UTBots@Home 2021 - Pionner 3-AT current and future developments

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Abstract— **This TDP describes the hardware and software solutions currently applied to allow the Pioneer robot from UTFPR (Federal University of Technology - Paraná - to execute domestic tasks related to the Robocup@Home initiative. The Pioneer 3-AT robot (a.k.a. "Apollo") has sensors, such as a laser scanner and a Realsense sensor, that provide information necessary for navigation, object recognition, environment mapping and auto-localization. An innovative human-robot interaction interface, using different facial expressions based on simulated emotions, is also presented. The robot is capable of executing some Robocup@Home tasks, such as voice synthesis and recognition, object recognition and navigation. All the programming uses ROS (Robot Operating System), so that the same control programs can be executed in similar robots with minimum alterations. Also, we present what is planned for this year edition, which will happen remotely, and the improvements planned for the future.**

I. INTRODUCTION

Robocup@Home is a competition that aims to foster the development of robots that will help people in domestic environments, being the biggest competition for service robots on the planet[1][2]. In order to perform household tasks, the robotics fields of human-robot interaction, navigation, map construction on dynamic environments and computer vision are developed, among many others [1]. To accomplish these tasks, a Pioneer research robot is being developed: "Apollo", presented in Figure 1. This robot is composed of a mobile base (Pioneer 3-AT), a manipulator with 3 degrees of freedom, a LiDAR laser range finder, a screen to present the "face" of the robot, and a depth/RGB camera.

The applications are running with ROS (Robot Operating System), a set of software libraries and tools that help to develop applications for robotics [3], that run on a laptop computer placed in the back of the mobile base. The control system of the robots is responsible for acquiring and interpreting various sensors and, from that data, make decisions to fulfill the tasks.

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In this document, the partial results and expectations of projects under development for this robot is presented. Section 2 presents a description of the robot's hardware, including specifications and characteristics. The software already developed, and what is still in development, is described in section 3. Conclusions and future perspectives are presented in section 4.

II. HARDWARE

A. Robot Specifications

The robot is based on a Pioneer 3-AT research robot: it weights only 12 Kg, with 12 Kg of payload, and maximum speed of 0.7 m/s. Its autonomy is of 2 hours, with 3, 12 volts, standard batteries. Its dimensions are: 50 cm wide, 50 cm deep and 28 cm high. The robot connects to an external embedded computer via a serial-USB interface allowing its connection to a ROS system (Figure 1).

A redesign is being planned, and a Jetson Nano [4] will be coupled to the robot, in order to process computer vision and other GPU-focused processes. The idea is to integrate the Jetson Nano to the ROS network on the external Nuc [5].

B. "Neck" Support

On the robot's surface is a support constructed of aluminium. This support is 1.2 meters long, allowing the positioning of the LCD display and the RealSense depth sensor [6] to a height comfortable enough to allow interaction with people (1.5 meters approximately).

III. SENSORS

A RealSense depth sensor has been incorporated. With this sensor it is possible to create a depth image, identify silhouettes of persons and objects, among other functions [7].

In order to establish the communication between the RealSense sensor and ROS the librealsense package was used. The data generated by RealSense and the laser sensor is published in topics in ROS, making the data available to algorithms used in this project. UtBot has a YDLIDAR X4, which is a low cost LIDAR sensor capable of 360 degrees distance measurements [8].

A. Manipulator

The original model of the manipulator used is a Beckman Coulter ORCA Robotic Arm, a planar manipulator that has three rotational joints and can be seen in Figure 1. To make the structure respond to the desired commands, a process of retrofitting was carried out, where the motors and encoders were connected to microcontrollers that allow the open programming of the mechanism. The robot is currently under remodeling and the addition of this arm to the Pioneer 3-AT robot is planned.

In addition to the three motors that define the degrees of freedom of the structure, each joint is also coupled to a quadrature encoder. This sensor emits digital pulses to the microcontroller when the joint is in motion, either by driving the motor or by the action of external forces.

