Vizzy: A humanoid on wheels for assistive robotics

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Abstract. The development of an assistive robotic platform poses exciting engineering and design challenges due to the diversity of possible applications. This article introduces Vizzy, a wheeled humanoid robot with an anthropomorphic upper torso, that combines easy mobility, grasping ability, human-like visual perception, eye-head movements and arm gestures. The humanoid appearance improves user acceptance and facilitates interaction. The lower body mobile platform is able to navigate both indoors and outdoors. We describe the requirements, design and construction of Vizzy, as well as its current cognitive capabilities and envisaged domains of application.

Keywords: Robot design, mechanical design, humanoid robots, mobile robots

1 Introduction

The increasing interest in service robotics for assisting people in daily life tasks is driving research in humanoid-like robots for human-robot interaction. This is a challenging goal since many humanoid technologies are still at its infancy, namely legged locomotion. To address this issue, the trend in assistive robotics has been the use of a mobile base combined with a more human-like upper torso.

Robots like Rollin' Justin [5], Twendy-one [7], the ARMAR III [2] and the iKart[1] mobile platform for the iCub [10] are showcases on the research side, while on the comercial side robots like Pepper[2] and REEM [3] are taking this research field to the market. Vizzy belongs to this group of human like upper-

[1] http://wiki.icub.org/wiki/IKart
[2] https://www.aldebaran.com/en/a-robots/pepper/more-about-pepper
[3] http://www.pal-robotics.com/en/products/reem/

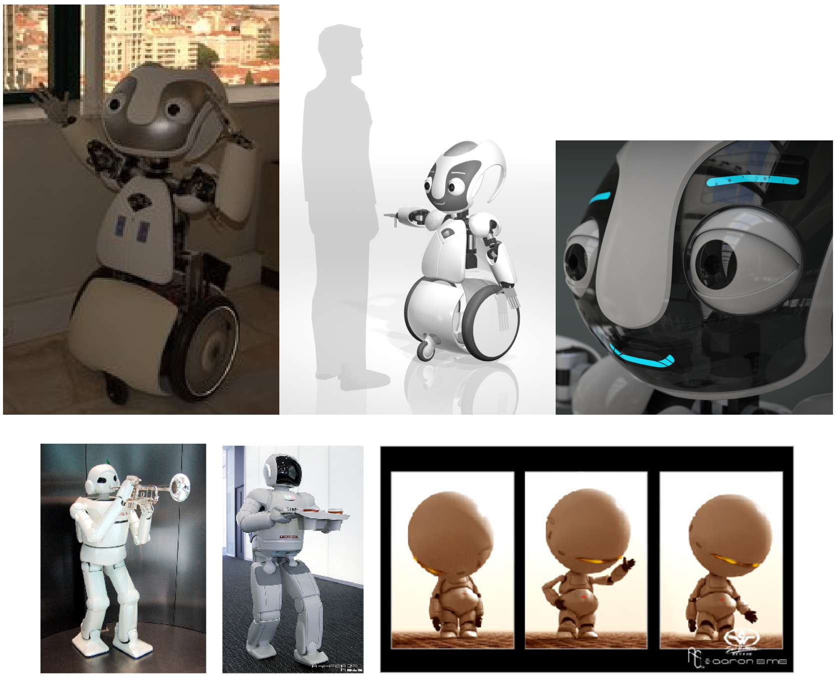

Fig. 1: The top left side image shows Vizzy with open arms, the top-middle a render of the final design compared to a person with 1.75m height, and the top right side a render of the facial expressions. Real vs. fictional robots. On the bottom, from left to right, the Humanoid Toyota partner, Honda Asimo and Marvin from the movie 'The Hitchhiker's guide to the galaxy' [4]. Note the friendlier poses of Marvin compared to Asimo and Toyota partner.

body and car-like lower-body robots, which are designed to interact and assist people in their daily tasks (see Figure 1). In comparison to the aforementioned robots, Vizzy has a more friendly and organic appearance, and a mechanical design guided by a modular approach, which facilitates production, storage and assembly. In addition, trajectories generated by the head and arm motions controllers are motivated by those of the humans [11]. In this article we describe the motivations, design and development phases of the Vizzy robot. In Section 2 we describe in detail the design concepts that guided us to the appearance and mechanical design of the robot: friendly and organic approach in the appearance and modularity in the mechanical design. Section 3 describes in detail the mechanical design of the mobile base, upper body and hand. Section 4 explains the sensorimotor capabilities of Vizzy and Section 5 lists the software libraries developed for its cognitive capabilities. Section 6 concludes and summarizes the current developments and future work.

