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A Robotic Platform for Edutainment Activities in a Pediatric Hospital

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***Abstract*—Social Robotics is a rapidly expanding field of research, but long-term results in real-world environments have been limited. The MOnarCH project has the goal of studying the long-term social dynamics of networked robot systems in human environments. In this paper, we present the MOnarCH robotic platform to the research community. We discuss the constraints involved in the design and operation of our social robots, and describe in detail the platform that has been built to accomodate the project goals while satisfying those restrictions. We also present some preliminary results of the navigation methodologies that are used to control the MOnarCH robotic platforms.**

I. INTRODUCTION

Designing robots for social purposes has been a trendy topic for the last decades. The literature in this area is huge and has yielded valuable lessons [1], [2]. However, experiments where robots and people coexisted for long periods of time, outside lab environments, meaning periods longer than the transient in the dynamics of human expectations, have seldom been reported.

MOnarCH[1] (Multi-Robot Cognitive Systems Operating in Hospitals, [3]) is an ongoing FP7 project with the goal of introducing (social) robots in real human social environments with people and studying the establishment of relationships between them.

The environment that acts as a case-study for the project is the pediatric ward of an oncological hospital (IPOL). We intend to introduce a team of robots in that environment, that cooperatively engage in activities aiming at improving the quality of life of inpatient children.

Key scientific hypotheses underlying the MOnarCH project research are that (i) current technologies enable the acceptance of robots by humans as peers, and (ii) interesting relationships between robots and humans may emerge from their interaction. These hypotheses are supported by extensive existing work on (i) autonomous and networked robotics, enabling sophisticated perception and autonomous navigation, and (ii) interfaces for human- robot interaction and expressive robots. MOnarCH addresses the link between these two areas, having robots playing specific social roles, interacting with humans under tight constraints and coping with the uncertainty common in social environments.

The constraints of the social environment partially translate into physical constraints on the robot platforms, such as its maximum allowable dimensions and velocities, and also behavioral constraints that can reflect on the methods that are used to control those platforms, such as its navigation algorithms.

In this paper we present the MOnarCH robot platform to the research community. The platform is well-suited to a wide range of applications that extend beyond the MOnarCH case-study: combining different high-level actuators and sensors, the base can be used in the office, domestic or industrial environments that are considered in the RoboCup@Home or @Work competitions, for example.

This document is organized as follows. We will first provide an overview of the constraints that were taken into account in the design of this platform (Section II). We will then describe the robot hardware (Section III); and also of the methods that were used to carry out its navigation (Section IV).

II. CONSTRAINTS ON ROBOT DESIGN & CONTROL

The MOnarCH project has a significant component of human-robot interaction (HRI) to be carried out in a very specialized social environment, namely that of IPOL pediatric ward. The nature of this environment implies concerns and constraints on the type of robots to be used, namely,

- The range of allowable linear and angular velocities;
- The volumetry of the full robot;
- Aesthetics;
- Maximum height of the platform;
- Payload;
- Power supply autonomy;
- Self-safety features;
- Human-oriented safety features.

Moving naturally is an essential capability for a robot to be able to “survive” in a social environment. In a sense, if a robot moves naturally, with velocities in the same order as those used by humans moving, then other HRI interfaces can be focused and their behaviour does not need to depend on the motion of the robot. Motion in 2D (as is the case in MOnarCH) is completely described by linear and angular velocities and

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[1] Reference: FP7-ICT-2011-9-601033. Website: http://monarch-fp7.eu/

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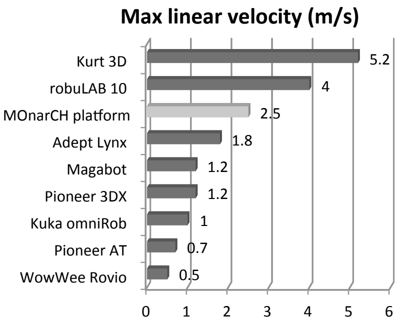

Fig. 1. A comparative study of linear velocities for common off-the-shelf platforms, and also for the MOnarCH robot platform.

hence the ability to combine these two velocities determines the baseline expressivity of the movement. This is a key aspect when designing a mobile platform for socially embedded HRI purposes, as in MOnarCH.

