RoboCup Rescue 2015 – Robot League Team P.A.N.D.O.R.A. (Greece)

Loukas Petrou, Andreas Symeonidis, Charalampos Dimoulas, Emmanouil Tsardoulias

School of Electrical and Computer Engineering

Aristotle University of Thessaloniki

54124 Thessaloniki, Greece

`loukas@eng.auth.gr, asymeon@eng.auth.gr, babis@eng.auth.gr, etsardou@eng.auth.gr`

Abstract. Within the context of the 2015 RoboCup-Rescue competition (www.robocup.org) the PANDORA Robotics Team of the Aristotle University of Thessaloniki has developed an experimental robotic platform dedicated to exploration and victim identification. Our robot is able to autonomously navigate through unknown space (e.g. building ruins after an earthquake), avoid obstacles, search for signs of life and identify victims. We are going to use a 4-wheel drive robotic platform aiming at identifying victims residing in the yellow arena and the radio drop-off zone.

Keywords. PANDORA, Robotics, Search and Rescue, Autonomous Agents

1 Introduction

The PANDORA Robotics Team (**P**rogram for the **A**dvancement of **N**on **D**irected **O**perating **R**obotic **A**gents) of the Department of Electrical and Computer Engineering (DECE) of Aristotle University of Thessaloniki (AUTH), Greece aims in developing an experimental robotic platform for indoor exploration and victim identification. The PANDORA Robotics Team was founded in 2005 and has already participated in the RoboCup-Rescue 2008, 2009, 2011 and 2013 competitions. This year, the team intents to participate in the yellow arena and the radio drop-off zone.

2 Control method and HRI interface

The PANDORA robot will operate in two modes: the fully autonomous mode, where a number of concurrent processes will be deployed in order to achieve autonomous exploration and victim identification and the teleoperation mode, where the robot will be manipulated by an experienced user. In order to ensure a flexible and modular scheme where reconfiguration is possible, we opted for component based software architecture. Next, the selected architecture is presented.

3 Software / hardware architecture

It is common knowledge that autonomous robots are highly complex systems that require both HW/SW integration, as well as the deployment of multiple heterogeneous modules. Middleware frameworks aim to minimize this complexity by providing infrastructure and tools for building modifiable and reusable solutions, while successfully dealing with communication issues, component heterogeneity, coordination, task scheduling and allocation [1]. Having considered various off-the-shelf middleware (including MSRS, OROCOS and ROS), we adopted ROS[1] for PANDORA's middleware. A number of factors were considered during the middleware selection process. A messaging communication scheme was preferred to a typical RPC-style middleware, due to its inherent ability to promote loose coupling. Furthermore, messaging provides asynchronous communication with the ability to control dataflow, an extremely important feature for complex interconnected systems.

To achieve maximum decoupling, a modular approach was followed, thus defining various levels of abstraction. Interfaces realizing communication between components are encapsulated and decoupled from the implementation, thus providing domain-specific functionality only at a component level [2]. Functionality is logically grouped and satisfied by different packages implementing nodes that perform different tasks. The adopted software design decouples nodes from each other as much as possible, thus minimizing the induced interconnection complexity. The modules developed are (http://pandora.ee.auth.gr/wp-content/uploads/2015/07/software_architecture.png) :

- *Hardware Interface*: it controls data flow from and to the microcontrollers, acting as a Hardware Abstraction Layer for the robot. This module handles most of the sensors and the motor controllers.

- *SLAM*: The SLAM module is responsible for performing Simultaneous Localization and Mapping.

- *Control*: solves the vehicle's kinematic model and produces linear and rotational velocities enabling the vehicle to move.

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[1] http://www.ros.org

- *Sensor Preprocessing*: handles raw data received from thermal, sound and CO2 sensors.

- *Vision*: responsible for handling the RGB (and D) cameras used for exploration and finding possible victim locations, as well as the camera used for detailed victim identification

- *Navigation*: responsible for motion planning and navigating the robot through the unexplored regions of the map or towards a possible victim for further identification.

