RoboFEI@Home Team Description Paper for RoboCup@Home 2023: France Edition

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Abstract. HERA (Home Environment Robot Assistant) is a robot developed by the RoboFEI@Home team, considering all mechanical, electronic, and computational aspects and classified to OPL (Open League platform). It's a platform capable of performing autonomous tasks in home environments, in addition to human-robot interaction, collaborating with people who share the same environment. The current platform version presents advances in the interacting methods with people and social navigation. Interaction with people and objects is supported by image segmentation processes, enhancing environment perceptions and people recognition during tasks. Throughout the text, the research goals and team interests will be presented, as well as the hardware and software stacks used in the robot development to solve the @Home competition tasks and some of the projects currently under development by the group. The article intends to cooperate with the sharing of results on the service robot development to RoboCup@Home 2023.

1 Introduction

The RoboFEI@HOME team started its activities in 2015 using the PeopleBot platform to perform domestic tasks. Research on human-robot interaction has been intensified with master's and doctoral projects. Research is carried out in different contexts considering human behavior, user modeling, interaction design, social navigation, among others [1,2,3]. The mechanics and electronics of the robot were completely redesigned after difficulties in purchasing spare parts from the robotic platform on the market.

The mechanical, electronic, and computational design is considered an economical platform for maintenance, but it can perform many domestic activities such as: social and safe navigation, object manipulation, interaction with people and appliances, and command recognition based on gestures or voice [4].

The RoboFEI@Home team seeks to be in constant evolution to always develop new technologies in the domestic assistant area. The main researchers developed by our team in these years are focused on making the HERA robot even more autonomous.

The Team Description Paper is organized into 6 sections. The first section is the introduction, which includes a brief team description. The second section describes the research focus and RoboFEI@Home team interests. The third section presents the team achievements, competition participation, and team collaborations. The fourth section shows the approach to solving RoboCup@Home challenges, including robot vision, voice recognition, manipulation, and robot navigation. The fifth section concentred on current research and talks about social navigation and dynamic power management. The final section presents the summary with conclusions and plans.

2 Research focus and interests

The main research focus conducted by RoboFEI@Home is the interaction between humans and machines. This interaction can be observed in a great amount of technology emerging, such as autonomous cars, robots, and smart houses. The research in the field of human-machine interaction is highly influential in the development of service robots.

Belonging to a University of Engineering and Computer Science, there is interest in research and development in areas related to undergraduate and graduate courses in engineering (mechanics, electronics, automation, robots and materials) and computer science.

The RoboFEI@Home also contributes to the development of methodologies, techniques, models, and algorithms in the following topics: adaptive interfaces, brain-computer interfaces; planning; intelligent home and building automation; autonomous systems; internet of things (IoT); and dynamic and intelligent power management.

3 Team Achievements, Participations and Collaborations

We are a passionate team for RoboCup@Home, participatory and active since 2016, in our first participation in the world competition. Participation in local competitions helps to promote the league in South America, being a powerful ecosystem of knowledge exchange and preparation. In the Brazilian Robotics Competition (partner RoboCup Brazil) five consecutive titles were won. In the last local championship we won second place at Brazilian Robotics Competition. The RoboCup 2022 edition in Thailand was the first in-person edition after the pandemic. That was the first time the RoboFEI@Hone team won first place in the RoboCup@Home Open Platform League.

For the next edition of RoboCup in France the platform has new features and using the environment RoboCup@Home arena, it's possible to perform tasks with new features of computer vision, new methodology with social navigation, and new software architecture that integrates the various packages.

4 Approach to solve RoboCup@Home challenges

The RoboCup@Home league aims to develop service robots for home applications. It's the largest annual international autonomous service robot competition. A domestics task group of varying themes is used to assess the skills and robots performance. The main skills required by robots are Human-Robot Interaction and Cooperation, Navigation and Mapping in dynamic environments, Computer Vision and Object Recognition under natural light conditions, Object Manipulation, Adaptive Behaviors, Behavioral Integration, Environmental Intelligence, Standardization, and Systems Integration [5].