For example, in what concerns linear velocity, if a social robot playing with a child needs to ask him/her to wait because it cannot move as fast as the child then there is a significant risk that the child looses interest in playing with the robot. Moreover, future interactions may be compromised because the child may feel that the robot can not do a simple thing such as moving the way he/she does. As for angular velocity, its combination with the linear velocity determines if the robot follows the child gracefully, i.e., with appropriate expressivity. Motion capabilities are thus a basic feature that potentiates the effect of all the other HRI interfaces, namely voice, vision, grasping, etc.

Differential drive mobile platforms can be found off-the-shelf in a wide variety of formats. Figure 1 shows the maximum values for the linear velocity of common robots. An adult moving normally in an indoor environment reaches frequently velocities in the range of 2 to 2.5 m/s. Under teens children move slower than adults when walking but may reach similar speeds when running.

The physical presence of the robot has a large influence in the way bystanders perceive the robot and its intentions. The physical dimensions of the robot must not be perceived by children neither as a menace nor as a physically diminished social entity.

The average height of an under teen (11 year) is around 1450mm and hence this determines the maximum height of a MOnarCH robot. The volumetry is selected in order to be socially acceptable and dynamically stable (not tilting under high accelerations/decelerations). The ability to carry a large number of sensors and interfaces if a key feature in a social robot, this meaning that payload is an important feature. Moreover, such payload has to comply with the volumetry/height/aesthetics concerns above.

Power supply autonomy severely constraints HRI capabilities if the robot requires too much time to recharge batteries or recharging occurs at an inadequate time. An HRI aware battery management system limits the situations in which children may perceive the robot as a flawed social entity.

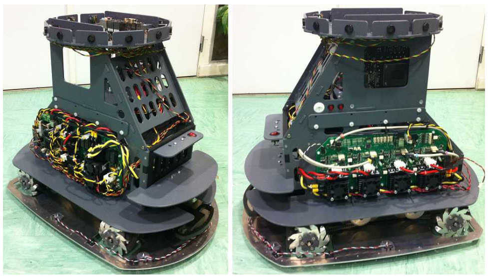

Fig. 2. Assembled MOnarCH robot platform.

Of extreme importance are the safety features in the platform. In addition to basic physical safety of the people handling the robots, safety concerns are directly related to Ethics issues and of paramount importance when in social environments such as that at IPOL.

Safety measures are embedded at both hardware and software levels. Unexpected collisions trigger can be detected at hardware level and bypass all decisions levels to stop the robot. Each of the software layers has their own safety measures.

III. ROBOT DESCRIPTION

The kinematics of a robotic platform can greatly impact the type of social interactions that it can be expected to perform.

As the user case scenarios for the MOnarCH were being defined and the constraints posed by the environment of operation were being discussed, it became evident that the mobility capability of the robots could be a critical issue to the achievement of project goals. Based on this evidence, we have opted to develop an omnidirectional robot platform based on four Mecanum wheels, actuated by four independent motors. The use of this kind of kinematics substantially increases the maneuverability and performance of the platform.

The development and assembly of MOnarCH robots has been divided in two phases. The first phase includes the platform base mechanics with the motors, batteries and low-level electronics. The resulting platform can be adapted to serve different applications. A second phase, which specifically targets the MOnarCH scenario at IPOL, includes the installation of high-level devices mounted over an upper structure and the design of an outer shell. For this purpose, two types of robots are being developed. Perception Oriented (PO) robots will have as primary goal to act as active sensors. Social interaction Oriented (SO) robots will target social interactions. As aforementioned, the SO and PO robots are built over the same platform base, differing in the onboard equipment and external appearance. An assembled platform is shown in Figure 2. At this time, the first phase of robot development has been concluded.