The quadrature encoder emits two pulses slightly out of phase. This allows to infer the direction in which the motor is rotating: The microcontroller triggers an interruption every time a pulse is received by the encoder at output A. If output B is already at a high level, it means that the direction of rotation is clockwise. If output B is at a low level, then this pulse will occur shortly thereafter and therefore the direction of rotation is counterclockwise.

Joints 1 and 2, respectively related to the manipulator's shoulder and elbow, are controlled by an Arduino that has an H-bridge for each engine. Joint 3, related to the handle, and the gripper are controlled in the same way by another Arduino. Each joint has a PID control system that aims to maintain the angle of the joint in the desired position in opposition to external forces, in addition to allowing a smoother displacement between one position and another. Arduinos are connected to a single USB port, external to the mechanism, via a hub. Through this connection, ROS commands are received.

Fig. 1. Pioneer AT (a.k.a. "Apollo") with its support for the RealSense sensor, and the display that is used to present simulated emotions.

Customized ROS messages were implemented for sending and receiving robot information. While the microcontrollers receive the messages containing the desired angle in the topic of the respective joint, it sends messages allowing the monitoring of the pose of the structure.

As the encoders do not have memory of the location where the joint stopped and also do not allow monitoring the movements that occur when the structure is off, the robot needs to perform a startup routine every time the system is powered. This makes all the joints assume an initial position and the control is done from these already known angles.

IV. SOFTWARE

A. ROS - Robotic Operating System

The robot is controlled via a Nuc computer with the melodic version of ROS, on the operating system Ubuntu 18 LTS. ROS allows the application of several tools, libraries and conventions that simplify the development of complex and robust tasks for robots [3]. In this system, you need to run a core process, *roscore*, which function as a server that manages threads and nodes. Topics are data buses through which nodes exchange messages, and multiple nodes may subscribe to each topic (receiving its data) or publishing to it (sending data). Nodes are computational processes, that process data coming from some topics, and publish results to other topics.

B. Emotion Simulation

Emotions are simulated by the robot through faces, displayed according to the present situation, for a better visualization of internal states of the robot, and better interaction between the robot and people. Emotions were based on Plutchik's wheel of emotions [9].

A unit-built app is used to read the theme responsible for the emotion and change the appearance of the affect when necessary. All emotions are shown through the display. Figure 2 shows some of the faces developed to express different emotions when interacting with people and Figure 3 illustrates an emotion being displayed by the robot.

C. Simultaneous Localization and Mapping

Odometry errors can lead to uncertainty in navigation. It is important that the robot is able to correct its location based on the feedback from sensors in real time. SLAM

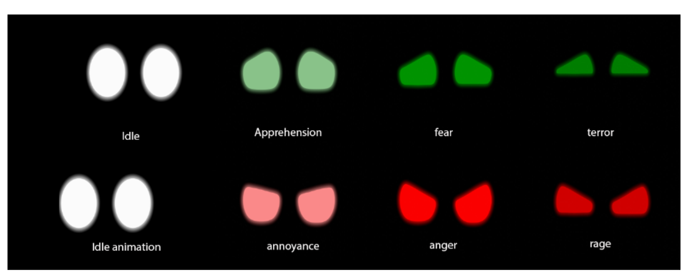

Fig. 2. Examples of faces developed.

(Simultaneous Mapping and Mapping)[11] algorithms can achieve this. Currently, the YDLIDAR readings and the robot's wheels odometry are feeding the standard ROS navigation stack and *move_base* is used to order navigation tasks to the robot. By constructing a map of the environment at the same time as it is updating the robot's position, the robot estimates it's position and updates wheel velocity. To accomplish this, SLAM has a number of tasks: extraction of reference points, data association, state estimation, status update, and reference point update. Parameters adjustments and tests under different SLAM configurations are crucial for improving navigation.

