RoboCupRescue 2013 - Robot League Team
PANDORA (Greece)

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Abstract. Within the context of the 2013 RoboCup-Rescue competition (www.robocup.org) the PANDORA Robotics Team of the Aristotle University of Thessaloniki has developed an experimental robotic platform for area exploration and victim identification. Our robot is able to autonomously navigate itself through unknown space (e.g. building ruins from an earthquake), avoid obstacles, and search for signs of life and identify victims. We are going to use one tracked platform aiming at identifying victims residing in the yellow arena and assisting victims in the blue arena (grasping and carrying a specific object, such as a small bottle of water). This is the TDP of the PANDORA robot.

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. Overall objectives of the team are the application of the existing know-how on a real-life problem, the advancement of the group's state-of-the-art expertise. The PANDORA Robotics Team was founded in 2005 and has already participated in the RoboCupRescue 2008, 2009 and 2011 competitions. This year, the team intents to participate in the yellow and blue arenas.

1. Team Members and Their Contributions

The team comprises 5 faculty members of varying expertise and a compilation of postgraduate and undergraduate students. The following list provides the names and responsibilities of the team members.

Team Mentors

- Vassilios Petridis, Professor
- Zoe Doulgeri, Professor
- Loukas Petrou, Associate Professor
- Andreas Symeonidis, Lecturer
- Charalampos Dimoulas, Lecturer

AI Team

Team Leader: Emmanouil Tsardoulias
SLAM: Aris Thallas, Dimitrios Tatsis, Nikos Tsakiridis
Navigation: Giorgos Gkioulis, Christos Zalidis
Data Fusion: Christos Zalidis, Giorgos Gkioulis
Planner: Aris Thallas

Software Architecture Team

Team Leader: Triantafillos Afouras
Testing: Nasia Irodotou, Aspa Karanasiou, Nikos Gountas
Simulation: Nick Pehlivanidis, Aggeliki Kargopoulou, Anna Minou
GUI: Theodoros Spathopoulos

Vision Team

Team Leader: Alexios Papadopoulos
Face recognition: Evdoksia Taka, Dimitrios Antonaras
Tag/Hole/Motion detection: Linta Koletsou, Despoina Paschalidou

Voice recognition Team

Sound control: Pavlos Chatzoudis

Electronic design Team

Team leader: Charalampos Serenis
Sensors: Dimitrios Kanlis, Konstantinos Tsourapas, Michalis Niarchos
Motors: Antonis Pappas, Anna-Maria Tirovouzi
Integration: Panagiota Vakoula

RoboArm Team

Team Leader: Ilias Sedikos
Arm Kinematics: Vangelis Apostolidis
Arm Gripper: Iakovos Tsimino

Logistics, Support

Athina Anoixiadou

The team is going to be represented by 11 members in the competition. Names are going to be listed in the registration form.

2. Operator Station Set-up and Break-Down (10 minutes)

Three operators are needed for setting up the PANDORA robot: the head operator of the system, who carries the base station case, and two operators that carry the platform case.

The initialization process is realized as follows:

- Transfer all objects in the area and deploy (3 minutes).
- Activate the platform and the base station (3 minutes).
- Launch the PANDORA robot OS (2 minutes).
- Perform communication check, in order to establish and validate Wi-Fi connection (1 minute).
- Perform system check and diagnostics, in order to verify that all the systems of the platform are working properly (1 minute).

3. Communications

Following RCR regulations, we are going to use W-LAN 802.11a (5 GHz) and will wait to be assigned with a channel/band from the organizers during the competition.

Table 1. PANDORA communication protocol

Rescue Robot League		
PANDORA (GREECE)		
Frequency	**Channel/Band**	**Power (mW)**
5.0 GHz - 802.11a		100

4. Control Method and Human-Robot Interface

The PANDORA robot will operate in two modes: the *fully autonomous mode,* where a number of simultaneous processes will be executed in order to achieve autonomous exploration and victim identification, and the *tele-operation mode,* where the robot will be totally manipulated by an experienced user.

In order to ensure a flexible and modular scheme where reconfiguration is possible, we opted for a component-based software architecture. The selected architecture ensures easy testing and integration, while it decouples the overall system from each component's actual implementation.

4.1 PANDORA Software Architecture

All state-of-the-art middleware provide an infrastructure for building custom applications, while providing tools to support robot software development. Apart from the above, middleware added-value relates to major non-functional requirements they ensure, such as real-time (or near real-time) performance, reliability and security. From the plethora of existing approaches, though, not many satisfy the above criteria.

Having considered various off-the-shelf middleware (including MSRS,OROCOS and ROS), we adopted ROS [ROS] (http://www.ros.org) 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 communications with the ability to control dataflow, which is extremely important for complex interconnected systems. Among others, the basic advantages of ROS are: open-source nature, transparent architecture, wide-spread usage, interoperability with other robot frameworks, quality of the development toolchain and extensive documentation.

ROS comprises a peer-to-peer network of components (denoted as nodes), which communicate via messages through the respective ROS infrastructure. The channels that messages are sent through are called topics. RPC-style communication is also achieved through services and data persistence is achieved through the Parameter Server.

