RoboCup Rescue 2017 Team Description Paper FinDER - UNAM

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Info

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RoboCup Rescue 2017 TDP collection: http://wiki.robocup.org/Robot_League

***Abstract*—This paper describes the work performed by the FinDER-UNAM team with the objective of creating a search and rescue robot, able to assist rescue brigades in tasks such as the exploration of semi-collapsed buildings and the search for survivors in disaster environments. Our team has been developing this project since 2012. During this time, we have obtained valuable experience to perform the search and rescue tasks required at this competition. Our participation in the RoboCup 2014 in Brazil, served as valuable experience and gave us important feedback that guided the improvements described in this document. As part of the developing process, we crafted four different prototypes of our robot, each time having better locomotion or manipulation capabilities. In this paper, we mainly focus on describing the systems that compose our most recent robot, called FinDER v3. This last version was designed with the goal in mind of participating in the RoboCup 2017 in Nagoya Japan, and, by doing so, of having the opportunity of extensively testing the design in a challenging arena, as well as receiving critical feedback from the search and rescue robotics community.**

***Index Terms*—Caterpillar system, arm robotic, suspension system**

I. Introduction

FinDER UNAM Team has been created by the workgroup Taller de Robotica Abierta. This team was formed in October 2011 with the objectives of researching and developing technology solutions by means of applied robotics which could help rescue brigades in search and rescue operations.

Due to its geographic location, Mexico City is vulnerable to earthquakes because it is between tectonic plates: the Pacific, the North American and the Cocos plates. Additionally the city was built in the residuaries of a lake. This causes displacements in the ground and building collapse. Due to this, there is interest in developing technology to help reducing death rate in the aftermath of this kind of disasters.

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Gerardo Ramos is undergraduate student of mechatronics engineering

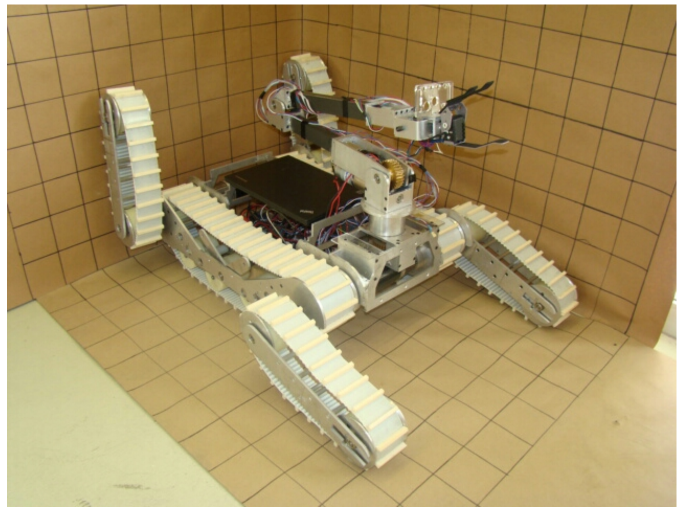

Fig. 1. Robot FinDER v3.

In our workgroup we develop search and rescue robots. Human localization, complex locomotion and manipulation of objects are some of our areas of interest.

Right now, we are working on a unmanned ground vehicle, small swarm robots, underwater robot for exploration and a quadcopter for navigation using artificial vision.

Our rescue robot, called FinDER (Finder in Disaster Environment Robot), has had three previous versions. FinDER v1 was the first prototype, it was a mobile base with four wheels , two of them omnidirectional to provide a differential wheel configuration, and a little robotic arm with 0.3 m range which was too little for its tasks requirements. Navigation and some sensors worked out correctly, but the main motors were overheating, and eventually failed. Consequently we had to move to a new mobile base.

The second mobile base which was adapted to the previous system, was called FinDER v0, a new robotic arm with 5 DOF, 1 m range and a load capacity of 0.2 kg in the end effector was coupled to it. On this version was improved manipulation, but the disadvantage was it only performed well on flat terrain. In Figure 2, the two versions of the robot described above are observed.

On the third version called FinDER v2 the mobile base was completely reengineered, giving it two traction caterpillars covered with rubber pieces to ease motion on irregular terrain. The design included articulated track extensions to achieve stairs and obstacles climbing. It had a onboard laptop and a

Fig. 2. The image a, is a photograph of the robot FinDER v1 and the image b, corresponds to the robot FinDER v0.

scanning range laser finder, and the robotic arm was equipped with some biometric sensors: 16 x 4 thermal imager, CO_2 sensor and several webcams. Disadvantages were the weight of 70 kg, and the propensity of the caterpillars to fail, blocking the traction mechanism and making impossible to move forward or backwards.