A. MOnarCH Robot Platform Base Main Features

All the robot platforms include the same basic configuration which can be described through the following design features:

- Body: Polyacetal - POM (PolyOxyMethylene) 10 mm thick plates; rigid PVC 4 and 6 mm; and transparent polycarbonate 2mm;

- Robot kinematics: Omnidirectional – 4 Mecanum wheels;
- Robot weight: 24 Kg (with batteries);
- Payload capacity: 30 Kg;
- Maximum Linear Speed: 2.5 m/s
- Maximum Angular Speed: 600 ^{o}/s
- Acceleration: 1 m/s^2 (low-level programmed)
- Emergency Stop Acceleration: -3.3 m/s^2 (low-level programmed)
- Mini-ITX computer Board with CPU, RAM and SSD
- Batteries:
  - Supports up to 4 batteries at the same time;
  - Capacity: (12v) 17-20 Ah 5.5 kg each;
  - Chemistry: lead acid or LiFePO4 block 12V batteries with PCM;
  - Autonomy: 4 to 6 hours;
- Actuators: 4 DC motors for locomotion
- Sensors:
  - Battery level;
  - Motor encoders;
  - Omnidirectional bumper;
  - 4 ground sensors;
  - 12 sonars;
  - Laser Range Finder (5m range);
  - Temperature sensors to measure the motors and drivers temperature;
  - Temperature and humidity sensor to measure the environment conditions;
- Installed Electronics Boards:
  - Sensor & Management Board;
  - Motor Control Board;
  - Sonars Board;
  - Ground Sensor Board;
  - IMU Board;

B. MOnarCH Robot Upper Body

The upper body of the platform will include different high-level devices. Some of these devices are still being defined and need further experiments to validate their use in the MOnarCH robots.

- Two depth cameras with microphone (Kinect type);
- Three servo motors to actuate two robot arms and a head (only SO robots);
- One 10” touch-screen (only SO robots);
- One pico-projector (only SO robots);
- One RFID reader;
- One Hagisonic StarGazer localization sensor;
- Audio amplifier with speakers;
- LEDs on the robot body;
- Capacitive cells on the robot body;

C. Sensors

The robot is equipped with perception, navigation, interaction, environment and low-level safety sensors. For locomotion the robot uses encoders to control the velocity of the motors, and for navigation it uses an inertial sensor to determine the angular speed and a laser range finder to detect obstacles and the geometry of the environment. For perception and interaction, the robot will use a depth camera for people tracking, face analysis and body gesture recognition, and also microphones. For environmental sensing the robot will be equipped with temperature and humidity sensors. Finally, the bumpers and sonar sensors provide low-level safety sensing. To increase the robustness of localization, some other sensors/solutions are also being evaluated, e.g., RFID, IR and UWB.

We now list the sensors that are used onboard.

1) Navigation Sensors: The robot will navigate in the environment while making a fusion of measures provided by different sensors. The robot will be able to use a depth camera, a laser range finder, encoders odometry and the IMU sensor to estimate its position and orientation. For obstacle avoidance, mapping and localization it can use the laser and sonar sensors.

Inertial Sensor IMU: MPU6050;
Function: Orientation estimation;
Position: In the robot’s kinematic center;

Front 2D laser range-finder: Hokuyo URG-04LX-UG01;
Function: Mapping, localization and obstacle avoidance;
Position: Frontal and horizontal;

Sonar Sensors: Maxbotix EZ4;
Function: Obstacle detection (e.g.: glass wall or objects);
Position: Ring of 12 sonars around the robot;

Depth camera: Asus Xtion;
Function: Obstacle detection, space geometry analysis;
Position: Top of the robot pointing to the floor;

Sensors being evaluated: RFID, UWB, and ToF 3D cameras.

2) Perception and Interaction Sensors: The robot will make use of a depth camera for people detection and sense visual user feedback for natural user interaction. It can also be used to detect changes in the surrounding environment. The perception sensors are the following.

Depth camera: Asus Xtion;
Function: Interaction, people and gesture recognition;
Position: Top and looking ahead;

Microphone array: Asus Xtion;
Function: Sound feedback for natural user interaction;
Position: Turned to the users;

10” Touchscreen (or tablet);
Function: User feedback on specific contents;
Position: Turned to the user;

Capacitive sensors;
Function: User feedback on specific points;
Position: Under the shell;

Other sensors still being evaluated: RFID and UWB.

3) Environment Sensors: The environment sensors are used to detect environment variations that can affect the normal operation of the robot. These sensors are: temperature sensor and humidity sensors.

4) Low-level Safety Sensors: The fundamental sensors for low-level safety are the sonar sensors, internal temperature sensors, motor current sensing and the bumper ring switches.