[4] http://www.imdb.com/title/tt0371724/

2 Design: Concepts and motivation

Aesthetics in humanoid robots can be divided into two main trends: The 'high-tech' appearance of the real robots and the more friendly and organic approach from science fiction. On one hand, the 'high-tech' appearance is driven by technology show-off, functionality and marketing constraints. On the other hand, the science fiction realm is driven by creativity and imagination and less constrained by functionality. Examples of both approaches are shown in Figure 1.

Vizzy's design guidelines combine the friendly and organic approach with the functionality. The main strategic design decision was the adoption of an upper humanoid-like torso and a wheeled platform for locomotion, which is the main constraint in the appearance. The selected mobile platform (Segway RMP 50 [5]) with its large wheels inspired the designer team with an upright marsupial (e.g. Kangaroo) that is less anthropomorphic from the waist down. The facial expresions and hand design of Vizzy was influenced by two robots: iCub [10] on the facial expressions and Baltazar [9] on the hand design. The iCub facial expressions are composed by arrays of LEDs in the eyebrows and mouth, litting a subarray of LEDs to generate an expression (see Figure 1). The LEDs are complemented with two plastic shells that act as the eyelids. Both the LEDs and the eyelids were adopted on Vizzy's face expressions. The Baltazar's hand has a planar palm and five underactuated fingers controlled by three motors. The motor pulls one or more strings being attached to the tip of the fingers, moving the three finger limbs with one power source. Vizzy's hands are underactuated too but with several improvements and just four fingers (details in Section 3). The remaining parts of the robot, which include the head, arms and the supporting structures were designed to have a humanoid robot as similar as the humans in terms of degrees of freedom and their corresponding range of motions, as presented in Table 1.

From the engineering point of view, the main concept is the definition of four motor modules, which are replicated over 22 degrees of freedom. Each of these modules are composed by a set of common parts that facilitates the storage and replacing of damaged parts, and reduces the production costs. In addition, the four modules are similar between each other with differences just in size and the presence or absence of a gearbox, which allows to have a general assembly procedure over all types of modules. Then, the assembly procedure for each module just adds specific details. Figure 2 illustrates the similarity and size differences between the modules.

Initially, Vizzy had a shell cover that completely wrapped its mechanical and electronic components. This concept later shifted to an open shell strategy that optimised weight and production costs. Figure 2 shows the evolution from the initial drafts until the current version of the robot.

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[5] http://rmp.segway.com/discontinued-models/

Joint			**Standard human**	**Vizzy**
Head		Rotation	-70 to 70	-53 to 53
		Neck flexion	-50 to 60	-18 to 37
		Eye rotation	-40 to 40	-38 to 38
		Eyes flexion	-40 to 40	-38 to 38
Arm	Shoulder	scapula	-45 to 130	-18 to 18
		flexion	-60 to 180	-135 to 75
		abduction	-135 to 90	-75 to 0
		rotation	-90 to 90	-85 to 85
	Elbow	flexion	-150 to 0	-110 to 0
	Forearm	pronation	-90 to 90	-85 to 85
	Wrist	abduction	-20 to 50	-35 to 35
	Wrist	flexion	-70 to 90	-35 to 35

Table 1: Range of human movements vs. Vizzy's range of movements. All the angular values are in degrees

