PMEC@HOME Team Description Paper

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***Abstract*—This paper describes the service robot Miss Piggy of team Pequi Mecânico that will participate on the RoboCup@Home competition which takes place annually in Brazil. This competition has influenced the development of research in natural language processing, computer vision, robotic manipulation, simultaneous localization and mapping.**

***Index Terms*—Robotics, Domestic Robot, Autonomous Assistant, Artificial Intelligence, Human-Robot Interaction, Pequi Mecânico,RoboCup Brazil.**

I. Introduction

The Pequi Mecânico Robotics Center, abbreviated as Pequi Mecânico, is a non-profit student organization that brings together students from various undergraduate and postgraduate courses at the Federal University of Goiás. Its aim is to foster interest, research and development of robotics in the academic environment. It is a self-managed group of students from the university, with guidance from teachers and support from scientific institutions linked to the Federal University of Goiás, such as the School of Electrical, Mechanical and Computer Engineering (EMC) and the Institute of Informatics (INF). This, coupled with the support of the Center of Excellence in Artificial Intelligence (CEIA) has been fundamental, providing resources and technical guidance that allow the team to overcome complex technical challenges.

Pequi Mecânico Robotic Team exists since 2011 and took part in Latin American and Brazilian Robotics Competition in various categories: IEEE Standard Educational Kit (SEK), IEEE Open, RoboCup Small Size Soccer (F180), IEEE Humanoid Robot Racing (HRR), IEEE Very Small Size Soccer (VSSS) and RoboCup Soccer Simulation 2D. In 2019 we decided to compete for the first time in the Robocup@Home league.

Service robots are hardware and software systems that assist humans to perform daily tasks in complex environments. In order to achieve this, they have to be able to understand spoken or gesture commands from humans; to avoid static and dynamic obstacles while navigating in known and unknown environments; to recognize and manipulate objects and performing several other tasks that a person might request. Our robot's name is Miss Piggy (see Figure 1).

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Fig. 1. Side view of the Miss Piggy Robot.

II. Miss Piggy's Robotic Systems

A. Manipulator

The manipulator model that accompanies Miss Piggy is a ViperX 300s 6DoF (Trossen Robotics), consisting of 8 Dynamixel servos (both XM540 and XM430) coupled in a way that 6 degrees of freedom were obtained, with a maximum payload of 750g. The automation approach varies between classic control applications and reinforcement learning algorithms, depending on the desired activity.

B. Human Interaction

The main way to interact with the robot is through voice commands, we use custom enhanced versions for embedded systems of Neural Networks, deployed into our Jetson Xavier via the [5]NVIDIA Riva SDKriva for the speech related capabilities (Automatic Speech Recognition and Speech Synthesis) that is able to provide state-of-the-art performance. To handle the NLU (Natural Language Understanding) core, the approach consists of a Large Language Model (a custom Llama 2) to handle its conversational operations, which consists of being able to help the operator based on the actual environment and also understand actions/commands to be executed on the context of a personal domestic robot.

Aside from the voice command is possible to input commands through it's Graphical User Interface (GUI) on his main screen in a simple text format. The GUI is in a web-based format that allow user's to access it remotely on any mobile device, it provides control and feedback over the actions of the robot through text and audio, the interface also show a friendly animated face that reacts to the user input.

1) Computer Vision: Currently our perception stack consists of several YOLOv8 based models, each one of them with a specific skill related, such as Object Detection and Pose Detection. The information provided by these models are included in different pipelines in order to achieve the tasks goals presented in the @Home category. These models were enhanced by TensorRT inference to achieve near real-time performance while mantaining good accuracy.

C. Navigation

In order to navigate through robocup@home environment, Miss Piggy uses *Navigation 2* [9]. Thus, the robot can move from wherever it is to a desired point avoiding obstacles in its map using three layers of costmap2d ros2 package[7]:

- obstacle_layer: uses data from LIDAR as laser_scan and point cloud provided from realsense's sensors as sources of observation;
- static_layer: map acquired from mapping stage (explained in next subsection);
- inflation_layer: propagating cost values out from occupied cells that decrease with distance as stated by environment.

To perform the best movement according to Miss Piggy's structure constraints (e.g. differential driver, acceleration limits, minimum velocity), we adopted a smac local planner. An implementation of this approach in Robot Operation System is available in [4]. We are using it to achieve optimization of global planner at during runtime and minimizing the trajectory execution time.

1) Mapping: Previous to the task's execution moment, the robot Miss Piggy will navigate the entire environment for the purpose of tracking objects and mapping the house. This way, using a Lidar as laser scanner and dead-reckoning sensors as odometry and IMU combined by Extended Kalman Filter, we can create a 2D map of occupancy performed by a *Simultaneous Localization and Mapping* approach.

By this day, we are searching for the best SLAM algorithm which attempts hardware limitations and sensors uncertainty. RTABMAP is accessible as a ROS package in [8]. It is a response that fit well into the faced problems and proved to be modularizable enough for testing and replicability in both virtual and real environments."