D. Actuators

For actuation, the robot is equipped with locomotion and interaction devices.

1) Locomotion Actuators: For locomotion, this omnidirectional platform uses four motors to drive its Mecanum wheels.

- Four Maxon RE 35 90W 15V motor with a Maxon GP 32 HP 14:1 Gearbox and encoder HEDS 5540 with 500 pulses;
  - **Function:** Provide a omnidirectional locomotion system to the robot;
  - **Position:** In the platform, connected to the drive system.

2) Interaction Actuators: Here follows the list of interaction devices. The robot is able to display the contents on the interaction monitor or project them over a surface.

- 10” Monitor with Touchscreen (or tablet);
  - **Function:** Interaction with displayed contents (e.g., AR contents);
  - **Position:** Front of the robot;
- Video Projector (pico type);
  - **Function:** Projection of contents;
  - **Position:** Projecting to the front of the robot;
- Arms and head servo motors;
  - **Function:** Human robot interaction;
  - **Position:** Mounted on the robot body;
- Body LED lights;
  - **Function:** Show robot expressions;
  - **Position:** Mounted on the robot body;
- Stereo Speakers;
  - **Function:** Content playback; robot communication;
  - **Position:** Turned to the user.

E. Electronic Power Architecture

The robot can be powered by several 12V 17-20AH batteries. It uses one 12V battery to deliver power to the motor drivers. Up to 3 other batteries to provide energy to all the other computers and electronic components. An individual charging unit is used inside the robot to charge each battery. The batteries and the power in the robot is managed by the Sensor &Managment Board that measures the battery levels, battery charge, and also controls the units (motors, sensors, actuators and inverters) powered by the batteries. All onboard electronic systems can be powered by the battery system. The ATX computer power supply provides regulated voltages (from 5V to 12V). Figure 3 depicts the onboard power architecture. Several DC-DC converters are also be used to provide the necessary regulated power for other DC-DC powered devices.

F. Low-level Communication Architecture

The onboard robot navigation computer communicates with the two boards (Sensor& Management Board and the Motor Controller Board) using 2 USB ports. In each board there are USB-to-RS232 converters that convert the USB data packages to serial RS232 packages for the board controllers. Each board controller communicates with the other allowing the exchange of information between them. This communication channel allows the execution of low-level behaviours, for example, react against an imminent collision, enter into charging mode with motors shut down, reduce the motors' velocity when the batteries are low, or react to changes that can affect the robot's operation, which is fundamental to the improvement of the overall system dependability. The main controller from the Sensor&Management Board communicates with other microcontrollers using Inter-Integrated Circuit (I2C) communication ports. The main controller acts as the master and the other microcontrollers behave like slaves. The Sensor&Management Board controls the battery management and charge, sensor acquisition, devices actuators and sonar acquisition boards. The Motor Controller Board connects to the PI Motor controllers and also to temperature sensors. Each controller has a low-level fault diagnosis that will check the operation state of each microcontroller and also monitor all the communication between the devices. The low-level communication architecture is depicted in Figure 4.

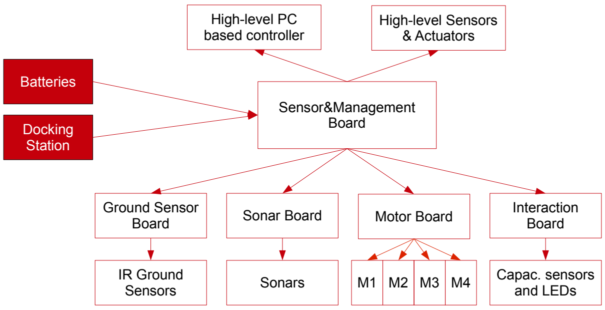

Fig. 3. MOnarCH robot power architecture.

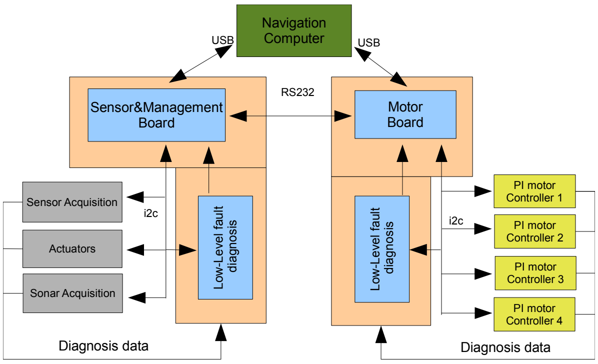

Fig. 4. Low-level communication architecture.