- *Data Fusion*: it decouples low-level sensor measurements for victim identification and high-level navigation components.

- *Agent*: it performs higher-level decision making and is responsible for orchestrating actions performed by all other modules by defining their state.

- *GUI*: provides a Graphical User Interface for the robot operator. In addition it provides the remote control features for teleoperation.

Regarding the hardware architecture (http://pandora.ee.auth.gr/wp-content/uploads/2015/07/hardware_architecture.png), PANDORA's system topology is based on the well-known Star-Network. In order to perform high computational power robot tasks, an Intel i7 CPU attached on a Mini-ITX motherboard (MI980 from IBase), is used as the central processing node. The first set is responsible for localization and navigation procedures, while the second for victim identification. A set of stand-alone sensors are currently installed on the robot platform:

- Two Web cameras: Used by QR and Hazmat detection procedures.

- Hokuyo UST-20LX[2] or alternatively Hokuyo URG-04LX[3] Laser Range Finder (LRF) used for mapping, localization and navigation procedures.

- Xtion Pro[4]: RGB-D camera used for identification procedures. Can also be used for localization and navigation.

- PNI Sensor Trax AHRS: Inertial Measurement Unit (IMU). Used for localization and navigation procedures. This unit is also currently used for the stabilizer module.

Furthermore two Pan & Tilt modules are currently installed. The first one is used for motion control of the head of the robot which carries the victim identification sensors. The second controls an RGB-D camera and the thermal camera, currently installed on the base of the platform's chassis. Furthermore a stabilization platform is employed in

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[2] http://www.hokuyo-aut.jp/02sensor/07scanner/ust_10lx_20lx.html

[3] https://www.hokuyo-aut.jp/02sensor/07scanner/urg_04lx.html

[4] http://www.asus.com/Multimedia/Xtion_PRO_LIVE/

order to ensure leveled readings from the LRF sensor regardless of the robot's inclination.

The main motion of the robot is achieved by four MAXON brushless DC motors, one for each wheel. Each motor is connected on an EPOS2 module motor controller. The motor controllers are all connected on a CANBus, thus each motor can be controlled separately. The central process node communicates with the motor control devices attached on the CANBus, via an RS232 interface.

4 Software modules

4.1 Map generation / printing

The 2D mapping algorithm used by the PANDORA team is CRSM SLAM [3], where CRSM stands for Critical Rays Scan Match. CRSM SLAM relies solely on the Hokuyo LRF sensor. A metric map and specifically an occupancy grid map is generated, where each cell holds the probability to be occupied.CRSM SLAM has the disadvantage of providing a two dimensional space representation, something that is rather limiting for advanced autonomous navigation capabilities. Thus, a 3D variant of CRSM SLAM is created. In order to do so, a depth providing sensor is required, which in our case is the Xtion Pro platform. The measurements required consist of a point cloud including the distances of the environment in a grid formulation of 640 to 480 pixels. Since the direct employment of the entire point cloud in a scan matching algorithm is impossible to be performed in an – almost – real time manner, a similar heuristic ray picking method to the CRSM SLAM will be employed. This time, the selected entities that represent the 3D scan's features, may not be just points, but even more advanced ensembles of rays, like lines or corners. The produced 3D map will have the form of an Octomap [4] and will be employed from the autonomous navigation module to perform path optimization techniques, in order to ensure safe and efficient robot navigation. Finally, the 2D map produced by the CRSM SLAM or a horizontal slice of the product of the 3D slam, will be transformed to a Geotiff form.

4.2 Navigation

PANDORA's navigation module combines state of the art techniques and algorithms, regarding path planning in 3D cluttered environments. Our path planning approach is oriented in environment exploration and full space coverage. As the main goal of the mission is to identify victims, as "covered" is denoted the space investigated by sensors responsible for victim identification. Navigation module comprises four sub-modules: the Global Planner, the Local Planner, the Target Selector and the Navigation Controller.