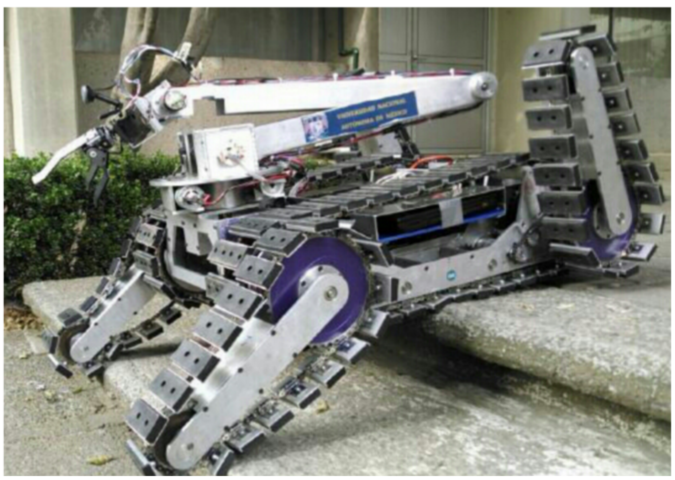

Fig. 3. Robot FinDER v2 during locomotion tests. In this photograph, the robot goes down a couple of steps.

Right now, we are working on the construction of a new version called FinDER V3, which counts with improvements in locomotion and manipulation. Figure 1 shows the new version of the robot and we add a YouTube link in the Reference section where we show our experiments [1].

II. System Description

A. Hardware

1) Locomotion: On this new version, a new locomotion mechanical design was developed taking into account the previous version issues. Caterpillars are made of a polyurethane timing belt which has on its exterior face prismatic pieces attached to get good traction. Also, it has four auxiliary arms or flippers with the same mechanical configuration to help with stairs and obstacles climbing. Traction subsystem has a new suspension system which has two purposes, first, it helps making smoother the movement of the robot, and it also works as a tension system for the polyurethane timing belts [2], [3].

Traction system has a new suspension subsystem powered by two Ampflow E30-400 motors with 25:1 reduction, it has

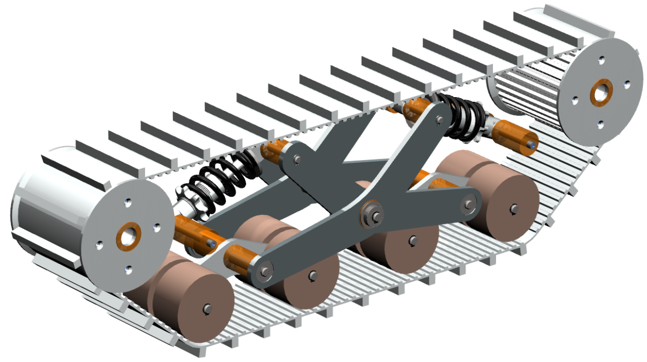

Fig. 4. Suspension subsystem. This is the improvement of the traction system of the previous version (FinDER v2).

a differential wheel configuration, auxiliary arms are powered by AndyMark PG71 motors each one with 44:1 with a self blocking mechanical configuration, which lets the system stay at its current working position without providing current to the motors.Image of this on Figure 4.

2) Power (Batteries): Five LiPo batteries in parallel connection are used to supply energy to the robot. With a backup of other five to switch between them for charge and use. Each battery has 4 LiPo cells of 3.7V and 5000 mAh. Therefore, on the whole, the robot energy supply are 14.8 V and 25,000mAh. This batteries are recharged individually using a quadruple balancing charge device.

