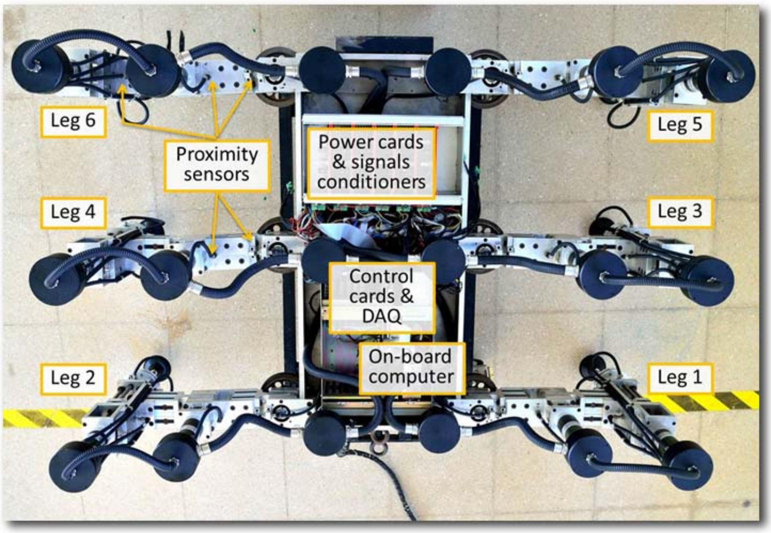


Figure 5. Subsystems of the control architecture for the hexapod robot.

The main idea is carry out stable gaits in order to the scanning manipulator can perform correct movements of its end effector, where is installed the metal detector head. To make this possible, the hexapod robot shall move to a fix position so that the manipulator arm carries out the ground scanning. Standard procedures with minimal requirements for the sweeping techniques must be considered. Some comments related with these standards can be seen in [21]. The motion of the robot is proposed by mean of the strategies demining tasks, which is sent to trajectory generation stage. This stage using the robot kinematic and the PID control performs the controlled movement of the hexapod robot. Figure 6 shows the general control architecture of the hexapod robot.

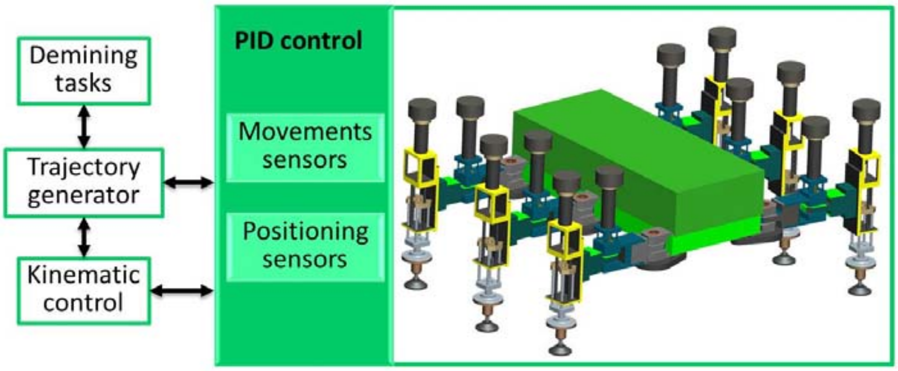


Figure 6. General control architecture of the hexapod robot.

4 Conclusions and future works

Preliminary experimental test in CSIC lab, the hexapod robot has demonstrated high stability during the performance of several gaits. The legged robot has carried a load of more than 50 kg during the tests, and power consumption has been insignificant, therefore, carries the scanning manipulator and other additional sensors on-board will be feasible.

The coordination between the scanning manipulator and the hexapod robot will be similar than the previous one concept carried out in the DYLEMA project [17-19]. However, a new phase of reconfiguration of the hexapod robot will be carried out in the next weeks. The hexapod robot reconfigured will be longer than the previous one and the shoulder joints will be modified. These will be displaced somewhat beyond the body, and the pulley-belt mechanisms that move them will be removed. This concept will provide a velocity increase of about twice in these joints. With the increasing size of the robot body, the legs will be slightly separated resulting in a larger working space than the previous hexapod robot. In general, the new hexapod robot configuration will have a higher forward speed and a capacity to support on it more sensors and other devices. In Figure 7 the general control architecture of the reconfigured hexapod robot is presented. Note that the new concept mechanical design of the hexapod robot is also shown.

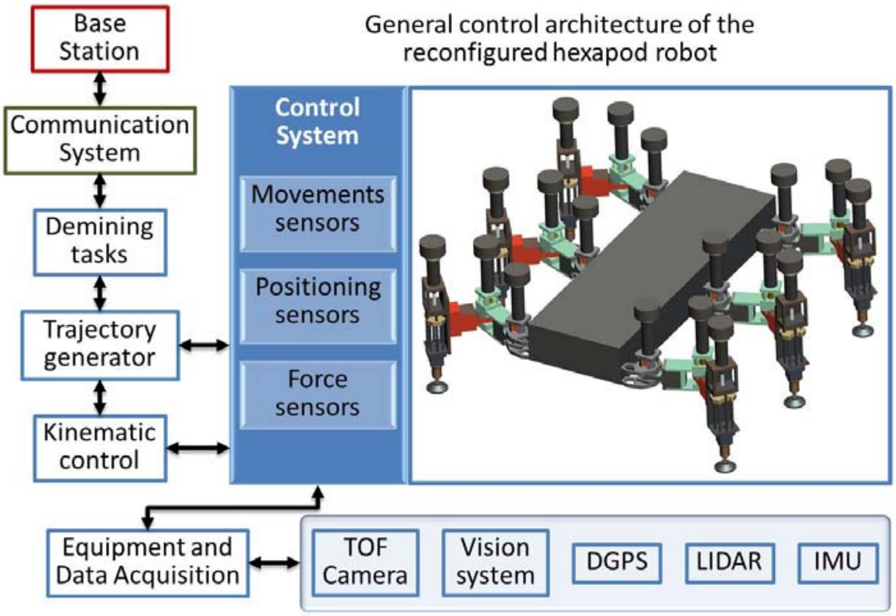


Figure 7. General control architecture of the reconfigured hexapod robot.

