LAR@Home 2024 Team Description Paper

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Abstract. This paper describes the development and progresses of the team LAR@Home from the University of Minho, Portugal, for the RoboCup@Home competition that will take place in Eindhoven, Netherlands, in 2024. After the robot's first participation in the 2023 edition, the main efforts focus on improving the mechanical and electronic structure in order to highlight its anthropomorphic approach and addition of a new robot manipulator. Moreover, further developments were made in topics such as localization, navigation and improving object point cloud of objects, in the ability to natural human interaction and the surrounding environment as well as manipulation with objects are exposed.

1 Introduction

The Laboratory of Automation and Robotics (LAR) is a highly active RoboCup team affiliated with the University of Minho in Portugal. The team competes in both the Midsize League (LAR@MSL) and the @Home League (LAR@Home). While LAR initially participated in RoboCup@Home in 2010 with the robot MARY, the project was temporarily suspended for ten years. It was revitalized in 2020 with a new robot named CHARMIE, an acronym for Collaborative Home/Healthcare Assistant Robot by Minho Industrial Electronics. CHARMIE made its comeback in the competition in 2023 in Bordeaux, France, where the team secured a 7th-place finish.

This team description paper is a component of the qualification package for RoboCup 2024, scheduled to take place in Eindhoven, Netherlands, on the RoboCup@Home Open Platform League and focuses on LAR@Home status. The primary efforts in preparing the robot for the 2024 competition center around incorporating new technologies and solutions to enhance various functionalities. These enhancements include improved navigation and obstacle avoidance using two LiDARs, segmentation, improving of point clouds for people and objects, and object manipulation through a robotic arm.

The document is structured as follows: Section 2 provides a mechanical description of the robot, followed by Section 3, which outlines the work conducted in terms of software. Finally, in Section 4, a brief conclusion summarizes the work carried out.

The team has been contributing to RoboCup since 1999 in the MSL League, venturing into the @Home league in 2010. LAR was the first team to introduce a three-wheeled omnidirectional platform in the @Home league. To introduce and further foster @Home League, Lar@Home prganized the @Home Educational 2022 event in Guimarães, Portugal, alongside the European RoboCup Junior competition. Moreover, in April 2023, to address the absence of a European preparation event for RoboCup@Home (the last German Open was organized in 2019), LAR organized the Portugal Open in Tomar, Portugal. At the moment, the team is already organizing the second edition of @Home league at the Portugal Open. Allowing all teams to have an European event to prepare for the RoboCup@Home 2024.

2 Mechanical Description

The CHARMIE (see annex 5) mobile manipulator follows a design inspired by humans to enhance human-robot interaction [1]. Wheeled locomotion was chosen for its efficiency in flat interiors [2]. The base incorporates four omni wheels set at 90º to enhance maneuverability, each with an independent suspension system to maintain continuous contact of all wheels with the ground and improve the robot's stability. Some enhancements were applied to the suspension system to increase durability and quality. Additionally, the position of the robot's microphone and speakers was adjusted to emulate human anatomy, placing them in proximity to the robot's face.

To expand the robot's operational workspace, an articulated trunk with two degrees of freedom was developed. This trunk allows the robot to perform linear crouching movements and flex its trunk forward. Static balancing and the use of self-locking linear actuators were implemented in both movements to reduce energy consumption [3]. A bearing system has also been incorporated to minimize oscillations in the torso.

CHARMIE is equipped with UFactory's xArm 6 robotic arm, featuring 6 degrees of freedom, a reach of 70 cm, and a weight of 12.2 kg. The arm includes a gripper capable of manipulating objects weighing up to 1 kg, with an opening of 85 cm, resulting in an arm payload of 2.4 kg.

The robot features an external start button, found to be extremely useful when performing tasks.

To create a more friendly and relatable interaction, the robot has a face called FaceShiningRGB. This face consists of a matrix of LEDs where images, animated gifs, videos, and phrases can be displayed. This feature allows the expression of emotions through the face. CHARMIE uses different faces for various actions, such as listening and navigating, and it can also serve as a debugging tool.

The robot is enhanced with two Hokuyo URG-04LX-UG01 LiDARs, optimizing navigation for improved obstacle avoidance, particularly with small objects. It also incorporates an Intel RealSense D455 RGBD camera, coupled with Shure V5 speakers and a microphone, ensuring advanced visual and audio sensing capabilities for a versatile robotic system.

The robot's neck has two degrees of freedom in series, controlled by rotary motors (Dynamixel MX-64), enabling it to bend and rotate. The resulting weight of the robot is 72 kg, and its height ranges between 128 cm and 142 cm. In addition to the up/down movement, the robot flexes its torso forward, reaching a minimum height of 92 cm. The torso and arm can pass under structures, such as tables, up to 80 cm, allowing the robot to reach objects on the floor that are 60 cm away from the robot platform.