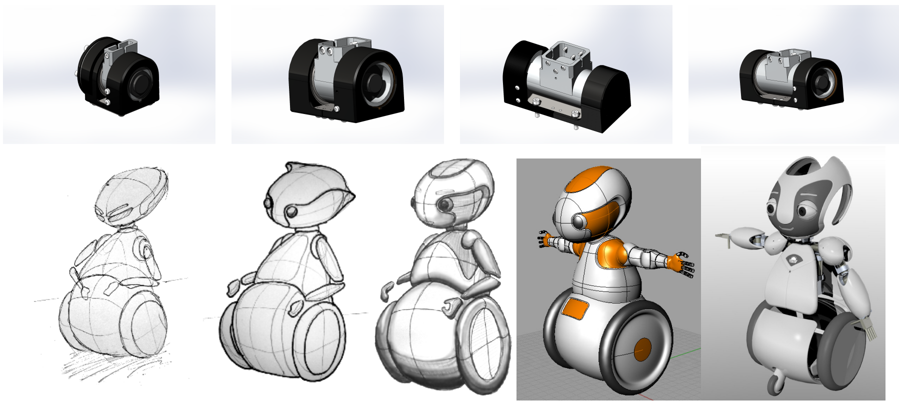

Fig. 2: In the top row, the four different motor modules designed for Vizzy. From left to right, the small, medium, large and extra large modules. For illustrative purposes, the same type of assembly is shown. In the bottom row, the design evolution of Vizzy. The stages shown are: initial sketches, the first concept with closed covers and the final design

3 Design specification

This section describes mechanical design contributions for building the mobile base, the torso, arms and the head. Vizzy has a total of 30 degrees of freedom, distributed as follows: 2 dof's for the mobile base, 23 dof's for the torso and the arms and 5 dof's for the head.

3.1 Mobile base design

The main guideline for the mobile base design was the autonomy, so the original Segway RMP50 supporting frame was redesigned for safe and robust motion of the torso ($\sim$ 30 kg) and for carrying all the electronics and computing resources. The main components are as follows: Segway box, battery, computer and the CAN interface board, which are shown in Figure 3. The first goal was to select a PC and battery set that allow to run experiments continuously during several hours, considering a high performance processor (Intel(R) Core(TM) i7-3930K CPU @ 3.20GHz) and a motherboard (ASRock X79 Extreme 4) with a large number of plugging interfaces. Then, based on the power consumption of the PC and the motors ($\sim 500W$), the battery was chosen to supply power to the PC and the torso motors during 4 hours continuously. The selected battery is the 125255255 (7 cells) from Kokam [6].

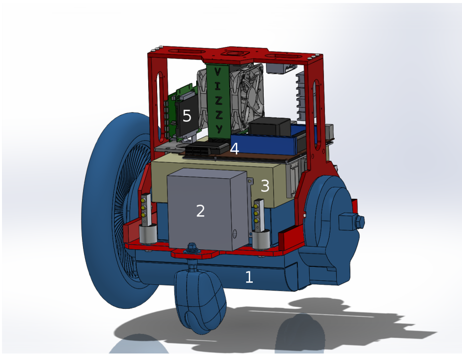

Fig. 3: Main components of the mobile base. The supporting frame is coloured with red, and the numbered items correspond to: (1) Segway RMP50 box with wheels, battery and motors (for better visualization one of the wheels was removed), (2) Voltage converter, (3) main battery, (4) PC motherboard, and (5) CAN interface board.

3.2 Upper body design

The upper body has a total of 28 degrees of freedom, which are distributed as follows: one for the waist; eight for each arm; tree for each hand; and five for the head. Vizzy is symmetric with respect to the sagittal plane, so the mechanical parts of the left side are replicated on the right side. 22 out of the 28 degrees of freedom are designed as one of the four types of modules. Figure 4 shows the serial assembly of the modules, where the motor names match the listed dof's in Table 2. The remaining 6 dof's correspond to the fingers, which will be explained in the following subsection.