G. High-level Communication Architecture

The MOnarCH robot connects to a local network. A wireless Ethernet router provides the IP address to the onboard computers and allows the exchange of messages between them. The Navigation Computer is connected to the navigation sensors and to the platform board controllers using USB ports. The Interaction Computer connects to the Projector using a HDMI output and to the Sound System using the audio line out, and will use USB connections to connect to the Interaction Board that will control the body LEDs, the capacitive sensors and the

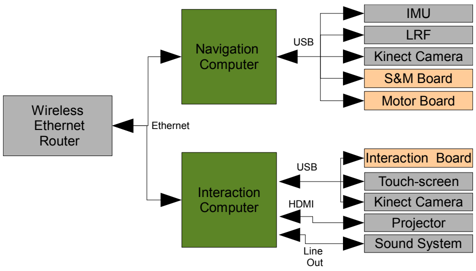

Fig. 5. High-level communication architecture.

upper moving parts of the shell (arms and head). The high-level communication architecture is depicted in Figure 5.

IV. NAVIGATION

For navigation we use a standard occupancy grid map [4], obtained from off-the-shelf SLAM software[2] This map is used both for motion planning, using Fast Marching Method (FMM) [5], and localization, using off-the-shelf software[3].

Motion planning is based on a FMM approach [5]. Unlike other methods based on explicit path planning, e.g., RRT [6], followed by path tracking, we adopt here a potential field approach. Given a map constraining the workspace of the robot, together with a feasible goal point, a (scalar) potential field $u(x)$, for $x \in R^2$, is constructed such that, given a current robot location $x(t)$, the path towards the goal results from solving the ordinary differential equation $\dot{x}(t) = -\nabla u(x)$. In other words, given an arbitrary current location of the robot x, the robot should follow a gradient descent of the field $u(x)$. Using potential fields for motion planning was proposed in the 80's [7] but they were found to be prone to local minima [8]. This problem can be solved by the use of harmonic potential fields [9], however it does not guarantee absence of local minima at the frontier. Thus, we decided to employ a more recent approach [10]. The use of FMM provides: (1) local minima free path to goal across the gradient, (2) allows the specification of a spatial cost function, that introduces a soft clearance to the environment obstacles, and (3) does not require explicit path planning and trajectory tracking.

The FMM is based on the Level Set theory, that is, the representation of hypersurfaces as the solution of an equation $u(x) = C$. The solution of the Eikonal equation

$$\begin{aligned} |\nabla u(x)| &= F(x) \\ u(\Gamma) &= 0 \end{aligned} \tag{1}$$

where $x \in \Omega$ is a domain, Γ the initial hypersurface, and $F(x)$ is a cost function, yields a field $u(x)$ [5]. The level sets of this field define hypersurfaces $u(x) = C$ of points that can be reached with a minimal cost of C. The path that minimizes the integral of the cost along the trajectory can be shown to correspond to the solution of $\dot{x}(t) = -\nabla u(x)$ with the initial condition of $x(0)$ set to the initial position and the initial condition $u(\Gamma) = 0$ set at the goal[4]. Intuitively it corresponds to the propagation of a wave front, starting from the initial hypersurface, and propagating with speed $1/F(x)$. This path minimization is usually considered a continuous space version of the Dijkstra's algorithm. FMM is a numerically efficient method to solve the Eikonal equation for a domain discretized as a grid. Its computational complexity is $O(N \log N)$, where N is the total amount of grid cells, which is comparable to Dijkstra's algorithm for sparse graphs.

