RoboFEI@Home Team Description Paper for RoboCup@Home 2024: Eindhoven Edition

Cauan V. E. de Sousa, Gustavo G. Bagio, Flora M. Aidar, Khaled H. Guimarães, Mateus Nogueira da Silva, Gabriela Bassegio, João Victor G. Prado, Cleuder Nathan C. Garcia, Victor Godoy Gaspar, Victor Caetano B. Silva, Plinio Thomaz Aquino-Junior, Fagner de Assis Moura Pimentel

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Abstract. The RoboFEI@Home team comprises undergraduate and postgraduate students in mechanical, electronic, and computer engineering, and has developed a robotic platform for participation in the Brazilian Robotics Competition since 2015 and the RoboCup since 2016. This platform is engineered to assist individuals with limited mobility and the elderly. The 2024 iteration introduces research advancements in object perception and recognition through motor effort and current analysis in the robotic manipulator. Further enhancements include robot pose tracking, and object segmentation via point cloud for refined object manipulation. Additionally, an innovative approach to domestic robot programming incorporates gamification elements. This paper details the platform's technical evolution, emphasizing the project's collaborative nature and its contributions to the field, with resources available on the team's repository `https://github.com/robofei-home`.

1 Introduction

Since launching in 2015, the RoboFEI team has developed home assistance robots for the @Home league, starting with the PeopleBot platform, but has also beem competing in SSL and Humanoid Leagues since 2009 and 2013, respectively. The @Home robots, designed for home interaction, combine safe human engagement with adaptive behaviors and specialized tasks [1]. Advanced academic projects have deepened research to enhance human-robot interaction, focusing on behavior, design, and navigation [2,3,4]. Confronting the challenge of parts scarcity, the team created an economical and sustainable robot design for diverse domestic tasks. For RoboCup 2024, they've advanced the HERA robot's autonomy with new object recognition, pose tracking, and gamification techniques for programming, enriching the robot's household integration.

2 Research focus and interests

The RoboFEI@Home team, affiliated with the postgraduate program in Applied Artificial Intelligence and Robotics, is deeply invested in the dynamic field of human-machine interaction. This sphere of research, reflecting the intersection of advanced technologies such as autonomous vehicles, robotic systems, and smart home automation, is pivotal in shaping the future of service robotics. Our university's strong foundation in Engineering and Computer Science propels our research and development endeavors, dovetailing with the curriculum of both undergraduate and postgraduate courses that span mechanics, electronics, automation, robotics, materials science, and computer science.

In addition to the core focus on human-machine synergy, the RoboFEI@Home group is dedicated to advancing methodologies, techniques, models, and algorithms across a spectrum of domains. These include adaptive interfaces, brain-computer interfaces, planning, intelligent automation for homes and buildings, autonomous systems, and the burgeoning field of the Internet of Things (IoT). Our collaboration extends into the realm of IoT with a particular emphasis on enhancing connectivity within robotic applications.

The group's research interests encompass a broad scope but particularly focus on the mechanical aspects, embedded electronics, sensor technology, battery management, and embedded computing. These interests are theoretical and practically oriented, aimed at addressing real-world challenges associated with designing and implementing intelligent, autonomous robotic systems. Through this multifaceted research approach, the RoboFEI@Home team aspires to contribute significantly to the field of robotics, forging new paths in the interplay of machines and the everyday lives of humans.

3 Team Achievements, Participations and Collaborations

The RoboFEI@Home team has garnered accolades and fostered robotic innovation, particularly noted for its consecutive victories at the Brazilian Robotics Competition, a testament to our standing in South American robotics. Our success extended to the international stage at RoboCup 2022 in Thailand, where we secured first place in the Open Platform League.

Investments from our university into a dedicated research space compliant with RoboCup standards have significantly bolstered our experimental capabilities, allowing for refining techniques and strategies in real-world scenarios. This has led to substantial improvements in areas human interaction, object recognition, and advanced navigation.

Recent advancements leading up to RoboCup 2024 have seen our team achieve significant strides in object perception and recognition, employing sophisticated analyses of motor effort and current in our robotic manipulator. Our team has greatly enhanced our robots' manipulation skills, coupled with developments in robot pose tracking and point cloud-based object segmentation. Additionally, the introduction of gamification into robot programming has made our approach more compelling and improved its effectiveness.