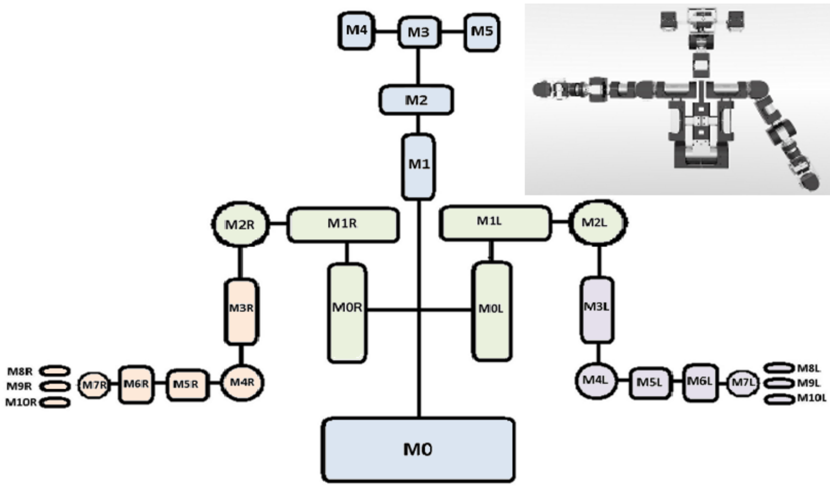

Fig. 4: The motor modules are assembled by following the lines between the modules in the picture. The final assembly of the modules is rendered on the top right of the picture. Each color correspond to the group of modules connected to each CAN bus. All the blue motors are connected to one CAN bus, all the green motors are connected to another CAN bus and so on. There are four CAN buses that control 28 dof.

Body part	**Motor#**	**Joint name**	**Module size**
Torso	M0	Waist	Extra Large
Head	M1	Head rotation (pan)	Medium
Head	M2	Head flexion (tilt)	Medium
Head	M3	Eyes flexion (tilt)	Small
Head	M4	Right Eye rotation (pan)	Small
Head	M5	Left Eye rotation (pan)	Small
Arm	M0R / M0L	Shoulder scapula	Large
Arm	M1R / M1L	Shoulder flexion	Large
Arm	M2R / M2L	Shoulder abduction	Large
Arm	M3R / M3L	Shoulder rotation	Medium
Arm	M4R / M4L	Elbow flexion	Medium
Arm	M5R / M5L	Forearm pronation	Small
Arm	M6R / M6L	Wrist abduction	Small
Arm	M7R / M7L	Wrist flexion	Small

Table 2: List of the modules and their corresponding body part and joint name. The motor names match the Figure 4

The common parts over all four type of modules are: the harmonic drive; the DC motor; the encoder; and the two bearings. The additional parts are

[6] `http://www.kokam.com`

Faulhaber gearboxes that scale the torque limit. In the case of the Large and Extra-Large modules, there is one additional Faulhaber gearbox (all small and medium modules do not have any Faulhaber gearbox). Figure 5 shows a planar cut of the both modules, one without the Faulhaber gearbox and the other one with an additional Faulhaber gearbox, and Figure 6 shows a render of all the module types. Notice the difference in assembly options across the same module, which are designed according to the localization of the module in the upper body. The small, medium and large modules have two assembly options: (i) on the middle top and (ii) on one side of the module.

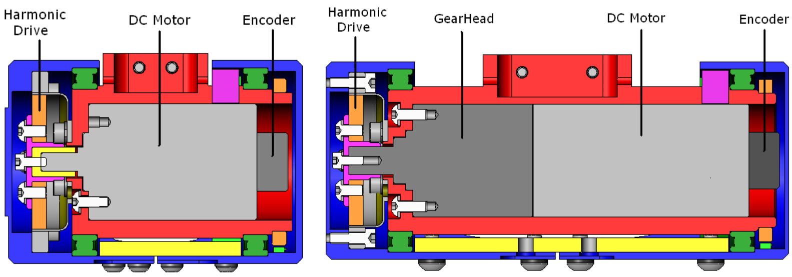

Fig. 5: The drawing on the left side shows the parts of the small and medium modules, while the drawing on the right side shows the parts of the Large and Extra-Large modules. The main difference is the additional Faulhaber gearbox (GearHead). The green colored parts correspond to the cut of the bearings. The blue and red colored parts correspond to the black and gray parts of the renders in Figure 6