3 ROS2 modules

This section introduces the ROS2 architecture developed for the robot, it was designed to enhance communication between all the robots components, making the most out of its real-time capabilities. Its modular design simplifies code organization and work on multiple components at the same time. The explain the robot in a more straightforward way, some of the most important packages are further explained.

3.1 CHARMIE arm Ufactory

This package was created to integrate the arm movements with the robot, serving as a centralized module for all manipulation tasks.

The package encompasses nine additional packages (xarm_api, xarm_ controller, xarm_description, xarm_gazebo, xarm_moveit_config, xarm_moveit_ servo, xarm_msgs, xarm_planner, xarm_sdk) provided by UFactory. This approach allows for the linkage of all existing arm-related packages within the robot. Consequently, the Ufactory arm package is employed to consolidate and coordinate these packages, enabling the assignment of values to individual joints, determining the gripper opening, specifying the maximum payload capacity up to a predefined limit, setting the arm's sensitivity, influencing contact sensitivity, using inverse kinematics for arm movement, planning and executing arm motions, among others.

Moreover, the presence of this package enables a more efficient and versatile response to high-level requests. It accommodates also specific high-level requests, with behaviors adjusting based on passed parameters.

3.2 CHARMIE Bot

This package is used to establish a link between the robot in the real world and in the simulation environment. Using the Gazebo simulator, the user can analyze the robot's behavior in a 3D environment. On the other hand, through RVIZ the user is able to visualize and understand sensor data, including LIDAR.

3.3 CHARMIE Speaker

Concerning the speakers package, two solutions have been developed: one online and one offline. The online Charmie speaker features a more fluid and perceptible voice, yet it has the drawback of relying on an internet connection. This limitation motivated the team to develop an offline solution, ensuring functionality in any scenario. The speakers package is designed to be used by any other package. To use any of the two packages, other modules must only send a string that will be reproduced by whichever of the two speakers packages in operational.

3.4 CHARMIE Audio

The audio package is responsible for perceiving the sound of user speech. Initially, the robot listens through the microphone, recording an audio file when it detects that the person has finished speaking or when a maximum timeout is reached. Subsequently, this file undergoes analysis using OpenAI's Whisper library, which returns a string representing what was said and a confidence level regarding whether it is considered noise or valid speech. This string is then processed to enhance comprehension.

The package directly interacts with the Speakers package if noise is detected or if the speech does not match an expected answer. In such cases, the audio package sends information directly to the speaker package to inform the user that it must repeat the command for a new audio analysis.

Additionally, the package performs string comparison to analyze the spoken words and check if they match the expected content. A calibration function for ambient noise is also incorporated, which can be invoked at any time by any of the other package. If the robot consistently detects noise instead of speech in the audio file after a certain number of attempts, it automatically recalibrates the background noise.

By recognizing that the robot may not always detect a specific word, a system has been developed to detect homophones and words with the same phonetic. This approach ensures the robot's robustness across different accents and dialects.

3.5 CHARMIE Visual Debug

This package was developed to provide a 2D visual representation of the robot's perception of the world. It illustrates the robot's position on the map, its orientation, the neck angle, the camera field of view, and the locations of every tracked person and object. The purpose of this package is to centralize all relevant information in one place. It subscribes to other packages that send information, consolidating and summarizing all visual data into a single package. This approach ensures that visual information is presented in a unified manner within a single package.

3.6 CHARMIE Diagnostics

Once all the packages are initialized, a request is sent to each of them, and a response is obtained. This process, allows for confirmation that all the packages are working properly. This information is then communicated to the user, ensuring that all the necessary packages for task execution are connected and operating as intended.

3.7 CHARMIE Face

The goal of the robot's face package is to ease the transmission of data to CHARMIE's face via WiFi in a simplified way (since the face has its own network). The goal is to have predefined facial expressions at a high level, and only the index information of the desired face needs to be sent to the face package for it to appear. As the robot, has an anthropomorphic body, humans tend to always look at the robot's face. By providing a visual interface that shows users how the robot is perceiving its surroundings and its communication, it eases the human robot interaction.

3.8 CHARMIE LiDAR

This package is used to interface with the two LiDARs. One LiDAR is positioned higher on the robot and is primarily employed for mapping (SLAM), for localization (AMCL) and navigation (Non-Linear Dynamic Systems), boasting a viewing radius of 240 degrees. The lower LiDAR, due to the physical characteristics of the robot, has a narrower opening angle of 90 degrees and is primarily employed to assist in detecting obstacles below 40 cm.

