i-Merc: A Mobile Robot to Deliver Meals inside Health Services

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***Abstract*— With the aim of increasing the quality of the meals transportation service inside hospitals and health care centers (HHCC), we are developing a dedicated mobile robot to perform this service, the *i-MERC*. This robot is equipped with a heating system in the meals compartment which guarantees the meals temperature and prevents bacteriologic proliferation. The *i-MERC* also integrates a personalized diets information system where information about patients' diets can be introduced and accessed by the service personnel. This project has been developed within the compass of the Master in Engineering Design, at the Technical University of Lisbon. The product development of the robot addressed many knowledge areas, some of which are presented in this paper. We finished the first stage of the project with a service concept, a virtual prototype which included some key specifications and a physical prototype. Presently, we are continuing the product development and searching some stakeholders that would be interested in the project.**

***Keywords*— Mobile Robots, systems design, prototyping, navigation, control, virtual reality**

I. INTRODUCTION

In the present times there is a great concern in endowing the health care centers with increasingly more qualified services. This concern has motivated the development of services and products within different application areas which had the final goal of improving the patients' quality of life. One of the great challenges inside hospitals is the creation of a logistic service which would be responsible for transporting the meals from the kitchen to the patients' rooms and for returning the respective soiled dishes safely, preventing all possible contamination, be it through the meal, or the service personnel.

In this paper we will present, in the second section, the current organization of the meals services inside hospitals and HHCC and the existing risks. We will also present the meals transporters normally used in common HHCC and in the more technologically advanced ones and, finally, we will present the main concerns of dieticians regarding patients' personalized diets.

In the third section, we will propose a new service concept and suggest how the product, the *i-MERC*, can improve the quality of the meals transportation service.

The product development will be addressed in the fourth section, where studies focusing on the meals compartment, chassis structure, control architecture, virtual simulation and orientation system will be presented.

The fifth section will present a physical prototype of *i-MERC*, which was used to demonstrate a real itinerary of the mobile robot inside a HHCC. This prototype can be used to attract potential partners or stakeholders to the project.

Finally, in the sixth section, we will present some conclusions about the present product development and define future tasks that should be undertaken in the near future.

II. THE MEALS SERVICE INSIDE HHCC

The meals distribution service is one of the most important aspects inside hospitals and similar health services since the quality of the food strongly influences the patients' recovery. Thus, extreme care is taken not only with regard to the food preparation but also to the transport between kitchen and patients. The later task normally takes between 10 to 30 minutes, a sufficient time for the meals temperature to decrease below 60ºC, the limit temperature below which bacteriologic proliferation may occur [1].

Normally, meals transportation is carried out by dedicated people that use trolleys specially devised for this service. A survey to some HHCC allowed us to conclude that the main drawbacks to traditional transport devices are their weight and the difficulty in handling them.

Some of the more innovative HHCC in the world started using mobile robots such as the HelpMate [2] or Transcar [3] to transport different types of cargos between persons in services. These mobile robots contributed to improving the quality of services, since these autonomous couriers can work 24-7 all year round with a constant performance, causing the service to become more efficient and faster. Additionally, there is the benefit of relieving some personnel to more critical activities [4].

However, because HHCC general purpose mobile robots transport different types of cargos, there is some the risk of meal contaminations, which could result in serious health problems to the patients.

Another major concern to hospital dieticians is the patient's personalized diet and the way of guaranteeing the information

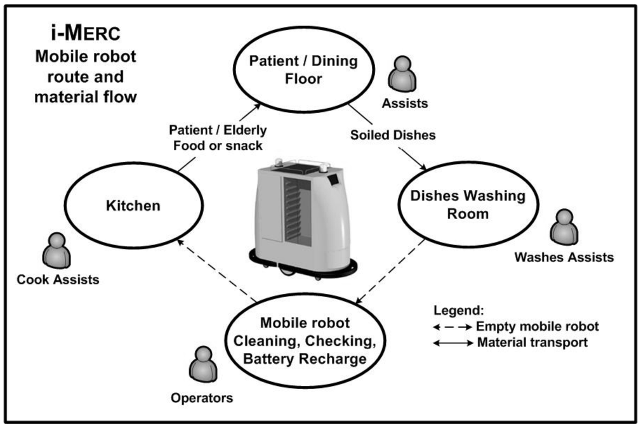

Figure 1. Routes and material flow of the i-MERC

flow between kitchen and patients rooms, so that the assistants do not change the meals trays by mistake. Normally, the personalized meals trays are indicated with tags that can be easily lost or changed during transport [5]. It is increasingly important that patients should have a personalized diet that guarantees an appropriate nutrition. These diets produce strong benefits to patients, such as better a tolerance to the treatment and attenuation of symptoms, thereby promoting the patients' quality of live [6].