Global Planner is responsible for generating a path, given a goal in space, without taking into consideration the kinematic constraints of the vehicle (holonomic constraints). We use OMPL (Open Motion Planning Library) [5], to solve path planning in 3D, using an efficient octree-based [6] representation of the 3D world.

Local Planner is responsible for generating a trajectory, given a path as input (previously generated by the Global Planner), with respect to the kinematic constraints of the vehicle, as well as performs 3D collision checking with obstacles using FCL. This is done by reducing the search space to a dynamic window [7], which consists of the velocities reachable within a short time interval.

Target Selector is responsible for selecting the next goal that the robot will move to. It uses heuristic and probabilistic approaches to optimize an objective function, based on the 3D representations of the free and covered space.

Navigation Controller plays a critical role, as a coordinator of all the above sub-modules. Navigation Controller distributes all the necessary information between the different sub-modules and coordinates the communication be-tween them.

4.3 Data fusion

The Data Fusion module is responsible for filtering out the messages generated by PANDORA sensors (CO2, Thermal camera, sound module). It stores thresholds of all sensors, denoting the probability values of an eligible valid measurement. Given that a sensor measurement exceeds the threshold, Data Fusion informs the Agent in order to provide details. One should mention that thresholds are not hard-coded and are not crisp; an elaborate data fitting scheme has been introduced in order to tune raw sensor input before accepting them. Furthermore, based on the proper modeling of data sources, sophisticated machine learning mechanisms for anomaly detection are applied in order to exclude any abnormal behavior of sensors. Messages communicated by Data Fusion abide by a predefined uniform format, containing the sensor type, the probability of a measurement to be valid, and its direction, in case the sensor is directional. Apart from its basic functionality, Data Fusion also blends low-level sensor measurements and high-level data from Navigation and Vision in order to create an advanced strategy for victim identification. Probabilistic, density-based and kernel machine approaches will be considered in order to build a robust data fusion mechanism.

5 Victim detection and identification

A multimodal vision system has been implemented in order to enhance the various aspects of the victim identification task. The core of the system is an RGB-D camera a thermal camera and two (or probably more) web cameras. This core module allows for both classical image processing techniques to be combined with depth-based features and imaging approaches in order to better serve the vision requirements. During teleoperation, the RGB camera transmits a video stream to the control station, for the operator to have a visual sense of the robot’s surroundings in real time. All vision modules have been developed in C++ and heavily exploit OpenCV libraries [8] through ROS. PANDORA Vision provides the following functionality:

- *Hole detection and localization*: Detection is performed by fusing the information extracted by two separate modules uptaking the task of computing BLOBS[9] in RGB and D images, after edge detection deployment. Fusion of the above cues results to connected components at the locations of holes on a single image. Time persistent BLOBs are detected as holes. Size and shape constraints enhance detection accuracy, while closer view decisions might be engaged (after vision and data fusion) in order to further improve detection accuracy.

- *Victim detection*: A superset of RGB-D-T features is utilized, including color depth and thermal – related metrics, along with their structural features and classical face recognition features /algorithms [10].

- *Motion detection.* A video motion detection module has been implemented in order to facilitate the victim identification task. The current system is triggered by a high possibility BLOB detection message and it operates while the robot is not moving. Frame and multi-frame differencing are adopted as in case of [11], in combination with adaptive foreground / background segmentation, by means of iterative exponential averaging in time-space or wavelet domain [11] - [12].

- *Hazmat and Eye chart pattern, QR code and Landolt-C detection.*

We consider that temperature differences in the environment could imply victims. Thus we have installed a long-wave infrared (LWIR) camera, in order to compare temperature values, find fluctuations and make an estimate of a victim's position, if one is detected. The FLIR LEPTON[5] is a LWIR camera module designed to interfere easily into native mobile-device interfaces. It captures infrared radiation input in its nominal response wavelength, from 8 to 14 microns. It has a Focal Array Plane (FPA) of, 80(h) x 60(v) active pixels, with active thermal sensitivity less than 50mK (Kelvin), 51-degrees horizontal typical field of view and 63.5-degrees diagonal. The FLIR LEPTON LIWR camera is connected on an ARM-based microcontroller. It provides a command and control interface (CCI) via a two-wire inter-face similar to I2C. Frame transfers are provided through the LEPTON video-over-SPI protocol (VoSPI) allowing efficient and verifiable transfer of video over a SPI channel.