3) Electronic system: Three ARM-Cortex M4F (Stellaris Launchpad) microcontrollers are used to move all the motors and also to communicate with some sensors and the illumination system. In order to control Ampflow E30-400 motors, which have a locked-rotor current consumption of 140 A at 12 V, we use two Open Source Motor Controller (OSMC) which support a maximum current of 160 A. GPIO pins are needed to communicate the microcontrollers with the OSMC. Four PG71 motors are used move the four robot flippers. They have a locked-rotor current consumption of 22 A. These motors are controlled by two RoboClaw 2x30A motor drivers which have a position control embedded using magnetic encoders AS5043 from Austria Microsystems as feedback. All the used RoboClaw motor drivers are communicated with the microcontrollers via serial communication. On the robotic arm, we use a Talon SR motor driver for the base rotation joint. Shoulder and elbow joints are actuated by AndyMark PG71 motors, they are controlled using RoboClaw 2x15A with AS5043 encoders for feedback. Two pololu 37D motors with 131:1 mechanical reduction provide roll and pitch wrist motion and they are also controlled by one RoboClaw 2x7.5A. All these motor drivers are communicated with one Stellaris Launchpad, which also controls a Hitec servomotor, for the yaw joint, and a Dynamixel servomotor which generates the gripper motion. Figure 5 shows the whole electronic diagram connection.

Finally, all sensors and illumination leds are described on next section, they were connected to another Stellaris Launchpad which also communicates with the onboard laptop.

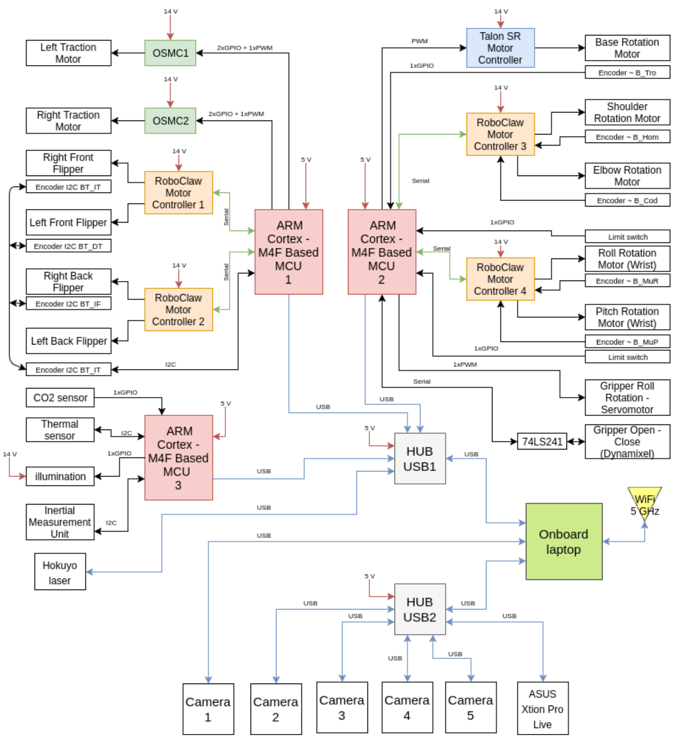

Fig. 5. Block diagram of the electronic system.

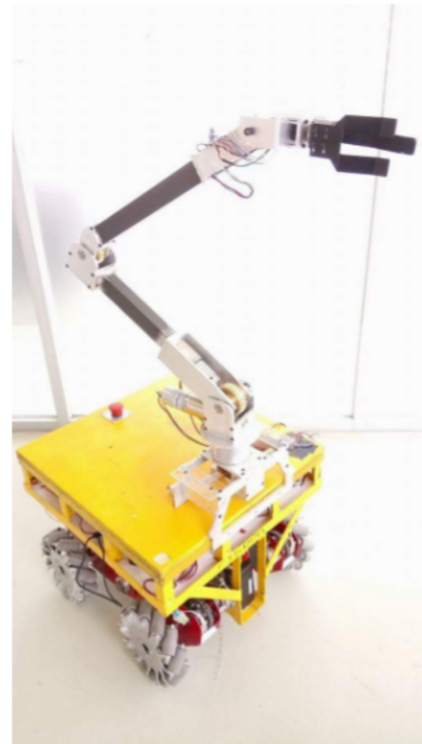

Fig. 6. The second version of the manipulator temporarily embedded in a multi-purpose base.

4) Sensors: The following is a brief description of the main sensors of the robot:

Cameras. Five PlayStation Eye cameras are used with 640x480 @ 60 fps, so the remote teleoperator can observe the environment and for image processing to achieve human detection and motion.