III. THE PROPOSED SERVICE CONCEPT

To increase the quality of the meals services inside HHCC, we propose a more hygienic and efficient meal transport service, through a dedicated mobile robot, the *i-MERC*. This robot is able to deliver personalized diets to patients and return to the washing room with soiled dishes to be carefully cleaned (view the service cycle in Fig. 1).

In a normal operation, the *i-MERC* moves from the park room to the kitchen where cooking assistants introduce dishes with normal and/or personalized diets inside the hot compartment and a tray with drinks and desserts inside the cold compartment. After the loading operation, a kitchen assistant gives indication to the *i-MERC* to start moving towards the respective patients' ward. Inside the ward, assistants deliver the meals to the patients and later they load the cold compartment with the returning soiled dishes. Consequently, the robot transports the dishes to the washing room.

To finalise, the robot returns to the park room to be cleaned, checked for eventual damages and recharge the batteries. The robot can be easily cleaned due to its shape without sharp edges. In the future a study will be made focusing on the cleaning products more adequate to this operation.

The *i-MERC* integrates a personalized diets management system where the information of patients' diets can be introduced by nurses, dieticians and assistants. This data can be accessed at any moment in the vehicle itinerary through a touch screen (Fig. 2).

To guarantee the meals temperature while being versatile enough to deliver different kinds of meals along the day, the *i-MERC* includes an area where different sizes of trays can be placed, by the installation of additional supports; a compartment with a preheating system for hot meal transportation and an area in the top to carry thermal bottles with milk, coffee or tea (Fig. 3).

IV. PRODUCT DEVELOPMENT

The development of this project involved various knowledge areas such as project management, geometric modelling, ergonomics, mechanical technology and materials, structural and thermal validation, microelectronic, control systems, artificial intelligence and communication networks. Some of these topics were focused more deeply, and will be presented in the following sub-sections.

