

# Pumas@Home 2013 Team Description Paper

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**Abstract.** This paper describes an autonomous service robot called Justina, built by the team Pumas in the laboratory of Biorobotics at the National University of Mexico. The robot is based on the ViRbot architecture for autonomous mobile robots operation. ViRbot defines a human-robot interaction interface based on Natural Language Processing, for understanding voice and gesture commands, Conceptual Dependence, Action Planning, based on the sensor's information and the state of the robot, and a set of Subtasks, performed by a Simple Task Planner which coordinates several modules that process information from the sensors and controls the hardware. For simplifying task planning along with real time awareness, all modules communicate with each other through a central module called Blackboard, which supports shared variables, with publisher/subscriber pattern, and message passing.

## 1 Introduction

The service robots are hardware and software systems that can assist humans to perform daily tasks in complex environments. To achieve this, a service robot has to be capable of understanding commands from humans, avoiding static and dynamic obstacles while navigating in known and unknown environments, recognizing and manipulating objects and performing other several tasks that the human beings ask for.

The main objective of the ViRbot architecture [11], is to operate autonomous robots that can carry out daily service jobs in houses, offices and factories. This system has been tested in the last six years in the RoboCup competition at the categories @Home and will be used again in the competition in Eindhoven, The Netherlands in 2013, with robot Justina (see Figure 1).

Robot Justina integrates the work of several research areas, such as expert systems, computer vision, action, path and motion planning, robot localization, arm control and place conceptualization.

Section 2 is an overview of the ViRbot Architecture; this system provides a platform for the design and development of robot Justina's software. Section 3 is about the implementation of ViRbot Architecture as a set of software modules that perform the control of the hardware and a Blackboard for the common data and communication management. In Section 4 we present the conclusions and the future work.

## 2. VIRBOT: A SYSTEM FOR THE OPERATION OF MOBILE ROBOTS

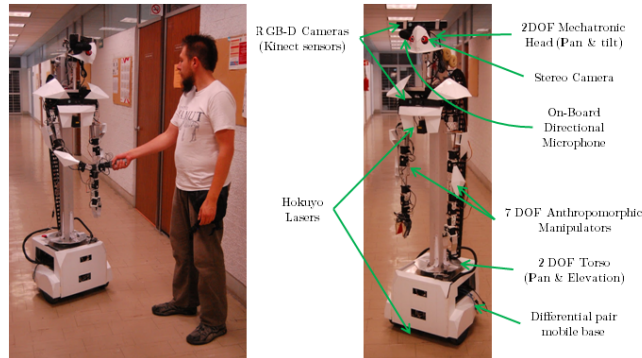


Fig. 1: Robot Justina

## 2 ViRbot: A System for the Operation of Mobile Robots

In this system, the operation of a mobile robot is divided in several subsystems, as shown in figure 2. Each subsystem has a specific function that contributes to the final operation of the robot. Some of this layers will be described in this section.

**Simulator** This subsystem was built for testing new algorithms, training navigation through new scenarios and visualizing of results.

**Perception.** This module generates beliefs using the symbolic representation generated by the Human/Robot Interface submodule and the Robot’s Task submodule configuration.

**Robot’s Tasks.** The set of tasks and subtasks that the robot can accomplish.

**Human/Robot Interface.** The purpose of this subsystem is to recognize and process the voice and gesture commands. It is divided in three modules:

- **Speech Recognition.** Using digital processing algorithms, it analyzes voice commands given to the robot.

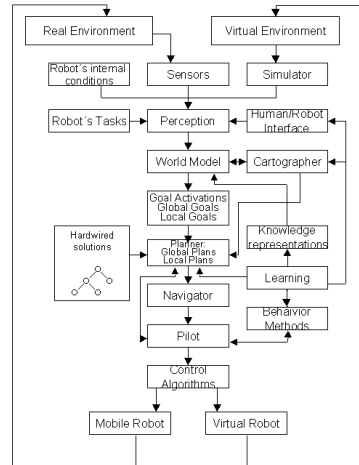


Fig. 2: ViRbot System Architecture

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- **Natural Language Understanding.** This module is used to find a symbolic representation of spoken commands given to the robot using the recognized sentences coupled with Conceptual Dependency techniques.
- **Conceptual Dependency.** The Conceptual Dependency (CD) [12] is used to represent meaning by finding the structure and meaning of a sentence in a single step. It allows rule based systems to make inferences from a natural language system in the same way humans do, using conceptual primitives that represent thoughts, actions, and the relationships between them.

**Cartographer** This module has different types of maps for the representation of the environment like:

- **Raw maps.** These are obtained by detecting the position of the obstacles using the robot's laser sensors.
- **Symbolic maps.** These contain all the known obstacles as polygons defined by their vertexes.

The subsystem can also contain topological and probabilistic (Hidden Markov Model) maps of the environment [13].

**World Model and Activation of Goals** The belief generated by the perception module is validated by the cartographer and the knowledge representation modules, thus a situation recognition is created. Given a situation recognition, a set of goals are activated in order to solve it.

**Knowledge Representation** A rule based system is used to represent the robot's knowledge, in which each rule contains the encoded knowledge of an expert.