The RoboFEI team takes on the pivotal role of organizing the Brazilian Robotics Olympiad, an event that engages elementary school students and fosters their learning in the field of robotics, encompassing all facets of service robotics. Hosted by the FEI University Center, the event has seen the participation of approximately 120 teams from across the state of São Paulo, with a total of 814 competitors in the 2023 edition. This initiative not only promotes educational development in robotics but also serves to inspire the next generation of engineers and innovators.

4 Approach to solve RoboCup@Home challenges

The RoboCup@Home competition is pivotal in advancing autonomous service robots for home use, testing them across a spectrum of household tasks. Robots are evaluated on their interaction and cooperation with humans, ability to navigate and map dynamic spaces, proficiency in computer vision and object recognition in natural lighting, and skill in object manipulation. The competition also assesses platform, behavioral integration, and overall system intelligence and integration [5].

4.1 Robot Vision

The object detection is accomplished using the YOLOv8 architecture within the PyTorch framework, enhancing detection accuracy. Synthetic data generation has expedited dataset creation, improving image tagging and expanding dataset volume. A Deep Salient Object Detection algorithm has been implemented for precise background segregation, isolating pertinent objects and generating binary object masks. These masks enable the synthesis of images against variable backdrops, thereby refining the detection process. Additionally, image segmentation via color extraction has been utilized for precise object manipulation without necessitating extensive model retraining for individual object recognition, thus optimizing training time. A people recognition system has been integrated for human interaction, employing the dlib library for facial and landmark recognition, supporting a broad spectrum of interactive tasks.

4.2 Voice recognition

The team has transitioned to the Whisper API for voice recognition, replacing the previous Google Speech Recognition API. This integration is supported by a specialized ROS package, optimized for Ubuntu, to enhance performance. The Whisper API is particularly adept at adapting to diverse speech patterns and word choices, suitable for various environments. The updated system efficiently processes voice commands and seamlessly interfaces with the robot's core system, ensuring robust and accurate voice command recognition across different settings.

4.3 Manipulation

The robotic manipulator, engineered by the mechanical team, mimics the human arm's degrees of freedom, enhancing domestic task efficiency and human-robot interaction by applying the anthropomorphic principle. Studies of human upper limb anatomy and kinesiology, emphasizing extension and flexion movements, informed its design.

Material innovation has been integrated into the manipulator's design, with 3D printing utilized for complex shapes and carbon fiber for flatter components, achieving increased durability and reduced weight and size.

The Dynamixel Workbench package is utilized for direct kinematics in basic movements for the manipulation system. For advanced trajectory planning and precision, Moveit with inverse kinematics is employed. OctoMap integration with the manipulation system ensures optimized and safe operations, incorporating environmental perception from vision systems into the robotic arm's trajectory planning, which enhances the success rate of "pick and place" actions.

4.4 Robot Navigation and Social Navigation

Autonomous robot navigation necessitates mapping, spatial positioning, and optimal route determination capabilities, facilitated by sensors that convert environmental data into navigable paths through Simultaneous Location and Mapping (SLAM). This process involves real-time corrections of path errors to avoid obstacles and select the most efficient route.

The robot has ontological framework was developed to guide socially acceptable robot navigation and approaches to individuals and groups, integrating semantic mapping and social navigation principles [3]. The robot's reasoning on this ontology informe its navigation strategies, adjusting its trajectory and approach based on proxemics and interaction zones, considering social norms. The outcome is a computational model enabling mobile social robots to interact suitably within social contexts, aiming to minimize human discomfort [4].

5 Current Research and Scientific Contributions

All the research topics discussed in this section represent functionalities currently under development and embedded in our robot, poised to be demonstrated at the upcoming competition.

5.1 Object Perception and Recognition Using Motor Effort and Current in Robotic Manipulators

The research project has advanced the manipulation module of the Hera robot, achieving synergistic development with the computer vision module for RoboCup 2024. The project's primary objective is to enable the robot to identify unknown objects and ascertain their positions solely through the generated Point Cloud and feedback from the motor effort exerted by the gripper. The motor's current during the grasping process indicates the object's category or even its specific identity. This inference is facilitated by the use of 3D printed flexible material in the robot's gripper, which molds to the contours of the object, allowing for enhanced interaction.