Depth Camera RGB. Many routes on these scenarios (disaster areas, collapsed buildings, rubble fields) are extremely uneven to be well characterized by a scanning laser rangefinder, therefore we use a RBD-D camera (in this case the ASUS Xtion Pro Live) for environment 3D data acquisition and determine the terrain accessibility. It has a 45° vertical by 58° horizontal field of view and a depth image size of 640x480 at 30 fps.

Thermal sensor. A MLX90620 16x4 far infrared array is used to detect heat sources. The body heat of a victim can be sensed this way, scanning the environment with the robotic arm.

CO_2 **sensor.** A CO_2 sensor is used to detect victim respiratory activity. While the sensor is slow and has relatively small range, for victim confirmation purposes the sensor is a good fit.

Microphone. A small microphone can pick up sounds produced by victims, helping human localization. When confirmed, it can also serve to listen for victims requests. While we currently do not implement a 2-way communication system, this is a relatively straightforward task.

IMU. A 9DOF inertial measurement unit is used to allow the operator to know the robot orientation and the sensor data properly filtered is used for the navigation algorithm. This sensor includes the ADXL345 accelerometer, the HMC5883L magnetometer, and the ITG-3200 mems gyro.

5) Manipulation: In order to improve manipulation capabilities, the robotic arm was redesigned. The new robotic arm version has 6 DOF and a gripper at the end effector. Pick and place operations can be achieved with objects up to 2 kg and a maximum distance of 1.10 m from the arm base. Additionally, some previous issues were solved. For instance, the oscillation that the previous arm had was significantly reduced. Controllability was also improved due to a new self blocking transmission which is composed by a worm drive. This new mechanical configuration allows the robotic arm to keep an extended position without electrical energy supply for the the first three joints motors. The last three joints, that provide the end effector orientation, were designed in an Euler-configuration. Figure 6 shows the robotic arm temporarily embedded in a multi-purpose base where the manipulator was tested.

6) Computation: Two computers are used to operate our robot. The onboard computer is a Lenovo Y50-70 laptop, with Intel i7 2.50GHz processor and 12GB Memory. The workstation computer is a Laptop Asus ROG G752VY-GC367T, Intel Core i7-6820HK 2.7GHz, 32GB memory and NVIDIA GeForce GTX980M 8GB graphics card. Both computers run ROS Indigo through Ubuntu 14.04.

7) Communication: An ASUS RT-AC5300 router, with tri-band system with dual 5 GHz and single 2.4 GHz, is used to communicate the robot and the workstation.

B. Software

The following describes the operation of the different parts that make up the software of the robot. The Table III lists the main software packages used.

1) Low level control: Five joints of the robotic arm are actuated by DC motors. The first joint is controlled using a Talon SR motor driver and it is controlled by a PID node programmed in ROS which sends PWM values to the corresponding Stellaris Launchpad. The following four joints are controlled by two RoboClaw motor drivers, they also have a PID controller programmed, so we only send position commands from the onboard computer to the corresponding Stellaris Launchpad via serial communication. The same low level control is going to be used in the auxiliary arms (flippers) that will also have RoboClaw motor controllers. A PWM signal is sent from the Stellaris Launchpad to a Hitec servomotor, which generates the gripper roll motion. The gripper opening and closing motion is generated by a Dynamixel AX12A servomotor which is controlled using the libraries provided by the manufacturer (Robotis).

2) Navigation localization and mapping: Mapping generation is performed using the ROS package Hector SLAM. Map is represented by a 2D occupancy grid, each one of the cells in the grid has associated a occupancy probability. This map is generated by the node hector_mapping, which has a SLAM algorithm. Despite it generates a 2D map, the SLAM algorithm actually does a 3D motion estimation. Sensors used to solve this are a IMU and a Scanner Range Finder. IMU is used to recognize the orientation of the base robot frame (roll and pitch angles), and the Scanner Range Finder exploration data are used to refresh the map and estimate the 2D position of the robot.

Finally, to trace the traveled trajectory by the robot, the *hector_trajectory_server* node is used, which tracks the robot pose and saves this data.

Figure 7 shows the traveled trajectory by the robot and a map generated using Hector SLAM ROS package. This is a map of a building of the Faculty of Engineering at UNAM.