Acknowledgment

The authors acknowledge funding from the European Commission under 7th Framework Programme (TIRAMISU Grant Agreement Nº 284747) and partial funding under Robocity2030-III-CM, S2013/MIT-2748. Dr. Héctor Montes also acknowledges support from Universidad Tecnológica de Panamá.

References

[1] Baudoin, Y., et al. 1999. EC Brite/Euram TN on Climbing and Walking Robots, including the Support Technologies for Mobile Robotic Machines, (CLAWAR), Year 2 Report: TASK 9, Humanitarian demining.

[2] Landmine Monitor 2010, International campaign to ban landmines. Available in: http://www.the-monitor.org/lm/2010/resources/Landmine_Monitor_2010_lowres.pdf

[3] Landmine Monitor 2011, International campaign to ban landmines. Available in: http://www.the-monitor.org/lm/2011/resources/Landmine%20Monitor%202011.pdf

[4] Baudoin, Y, and Doroftei, I. 2012. TriDem - A Wheeled Mobile Robot for Humanitarian Mine Clearance. In Proc. 6th IARP Workshop on Humanitarian Demining (HUDEM), 24-26 April, Sibenik, Croatia, pp. 93-98.

[5] Baudoin, Y., Habib, M.K., Doroftei, I. 2011. Mobile robotics systems for humanitarian demining and risky interventions. Using robots in hazardous environments. Woodhead Publishing Limited.

[6] Kopacek, P., Silberbauer, L. 2008. A new Locomotion Concept for Humanitarian Demining Robots. 7th IARP International workshop on Humanitarian Demining, El Cairo, Egipto.

[7] Fukushima, E., Freese, M., Matsuzawa, T., Aibara, T., and Hirose, S. 2008. Humanitarian demining robot gryphon. Current status and an objective evaluation. Intl. Journal on Smart Sensing and Intelligent Systems, Vol. 1, No. 3, pp.735-753.

[8] Munsang K., et al. 2002. Development of a Mobile Robot with Double Tracks for Hazardous Environment Applications (ROBHAZ-DT). IARP WS on Robots for Humanitarian Demining. Vienna, Austria.

[9] Waterman, D., Nonami, K., Yuasa, R., Amano, S., Masunaga, S., Ono, H. 2005. Control and operational of a teleoperated hydraulic manipulator for landmine prodding and excavation. IARP WS HUDEM 2006, Tokyo, June 2005.

[10] Gonzalez de Santos, P. and Jimenez, M.A. 1995. Generation of discontinuous gaits for quadruped walking machines. Journal of Robotics Systems, 12(9): 599-611.

[11] Habumuremyi, JC., et al. 1998. Rational designing of anelectropneumatic robot for mine detection. CLAWAR'98, First International Symposium, Brussels, Belgium; November, 26-28.

[12] Hirose, S. and Kato, K. 1998. Quadruped walking robot to perform mine detection and removal task. In Proc. of the 1st International Conference on Climbing and Walking Robots, Brussels, Belgium, pp. 261-266.

[13] Gonzalez de Santos, P., Garcia, E., Estremera, J., and Armada, M.A. 2002. Silo6: design and configuration of a legged robot for humanitarian demining. IARP WS on Robots for Humanitarian Demining. Vienna, Austria.

[14] Nonami, K., et al. 2003. Development and control of mine detection robot comet-II and Comet-III. JSME International Journal, Series C, Vol. 46, Nº3, pp. 881-890.

[15] Gonzalez de Santos P, Cobano J, Garcia E, Estremera J, Armada M. 2007. A six-legged robot-based system for humanitarian demining missions. Mechatronics, 17: 417–430.

[16] Marques, L., Rachkov, M., and Almeida, A.T. 2002. Control system of a demining robot. In Proc. of the 10th Mediterranean Conference on Control and Automation. Lisbon, Portugal.

[17] P. Gonzalez de Santos, E. Garcia, J.A. Cobano, and T. Guardabrazo. Using Walking Robots for Humanitarian De-mining Tasks, Proc. 35th ISR, Paris, France, March 23-26, 2004.

[18] Cobano J, Ponticelli R, Gonzalez de Santos P. Mobile robotic system for detection and location of antipersonnel land-mines: field tests. Ind Robot, 2008; 35(6):520–7.

[19] Armada, M., Cobano, J., Garcia, E., and Gonzalez de Santos, P.. Configuration of a legged robot for humanitarian de-mining activities. IARP International workshop on Robotics and Mechanical Assistance in Humanitarian Demining, Tokyo (Japan), 2005.

[20] Ponticelli, R., Garcia, E., Gonzalez de Santos, P., and Armada, M. 2008. A scanning robotic system for humanitarian de-mining activities. Indus- trial Robot, 35(2), pp. 133-145.

[21] Fernández, R., Montes, H., Salinas, C., González de Santos, P., Armada, M. (2012) "Design of a training tool for improving the use of hand-held detectors in humanitarian demining", Industrial Robot: An International Journal, Vol. 39 Iss: 5, pp.450 – 463.