Experiments have been conducted to validate the system's object perception and recognition capabilities. The motor control system's response to varying degrees of effort and current was meticulously recorded in these trials as different objects were grasped. The results consistently correlate the motor's effort feedback and the object's type, size, and required grip strength. Objects ranging from soft textiles to rigid geometrical shapes were successfully categorized, underscoring the system's versatility (figure 1).

The practicality of this method was highlighted in experiments where the robot performed a series of object manipulations without prior knowledge of the items. The gripper's adaptive behavior, coupled with motor current analysis, reliably classified objects in real-time, showcasing the potential for this technology in scenarios where quick and accurate object identification is critical.

This research contributes to the field of robotic manipulation by demonstrating that motor effort and current can be effective indicators for object recognition. The findings suggest significant potential for applications in domestic robots, where the ability to adapt to various objects is paramount. The team's approach presents a step forward in robotic perception, potentially reducing the reliance on extensive object databases and complex vision systems for object identification tasks.

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

5.2 Object Segmentation Using Point Clouds for Robotic Manipulation

Within the scope of autonomous service robotics, point cloud segmentation for object manipulation has been an area of intensive research. This approach necessitates the reconstruction of an object's three-dimensional geometry within the Omniverse Replicator. It leverages domain randomization to generate a synthetic dataset, where desired objects are accurately labeled. Subsequently, this dataset is used to train a Convolutional Neural Network (CNN) model, which is adept at detecting and segmenting objects using point cloud data

This research is focused on developing a Convolutional Neural Network (CNN) model and crafting an algorithm capable of classifying whether a target object is graspable, based on the manipulator's properties. This advancement will enable all robots equipped with LiDAR or RGB-D sensors to segment and manipulate objects with heightened precision. The proposed method is anticipated to significantly enhance the robot's proficiency in recognizing and interacting with objects, taking into account their geometric characteristics.

The current objective is to construct a robust and consistent neural network that achieves high accuracy, utilizing the synthetic dataset generated in Omniverse. This endeavor aims to ensure that the network is not only reliable but also capable of replicating its performance with any labeled objects.

5.3 Detection and Analysis of Joints and Movements Applied in the Context of Robotics

In the domain of service robotics, the utilization of sophisticated computer vision systems, such as the OpenPose algorithm for human pose tracking, has been instrumental. Originally aimed at the meticulous observation of physiotherapy exercises via joint detection, the scope of application extends significantly into the operational domain of assistive robotics.

Employing the OpenPose algorithm, robot have been endowed with the ability to accurately track human poses in real-time. This technology has been integrated with the robot's processing units to allow for immediate and responsive interaction with users, adapting to their movements and gestures. Such advancements have facilitated the robot's capacity to preemptively recognize potential hazards, such as fall risks or ergonomic discrepancies in elderly users' postures, offering swift assistance or alerting support systems.

In the home environment, robots equipped with pose tracking can now adjust their actions to the residents' body language, thereby personalizing task execution, whether it be household chores or engaging in interactive activities. This level of adaptability is achieved through continual feedback loops where the robot's sensors and motors adjust in response to the pose data processed by OpenPose.

Furthermore, the research has extended to telemedicine applications. Robots serve as data collection points, accurately capturing patient movements for remote diagnostics and treatment efficacy assessments in physiotherapy, with the OpenPose algorithm ensuring high fidelity in data.

Institutional settings, such as nursing homes and hospitals, benefit from robots that continuously monitor patient safety, using pose detection to assist mobility and prevent accidents.

This research has been substantiated through testing. Experiments have been conducted where robots, utilizing the OpenPose algorithm, have successfully navigated complex human interactions. They have demonstrated proficiency in recognizing and mimicking human joint movements, highlighting the potential for these systems to contribute meaningfully to the field of assistive robotics.

Such technological integration represents significant progress in human-machine interaction, with the OpenPose algorithm at the forefront of this transformation. The ongoing research and development in this area promise to yield functional and empathetic robots to the nuanced needs of human companionship and assistance.