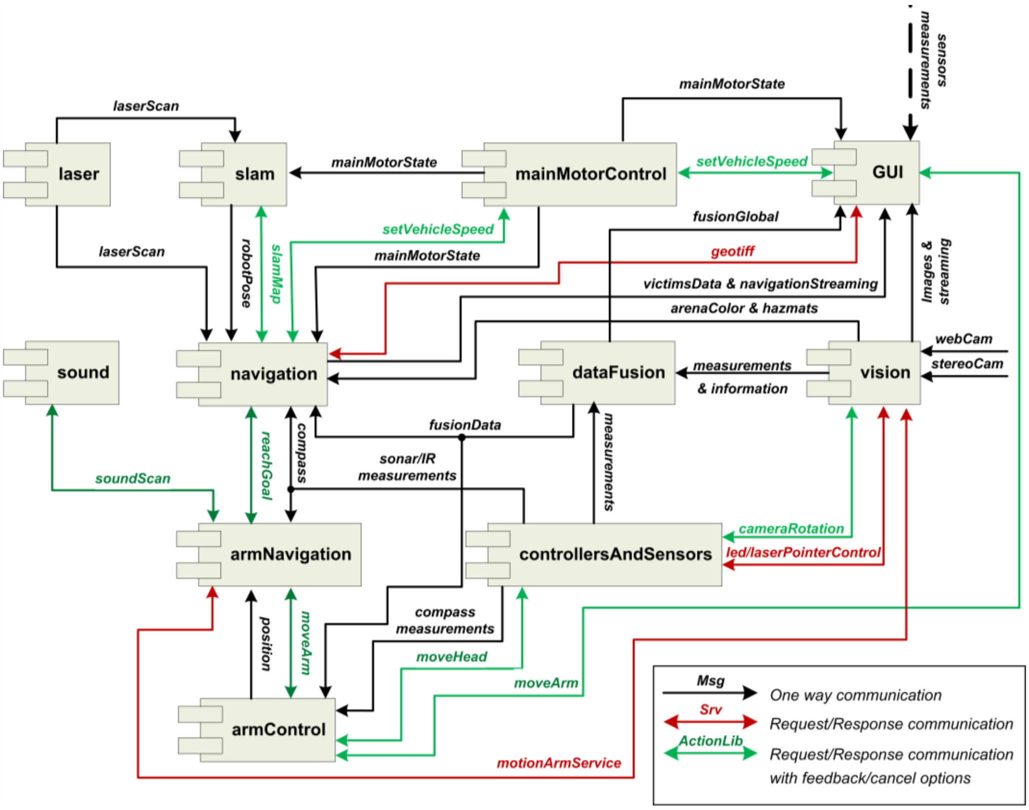

Fig. 1. PANDORA nodes and their interaction through messages, services and action libs

To achieve maximum decoupling, we followed a modular approach, thus defining various levels of abstraction. Interfaces realizing communication between components are encapsulated and decoupled from the implementation, thus providing domainspecific functionality only at a component level [1]. 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. Figure 1 depicts the robot software architecture, where one may identify, apart from the functional nodes that are responsible for obstacle detection and avoidance, navigation, SLAM and victim identification, the especially designed nodes responsible for system overall health control and management. The fact that the robot integrates various controllers, sensors and actuators, thus handling different types of data, led us to the establishment of a data fusion layer. This layer aggregates low-level sensor measurements for victim detection and identification and is responsible for performing sensor fusion, filtering and forwarding values which may correspond to candidate victim locations or directions. This way, we succeeded in substantially reducing the information overhead, a key factor for the efficiency of the robotic system. The basic ROS nodes developed are:

- ***Controllers & Sensors:*** it controls data flow from the microcontrollers, acting as a Hardware Abstraction Layer for the robot. This package handles most of the sensors, such as thermal and voice sensors. In addition, some actuators are also controlled.
- **Laser and *SLAM:*** SLAM is responsible for performing the Simultaneous Localization and Mapping (SLAM) for the robot, as well as storing and providing map data. It is based on measurements received by the Laser node.
- ***Robot Kinematic:*** a library package (not shown) solving the kinematic model of the vehicle, providing utility functions for other components.
- ***Main Motor Control:*** responsible for controlling the main motors of the robot and implements basic error handling. Through the *Robot Kinematic* library, the desired robot linear and rotational velocities are set. This package has been designed to be common in all two robot operation modes.
- ***Arm Control:*** responsible for solving the kinematic model of the robotic arm, controlling the arm actuators to reach a goal via a specified trajectory.
- ***Vision:*** responsible for handling the stereo camera used for exploration and possible victim locations, as well as the camera situated on the robotic arm, used for detailed victim identification.
- ***Sound:*** responsible for handling a 4-microphone construction used for the identification of victim sounds and their location.
- ***Navigation:*** responsible for motion planning and navigating the robot through the unexplored regions of the map or towards a possible victim for further identification. The package is also responsible for storing and providing victim-related data, such as victim position.
- ***Arm Navigation:*** responsible for navigating the arm configuration space searching for a victim in that area.
- ***Data Fusion:*** it decouples low-level sensor measurements for victim identification and high-level navigation components. Furthermore, it is responsible for performing sensor fusion and forwarding possible victim positions (or directions) to the navigation packages.

- ***GUI:*** provides a Graphical User Interface for the robot operator. In addition it provides the remote controls for tele-operation.