3.9 CHARMIE Localisation

This package combines the data between all sensors/middleware which contribute to localisation. It fuses data from odometry and AMCL (Adaptive Monte Carlo Localization). It collects odometry values from the motors, using wheel encoders to determine the robot's position. This data is then integrated with AMCL data, which is the algorithm used for Mapped Localisation. This process determines the robot's location within a mapped space.

3.10 CHARMIE Low Level

The low-level package handles communication with all the low-level components on the robot. This includes tasks such as managing torso positions, controlling limit switches, communicating with RGB LEDs (used as one of the main debug tools), interacting with the emergency buzzer, reading the star button and other test buttons inside the robot and the communication with the motor board.

3.11 CHARMIE Navigation

This package enables the robot to navigate on the map. After parameterizing static and dynamic obstacles within a close radius and defining a target location or orientation using two possible commands (rotation and translation), CHARMIE utilizes a non-linear dynamic system as a distributed control architecture for navigation.

The task constraints involve component forces integrated into the vector field of this dynamic system. These forces, represented by attractive and repulsive components, act in the direction of the heading. The attractive force pulls the system towards the desired heading direction, while repulsive forces deter the system from moving in an undesirable direction. Given that the robot's directions to the target and obstacles vary, the attractors and repellers also adjust accordingly.

This solution addresses the challenge of maintaining the robot's front always facing the direction of movement. This is crucial for two reasons: firstly, it enhances human perception of the robot's movement, and secondly, the robot's navigation sensors are oriented forward. The package also allows indicating a specific position for the robot to navigate while disregarding obstacles, a feature that may be useful depending on the objective.

3.12 CHARMIE Neck

This package governs the movement of the robot's neck and offers several modes, including pan and tilt control, that can be transmitted to the robot. In position mode, the robot's neck is adjusted to a desired angle. Meanwhile, in move-to-coordinates mode, the robot uses its awareness of its position and orientation to align its neck with specified map coordinates. Additionally, there are modes for following a person or object. In these modes, the package receives information about a person or object, and the robot extrapolates the point it should be looking at, adjusting its neck to keep the person or object in view.

3.13 CHARMIE Obstacles

This package collects information from all obstacle sensors, specifically the two LiDARs on the robot. The LiDARs provide data on obstacles detected by their laser sensors. This package processes the obstacle data and maps their positions from the center of the robot. The information from the two LiDARs is merged to identify obstacles that are detected by both LiDARs, as well as those that are detected by only one of the sensors.

3.14 CHARMIE Odometry

This package reads information from the encoders and translates the encoder ticks into the speed of each wheel. Using information about the wheel diameter, it calculates the displacement for each of the four wheels. This odometry allows the derivation of the robot's translation in the x and y axes, as well as its theta (angular position).

3.15 CHARMIE Person Recognition

This package encompasses functions related to human interaction. It includes functions such as face detection and extraction, useful for tasks like the receptionist task. Additionally, there are functions for person detection, isolating specific features like feet and hands, as well as the area around the feet, enabling the analysis of these images. This capability is essential for the stickler for the rules task. The package is also responsible for people tracking, which is particularly relevant in scenarios such as the Restaurant task.

3.16 CHARMIE Point Cloud

This package uses information from the camera, including both the RGB image and the depth image, to compute the positions of all points in the environment. Each RGB pixel in the image corresponds to a distance that is transformed into a spatial point, providing knowledge of the position of objects or individuals in relation to the robot. One of the features, is its automation to receive a detected object or person and return all filtered space point of the received object or person. Additionally, it enables the perception of dimensions for both people and objects, including those that may require avoidance. The package conducts a 3D calculation of all points within the robot's field of view.

3.17 CHARMIE Yolo Pose

The Yolo Pose package performs people detection and identifies keypoints on individuals. This allows the coordinate perception of body partes such as the nose, eyes, ears, shoulders, hips, elbows, hands, knees, and ankles. It provides confidence values for each keypoint. The package also includes features to detect the person's index, using the Yolo v8 Pose tracking system.

Moreover, it enables the determination of the person's position on the map and in relation to the robot, allowing identification of the specific room in the house where the person is located. The package analyzes the pose of each person, distinguishing between standing, sitting, having their arm raised, or lying down.

Several configurable parameters exist at a high level to tailor the results. Notably, people are detected only if their legs are visible, a crucial consideration due to restrictions in the RoboCup@Home arena. Additionally, there are conditions such as a minimum confidence level and a minimum number of keypoints required to consider a person. The package also incorporates a proximity condition, ensuring that it only detects a person if they are close to the robot. This feature is particularly useful in scenarios such as the receptionist task, the stickler for the rules task, and instances where the user is instructed to follow the robot.