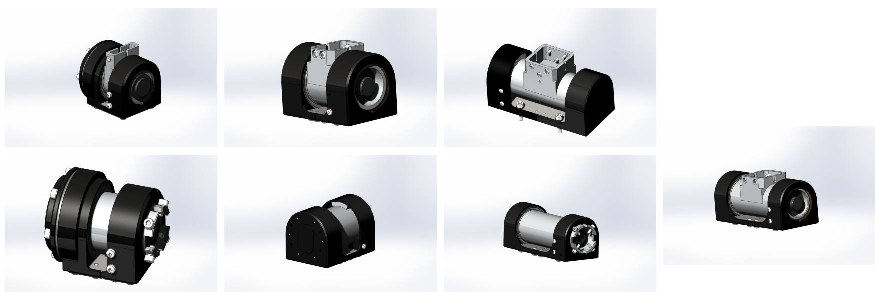

Fig. 6: The four different motor modules designed for Vizzy. From left to right, the small, medium, large and extra large modules. The top row shows the modules that are assembled on the middle top, and the bottom row shows the modules that are assembled on the side.

3.3 Hand design

Following Baltazar's hand design, Vizzy's hand skills include basic manipulation actions and gesture execution. The manipulation skills include three types of power grasps (cylindrical, spherical and hook) and one type of precision grip (tip-to-tip) [14]. These types of grasps can be executed successfully with four fingers, which are moved with just three motors. Like all the other modules, the four fingers are similar between each other, facilitating the storage and replacement of the damaged parts and reducing the production costs. Figure 7 shows the palmar and dorsal sides of Vizzy's hand, where the motors are on the dorsal side and the contact sensors are visible on the palmar side. Every finger has a string that goes through all the finger limbs, from the pulley to the finger tip. Figure 7 illustrates the position of the string for the last finger. The motor pulls the string, moving the fingers limbs towards the palm. The final position of the finger limbs can be controlled by changing the velocity of the motor. An improvement added to Vizzy's hand with respect to Baltazar is a group of dental rubber bands on the dorsal side of the fingers, which guarantees that the fingers return to the open hand position. Figure 7 shows the positions of the dental bands. The grasp types already implemented and shown in Figure 7 include the cylindrical and spherical power grasps, which work currently in open loop. The contact sensors will close the control loop.

4 Sensorimotor description

4.1 Kinematics and controllers

The Segway RMP 50 has two motors that allow omni-directional motion in the 2D plane. The low-level controller is a velocity controller that accepts the linear + angular target velocities. The Denavit-Hartenberg parameters [6] of Vizzy's torso and their corresponding joint limits are shown in Table 3. Vizzy's upper body joints motors (28 motors) are Faulhaber DC motors that can be controlled in angular position or velocity. The upper body motors are controlled by 10 electronic boards that process the encoder signals and generate the control signals for motor motion, which are amplified with pulse width modulation (PWM) [10]. In addition to the low-level controller interfaces, we implemented mid-level interfaces that control the arms' motion and the gaze: (i) the cartesian controller interfaces [11] for the left and right arm, which are based on the iKin library [12]; and (ii) our gaze controller implementation [7], which is largely inspired on the iCub's gaze controller [12]. The arm controller generates trajectories in the cartesian space from the current arm pose to the desired end-effector pose . The gaze controller generates trajectories for the head and eyes motors, moving the head from the current gaze point to a desired gaze point. These controllers were developed as YARP [3] modules.