**Learning** The following learning algorithms are used for the robot:

1. *Map building.*- Fuzzy Clustering Networks are used to locate and represent obstacles in the environment.
2. *Self Localization.*- Hidden Markov Models using Vector Quantization & Self Associative Neural Networks are used to estimate the robot's position and orientation.
3. *Behaviors.*- Genetic Algorithms are used to learn new behaviors.

**Task Planner** The objective of the action planning is to find a sequence of physical operations to achieve the desired goal. This takes as input the output of the World Model subsystem.

**Navigation** Determines the robot's position, and controls the robot's movement in order to follow a specified path along the environment. This specified path is given by the Cartographer module.

### 3. VIRBOT IMPLEMENTATION ON ROBOT JUSTINA

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**Hardwired Solutions** A set of hardwired procedures is used to partially solve specific problems, including movement, object manipulation, etc.

**Behavior Methods** A set of solutions encoded in State Machines, which are used in repetitive tasks. For example, in obstacle avoidance, the repetitive task consists of following a sequence of goals until reaching the final one.

**Control Algorithms and Real and Virtual Actuators** Control algorithms, like PID, are used to control the operation of the virtual and real motors. The virtual and the real robot receive the commands and execute them by interacting with the virtual or real environment and with the user.

## 3 ViRbot implementation on Robot Justina

ViRbot is implemented in robot Justina by means of a Blackboard architecture. This allows to use more than one platform and run software modules programmed in different languages in different computers. Robot Justina uses computers running both Linux and Microsoft Windows, and modules programmed in C#, C++ and CLIPS.

### 3.1 Software

**Blackboard** A general purpose service robot requires several highly specialized systems which must communicate with each other, therefore, a Blackboard is included: a flexible system to control the transmission of messages between modules, monitor their status and store the common data used by all the modules that integrate the system. All common data is stored in the Blackboard as shared variables to grant access at any time to other modules. It also uses a producer/subscriber paradigm to enhance the Real Time Awareness of the system and reduce communication overloads. Also the Blackboard offers a flexible platform to implement ViRbot as shown in figure 3.

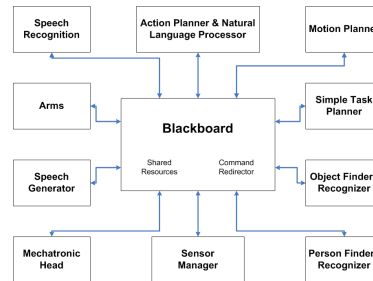


Fig. 3: Blackboard structure

**Action Planner** For the Action Planner, the rule-based expert system CLIPS, developed by NASA [10], is used. With CLIPS it is easy to implement tasks of several subsystems of ViRbot Architecture such as the Robot's Tasks, Perception and Knowledge Representation subsystems. The Action Planner works in the highest level of abstraction, coordinating the tasks that the robot must perform and choosing the adequate behaviour in each situation.

**Simple Task Planner** In the ViRbot system, the Hardwired Solutions involve simple and repetitive tasks which requires little or no planning but several transformations and can be easily achieved by state machines (like look for a person/object or grasp an object). Those tasks are performed by the Simple Task Planner module. Also this module incorporates reactive behaviours if the Action Planner is not available.

**Motion Planner** The motion planner is responsible for finding the best sequence of movements to reach the final destination given by the Action Planner or the Simple Task Planner combining classic and modern techniques. It uses Cartographer’s maps to calculate the path planning. In parallel to the geometrical representation, it generates a topological representation of the environment and, by Dijkstra algorithm [5], finds the optimal path between the current and goal positions. Obstacle avoidance is achieved using Potential Fields and Finite State Machine based behaviors.

**Vision Subsystem** The Vision Subsystem of the ViRbot architecture has been specialized in five modules: the Kinect module, Person Finder module, the Object Finder module, the Human Pose Detection module and the Visual Localization module.

**Object Finder** The Object Finder Module features a robust implementation of an object tracker where objects are segmented using receptive fields [4][3][2], and represented by feature points which are described in a multi-resolution framework, that gives a representation of the points in different scales.

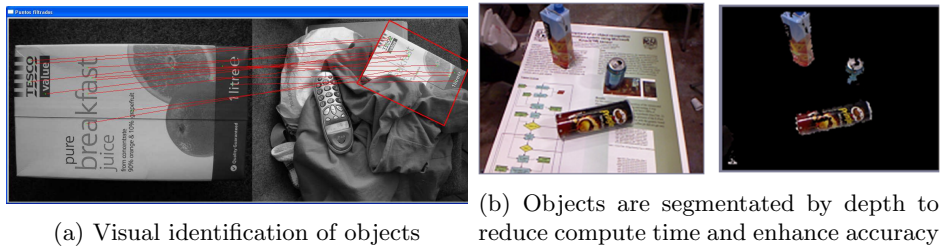


Fig. 4: Object recognition and location using depth sensors

Detection and description of interest points are based on the SIFT (Scale-Invariant Feature Transform) algorithm [6] after a first segmentation by depth, see figure 4a. After an object recognition, the geometry of the object is computed from the depth map to fetch the object’s centroid and orientation.