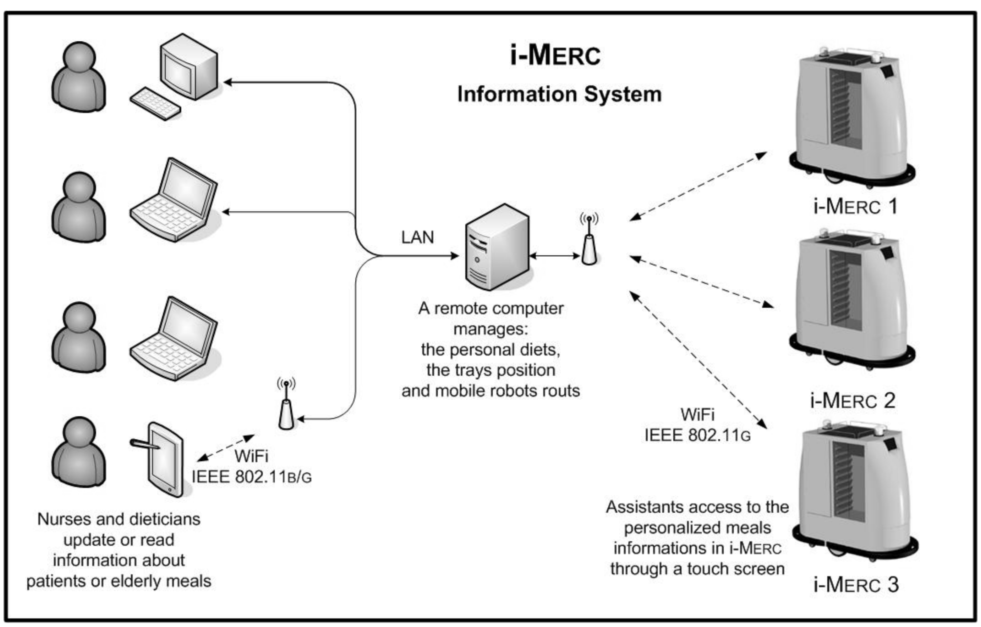

Figure 2. Architecture of the personalized diets information system

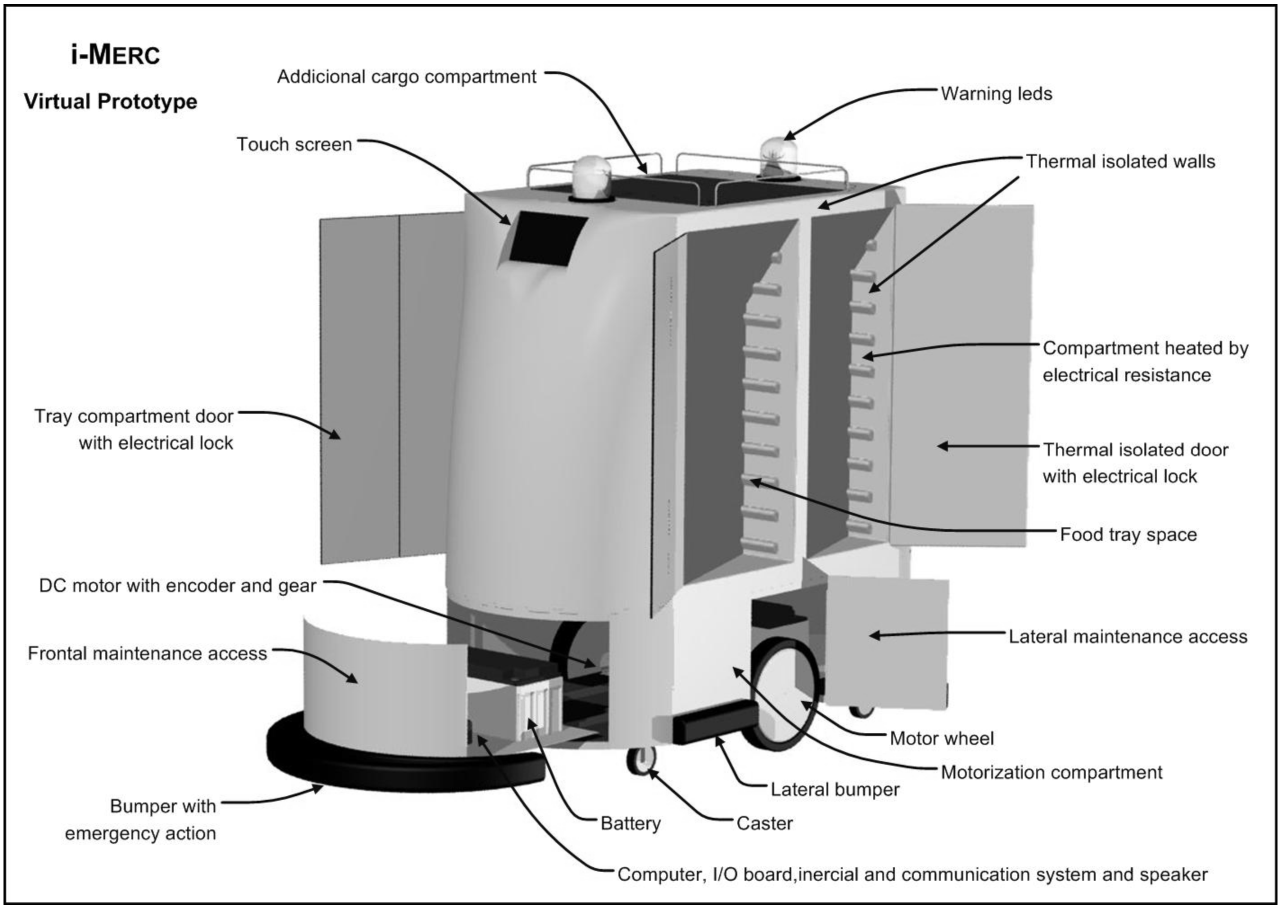

Figure 3. Virtual prototype and concept product of the *i-MERC*

A. Meals Compartment Development

The meals compartment structure is designed to have high resistance to thermal conduction, due to properties of the material applied in the sandwich panels. These panels are composed of a sheet with 40mm of thickness of polyurethane (PU) covered by thermoformed polypropylene (PP) with 5mm thickness.