[7] `https://github.com/vislab-tecnico-lisboa/vizzy/tree/master/vizzy_yarp_icub/src/modules/vizzy_iKinCtrlGaze`

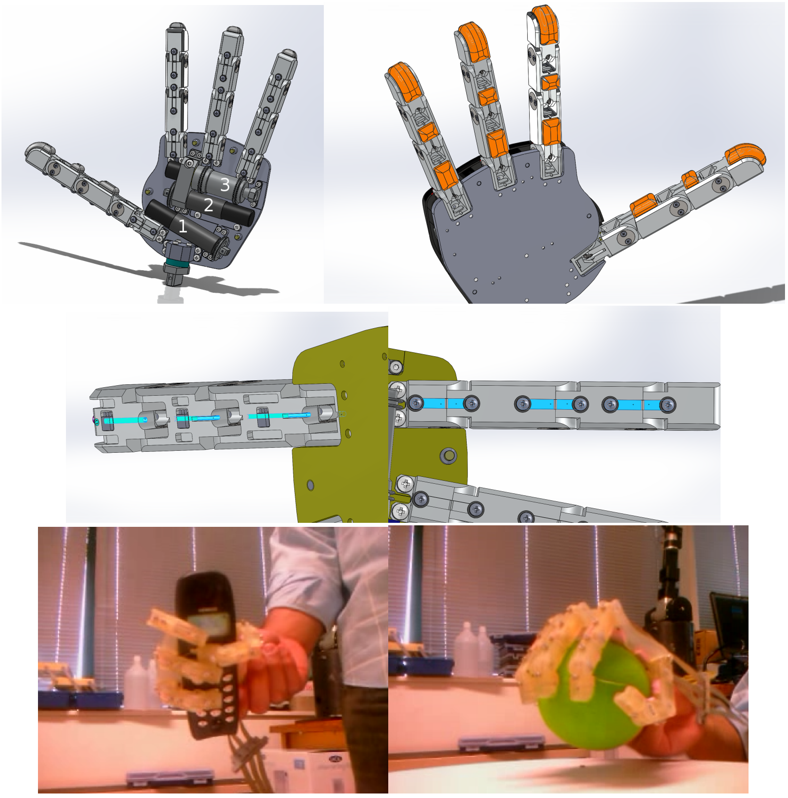

Fig. 7: The top left side image shows the dorsal view, where the numbers correspond to finger motion as follows: (1) thumb, (2) index and (3) the remaining two fingers. The top right side image shows the planar view, where the contact sensors are orange colored. The middle left side image shows the planar hand view, where the cyan colored regions correspond to the string path. The middle right side image shows the dorsal view, where the cyan colored regions show the position of the dental rubber bands. The bottom left side image shows the cylindrical power grasp of a phone. The bottom right side image shows the spherical power grasp of a ball.

4.2 Sensors

The sensing capabilities are provided by the following devices:

- One laser scanner Hokuyo URG-04LX, which is located in the front bottom of the mobile base.
- Two PointGrey cameras (Dragonfly 2) that act as the left and right eye of Vizzy, located in the robot's head.
- One ASUS XTION, which is located on the chest.
- One inertial sensor xSens Mti-28A, which is located in the head behind the cameras.

Kin. chain	Joint	A	D	α	θ offset	Limits
Left Eye	Waist	0	0	90	0	-20 to 20
	Rotation	0	-0.37	90	0	-53 to 53
	Neck flexion	0.1362	0	180	201.2	-18 to 37
	Left Eye flexion	0	0.102	90	201.2	-38 to 38
	Left Eye rotation	0	0	90	-90	-38 to 38
Right Eye	Waist	0	0	90	0	-20 to 20
	Rotation	0	-0.37	90	0	-53 to 53
	Neck flexion	0.1362	0	180	201.2	-18 to 37
	Right Eye flexion	0	-0.102	90	201.2	-38 to 38
	Right Eye rotation	0	0	90	-90	-38 to 38
Left Arm	Waist	0	0.0805	90	0	-20 to 20
	shoulder scapula	0	-0.212	90	0	-18 to 18
	shoulder flexion	0	-0.10256	90	-90	-75 to 135
	shoulder abduction	0	0	90	110	0 to 75
	shoulder rotation	0	-0.16296	90	90	-85 to 85
	Elbow flexion	0	0	90	0	0 to 110
	Forearm pronation	0	0.18635	90	0	-85 to 85
	Wrist abduction	0	0	90	-90	-35 to 35
	Wrist flexion	0.1	0	90	180	-35 to 35
Right Arm	Waist	0	0.0805	90	0	-20 to 20
	shoulder scapula	0	0.212	90	0	-18 to 18
	shoulder flexion	0	0.10256	90	-90	-75 to 135
	shoulder abduction	0	0	90	110	0 to 75
	shoulder rotation	0	0.16296	90	90	-85 to 85
	Elbow flexion	0	0	90	0	0 to 110
	Forearm pronation	0	-0.18635	90	0	-85 to 85
	Wrist abduction	0	0	90	-90	-35 to 35
	Wrist flexion	-0.1	0	90	180	-35 to 35