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**Kinect** The Kinect module uses the Kinect Microsoft Xbox 360™[7], which features an RGB camera and a depth sensor. This sensor enables the robot to see objects in three dimensions, which is essential for object manipulation and environment navigation. The data acquired from the Kinect sensor is stored in the Blackboard as a RGB bitmap, depth bitmap and human skeleton array to be used by the other vision modules.

**Person Finder** The Object Finder Module uses a proprietary software based on the algorithm of Viola Jones for multiple face detection and recognition. The name associated to the detected faces (if known) and its confidence is stored in the Blackboard.

**Human Pose Detection** The Human Pose Detection Module uses data from the Kinect module to retrieve the detected human skeletons which are converted to Orthogonal Direction Change Chain Codes [1] which are used as input for a Hidden Markov Model [9], with a state grammar to detect, recognize and label human movements like stand-up, sit-down, walk-run, etc.

**Cartographer** The Cartographer module stores the several maps used by the motion planner and also generates topological maps with the 3D points obtained from the depth map of the Kinect module.

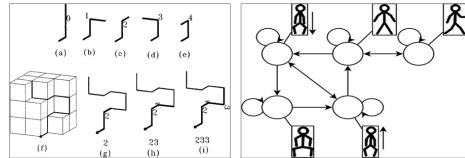


Fig. 5: Human skeletons are processed in a state grammar.

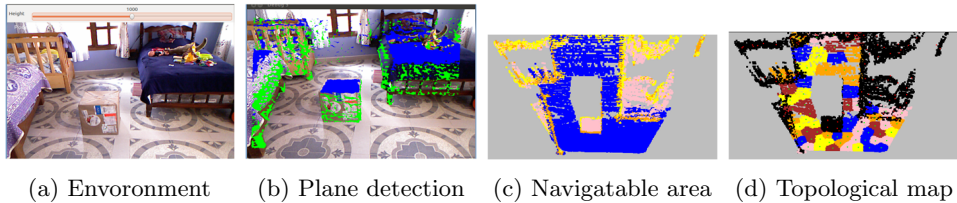


Fig. 6: Topologic map generation from 3D points.

**Speech Recognition** This module is part of the Human/Robot Interface ViRbot subsystem and uses the MS SAPI 5.3. An array of hypothesized strings with its confidences is stored in the Blackboard to let the Action Planner to choose the most adequate candidate for the robot's current context.

**Speech Generation** This module is part of the ViRbot's Human/Robot Interface and allows the robot to interact with humans by synthesizing voice. It uses the Microsoft SAPI 5.3 with the Loquendo Susan voice [8].

**Sensors** The Sensors module controls the data acquisition from several sensors like lasers and sonars. The acquired data is stored in the Blackboard to be used by other modules.

### 3.2 Hardware

**Sensors** The robot has several sensors for getting information on the surrounding environment: laser range finder for motion planning and obstacle avoidance, a Kinect system for seeking humans and objects, a stereo VGA camera for pattern recognition and a directional microphone for natural-speech command interpretation. Digital signal processing techniques are applied to the obtained signals to interact with the dynamic environment.

**Differential Pair Mobile Base** The robot uses a differential pair mobile base to navigate. A microcontroller-based board sends and receives commands for motor control and encoder reading, using a serial communication interface.

**Manipulator** The robot has two 7 DOF articulated arm with anthropomorphic configuration built with Dynamixel servomotors and a microcontroller based embedded system for control and trajectory planning. The arm has an anthropomorphic design in order to perform a better obstacle avoidance and natural human-like movements. For path tracking, a PID plus gravity compensator control is used and a vision based control is implemented for handling objects.

**Mechatronic Torso** The robot has a Mechatronic Torso with 2 DOF for control the elevation and pan of the arms and head. The torso increases the grasping range of the manipulators and allow the robot to look straight to both, small and tall humans.

**Mechatronic Head** The Mechatronic head design is based on the corresponding movements of the human head with 2 degrees of freedom: pan and tilt. This freedom of movement allows to point the sensors to obtain accurate readings of the environment and perform a systematic search in a particular zone of interest. It carries three different sensing devices on it: a Kinect system, a directional microphone and a stereo camera. The sensors are integrated with a friendly plastic face providing confidence to humans that interact with the robot.

## 4 Conclusions

The ViRbot system was successfully tested in the Robocup@Home category in the last four RoboCup competitions and in Atlanta 2007, the robot obtained the third place in this category. In these years, the full system has been improved having reliable performance and showing promising results. In the future, the structure of the robot will be redesigned to reduce its weight and make its assembly and maintenance easier. Also, new algorithms for the recognition of human faces and objects, along with localization, 3D mapping and more complex behaviours arbitred by the Action Planner's expert system.

To improve navigation, SLAM technics are being developed using the visual relationship between two different views of the same scene. Also, to provide compatibility with the most used framework for robots, a bridge between the Blackboard and ROS is being developed.

Some videos showing the operation of the ViRbot system can be seen at <http://biorobotics.fi-p.unam.mx>.

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