To guarantee that the temperature is always above 60ºC, the hot compartment has a heating system composed of electrical resistances with 75W. This system is switched on each time the temperature is below 65ºC and is turned off when temperature rises above 70ºC. However, to guarantee the quality of the meals' distribution in case of damage of the heating system, the robot has a security system which informs the user and does not allow opening the doors if the temperature of the hot compartment is below 60ºC.

To analyse the evolution of the temperature inside the heat compartment, a preliminary study on the heat transfer through the walls of the compartments was carried out, considering the heating produced by the electrical resistances. This study was performed in MATLAB® / SIMULINK® and assumed that the environment is at 20ºC and the temperature of the hot compartment is controlled to be between 65ºC and 70ºC.

Equation 1 describes the heat loss through each wall of the compartment at instant k, where K_{PU}=4x10^2 $W/(m.K)$, K_{PP}=10^{-1} $W/(m.K)$, h_{out}=2$W/(m^2.K)$, h_{in}=10$W/(m^2.K)$, L_{PU} and $L_{PP,}$ are the thickness of each layer of the wall and A, is the area of the wall through which the heat flows.

$$Q(k)_i = \frac{T(k-1)_{in} - T(k-1)_{out}}{\left[\frac{1}{h_{in}\times A} + \frac{L_{PP}}{K_{PP}\times A} + \frac{L_{PU}}{K_{PU}\times A} + \frac{L_{PP}}{K_{PP}\times A} + \frac{1}{h_{out}\times A}\right]} \tag{1}$$

Equation (1) only allows for the determination of the heat loss through a wall i of the hot compartment. The heat loss of the compartment is given by the sum of the losses through each of the six compartment walls. Through (2) temperature inside the hot and cold compartments in instant k is determined, where m is the mass of air inside the compartment and c_v is the coefficient of the air heat transfer with constant volume:

$$\sum_{i=1}^{6} Q(k)_i = m \times c_v \left(T(k) - T(k-1)\right) \tag{2}$$

In this analysis, we assumed that the hot compartment is initially at environment temperature and the doors were open for 15 seconds during each minute. For these instants, (1) is only applied to the 4 compartment walls, since at the doors surface only thermic convection between the indoor and

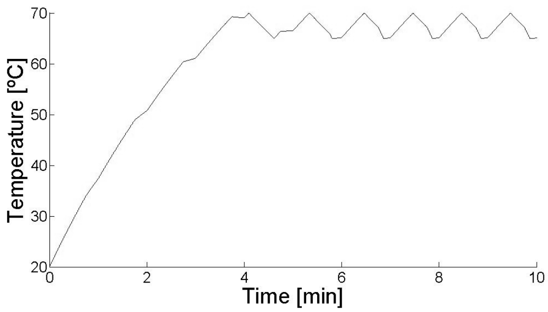

Figure 4. Temperature inside hot compartment

outdoor air exists. Thus, to the door area, the denominator of (1) reduces to the first and the last parameters, with the part referring to the thermic conduction thought the doors being removed. Figure 4 represents the temperature evolution inside the hot compartment during the first 10 minutes of the delivery work. With these conditions the heating system had consumed 47,1Wh of energy.

Even though these are preliminary studies, the results obtained so far indicate that it will be possible to keep the meal temperature above 60ºC and therefore prevent the risk of bacteriologic proliferation [5].

B. *Chassis structure analysis*

During the product development stage, a preliminary study on the base structure chassis was carried out, which led to the definition of some aspects of its shape and chemical and mechanical characteristics. Mainly, the shape of the chassis was designed to allow the easy opening of the doors and the operator access to perform the maintenance of the components. The chassis and the other parts of the base structure were designed for stainless steel construction, since it has good strength and stiffness and is resistant to corrosion. This detail is especially important since *i-MERC* will be washed after each task.

The *i-MERC* chassis must have the proper mechanical characteristics that will allow supporting the expected loads:

- Weight of the compartments: 200N
- Weight of trays and cargo in cold compartments: 300N
- Weight of dishes in hot compartments: 200N
- Weight of batteries, control components, orientation system and other components inside the base: 200N

These loads must be supported by a chassis mounted on 6 wheels, 2 motorized and 4 casters, as shown in Fig. 5.

The structure was designed with a square section tubular beam with 20mm on each side and 2mm thickness.