Since FMM employs a grid discretization of space, it can be directly applied to the occupancy grid map, where domain Ω corresponds to the free space in the map. As cost function we use

$$F(x) = \frac{1}{\min\{D(x), D_{max}\}} \tag{2}$$

where $D(x)$ is the distance to the nearest occupied cell in the map and D_{max} is a threshold to clip the cost function. This cost function induces a slower wave propagation near the obstacles, and thus making the optimal path to display some clearance from them. The clipping at D_{max} prevents the robot to navigate in the middle of free areas, regardless of their size. The $D(x)$ function can be directly obtained using an Euclidean Distance Transform (EDT) algorithm taking the occupied cells as boundary. Figure 6 illustrates the results of this approach: the cost function for the given map, allowing a certain clearance from mapped obstacles, is shown in (a), from which, given a goal location, a field $u(x)$, shown in (b) is obtained (the goal corresponds to the minimum value of the field), and in (c) the real path taken by the robot is shown.

Using FMM on a previously constructed map does not account for unmapped or moving obstacles. Thus, the field $v(x)$ used to control the robot in real-time results from combining the field $u(x)$ obtained from FMM with a repulsive potential field $r(x)$ of obstacles sensed by the LRF. This repulsive field is obtained from running EDT on a small window around the robot, such that the value of $r(x)$ corresponds to the minimum distance between any obstacle and point x. The fields are combined using

$$v(x) = u(x) + \frac{\lambda}{r(x)} \tag{3}$$

where λ is a parameters specifying the strength of the repulsive field (higher values of λ tend to increase the clearance from perceived obstacles). Note that (3) destroys the property of a single local minima of the field. We acknowledge the need to complement our navigation approach with a mechanism for detecting and coping with stuck robot situations, such as re-planning or asking for help.

The method described above have proven to be very effective, even in cluttered environments full of people crowded around the robot. We have demoed this method on a public event — the European Researcher's Night (September 27th, 2013, in the Pavilion of Knowledge science museum, Lisbon) — where people from all ages crowded around the robot.

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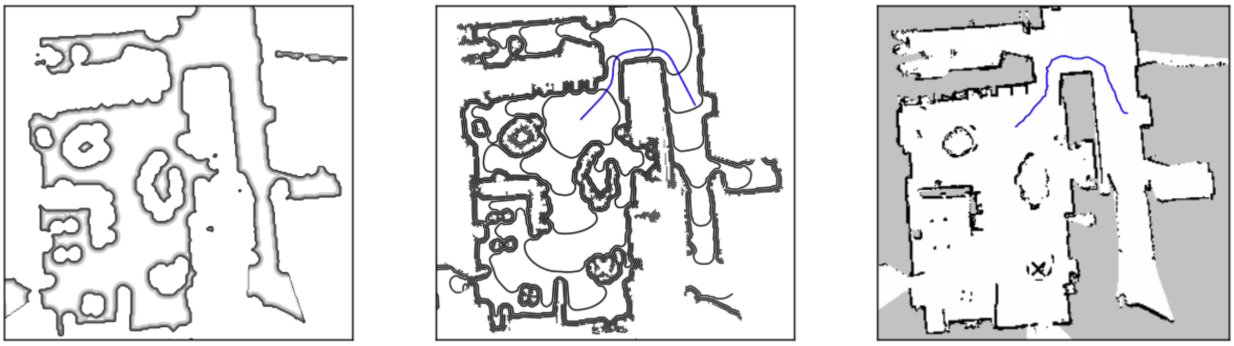
[2] GMapping (http://wiki.ros.org/gmapping, retrieved 16-Oct-2013).

[3] AMCL, (http://wiki.ros.org/amcl, retrieved 16-Oct-2013).

[4] Γ is set to the boundary of an arbitrarily small ball around the goal.



(a) $F(x)$ (b) $u(x)$ (c) real path

Fig. 6. Motion planning using FMM: (a) the cost function $F(x)$ (darker means a higher cost), (b) the solution field $u(x)$ (level curves) together with the gradient descent $\dot{x}(t) = -\nabla u(x)$ solution (from the right to the left), and (c) the real path traveled by the robot.