4.1 Robot Vision

The object detection system consists of Efficientdet-d0, using TensorFlow 2.0. To create this dataset of objects, have been used synthetic data generation to save time in tagging the images and create a larger amount of data. An efficient background removal method based on Deep Salient Object Detection, is an algorithm to detect the most noticeable and important object in an image, returning a binary mask of the image with the object. After generating the mask, the object image can be used to compose new images with different backgrounds.

Integrating a system of vision and manipulation of specific objects, with image segmentation techniques using color extraction to perform the fine adjustment in the object manipulation, not being necessary to train a model from scratch to recognize a single object, reducing the time spent in the training. The robot has people recognition, capable of memorizing names and faces using the library dlib that can identify a landmark, which allows guaranteeing a wide variety of tasks with people.

4.2 Voice recognition

The team decided to use Google's Speech Recognition API. For this, a ROS package was developed that operates through an APIs set. They are online tools that work directly on Ubuntu. In addition, a comparison is made with generic sentences using the Hamming distance to recognize sentence variations. This API was created from methods that facilitate the code adaptation to a given environment, creating a new use of word choices in speech. In competition, the team is using the MATRIX CreatorTM, a board with sensors, wireless communication and an FPGA.

The main objective of using this board is to perform directional voice recognition, thus being able to recognize where the operator is talking to the robot from. The Raspberry Pi connected to the MATRIX is used for communication with the core of our robot. The Raspberry is responsible for reading the information from the various sensors on the board and sending this information to the main system.

4.3 Manipulator

The manipulator has a number of degrees of freedom (DOF) contained in a human arm, aiming to obtain a great similarity with real movements using the anthropomorphic principle. From this, a study of human anatomy and kinesiology began, more specifically in the skeleton of the free portion of the upper limbs, namely: arm, forearm, carpus, and metacarpal. It was noticed that the main movements are extension and flexion.

A new change in the manipulator is the new materials we are using, for parts with more complex shapes we use 3D printing and for flat parts we are using carbon fiber, resulting in greater resistance with less weight and smaller dimensions.

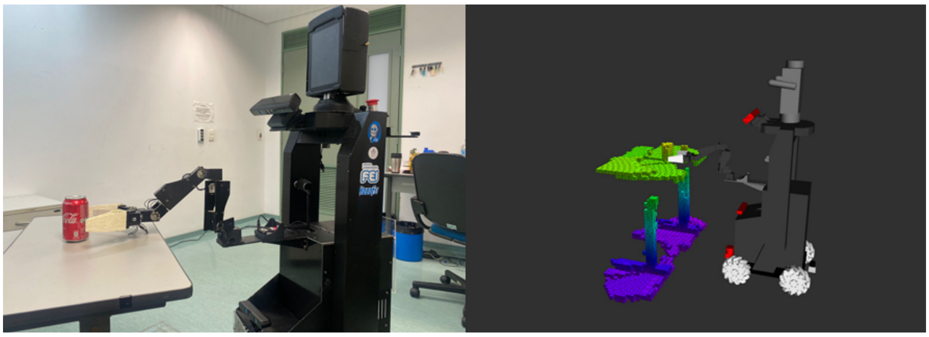


Fig. 1: Sensor interpretation using octomap in manipulation system.

In the manipulation system, is used the Dynamixel Workbench package for direct kinematics control when need simpler movements. When needing trajectory planning and deeper precision, is used Moveit with inverse kinematics. For a more optimized and safer manipulation, is used the octomap integrated with the manipulation system (figure 1). With this, it's possible to have the environment perception through the vision, considered in the robotic arm trajectory planning, allowing a safe movement.

4.4 Robot Navigation

An autonomous robot, to be able to navigate alone, needs the ability to map where it is, define its position in space and decide the best possible route. For this to be possible, sensors that capture external environments are used, and this information is transformed into interpretable data so that the robot chooses the best route. When the robot is in an unknown location, it must map the environment, where it is located, and at the same time define its position in space. This technique is known as Simultaneous Location and Mapping (SLAM). In navigation, the robot has the ability to choose the best possible route and avoid possible obstacles using parameters where the smallest path error is corrected instantly.

5 Current Research

5.1 Social navigation

The main focus of this research is on people's comfort in spatial interactions with a social robot. This research has as motivation the difficulty found when dealing with the social robot´s navigation in a safe, natural and social way, making the robot´s presence comfortable for the people interacting around it.