Through a finite element computational analysis carried out using ANSYS®, the static behaviour of the structure was obtained (Fig. 6), from which the most relevant values were extracted:

- Max deformation: 0.215mm

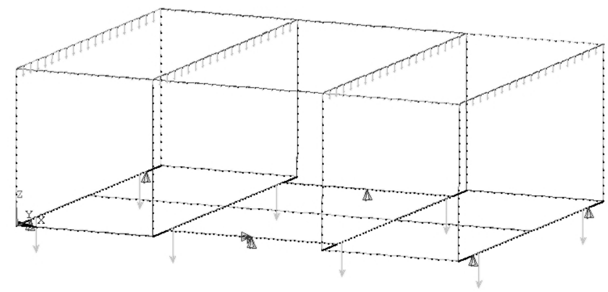

Figure 5. Loads and containments applied in chassis

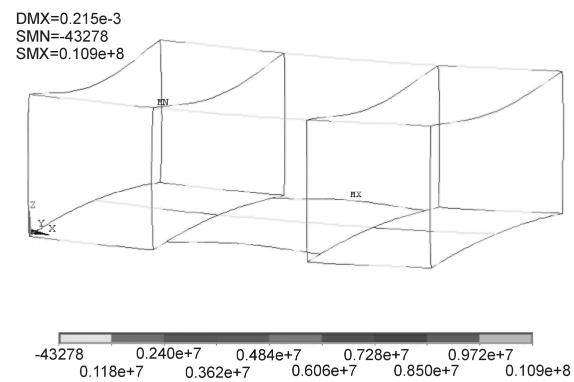

Figure 6. Finite Element Analysis of the chassis

- Max stress (Von Misses): 10.9MPa (traction)
- Min stress (Von Misses): 0.04MPa (com-pression)

These results allow concluding that the structure can support the expected loads without plastic deformation, since the maximum stress is well below the stainless steel yielding stress (20 MPa) [5].

In this study, we only considered the static loads, because the velocity and accelerations of the robot are small, and will originate dynamic loads that can be neglected.

C. *Control Architecture*

To implement the functionalities described above, we propose the control architecture shown in Fig. 7. This architecture supports the trajectory control of the robot, the management of the system and the requests and execution of tasks. The i-MERC has a set of sensors, actuators and a central board (PC104), as shown in Fig. 8, running a control application that controls the robot and guarantees a safe movement and reliable communication with the management system.

The PC104 boards have small dimensions, great reliability, low price and IDE, USB and RS232/485 interfaces that allow easy connection with hard disk drives and wireless networks and data acquisition cards.

With this board, a touch screen for Man-Machine Interface and a WiFi connection, *i-MERC* will be able to communicate with other mobile robots, management system, elevators, automatic doors and other devices which have a wireless

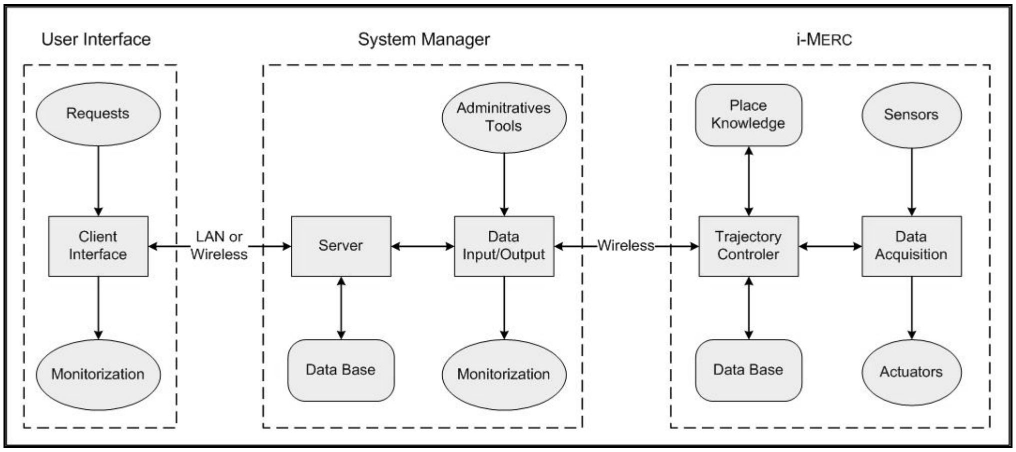

Figure 7. Architecture of the *i-MERC* concept

network device. To manage *i-MERC* and gather information about its availability, position, energy, etc., the communication between the management system, *i-MERC* and other user devices is established by a TCP/IP protocol, an inexpensive and easily integrated communication system.