4.2 PANDORA Graphical User Interface (GUI)

PANDORA provides a user friendly GUI for visualizing information and operating the robot. Three tabs are available, containing information related to navigation, victim identification and debugging. In each of the tabs, related information is displayed, as depicted in Table 2. Nevertheless, the operator can dynamically add/remove sensor information and modify the type and the layout of the widgets displayed in each tab, since PANDORA GUI adopts a widget-like architecture. A mockup of the GUI is provided in Figure 2.

Table 2. Information displayed in the respective GUI tabs

PANDORA GUI		
Navigation Tab	Victim identification Tab	Debugging Tab
Map	Map	Map
Web camera streaming	Coverage	Web camera streaming
Operating mode	Voronoi diagram	Stereo vision camera streaming
Temperature reading	Victims number	Motors speed
Distance from Sonar sensors	Victims places	Current robot position
Distance from IR sensors	Goals	Sensors status
CO_2 measurement reading	Path to current goal	Temperature reading
Noise source direction	Noise source direction	Compass bearing
Compass bearing		Distance from Sonar sensors
Robot angle state		Distance from IR sensors
Platform inclination on rear and side view		CO_2 quantity reading
Wi-Fi signal strength		Noise source direction
Battery level		

When on *tele-operation* mode, the robot vehicle is controlled using a wired gamepad or a keyboard, while the robot arm is controlled using a joystick. When on the *autonomous* mode, GUI is only for visualizing/monitoring and no intervention is allowed, up to the point that a victim is recognized. Then, PANDORA sends an interrupt signal to activate the GUI and expects proper operator action in order to continue.

4.3 PANDORA Hardware Architecture

Figure 3 provides an overview of the hardware needed to interface with the various sensors of the system. The platform is equipped with two sets of sensors, the first one is responsible for localization and navigation procedures, while the second one for victim identification.Two PCBs have been built, the Main Board and the Head Board.

The Main Board communicates with the sensors mounted on the main chassis i.e. the distance sensors (ultrasonic and infrared) and thermal sensors and controls the servos of the LRF stabilizer. The I2C communication protocol is employed. This option reduces the wiring, facilitates the expansion of the sensor subsystem and simplifies the software development. The employment of I2C-bus drivers / buffers allows the removal of noise introduced into the bus system. Thus a dynamic and scalable system has been developed that provides the interconnection of up to 127 sensors. Communication error handling algorithms have been developed to ensure error free data acquisition.

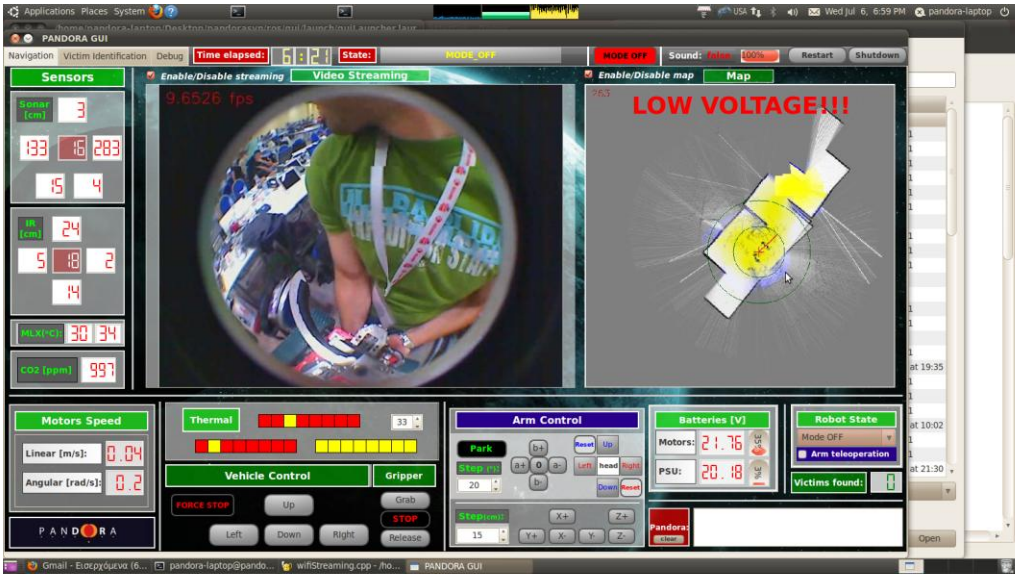

Fig. 2. PANDORA GUI – Navigation tab overview

The I2C bus is connected to an Atmel AT90XMEGA128A1 microcontroller. Sensor data are read through a DMA process in parallel and send to the PANDORA software infrastructure through the serial port (RS232), employing a custom-design communication protocol.

In order of implementing a redundant architecture, an additional AT90XMEGA128A1 microcontroller is mounted on the PCB, acting as offline standby microcontroller.

The Head Board accesses the data provided from the victim detection sensors (temperature, CO_2, microphones and distance) and controls the pan servo and the gripper. A 32 bit microcontroller is used (AT32UC3A0256) running a RTOS. The Head Board is connected to the PC via USB.

In order to ensure easy debugging of the hardware components and their intercommunication, a detachable module with an embedded microcontroller and a LCD touch screen can be connected to the microcontrollers and probe the system for correct functionality and possible errors.