2) Localization: An implementation of Extended Kalman Filter (EKF) available in ROS is [2]. By using that, we can combine odometry of wheels, visual odometry and IMU data to provide more accurate relative position measurements. Collecting absolute position measurements like laser_scan data from Lidar, we merge information and pass it through a Localization based on map approach.

By now, ORB-SLAM is a good solution to acquire visual odometry data, and we are using a self-adapting ROS package inherited from RGB-D application [3]. Our solution changes some stacks of algorithm to obtain odometry messages and parameterize the code for realsense sensor.

There are a lot of solutions to the problem of localization with a map (e.g. EKF-Localization, Multi-Hypothesis Tracking, Grid Localization, Monte Carlo Localization explored by [10]). Nevertheless, each of them has great complexity measures in practice. Therefore, an Adaptive Monte Carlo Localization (AMCL) has been used as state-of-art localization problem. We are working with an AMCL available in [**shauhuas**] and parameterizing the code to hitch our sensors.

III. Current Research

A. Human Robot Interaction

Looking for amplify the user experience of the robot the PMEC@HOME Team is developing models for voice biometrics (to enable speech recognition of people) and wakeword detection openWakeWord Framework [6], enabling more refined robot interaction. Aswell as being capable to maintain sparses conversation over time with the same person, being able to recover past information from a speaker to personalize usage of the robot.

B. Computer Vision

1) Person recognition: The skill of recognizing a person among the orders is one of the fundamental skills for the robot. The team is developing a way to extend the current capability of recognize people's face via DeepFace, to also be able to differentiate people from their whole body image, reducing the limitation of the previous approach that needed the person's face in the reach of the camera to perform the recognition.

C. Robot Behavior

The task execution is a challenge in the @Home category, each test in the competition consists of several steps that we currently implement via scripts that make use of the ROS interfaces (services, actions, node) and Nav2 Behavior Trees. One of our lines of research is approach the task planning and execution in a more generalistic fashion. Using our LLM to organize the steps that the robot should execute and interact with the well established behavior trees.

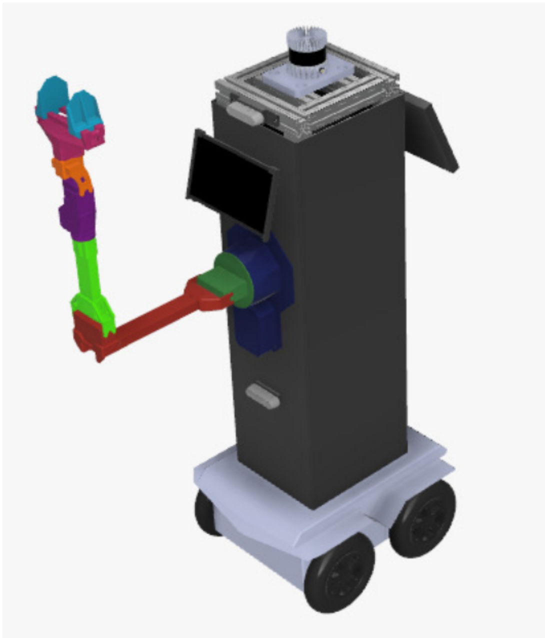

Fig. 2. Miss Piggy 3D Model.

D. 3D Modeling and Simulation

After the development of the first 3d modeling software, the sketchpad, in 1963, the creation of solid objects through the representation of a volumetric object became possible and increasingly used - in fields ranging from cinema to robotics.

The modeling in its most common aspect is performed by creating a mesh of segments that will give shape to the object, this is developed by several techniques, the most common being the polygon technique, the vertex technique and the edge technique.

In Robotics, the robot geometry description is based on the Unified Robot Description Format (URDF), which is a package with XML format to represent the robot model.

The new 3D modeling done for Miss Piggy was entirely based on the formulations of the Unified Robot Description Format (URDF), but completely implemented using the updates contained in the Foxy distribution of ROS2, aiming to enhance the transcription from the real robot to the virtual one and its performance in simulation.

IV. Miss Piggy's Components

This section describes the organization of the Miss Piggy's electronic components, detailing the role of each component in the system's composition, as well as the methodology applied to ensure efficient communication between components and system performance.

The layout of the robot's electric components and their connections are illustrated in the figure below. Next, the specifications and application methodology for each element that makes up the aforementioned system will be outlined. Finally, the methodology used to implement communication between the selected computers and sensors

TABLE I
Miss Piggy's Software Stack

Role	**Item**
Operating System	Ubuntu 22.04
Middleware	ROS2 Humble
Navigation	ROS2 *navigation stack*
Localization	*EKF*
Mapping	*RTABMap*
Object Recognition	YOLOv8
Face Detection	YOLOv8
Human Detection	YOLOv8
Gesture Recognition	MediaPipe
Face Recognition	DeepFace
Speech Synthesis	FastSpeech
Speech Recognition	Conformer-CTC
Natural Language Understanding	Llama 2