Furthermore, our CO2 sensor (DYNAMENT , Premier High Range Carbon Dioxide Sensor, Non-Certified Version Type MSH-P-HCO2/NC) measures the concentration of CO2 gas in the environment. For the detection of the human respiration, we simply track fluctuations in the concentration of CO2 in the air. The selected sensor can detect concentration of CO2 gas, from 0 to 50,000ppm.

Pandora's sound system implements two different spatial audio processing units that can be alternatively and/or collaboratively utilized in order to serve audio event detection and sound source localization. The first module is a prototype coincident microphone array consisting of 4 miniature electret microphones with cardioid pickup, favoring the implementation of energy-based (direction of arrival) localiza-

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[5] http://www.flir.com/cores/content/?id=66257

tion, along with feature-based audio event detection-segmentation. The approach was inspired by the sound field microphone theory and the related sound source localization approaches, whereas multi-band estimation can be further deployed for noise reduction and accuracy improvements purposes [13][14]. The unit comprises the following components:

- Four electret-cardioid microphones placed at the same level (considered to be the z=0 plane) and position, forming a coincident microphone array. Thus, the principal pick-up axes (main directivity vectors) form a cross shape, with each pair of successive microphones having an angular main axis distance of 90o. In geometrical terms, each microphone points on one of the four distinct directions x+(1,0,0), y+(0,1,0), x-(-1,0,0), y-(0,-1,-0) of the Cartesian XYZ.
- Four-channel signal conditioning circuits and analog to digital convertors (ADCs).
- The ARM Cortex M4F microcontroller

This unit is used for audio events detection (adaptive thresholding) and energy based sound source localization. Once event detection is decided, direction of arrival (DOA) localization is performed to estimate the horizontal DOA angle (θ).

The second audio module is built around the Kinect sensor, taking advantage of the integrated microphone array and A/D converters. The microphone array consists of four logarithmically spaced, cardioid microphones coupled with their corresponding A/D converters operating at 32bit /16 kHz. Hence, higher-level APIs are provided for the implementation of alternative sound source localization algorithms.

6 Robot locomotion

This year the Gears Surface Mobility Platform (SMP)[6] will be used. It is a four-wheeled all-terrain vehicle with one motor per wheel. The chassis is made from aluminum. The mainboard, microcontrollers, servos, sensors and batteries are attached in a custom made chassis box using bars of an aluminum profile. The vehicle also has a sway bar, made from a titanium alloy, attached to the central chassis box that allows for the chassis box of the robot to remain in an almost horizontal plane relative to the horizon. The chassis is constructed in such a manner that the right and left wheel-set can rotate independently from the crossbar which fixates the main chassis box. The chassis is scalable, with the ability to extend the wheelbase, but also increase the ground clearance. The weight of the robot is 8 kg with a payload capacity of 10 kg. The size of the platform is (LxWxH) 540x590x500 mm. The platform is equipped with four 50W brushless DC motors with a reduction planetary gearhead where each motor is fitted to each wheel axle of the vehicle.

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[6] http://www.gearseds.com/

7 Team members

V. Bosdelekidis, E. Chatzieleytheriou, V. Choutas, P. Evaggelakos, A. Filotheou, D. Geromichalos, D. Kirtsios, M. Kofinas, G. Kouros, G. Lykartsis, N. Michailidis, E. Mylonakis, K. Peppas, K. Panayiotou, E. Papadopoulou, M. Protopapas, K. Samaras Tsakiris, K. Sideris, N. Taras, A. Triantafyllidis, N. Tsipas, C. Tsirigotis, K. Zisis

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