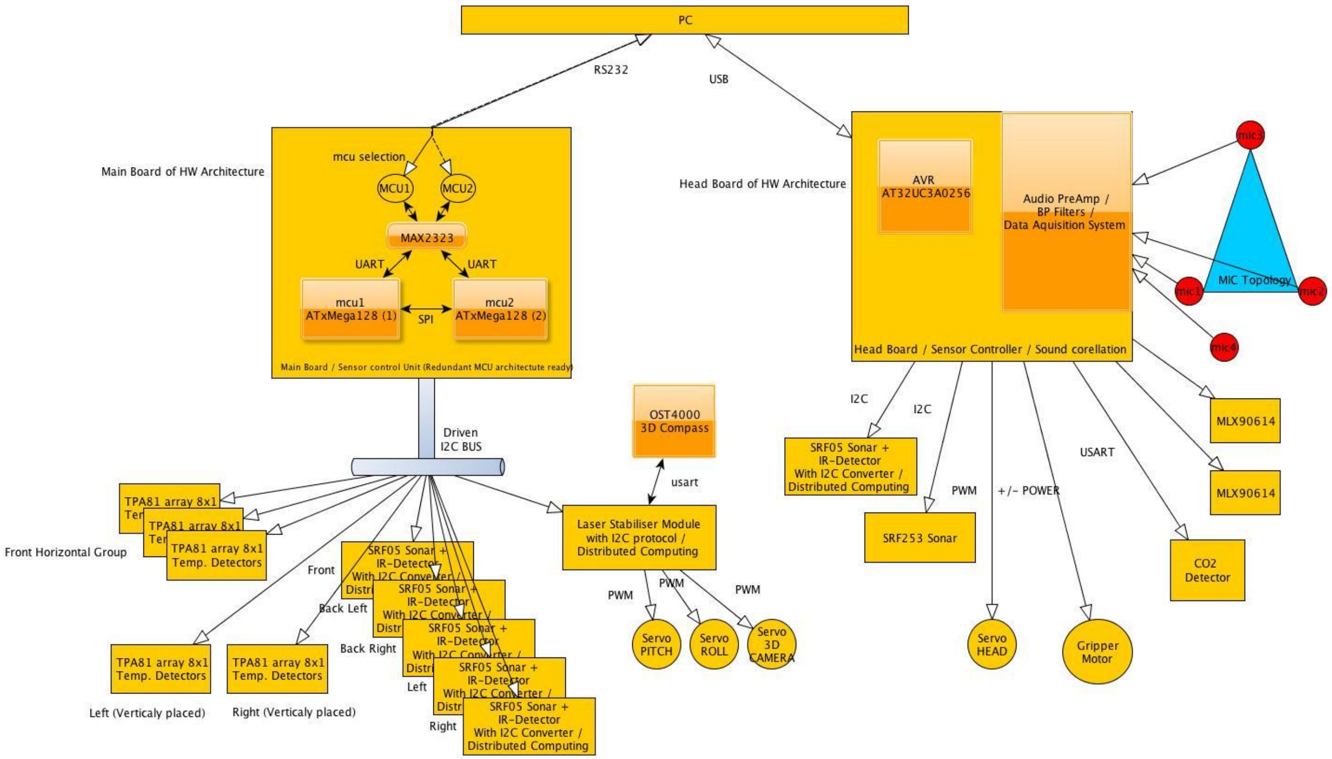

Fig. 3. Layout of the sensors connected on the microcontrollers

5. Map generation/printing

5.1 SLAM

PANDORA implements a CRSM (Critical Rays Scan Matching) SLAM scheme for space exploration [2]. It employs an occupancy grid map and performs a scan-to-map match, instead of the traditional scan-to-scan matching. Scan matching is realized through a genetic like algorithm mechanism (Random Restart Hill Climbing) and ray reduction is employed for performance reasons.

One of the two most important features of CRSM SLAM is ray-picking; the main idea is to reduce complexity and time needed for matching by preprocessing the scan and selecting rays that are "critical" for the matching process. We define "critical" in the sense that the remaining ray information is redundant to the matching process, since the "critical" scans act as features of the scan, even if they are extracted from heuristics and not from any feature extraction method. A hill climbing mechanism has been adopted for the identification of the correct transformation between the current scan and the global map (which is the inverse of the robot translation and rotation). Hill climbing is a very popular and efficient method for finding optimal solutions to complex problems. Its setup is like a genetic algorithm but the population consists only of one individual.

The individual genome in the genetic method comprises three numeric values ($<D_x, D_y, D_{theta}>$), representing the correct transformation for scan matching. The fitness value for the individual is calculated by summing the possibilities of occupancy in the selected laser rays, according to the transformation of the hill climbing individual.

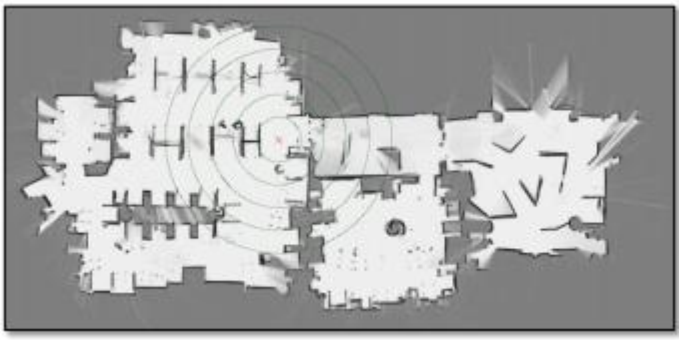

Fig. 4. Initiating the CRSM SLAM process

RRHC (Random Restart Hill Climbing) or SHC (Shotgun Hill Climbing) are employed for hill climbing [3]. Upon random restart of the hill climbing process, the individual genome is initialized at the supposed new robot transformation, based on the speed or the kinematic model, and a mutation is performed. If the fitness value of the individual is higher than the previous one, we perform a mutation at the new individual. The process concludes when an individual has a lower fitness value than its predecessor; the global best result is updated (if needed), and the individual is randomly initialized. The above process stops after 10000 iterations or when the best fitness value reaches a satisfying threshold. This method, adding the time of the ray reduction, has a frequency of 10 Hz. The result of the CRSM SLAM is shown in Fig.4.