The *i-MERC* will be powered by ion lithium batteries. In spite of being expensive when compared to other kinds of batteries, they have good energy density and cycle of life, small time of recharge and no memory effect. Concerning the power management, preliminaries studies were performed but further work is still necessary to quantify *i-MERC* real autonomy.

The sensors, which will be used to perform orientation and obstacle avoidance, will connect to a USB data acquisition card or directly to the PC104 board through a RS232 interface. In section E we address the use of the sensors in the orientation system with more detail.

Obstacle avoidance was left for further developments; in the current stage, we propose ultrasonic and/or optical sensors to detect obstacles in the robot's path. *i-MERC* will reduce its speed and go round the object or person. If it cannot avoid the object or person, it stops. Further developments will include algorithms for negotiating the obstacle changing the robot's trajectory.

The robot must have an emergency button with easy accessibility to be used in case of failure of the obstacle avoidance system; the frontals bumpers also send an emergency action to stop motors. To prevent accidents, the robot has LEDs which flash and a buzzer that sounds smoothly when it moves.

The control and data manipulation will be performed by a control application based in LabView® and/or MABLAB® and a MySQL® data base server which will run over a Windows

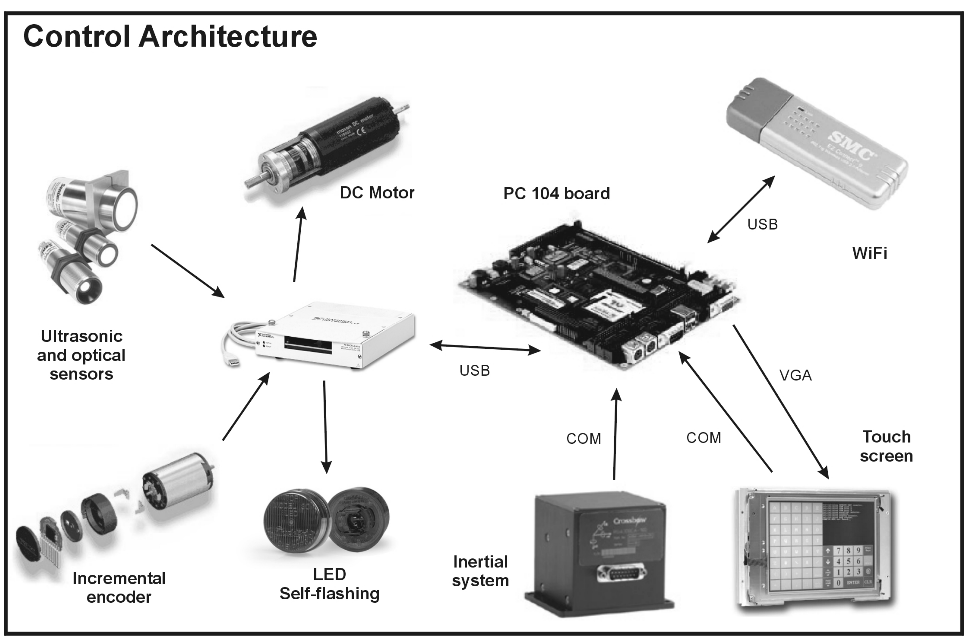

Figure 8. Control architecture of the mobile robot

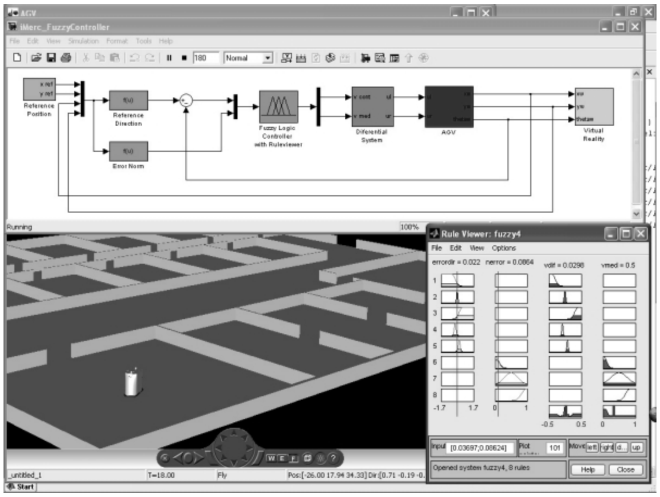

Figure 9. Virtual simulation of the *i-MERC*

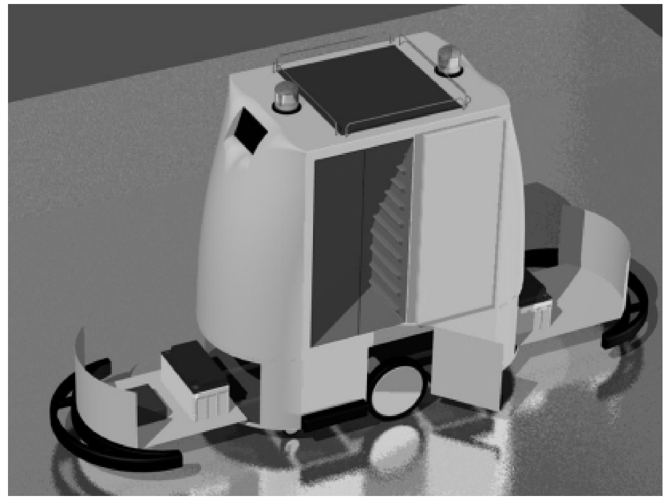

Figure 10. Virtual prototype of the *i-MERC*

XP® operating system.

With this architecture, the control is done directly inside *i-MERC* and the data is sent to the server at the same time. Thus, if a failure occurs during data transmission, this will only result in a monitorization delay.

Communications delays and reliability of the wireless network seem not to be a problem because the amount of data transferred between the robot and the central system does not have real time constraints and can cope with temporary communication losses.

D. Virtual Simulation

With the purpose of demonstrating the service concept and to perform a study on the trajectory control, we developed a simulation model in MATLAB® / SIMULINK®. In this model, a fuzzy controller [7] was added to control the robot movement, along a path between the robots' room and the kitchen (Fig. 9).