D. Voice recognition and synthesis

For speech synthesis, a ROS package called *espeak_ros* is being used. This package works by running a ROS node that subscribes to the topic *speak_line*, and performs voice synthesis based on the specified parameters. The configuration of these speech parameters is done through the *dynamic_reconfigure* package, which allows you to change parameters on ROS nodes without having to restart them. The configuration of the speech parameters encompasses several characteristics, such as speech speed, volume, pitch (lower or higher), the space between words, age and intonation variation. By altering these parameters, the speech characteristics can be defined in accordance with the emotion displayed on its "face".

E. Object Recognition

For object recognition, a new dataset is in development, that allows capturing of a large number of images of each object. This system has two Logitech C920 cameras (stereovision) and an ASUS Xtion depth sensor, which allows the capture of 2,600 RGB images by the camera and 2,600 point cloud images. Due to the way the images are collected, it will be possible to create 3D objects by applying only the texture.

A new method for object 3D pose estimation is under development. It is based on the intersection of 3D arrays in the environment's 3D space. The most significant singularity is that it requires no prior knowledge about the 3D shape of the target object. Its detection occurs in an earlier step, using YOLOv3. Since YOLOv3 works only with the RGB layer, the object's 3D shape information does not influence directly the object detection. This allows for the detection of objects with varying shapes, such as apples and bananas. Furthermore, upon training the YOLOv3 model, a variety of objects can be grouped under a certain class - for example, we can label the same class to different instances of apples, with different sizes, poses and colors (green and red apples). YOLOv3 can even identify new instances of objects: instances never seen before by the robot. By identifying a point in the center of the visible face of the object, and a point on the RGB-D sensor, a 3D array is defined. By moving the robot, other 3D arrays are defined. The method makes use of those 3D arrays to estimate a point that represents the object's 3D center. This new method is being tested and experiments are being conducted to determine it's accuracy and usability. The intention is to run it on the Jetson in the Pioneer 3-AT.

Fig. 3. Simulated emotion presented on the tablet (face) of the robot.

F. Manipulation

In a new project involving optimization and alternative robotic kinematics techniques, the retrofit process of a Mitsubishi RM-M2 manipulator was carried out. The control block was reconstructed using a set of Arduino microcontrollers, each coupled to two H-bridges, so that each device controls two joints. The manipulator has five rotational degrees of freedom and a claw for manipulating objects. Through 3D printing, a support for a depth camera was adapted near the handle, so that the camera can observe the operation of the claw, and then give the feedback on the posistion of the objects.

The attached camera is a RealSense F200 that records distances at a resolution of 480p, enough to detect different surfaces in the manipulator's working space. This data is sent as a PointCloud via ROS network which are then read and processed via Matlab.

The manipulator movements are measured through quadrature encoders, limited by limit switch sensors and are also sent through the ROS network. Setpoint angle commands for each joint are sent through ROS where forward and inverse kinematics calculations are computed using Clifford's Algebra. Such techniques seek to implement more efficient calculation tools using the algebraic advantages of the dual quaternion, which are a subset of Clifford's Algebra. Clifford's Algebra is also used to relate the objects detected by the camera to points and planes that constitute a collision and manipulation control system. The objective in joining these techniques is the manipulation of a Tower of Hanoi game in a totally autonomous and generic way by the manipulator.

V. CONCLUSIONS

The team is capable of fulfilling several tasks of the Robocup@Home category successfully. Among the tasks under development are the more accurate recognition of voice commands, and the integration of SLAM and manipulation tasks. The remote characteristic of this year's event allowed the planning of a redesign of the Pioneer 3-AT robot, which will allow the execution of GPU-based algorithms such as convolutional neural networks. Object recognition is expected to be the main advance this year. For the future, research projects focused on the manipulation arm and in the human-robot interaction can result in new ideas and approaches for related tasks.

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