Finally, a particle filter is implemented in order to cope with the loop closing problem. Each particle has an assumption on the environment (the map) and an assumption on the robot pose. For each iteration of the particle filter, Gaussian noise is inserted on the motor velocities, based on the results of the kinematic model. Then scan matching is performed, the particles update their maps and a weight is calculated for each particle. Finally re-sampling is performed, resulting to a better particle population, based on a topological graph created on-line from each particle. When the robot detects a node that is close to its pose but has a large topological distance from the last node inserted, a loop closure is detected and re-sampling is performed.

5.2 Navigation

PANDORA's navigation module comprises three sub-modules: the *Path Planner*, the *Navigator* and the *Streamer*.
The *Path Planner* is the coordinator of the robot's computational intelligence. It monitors all other PANDORA nodes, providing them with input and allowing them to take control and perform specific tasks. It defines a goal (target) in the environment according to the circumstances, creates the path to it, and feeds the navigator in order to follow it. Also, it (de)activates the camera, sound and arm navigation nodes (subsystems).

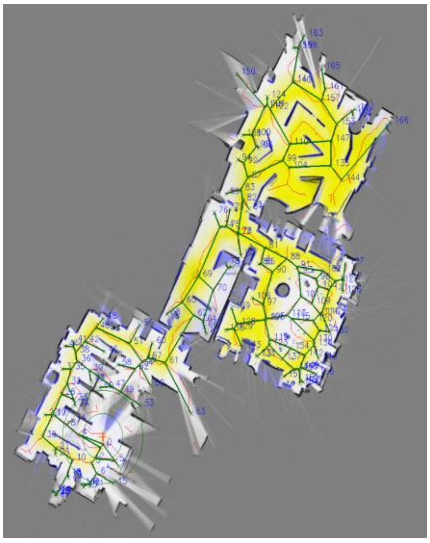

Fig. 5. Creating the map in an explored space

In the default operation mode the *Path Planner* performs simple space exploration. Goals are defined by applying the GDV (GeneralizedVoronoi Diagram) [2] in the unoccupied space. The result of the process is the construction of a topological graph, where nodes are the boundaries of the GDV, as well as its cross-paths. The main idea is to explore all GDV nodes in an efficient manner, since the resulting GDV graph is a skeletonization of the free space. Thus, graph exploration implies environment exploration to a great extent. The covered space is stored in an occupancy grid called *coverage*, having the same size as the map, and holding the information of covered space by means of victim coverage. The coverage map is updated in every SLAM iteration by applying a patch on the coverage map, depending on the robot's pose. The patch is a sum of the effect of all the victim sensors on the robot. The OGM with topological graph and coverage information is shown in Fig. 5.

After the goal is selected, the *Path Planner* has to propose a path for the robot to follow. Uniform space decomposition is employed for path creation, given its speed, efficiency and capability to cope with complex routing problems. As a result, a graph is constructed that comprises, as its nodes, the points from a uniform decomposition of the free space, as well as the robot's position and the current goal. The optimal path is extracted by applying the A* algorithm [3].

Upon victim identification, the *Path Planner* communicates with *Arm Navigation* dictating the arm where to move in agreement with the sensor that depicted the possible victim and the position of the robot. At the same time, *Data Fusion* is set on a different mode to conclude on the validity of the victim according to the measurements of the sensors.

Finally, the *Path Planner* creates the geotiff that is sent to GUI when it is requested with the necessary information about the map, victims, QRs and hazmats.

The *Navigator* follows the path dictated by the *Path Planner*. Specifically, it provides input (velocities) to the *Main Motor Control* node, in order to navigate on the given path. When the robot reaches the designated goal (the end of a path), the *Navigator* informs the *Path Planner* and waits for a new path. It follows a two-layered architecture: the "path follower" and the "obstacle avoider" layer. In each step, the "path follower" calculates the appropriate velocities for the robot, while the "obstacle avoider" is assigned to correct the velocities, so that the robot avoids the obstacles efficiently, irrespective of the path. The *Navigator* may also be assigned with another task (goal) before completing its current one (e.g. a possible victim location is identified). In that case, the *Navigator* serves the new path request ignoring the previous. In case no path is received from the *Path Planner*, the *Navigator* guides robot to move according to obstacle avoidance.

The *Streamer* sends the image of the map alongside with victims that were visited or are about to be visited to GUI, so that the exploration progress can be fully observed while the robot navigates itself in the environment. In addition, the image includes information about the path that is being followed and the space that is already covered by the robot. Image processing is done using OpenCV library.