Initially, simulated experiments presented in [2] were carried out, then 20 volunteers were invited to participate in the real experiments. The characteristics of the volunteers varied in terms of age, gender, previous experience with a robot and previous knowledge of robotics. The real experiments were carried out following the project with a Certificate of Presentation of Ethical Appreciation number 43096121.7.0000.5508 presented to the ethics committee in research in Brazil.

For the real experiments, two types of spatial interaction between people and the robot were applied. In the first type, the robot navigated through the environment passing through some specific points. Between each point, there were people performing a certain action (standing, moving, interacting with other people or objects). In the second type, the robot approached a person or a group of people in a certain location. From these experiments, an ontology was developed, initially proposed in [3] where it was possible to determine the type of navigation that the robot performs, social distancing and how to approach people in a socially accepted and comfortable way.

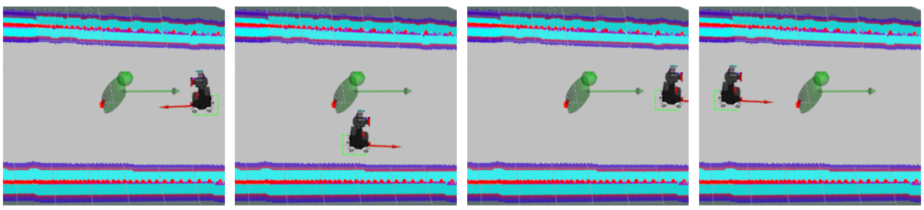
The robot receives objects information, people and the relationships between these entities. 3 layers of cost maps are created representing objects, people or people formations and relationships as areas of interaction. Then, the expansion of obstacles is performed in each of the elements of the classes of objects, people and formations. The robot's radius is used to expand objects and areas where interactions take place, and proxemics are used to expand the area of people and formations. The cost maps are used by ROS Navigation Stack to plan the robot's trajectories.

The robot also receives an identification of a place or a person existing in its knowledge base and performs the navigation to this place in a social way, respecting the social norms and rules based on the ontology. The robot receives the destination name and Navigation type and returns a robot pose at the target. Checks if the destination is a location or a person. If is a location, the destination is set to the location itself, if it is a person, the destination is defined as a location close to the person within its field of vision, respecting the proxemics and within a possible trajectory for the robot, so the robot send a new destination to the navigation system. During navigation, constant changes are made to the trajectory to prevent it from passing through people's personal space.

The robot performs reasoning on ontological information to perform social navigation respecting social rules and norms. The type of formation group is not classified here, however, the positioning of the formation members and the best approach can be found based on the guidance of the closest person and cost maps. Thus, it is possible to generalize the solution to any formation of groups.

The ontology identifies the type of navigation (location, person, walking side by side, guide, follow). Calculates the robot's destination coordinates depending on the navigation type. It publishes information about people, formations, objects and the interactions between them. Then from the navigation type and proxemics it returns the approach pose.

The type of social navigation the robot is currently performing can be To-Local, To-Person, Side-to-Side, Guiding or Following navigation. The type of navigation determines the robot's destination, the angle relative to the destination, safe distance from the destination, and orientation relative to the destination. as seen in the figure 2 which presents a robot positioning depending on the type of navigation performed. In figure 4, the cost maps of people and areas of interaction are shown (in yellow it is possible to check the possible approach points that a robot can use, these points are inferred using the ontology).



(a) To-person (b) Side-by-side (c) Guiding (d) Following

Fig. 2: Types of navigation when a destination is a person.

At the end of this study, a computational solution was obtained that allows a mobile social robot to be able to interact properly in spatial terms in a social environment, reducing the feeling of discomfort for the human being during this type of interaction. This study is designed to address current scientific and social challenges. Having potential for a positive impact both in the academic environment and in the daily life of the common citizen.