3.18 CHARMIE Yolo Object

This package performs a similar function to the Yolo Pose. It detects various objects, and to date, the robot can identify 42 different objects, all similar to YCB dataset. Similar to the Yolo Pose package, it provides information on the object's confidence, its position on the map, its location relative to the robot, the room where the object is situated, and whether the object is underneath another object, such as furniture.

4 Conclusions and future work

This article introduces the CHARMIE robot, the new improvements and reviwes the team's participation in the 2023 RoboCup@Home competition, which showcased certain limitations and prompted the team to consider and implement improvements. Notable enhancements include the acquisition of a robotic arm to boost the robot's performance in tasks involving obstacle manipulation, and the integration of a new LiDAR to enhance navigation and obstacle avoidance. Mechanically, bearing systems were added to the torso, reducing instability, and improvements were made to the suspension system.

Substantial developments occurred at the software level, involving the creation of various ROS2 modules. Notably, these modules operate offline, a crucial aspect given the competition space limitations and their contribution to the robot's robustness in these environments. These hardware and software advancements represent a paradigm shift for the team, bringing the platform much closer to its final objective and aligning with the goals set for the 2024 RoboCup@Home competition. Further details on the robot's hardware and software can be found in the extended paper from 2021 [4].

For those interested, our public repository for the CHARMIE project is available at: https://github.com/LARobotics

References

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5 Annex

CHARMIE robot's current configuration

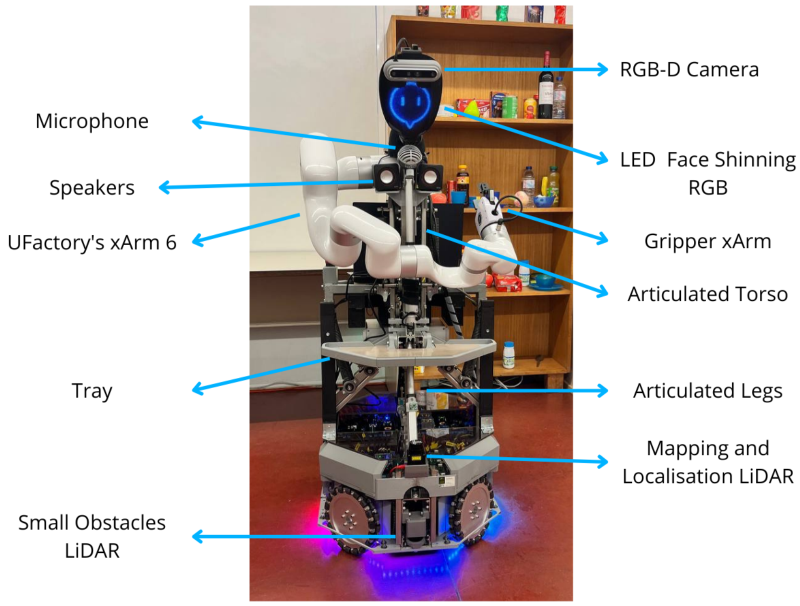

Fig. 1. Front view of the CHARMIE robot

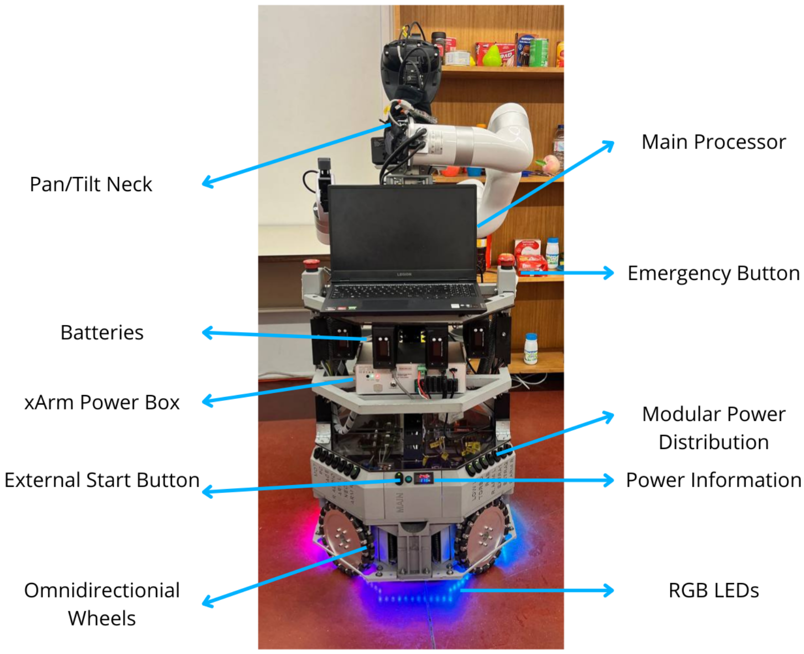

Fig. 2. Rear view of the CHARMIE robot