5.3. Data fusion

The *Data Fusion* module is responsible for filtering out the messages generated by PANDORA sensors (CO_2, MLX thermal sensor, TPA thermal sensor, sound module and camera). It stores a set of thresholds of all sensors, which are the possibility values of an eligible valid measurement. Given that a sensor measurement exceeds the threshold, *Data Fusion* informs the *Path Planner* with details. One should mention that thresholds are not hard-coded and are not crisp; rather, a flexible mechanism has been implemented so that the *Path Planner* is informed if a sensor has an almost "valid" value. 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.

6. Sensors for Navigation and Localization

The PANDORA robotic platform is equipped with several sensors in order to determine its current position and its distance from various objects. These sensors are discussed next.

6.1 Laser Range Finder (Hokuyo URG-04LX)

For map creation a Hokuyo URG-04LX Laser Range Finder (Figure 6) has been installed. It has a viewing angle of 240° and a detection range of 20mm up to 4m. The angular resolution is 0.36°, which gives 667 measurements in a single scan, while its linear resolution is 1mm. Measurement accuracy varies from 10mm (for distances from 20mm to 1m) to 1% of the measurement for distances up to 4m (Fig. 6). It operates on 5V DC (possible error of +/- 5%) and has a current consumption of 500mA.

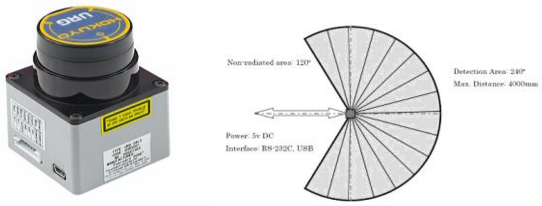

Fig. 6. Laser sensor (Hokuyo URG-04LX) and its field of view

6.2 Ultrasonic Sensors

Five ultrasonic SRF05 sensors (Figure 7) are situated around the robot. They communicate via the I2C bus with a microprocessor, publishing a pulse with width proportional to the distance of the object. Their power consumption is very low (approx. 0.02W). In the front part of the vehicle they will be used to prevent the vehicle from bumping on obstacles. SRF05 sensors have a detection range of 3cm to 4m and will be used as a complement to the Laser Sensor.

Fig. 7. Devantech SRF05 Ultra Sonic Ranger

6.3 Infrared Sensors

Infrared sensors are placed both on the left and on the right side of the robot and they will cooperate with the ultrasonic sensors in order to give an accurate measurement of the distance of the robot from any obstacle. GP2Y0A21YK (Figure 8) infrared sensors were selected. Their detection distance range is small (10 cm – 80cm), thus they are assigned with monitoring the close surroundings of the robot. One of the sensors is assigned to measure the distance between the bottom side of the robot and the ground, so as to fire an alarm in case the robot is in danger of falling.

Fig. 8. Sharp GP2Y0A21YK Distance Measuring Sensor

7. Sensors for Victim Identification

In order to accurately identify a victim and pinpoint his/her location, a number of sensors have been installed, providing input to sophisticated detection algorithms. Specifically, a stereo vision camera, thermal sensors, a CO_2 sensor and four microphones are being used. Sensor results are then fused to determine the behavior of the robot.

7.1 Vision

The autonomous platform is equipped with a stereo vision camera of custom design, based on two Sony's Playstation Eye cameras (Fig.9) on stereo configuration and a standard web camera to offer the requested set of detection and identification services. Furthermore, stereo vision processing enhances PANDORA's ability to calculate distance from the victim.

Fig. 9. Sony's Playstation Eye

During *tele-operation*, the web 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 [6] through ROS. PANDORA *Vision* provides the following functionality:

- *Hole detection and localization.* Detection is performed by fusing the information extracted by four separate modules:
  i. Edge detection of a de-noised version of 2D scene image is used to detect closed boundaries which are next filled and considered as BLOBs [7].
  ii. Color segmentation of the scene image detects areas neighboring to wall surfaces.
  iii. Intensity thresholding outputs dark regions usually corresponding to holes.
  iv. Hole detection is enhanced by depth information of the scene

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. Localization consists of 2D information and corresponds to the specification of the direction at which the hole is detected.

- *Three Dimensional Wall Reconstruction.* The stereo camera is used to extract 3D points of the scene. A laser light grid is used to increase registration accuracy and thus more accurate depth estimation. The set of 3D points is next fed to a RANSAC like algorithm that clusters points to coplanar groups. The output is both the number and parameters of the detected walls, plus a label for each of the input points indicating the id of the wall it resides on.
- *Face detection.* The innovative R. A. Fisher Linear Discriminant Analysis algorithm will be used as presented by Belhumeur, P. N., Hespanha, J., and Kriegman paper on face recognision [8]. A support utility allowing training on a custom set of faces has been developed to allow for replacing real human faces by other human-like artifacts (e.g., dolls).
- *Skin detection.* Skin detection is based on a pixel by pixel classification of its color coordinates. Statistical analysis of skin-colored pixels has been performed for determining the boundaries of the region of the color space representing human skin.
- *Hazmat and 3EWM pattern detection.* A general purpose logo detection algorithm has been developed for detecting specific flat shape patterns been robust w.r.t. affine transformations based on [9] and [10]. The algorithm is trained to recognize a pattern on the basis of the SIFT [11] salient point descriptors – their value and the geometry of their locations. Test images are processed for the extraction of SIFT local points and a greedy procedure is followed in order to obtain the best possible alignment of pattern's local descriptors to the (many) similar descriptors of the test image. A K-D tree is used for speeding up this procedure. Geometric compatibility combined with appearance compatibility (measured as the similarity between the descriptors) is used to determine whether the pattern appears on the examined image. The same process is repeated for each pattern.
- *Qr code detection.* For the purpose of detecting and decoding Qr codes, the use of Zbar, a dedicated bar code recognition API will be used.
- *Map boundary detection.* Colored lines are detected on the basis of their RGB content, a scheme similar to skin detection is employed.