In the simulation stage, we used the virtual prototype built in a 3D modeling software (Fig. 10), which was converted to VRML (Virtual Reality Modeling Language) format. A model of the hospital was also included in the virtual world as the scenario where the robot moves. To simulate the robot movement over the layout, we used the XY translation of the robot model and the rotation about Z as the inputs to the VRML virtual world.

During simulation, these values are sent from the robot model to the VRML world, through the Virtual Reality Toolbox, thereby producing an animation of the simulated situation.

E. Orientation System

The proposed orientation system has a combination of relative and absolute localization measurement systems in order to achieve good localization precision.

Thus, the relative localization measure is provided by two encoders and an inertial unit. Nowadays, the use of encoders in mobile robots is a common practice for obtaining a relative localization measure, through the wheels displacement. These devices have good accuracy, small dimensions, easy connection with motors shafts and are cheaper when compared with others sensors.

On the other hand, the use of encoders leads to systematic errors due to misalignment, different dimensions of wheels, or uncertainty about the contact point with the ground. Also, these sensors are prone to non-systematic errors due to irregularities or small obstacles on the ground, as well as slipping of the wheels due to slippery ground, high accelerations or faster rotations.

In order to improve the accuracy in the position measurement, we propose the use of an inertial measuring unit which analyzes with high sensibility the robot movements and provides information about rotation on X, Y and Z axis as well as the acceleration in each axis. The inertial measuring unit can also be acquired at low prices and can be easily connected to the PC104 board through the RS232 interface.

On the negative side, this component may also exhibit measuring errors, due to the influence of the movement of the earth on gyroscopes. Since the inertial measurement is integrated in order to give the robot position, this problem should be carefully addressed, because the error tends to increase faster.

To eliminate errors that occur in encoders and inertial devices, some absolute measuring systems must be implemented. Thus, to recalculate the real position of the robot, reflectors are installed in known places which are detected by optical sensors. These reflectors act like beacons that are detected by a boat that is approaching the coast.

When an optical sensor detects a reflector, the control system will search through the known positions of the existing reflectors in order to identify it and readjust the current position value of the robot.

The real position of the mobile robot is inferred from the comparison between the measures obtained from these devices and a model of the place where the robot circulates.