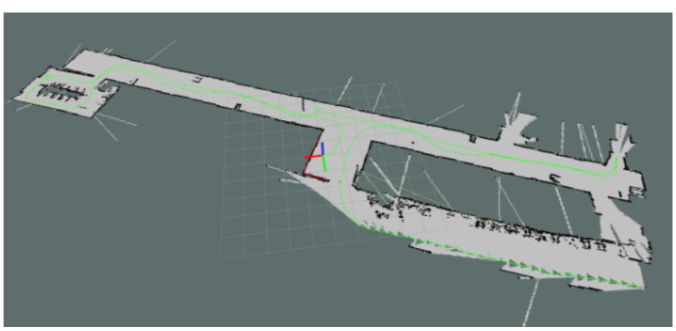

Fig. 7. Map generated by hector_slam package.

3) Victim detection: Simulated Victim identification is based on a signal weighing, these are: temperature, CO_2 environmental concentration and humanlike (anthropomorphic) shapes, the detection of these signals is described next. Using a thermograph previously calibrated with human temperature gradients ranges, we detect the characteristic heat of the body. For the CO_2 environmental concentration, the signal from a MLX90620 sensor is compared to a victim simulated breathing CO_2 emission using a threshold classifier. Humanlike shapes are characterized using Haar cascade classifiers [4], which are applied using the webcam attached to the end effector of the robotic arm.

Additionally there is research with an infrared camera which detects human temperature gradients. Also for the detection of small ditches and holes which could be occupied by victims we are working with an Asus Xtion Pro sensor, to measure depth gradients and detect on an independent way possible places where victims could be located. To enhance identification, we are testing deformable models for the human-like shapes as well as search of the characteristic color of human skin using back projection.

4) Hazmat label recognition: For Hazmat labels identification we use the method proposed by [5], which consists in characterize each label through back projection and a SURF detector, using a Logitech C920 camera because it has automatic white balance and focus.

5) Motion Detection: Movement detection is achieved using optic-flow-pattern to the candidate regions, which are acquired through the differences between frames when the camera is static.

6) Pattern C gap recognition: The detection of this pattern is achieved using a SURF detector. In order to identify the regions corresponding to the ditches and locate such regions, segmentation the image and be able to calculate the opening angle of the pattern. The symbol selection is made by contour detection.

7) Acoustic number identification: We are working with the linear predictive coding algorithm LPC [6] in order to obtain the quantization vectors by comparing the minimum distortion measure of Itakura-Saito. Previously to this phase, a preprocessing of the audio is performed to obtain better results, which consists of a filtering through a Hamming window and the autocorrelation of the signal.

8) Arm control: The teleoperation of the robotic arm is done with an Xbox control. Moving joint by joint (forward kinematics), the end effector is located at a desired position and orientation. A virtual model of the robot was made to provide visual feedback for the teleoperator. An intermediate node subscribes to the encoders lectures topics, maps the values and publishes the joint states. Robot State Publisher (a node provided by ROS) subscribes to the intermediate node and publishes the right data to RViz, which displays the whole robot joints states and orientation. Figure 8 shows the virtual model representation.

C. Communication

Our communication system uses a wireless LAN, we connect the robots onboard computer with the operator's workstation using the router, enabling remote operation through ROS. All microcontrollers are connected to the onboard computer in a master/slave architecture using the serial protocol and ROS. If fail the current communication, the robot had backup system with Xbee modules that enable control only the locomotion system.

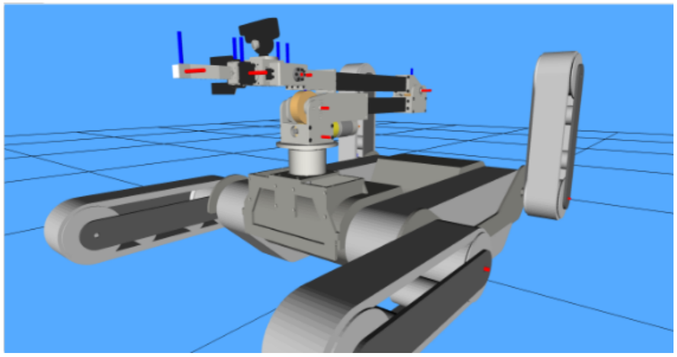

Fig. 8. Virtual model of the robot used in simulations in RViz.

D. Human-Robot Interface

The Human Robot Interface (HRI) used is a web page deployed on the operator's workstation. The web interface uses Bootstrap framework, which facilitates the design process using HTML and CSS based element templates. The HRI displays information about the robot's sensors, the views of the cameras, as well as the status of the robot. Addittionally, RViz is used to visualize the map generated, the model of the robot and its location within it.