7.2 Temperature

We consider that temperature differences in the environment could imply victims. Thus we have installed Focal Plane Array (FPA) thermal sensors, in order to compare temperature values, find fluctuations and make an estimate of a victim's position, if one is found. The TPA81 (Figure 10) is a thermopile array (thermocouples connected in series), together with a silicon lens and associated electronics, which detects infra-red in the 2um-22um range (the range of radiant heat). It can measure the temperature of 8 adjacent points, as well as the ambient temperature, simultaneously. It can detect victim's temperature within 2 meters and its typical field of view is 41˚ by 6. It is connected to the Main Board via an I2C interface and updates its values at a rate of approximately 20Hz. The TPA81 are mounted on top of the stabilizer module and on both sides of the robot.

Fig. 10. TPA81 IR thermal sensor

The MLX90614 Infrared Thermometer Module is a high accuracy non-contact thermometer based on a thermopile developed by Melexis. The sensor has a 90° field of view and 0.1 °C resolution. Communication is achieved through the Parallax basic Stamp serial protocol. The MLX90614 sensor is designed for non-contact temperature measurements of objects placed within the sensor's cone of detection. The sensor is used to identify a heat source as a victim or reject it as a false alarm. Therefore, two sensors are located on the head of the robotic arm.

Fig. 11. The MLX90614 Infrared Thermometer

7.3 CO_2 sensor

The CO_2 sensor (Figure 12) measures the concentration of CO_2 gas in the environment. For the detection of the human respiration, we simply track fluctuations in the concentration of CO_2 in the air. The selected sensor can detect concentration of CO_2 gas, from 0 – 50,000ppm.

Fig. 12. DYNAMENT, Premier High Range Carbon Dioxide Sensor, Non-Certified Version Type MSH-P-HCO2/NC

7.4 Sound

Pandora's voice processing unit comprises the following components:

- Four electret-cardioid microphones (Figure 13) located on the head of the robotic arm. All the four microphones are 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 90^o. 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 axes-coordinates.
- One amplifier with four channels, one for each microphone.
- One analog band-pass filter per microphone.
- One DAS with four inputs with sample and hold, in order to achieve simultaneous recordings, one Analog to Digital converter, and digital filters.
- One Atmel AVR AT32UC3 microcontroller mounted on the Head Board.

PANDORA *Voice* node is assigned with two tasks: to find a victim and identify its state. In exploration mode, *Voice* scans the space in order to grasp a sound that could direct to a victim. Upon the identification of a sound, a request is sent for thorough scan. If granted permission, *Voice* performs a second scan and provides *Data Fusion* with an estimate of the position of the victim, as well as a level of certainty of the estimation. When the vehicle approaches the victim and the robotic arm extends to approach him/her, *Voice* is assigned with the task to recognize his/her state. To do so, *Voice* measures the volume of the sound, transforming it to dB. Then, the estimate of the state of the victim, as well as a level of certainty of the estimation is sent to *Data Fusion*.

Fig. 13. JOGA EM1.3 Microphone

In particular, an iterative audio event detection procedure is utilized, whereas multi-channeled background noise is continuously estimated along with thresholds adaptation. In case that audio-channels activity exceeds the corresponding detection thresholds, positive event detection is indicated, whereas both sound levels and potential direction of arrival (within a range of 45^o) are also estimated. Consistency measures regarding short-term direction-of-localization stability, but also expected spectrum and minimum duration of the detected events are extracted to verify the true positive audio event detection (taking also vehicle navigation coordinates into account). Once event detection is decided, direction of arrival (DOA) localization is performed to estimate the horizontal DOA angle (θ). Specifically, the four microphones are grouped regarding their pointing axis (x or y), in order for their signals to be sequentially added and subtracted. In this context, the polar responses of two figure of eight microphones (oriented in the x and y axes) and two omni-directional microphones are obtained, allowing the horizontal direction of arrival angle to be easily estimated.

8. Robot Locomotion

8.1 Platform mechanical design

The PANDORA vehicle employs an improved track system for its locomotion. The basic improvements are as follows:

- the use of a tensioner mechanism for the synthetic track
- the adjustment of idle rollers, so as to avoid track oscillations and damage

The metal frame of the robot is made of aluminum. The platform is equipped with two 50W brushless DC motors with a reduction planetary gearhead. The size of the robot is 560x230x200 mm. It is solid enough, appropriate to move in different types of terrain and climb easily a 40^{o} slope.

9. Other Mechanisms

9.1 Robotic Arm

The PANDORA Robotic Arm was designed in order to provide the ability to reach most of the points of interest. The geometry selected led to a five degrees of freedom robotic arm, with rotational joints and cylindrical links as shown in Figure 14.