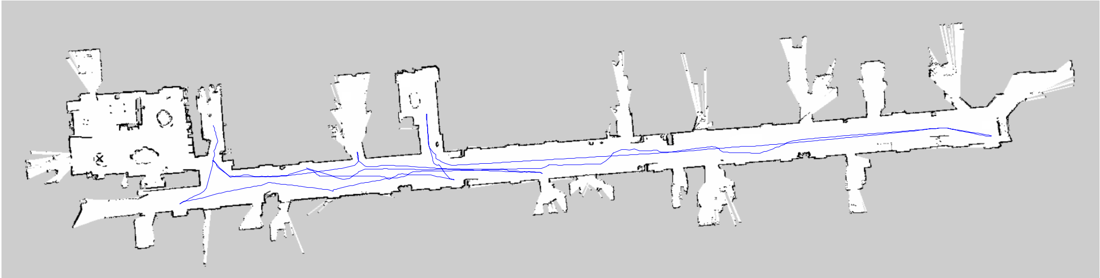


Fig. 7. Trajectory of ISR-CoBot autonomously navigating along the IPOL premises. The task consisted in a sequence of waypoints.

We have also tested this method at IPOL, where we run extensive autonomous navigation tasks during several hours (Figure 7). These tests were performed on a previous platform [11]. Even though that previous platform is differential, minor modifications on the guidance method were required to adapt it to the MOnarCH platform. A video showcasing the application of these methods to the autonomous navigation of the MOnarCH platform can be found at: http://tinyurl.com/olounbn.

V. CONCLUSIONS AND FUTURE WORK

In this work, we have introduced the robotic platform that was developed in the context of the MOnarCH project. This development explicitly took into account a set of constraints that are induced by the social nature of the project's case-study environment, namely, the pediatric ward at IPOL. We described these constraints; detailed the hardware that was (and is being) included in the robotic platform; and presented preliminary results regarding the methods that were developed for reliable robot navigation.

The qualities of the MOnarCH platform make it a good choice for other applications beyond the project's case-study, such as the RoboCup@Home or @Work scenarios.

As immediate future work, we will integrate the high-level sensors and devices discussed in Section III, as part of the second phase of robot development. This will endow the robot platform with HRI capabilities, establishing a basis for the future development of the socially-aware interaction methods that are crucial to the outcome of the project.

ACKNOWLEDGMENTS

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REFERENCES

[1] C. Breazeal, *Designing sociable robots*. The MIT Press, 2002.
[2] G. Metta, G. Sandini, D. Vernon, L. Natale, and F. Nori, "The iCub humanoid robot: an open platform for research in embodied cognition," in *Procs. of the 8th Workshop on Performance Metrics for Intelligent Systems, PerMIS '08*, 2008, pp. 50–56.
[3] J. Sequeira, P. Lima, A. Saffiotti, V. Gonzalez-Pacheco, and M. A. Salichs, "MOnarCH: Multi-robot cognitive systems operating in hospitals," in *ICRA 2013 Workshop on Many Robot Systems*, 2013.
[4] A. Elfes, "Using occupancy grids for mobile robot perception and navigation," *IEEE Computer*, vol. 22, no. 6, pp. 46–57, 1989.
[5] J. A. Sethian, "Fast marching methods," *SIAM review*, vol. 41, no. 2, pp. 199–235, 1999.
[6] S. LaValle and J. Kuffner Jr, "Randomized kinodynamic planning," *The International Journal of Robotics Research*, vol. 20, no. 5, pp. 378–400, 2001.
[7] J. Borenstein and Y. Koren, "Real-time obstacle avoidance for fast mobile robots," *IEEE Transactions on Systems, Man and Cybernetics*, vol. 19, no. 5, pp. 1179–1187, 1989.
[8] Y. Koren and J. Borenstein, "Potential field methods and their inherent limitations for mobile robot navigation," in *Proceedings of the IEEE International Conference on Robotics and Automation (ICRA-91)*, 1991, pp. 1398–1404.
[9] J. Kim and P. Khosla, "Real-time obstacle avoidance using harmonic potential functions," *IEEE Transactions on Robotics and Automation*, vol. 8, no. 3, pp. 338–349, 1992.
[10] S. Garrido, L. Moreno, D. Blanco, and M. L. Munoz, "Sensor-based global planning for mobile robot navigation," *Robotica*, vol. 25, no. 2, pp. 189–199, 2007.
[11] R. Ventura, *New Trends on Medical and Service Robots: Challenges and Solutions*, ser. MMS. Springer, 2014, ch. Two Faces of Human-robot Interaction: Field and Service robots.