In order to establish the communication between ROS and the HRI, the rosbridge_server package is used, which provides a WebSocket transport layer between client and server. rosbridge_library and roslibjs are the libraries for interacting with ROS from the browser. Finally, web_video_server package provides a video stream.

III. Application

A. Set-up and Break-Down

The operator station consist of a laptop connected to one joystick for controlling the robot navigation and the robotic arm. The laptop is connected to a router placed in the operator station with a battery system, all these are fitted in a backpack carried by the operator and let it use in any place. The robot has to be transported by two persons from the worktables to the start point in the test arena using handlers in the robot.

B. Mission Strategy

In a real environments, ground robots are tested against bad conditions when they are exploring, with the mission of finding victims or map unknown areas that are hard to access or dangerous for humans.

In this RoboCup, we are trying to test a teleoperated robot with independent algorithms, so it can detect victims based on different types of signals (audio, video and CO_2 emissions) that may happen in disaster situation. In addition the FinDER v3 will test the operation of a damped traction system, which is able to adapt at irregular terrain, as well as handling objects with a robotic arm. Also incorporates recognition of hazardous materials, allowing special tasks teams to use our prototype in situations of chemical risk, which could be present industrial scenarios.

C. Experiments

In the Robocup 2014 we tested the previous version of our robot in differents arenas and obtained important feedback for our current robot version. When victims are in lateral walls the wrist did not have a pan displacement and could not rotate the camera and sensors to face the victim. When the robot crossed a void section or was climbing stairs, the auxiliary arms had not enough torque for fixing a specific position and was hard to get through the test. Due to the distribution of cameras and without feedback position of the robot, the robot crashed and pushed the walls of the arena.

D. Application in the Field

In a real disaster field the Team arrived with only two backpack, the first one contain the robot that only need power on for start the mission, because the onboard system start on the boot the necessary programs. The second backpack contain workstation computer with autostart the programs, the router, backup batteries and joystick already connected. The interface deploy the generated map, real time video, sensor states and robot states.

IV. Conclusion

In this new FinDER version many problems that we faced in the RoboCup 2014 were solved. The problem of keeping tensed the caterpillar was solved due to the new traction system. We hope the damping system, added in the robot base, to minimize the physical damage caused by crossing through difficult terrains.

According to our experiments, the new robotic arm has a better performance, the oscillation that the previous robotic arm had is significantly less in this version. Loading objects for a large period of time when the robotic arm is totally extended is now possible because of its new self blocking transmission. The improvements in manipulation will be reflected in a faster victim detection because most of the victim sensors are embedded in the robotic arm end effector. The real-time robot state simulation allow us to know the precise position and orientation of the robot. Together, cameras and robot simulation will enhance the robot teleoperability and obstacle avoidance. Finally, we hope the flippers to have a better performance, our mechanical design and calculations suggest them to be able to load the whole robot for a relatively large period of time.

APPENDIX A
TEAM MEMBERS AND THEIR CONTRIBUTIONS

- Gerardo Ramos — Team Leader
- Sergio Hernandez — Mechanics design
- Humberto Cruz — Mechanics design
- Mauro Rivero — Architecture design
- Cesar Pineda — Control set-up
- Jorge Azuara — SLAM programming/user interface design
- Carlos Garcia — Computer Vision
- Eli Baron — Sensor set-up
- Miguel Fernandez — Sensor set-up/Motor drivers set-up
- Stalin Muñoz — Artificial Intelligent advisor
- Ulises Peñuelas — Mechanical design advisor
- Yukihiro Minami — Faculty advisor