Table 3: Vizzy's Denavit-Hartenberg parameters. A and D units are meters and α and θ offset are in degrees

– Twelve contact sensors for each hand that are located on the finger limbs. These sensors are a combination of an Hall effect sensor and a magnet. The magnet is inserted in a silicon shape (shown in Figure 7), which is deformed during contact between the object and the fingers. The deformation will change the Hall sensor readings since the magnet will be positioned closer to the Hall sensor.

5 Perception, navigation and manipulation and human robot interaction

The software libraries and modules for perception, navigation and human-robot interaction are available on the official Vizzy github repository [1]. The majority of these skills are based on existing software, and the rest have been implemented at our laboratory. The detailed list as follows:

- Simulation of the Segway RMP 50 in Gazebo[8] (segbot simulator [8]), which was adapted for Vizzy. For the upper-body simulation, our code allows to run fake control boards using ROS controllers [9] and a Gazebo plugin that simulates the actual control boards[10]. The motion planner interfaces for MoveIt [11] (i.e. configuration files) are available on the fake ROS controllers.
- The adaptive Monte-Carlo localization [4], available as the amcl ROS package [12]
- The Elastic Bands local-planner [13], available as a ROS package [13]
- The monocular ball tracking [16] and grasping YARP [14] modules [15]
- The Aggregated Channel Features (ACF) for pedestrian detection [15] [16].

Vizzy's skills are implemented in two differente middlewares: YARP and ROS. This constraint pushed the development of the interoperability between the two middlewares to a working level, but like any interoperability, additional software needs to be written. Recently, we have been developing an automatic code generator that reduces the code to be written in the 'bridging step', which is in the testing phase now [17].

6 Conclusions and future work

We present the design guidelines of a humanoid robot on wheels: Vizzy. Its design based on a more organic approach and friendly postures have produced an upper body humanoid with range of motions very similar to the human ranges. The large wheels of the Segway mobile base inspired our team on a marsupial-like shape of the lower body cover. The head covers were designed to match the lower body covers, leading to large head covers that gives Vizzy its unique shape.

The mechanical design follows a modular approach, which facilitates the storage, replacing of damaged parts and production costs. All the modules have similar structure and parts, simplifying the assembly procedure of the robot.

The current skills of the robot include: (i) Indoors navigation using laser, (ii) reaching and grasping for simple shape objects, and (iii) pedestrian detection for human-robot interaction. Current developments include: (i) Complex manipulation skills by considering the contact sensors, and (ii) interoperability of ROS and YARP platforms for upper and lower body simultaneous control. The list of work to do includes: (i) The lights of the facial expressions, (ii) the closed loop for grasping using the touch sensors, (iii) the simultaneous control

[8] https://github.com/utexas-bwi/segbot_simulator
[9] http://wiki.ros.org/ros_controllers
[10] https://github.com/robotology/gazebo-yarp-plugins
[11] http://moveit.ros.org/
[12] http://wiki.ros.org/amcl
[13] http://wiki.ros.org/eband_local_planner
[14] http://wiki.icub.org/yarpdoc/index.html
[15] https://www.youtube.com/playlist?list=PLU2313o-fhv2grck4iEa5dR8Tpx2bYHZs
[16] https://www.youtube.com/watch?v=Hlfhw6ALJ-c
[17] https://github.com/vislab-tecnico-lisboa/yarp-bottle-generator

of the mobile base and upper body for reaching and grasping. Currently Vizzy has been chosen as a test platform for the CMU-Portugal project AHA [18].

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[18] `http://aha.isr.tecnico.ulisboa.pt/`