Cabling issues specified link diameter. Joints are designed to allow folding of the arm and maximize angle limits in order to achieve optimal system workspace. Joints are powered by dc motor-encoder-reduction gearbox assemblies connected to appropriate drivers for control implementation. Joints are monitored by external optical or magnetic encoders so as to determine the absolute position of the arm and thus avoid recalibration hazards due to power loss. The head of the arm accommodates all essential sensors for victim identification and partly for navigation. The Robotic Arm is equipped with a gripper attached at the end of its fourth link for object manipulation. The gripper uses traction and smart construction so as to make optimal use of its four degrees of freedom based movement and orientation.

Solutions for direct and inverse kinematics are incorporated in the arm’s software. Different types of trajectories, such as linear or along the approaching vector have been implemented covering the range of required motions. Other kinematic calculations are also made related to the reachability of target points and the location of the arm's center of mass for a specific configuration and ground inclination to avoid vehicle turnover.

9.2 Stabilizer

The stabilization mechanism (Figure 15) is mounted on the chassis of the robotic platform. It allows the laser, the thermal sensors and the stereo vision camera to stay on the horizontal level, regardless of the robot’s inclination. The stabilization is achieved via two linear DC-servomotors with fast response using a three dimensional Ocean Server's OS5000 compass, which gives measurements in degrees (Figure 16). It provides the inclination of the robot with respect to the starting inclination. The compass communicates with the Main Board, through UART protocol. The compass is also used to stabilize the laser of the robot at the desired position. Its accuracy is not higher than 0.5 degrees with 0.2 degrees resolution. Its refresh rate is at 40 Hz.

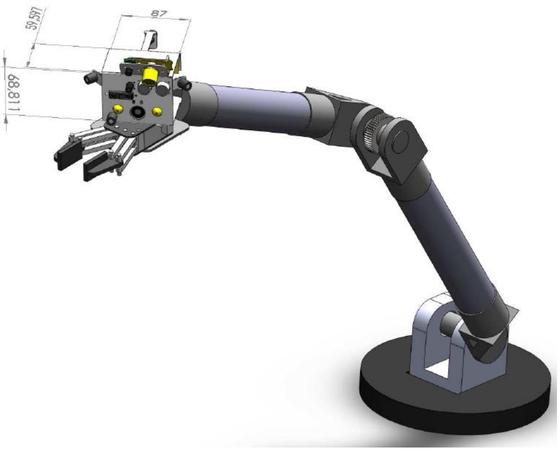

Fig. 14. The PANDORA Robotic arm

Fig. 15. The PANDORA stabilizer

Fig. 16. Ocean Server OS5000 3 Dimensional Compass

9.3 Computing System (Single Board Computer)

In order to accommodate the processing needs of PANDORA, we employ a Mini-ITX system (Figure 17) placed it in the main body of the robot. The specifications of the system are the following: ibase MI953F mainboard, Mini-ITX, Socket G1 (988), Intel QM57 Express Chipsatz, Intel i7-840QM Mobile Processor, 4GB of DDR2 SO-DIMMs, a Solid State Drive with 32GB capacity, all power from a M4-ATX Pico PSU. The board's dimensions are 17x17cm and for peripheral interconnection there are 8 USB ports, 5 RS-232 serial ports, a PCI FireWire, and a MiniPCIe WiFi capable add-on card with 2 pigtails for external antennas. The system power consumption is estimated at 80Watts at full computing load, without the USB, Serial and FireWire peripherals connected.

Communication between the single board computer (SBC) and the sensor network is performed through a serial interface. The higher level protocol designed allows strict timings and deterministic prediction of the CPU load generated by the sensors. This allows PANDORA to operate almost in real time.

Fig. 17. The ibase MI953F Mini-ITX mainboard

10. Team Training for Operation (Human Factors)

The operator(s) should be familiar with the GUI and the gamepad. He/she should be able to understand the readings of all sensors and act accordingly when allowed. He/she should go through extensive training and accomplish test missions in the specially constructed arena, which emulates a destruction scene.

11. Possibility for Practical Application to Real Disaster Site

The fully deployed robotic platform has not been tested in a real environment yet. Nevertheless, the previous platform was exhibited at EXPO 2008 in Thessaloniki, and it was widely accepted. The Hellenic Rescue Team and the Institute of Engineering Seismology and Earthquake Engineering showed vivid interest in the potential of using the platform in real life. Additionally, we are planning to develop a similar platform with a local company for surveillance purposes.

12. System Cost

The following table provides information on the cost of the parts of the PANDORA platform.

Table 3. Part names, quantities and cost

Part Name	Quantity	Price (€)	Website
Mobile Platform	1	4000	Custom made
Arm	1	2000	Custom made
Platform Motors and Controllers	2	1500	http://www.maxonmotor.com
Arm motors and Controllers	5	4400	http://www.maxonmotor.com http://www.hitecrcd.com
Laser sensor	1	2300	www.active-robots.com
Single Board Computer	1	850	http://www.mini-tft.de
Sensors	20	1150	http://www.active-robots.com
Stereo vision camera	1	150	http://www.scei.co.jp/
CO_2 sensor	1	200	http://www.dynament.com
compass	1	250	http://www.ocean-server.com
Microcontrollers	4	300	http://www.atmel.com
Touch screen	1	100	http://www.olimex.com
Batteries	2	800	http://www.hoelleinshop.com
Cabling and connectors		1000	
TOTAL		**19000**	

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