5.2 Dynamic Power Management

The constant development of our robotic platform substantially increased its power consumption. As a consequence, our first solution was to increase the our robot. After that, the next step was to migrate to higher energetic density batteries, which solved our problem but wasn't a good solution due to its prices so we started research into Dynamic Power Management [6]. Dynamic Power Management (DPM) is a method developed with the purpose of optimizing available energy sources. DPM proposes to optimize energy use through the control of the energy used by the system's modules, made by the idleness exploitation: If a device (or components of a device) is idle, its energy consumption should be reduced as much as possible to save for when it will be needed. There are several ways to implement the DPM, but the first step is to detect with accuracy the idleness in the system´s module to quickly deactivate and force it into an energetic dissipation state in which the wasted energy is as low as possible. To develop the research and implement the most suitable DPM [6]. in our system, it was necessary to conduct a lot of tests, which consisted into analyse the operating current of each module as a function of time, while the robot performs a task. The current was acquired using an ACS712 sensor and the data was sent to a computer through an Arduino. Then the operating current of each module was multiplied by its operating voltage to obtain the energy consumption of each module, generating the graph shown in figure 3.

Analyzing the graph, the Average Consumption per Second (Cps), Execution Time (Texec) and the Total Consumption (Ct) were calculated. From the data obtained, simulations were made considering different DPM methods, and the one closest to the ideal was the predictive method with pre-wake up, saving more than 35% of wasted energy, increasing the running time substantially and by consequence, the batteries lifespan. Our team implemented this DPM module on HERA utilizing an electronic relay module to deactivate the module that is in idleness and is conducting new research into implementing a battery bank to supply energy to the entire robot and make the management even more efficient.

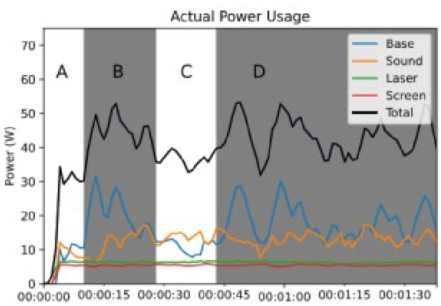


Fig. 3: Consumption of each module and total consumption.

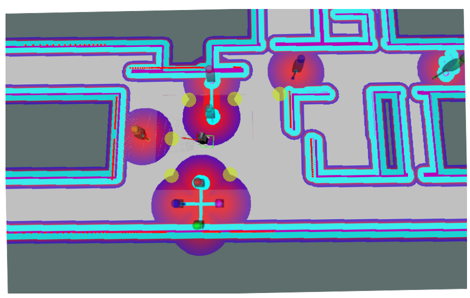


Fig. 4: People approach points.

6 Conclusion

This Team Description Paper describes the main strategies and technologies used on robot HERA to win first place in the RoboCup@Home 2022 (Open Platform League), focusing on the organization of tests and rapid implementations of technologies for validation. In addition, we modulate our strategy to be easily adapted to different environments and situations. With this, we hope that the strategy presented can be applied to different contexts and replicated by other groups.

References

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Robot HERA Hardware Description

Robot HERA has been designed for human interaction in the domestic environment. Specifications are as follows:

- Base: Mecanum Wheel Robot platform.
  - Sensors:
    - Hokuyo UTM-30LX(front)
    - Hokuyo URG-04LX(back)
  - Actuators:
    - 4 Omnidirectional wheels
- Chest: PeopleBot extension
  - Sensors:
    - Emergency switch
    - Asus Xtion
  - Actuators:
    - 6 DOF manipulator
    - 1 DOF flexible gripper
- Head: Apple Ipad
  - Sensors:
    - Microsoft Kinect 2
    - Logitech c920 webcam
    - 2 directional microphones - RODE VideoMic GO
- Control: Zotac Mini-PC i5 7500T CPU.

Robot's Software Description

For our robot we are using the following software:

- OS: Ubuntu 20.04;
- Middleware: ROS Noetic;
- Localization/Navigation/Mapping: SLAM;
- Face detection: Haar cascades;
- Face recognition: LBP Algorithm;
- People detection and tracking: OpenPose
- Gestures/movement recognition: Wave! and NITE;
- Object recognition: MobileNet v2 + SSD on Synthetic Data;
- Object manipulation: Moveit!;
- Speech recognition: DeepSpeech (offline) or a package based on the Speech Recognition library (online);
- Speech synthesis: Flite (offline) or GTTs (online).
- Simulation environment: Gazebo inside a Docker Container

External Devices

HERA robot relies on the following external hardware:

- Mini PC Zotac for image processing.

Cloud Services

HERA connects the following cloud services:

- Google API for voice recognition and synthesis.