APPENDIX B
CAD DRAWINGS

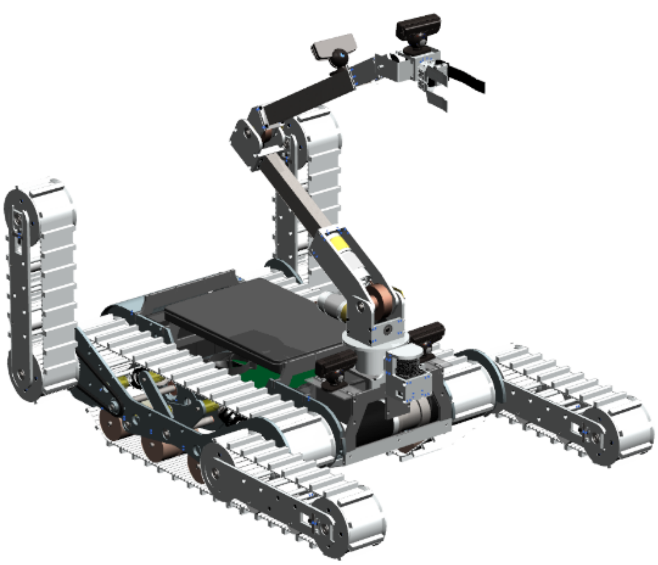

Fig. 9. 3D model of the robot FinDER v3.

APPENDIX C
LISTS

A. Systems List

See Table I. The prices are referenced in American dollars.

B. Hardware Components List

See Table II. The prices are referenced in American dollars. The total cost does not consider the components marked with the symbol *.

C. Software List

See Table III. The prices are referenced in American dollars.

Fig. 10. 3D model of the new arm version.

ACKNOWLEDGMENT

Research carried out thanks to the program UNAM-DGAPA-PAPIIT IT102615 No conventional robots for exploration and searching tasks (Robots no convencionales para tareas de exploracion y busqueda).

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TABLE I
MANIPULATION SYSTEM

Attribute	Value
Name	FinDER v3
Locomotion	2 AmpFlow E30-400
System Weight	70 kg
Weight including transportation case	90 kg
Transportation size	6 suitcases 0.76 x 0.5 x 0.32 m
Typical operation size	0.7 x 0.8 x 0.5 m
Unpack and assembly time	360 min
Startup time (off to full operation)	10 min
Power consumption (idle/ typical/ max)	60 / 200 / 800 W
Battery endurance (idle/ normal/ heavy load)	160 / 80 / 40 min
Maximum speed (flat/ outdoor/ rubble pile)	0.7 / 0.3 / - m/s
Payload (typical, maximum)	1/ 10 kg
Arm: maximum operation height	1.1 m
Arm: payload at full extend	2 kg
Support: set of bat. chargers total weight	2.5 kg
Support: set of bat. chargers power	1,200W (100-240V AC)
Support: Charge time batteries (80%/ 100%)	90 / 120 min
Support: Additional set of batteries weight	2 kg
Cost	5000 USD

TABLE II
HARDWARE COMPONENTS LIST

Part	Brand & Model	Unit Price	Num.
Drive motors	AmpFlow E30-400	109	2
	PG71-AM9015	69	4
Chassis	Custom design	3000	1
Drive gears	Custom	1000	2
	BeDaVi carterpillars	1200	1
Drive encoder	AS5043 magnetic encoder	0	9
Motor drivers	OSMC	200	2
	Roboclaw 30A	120	3
	Roboclaw 7A	70	1
	Talon speed controller	60	1
DC/DC		40	1
Battery Management		50	1
Batteries	PS-12180	70	2
Micro controller	Stellaris Launchpad	13	3
Computing Unit	Lenovo Y50-70	1200	1
WiFi Adapter	ASUS RT-AC5300	500	1
IMU	Sensor stick	100	1
Cameras	Play Station Eye	50	4
RGB-D Camera	Asus Xtion	200	1
∗Infrared Camera	FLIR A35	6000	1
LRF	Hokuyo URG-04LX	1000	1
CO_2 Sensor	MLX90620	20	1
Battery Chargers		80	1
6-axis Robot Arm	Custom	1500	1
	PG71-AM9015	89	1
	PG188-RS775	89	1
	Pololu 37D 131:1	40	2
	Hitec HS-5625MG	30	1
	AX-12 Robot Gripper	99	1
*Rugged Operator Laptop	ASUS ROG G752	3000	1
Total cost		9000	

TABLE III
SOFTWARE LIST

Name	Version	License	Usage
Ubuntu	14.04	open	
ROS [7]	indigo	BSD	
PCL [8]	1.7	BSD	ICP
OpenCV [9], [10]	2.4.8	BSD	Haar: Victim detection
OpenCV [11]	2.4.8	BSD	SURF: Hazmat detection
Hector SLAM [12]	0.3.4	BSD	2D SLAM
Proprietary GUI from Azuara.	0.7	closed source	Operator Station