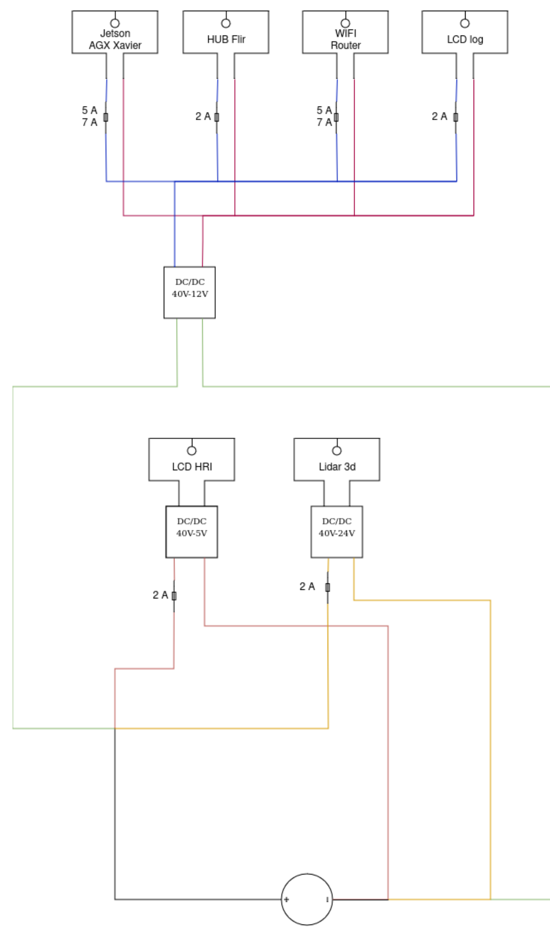

Fig. 3. Miss Piggy's Electric Diagram

A. Jetson Xavier AGX

The Jetson AGX Xavier is a cutting-edge AI computing platform designed for high-performance and efficient processing. It features an 8-core ARM v8.2 64-bit CPU, a 512-core Volta GPU with Tensor Cores, and a dedicated Deep Learning Accelerator, making it capable of handling complex AI and deep learning tasks. With 32GB of LPDDR4x memory and a high bandwidth of 137GB/s, it ensures smooth and rapid data processing. Its compact form factor and energy-efficient design make it suitable for embedded applications. In Miss Piggy the Xavier is dedicated for the AI applications, such as inference in the LLMs, Speech-to-Text/Text-to-Speech, Vision, Reinforcement Models.

B. Clearpath Jackal UGV

The Clearpath Jackal UGV is a versatile and robust mobile base designed for outdoor and indoor applications. The Jackal UGV boasts an open-source ROS (Robot Operating System) interface, facilitating seamless integration and development of advanced robotics applications. Its precise control, reliable performance, and adaptability make it an ideal choice for our context in the @Home competition. Equipped with powerful onboard computing which handle all the sensors input and ample payload capacity the usage of the jackal as our mobile base allowed the focus more developing the autonomous section of the robot, giving more time to our hardware team to develop our on mobile base. With some refactoring, we encapsulated the communication solution within Docker containers, ensuring the reliability of the interface's usage. This also enhances the usability of various packages for sensor access via micro-ROS[1] and ROS2, connecting to the base and the computers responsible for the intelligent autonomous behavior of the Miss Piggy system.

C. TPLink Archer AX72

The TP-Link Archer AX72 is a high-performance Wi-Fi 6 router designed to deliver fast, reliable, and extensive wireless coverage. It supports the latest Wi-Fi 6 standard, providing speeds up to 5400 Mbps, which ensures smooth streaming, downloading and uploading. The router network is bridged between the computers to enable fast communication of sensors and processes data that is fundamental in ROS2. The Wi-fi 6 capability enables us to monitor all the information from the robot without the need to be connected by any cable or to be close to him.

D. Ouster OS-1

The Ouster OS-1 is an advanced lidar sensor designed for high-resolution 3D mapping and autonomous navigation. The OS-1 utilizes digital lidar technology to deliver accurate and reliable performance in various lighting and weather conditions. Additionally, its low power consumption and flexible integration options made it a practical choice for developing new ideas. Currently the OS-1 is not required for the robot to execute its functionalities, the PMEC@Home team is performing experiments with applications that make greater usage of this component.

V. Conclusion and future work

This is Pequi Mecânico's fourth attempt to compete in this category. Our robot was designed based on other team's projects, information available at ROBOCUP @home wiki, and our own insights on the competition's challenges.

We have been looking towards to make the @Home experience more immersive, there are lines of research in the team coming up with new strategies based on point clouds obtained via a 3D Lidar using Geometric Deep Learning techniques to transpose the robot view of the world to VR/AR visualization.

The Deep Learning approaches we use will allow the robot to learn throughout the course while it receives commands and perform tasks. We already have several versions of Miss Piggy which perform different sets of tasks, and, until the competition, we will have many more.

Acknowledgment

The support from the Center of Excellence in Artificial Intelligence (CEIA) and the Federal University of Goiás (UFG) has been essential, providing resources and technical guidance that allow overcoming complex technical challenges. These efforts highlight the significant advancement in the development of autonomous robots, contributing to the field of robotics and ensuring the ability to carry out missions proposed in the competition effectively.

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Addendum

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