5.4 Gamification in ROS-Based Programming of Domestic Robots

The research has been conducted to make the programming of domestic robots using the Robot Operating System (ROS) more engaging and accessible, particularly for novices at RoboFEI. The project involved developing a game with Unity engine, where players complete tasks modeled after those in the RoboCup@Home competition. The game introduces a block-oriented programming puzzle that simplifies the coding process in an entertaining manner, imparting fundamental concepts of programming, logic, and robotics. As players progress through the game's levels, the complexity of the concepts gradually increases, easing the initial learning curve commonly faced by new robotics students.

This educational tool has been designed to reinforce the concepts learned, aiding players in retaining information and potentially easing the transition to studying robotics in a tangible setting. Moreover, the game translates the constructed code into executable scripts that can be run on the Hera robot, the same model used by FEI in competitions. This feature demonstrates the practical application of the players' creations in a real-world context and allows for the dynamic creation of functional code.

Advances in this research have been demonstrated through a series of experiments. The motor control systems of the Hera robot have been calibrated to measure effort and associate it with the type of object manipulated, mirroring the block-based tasks within the game environment. These experiments have verified the game's feasibility as a learning platform, with the robot successfully executing tasks based on the generated code, thus bridging the gap between virtual learning and real-world application in the field of robotics.

6 Conclusion

In conclusion, the RoboFEI@HOME team's journey reflects a steadfast commitment to advancing the field of domestic service robotics. Participation in the RoboCup has been instrumental in this process, offering a valuable platform for showcasing our technological developments and engaging in exchanging knowledge with leading teams worldwide. The challenges and competitions faced have tested our designs and served as a catalyst for innovation, driving the team to develop cost-effective and sustainable robotic solutions that cater to the dynamic needs of home environments.

The advancements made in the HERA robot for RoboCup 2024, including enhanced object perception, sophisticated pose tracking, and the introduction of gamification in robot programming, underscore our pursuit of excellence and the continuous evolution of our robotic platforms. The collaboration and competition inherent in RoboCup have significantly contributed to our growth, allowing us to benchmark our research against the best in the world while fostering an environment of mutual learning and improvement.

As we prepare for the upcoming competition, we are reminded of the importance of such international forums in the broader context of robotics research. They are not merely contests but opportunities for collective advancement and shared triumphs in the field of robotics. The RoboFEI@HOME team is proud to be a part of this global community, contributing to the ongoing dialogue that shapes the future of robotics and the role these extraordinary machines will play in enriching human lives.

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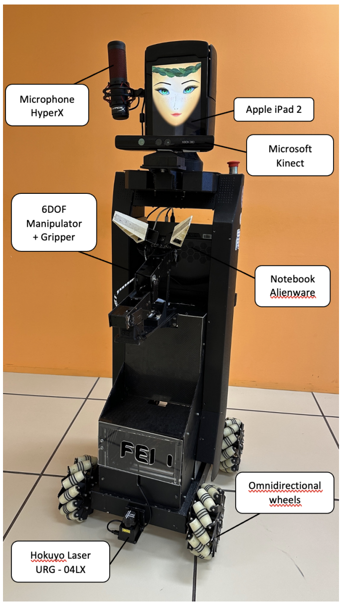

Robot HERA Hardware Description

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

- Base: Mecanum Wheel Robot platform.
  - Sensors:
    - Hokuyo URG - 04LX
  - Actuators:
    - 4 Omnidirectional wheels
- Chest: PeopleBot extension
  - Sensors:
    - Emergency switch
    - Asus Xtion
  - Actuators:
    - 6 DOF manipulator
    - 1 Flexible gripper
- Head: Apple Ipad 2
  - Sensors:
    - StereoLabs ZED2
    - Microsoft Kinect
    - Logitech c920 webcam
    - 2 microphones - HyperX QuadCast S
- Control: Notebook Gamer Alienware m15 R7 i7.

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! and OctoMap;
- 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:

- JBL Charge 5
- Nvidia Jetson Xavier NX.

Cloud Services

HERA connects the following cloud services:

- Google API for voice recognition and synthesis.