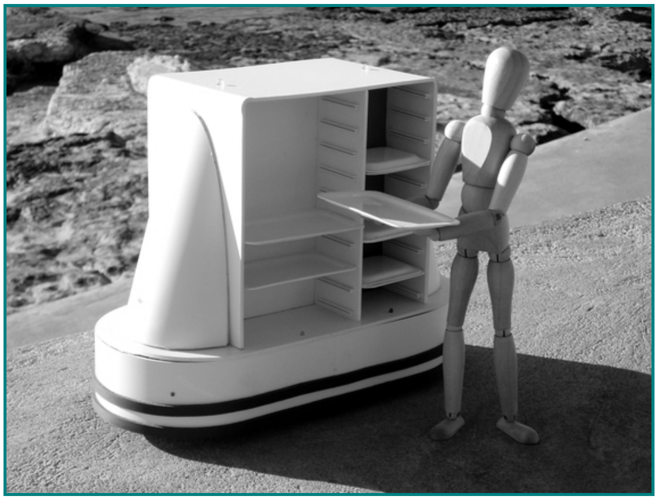

Figure 11. Physical prototype of the *i-MERC*

To detect objects and people that cross the path of the robot, it is equipped with optical sensors in both frontal sides of the base. These sensors have different orientations, in order to detect objects in different positions and during the rotation of the robot.

V. PHYSICAL PROTOTYPE

During the product development some prototypes were built, which allowed to:

- Analyze shapes and dimensions;
- Visualize aesthetics and design;
- Analyze the human-robot interactions, through dummies with the same scale of the robot;
- Study the position and dimensions of some mechanisms;
- Demonstrate a real itinerary of the mobile robot inside a HHCC.

The last physical prototype was built using a 1:5 scale, allowing easy transportation. The main scope of this prototype was to demonstrate a real itinerary of the mobile robot inside a HHCC, to attract potentials partners or stakeholders to the project. Thus, we built the prototype with an approximated shape of the real robot (Fig. 11), and introduced in it some components that allowed it to move over a pre-programmed path, simulating a real service.

The prototype was built in PVC plates with 1 and 3 mm of thickness, that were formed and glued to acquire the desired shape. The final form of the plates was obtained with the aid of a mould of wood where the PVC plates were placed and then thermoformed by heat applied by a hot air pistol. The front and lateral dumps were built with expanded polyurethane.

The motorization of the prototype was guaranteed by two servos of model aircraft, which already included a transmission gear. This option allowed the motor system to be compact enough and fit in the small space available in the base of the prototype.

The servos were changed (mechanically and electronically) and transformed into simple DC motors, to create a continuous movement, with rotations above 360º. These servos were coupled with two wheels with 50 mm of diameter placed in the center of the lateral side of the robot.

The prototype also exhibits a set of LEDs that indicate when *i-MERC* is moving or is communicating with the computer server. Some LEDs were included in order to signal the interactions between *i-MERC* and the assistants that using it. For example, there were LEDs to indicate when an assistant is taking a tray or a hot meal. Even though this prototype could simulate a real process taking place in a known environment, it doesn't have the functions of a real autonomous mobile robot. It is only a small motorized model with pre-programmed actions. The control of the movement is accomplished by an 8 bits microcontroller which was installed in the base of the prototype. The circuit was implemented with a set of electronic components like voltage regulators, resistances, capacitors, buzzers, LEDs and a 4 MHz crystal to regulate the circuit speed. The motor control circuit was powered by 5 V batteries.

With the aim of demonstrating the service concept of *i-MERC* through a prototype, two programs were created and downloaded to the microcontroller. The first program demonstrates several small movements and the LEDs signaling interface. In the second program, the *i-MERC* follows a pre-defined path through some dummies, assuming the role of the kitchen assistants, nurses, patients, cleaning assistants or technical maintenance staff.

VI. CONCLUSIONS

The work developed in this project allows defining a new and innovative product and service concept, greatly improving the meals logistic service in HHCC. A set of problems in different knowledge areas, that must be carefully resolved, were addressed in this work. In some areas, some preliminary studies were carried out, in order to define the materials that must be applied, as well as the orientation system and control architecture.

The physical prototype was used to simulate this new concept service and to present the product to the external accompanying committee of the Master in Engineering Design, with great success. We hope that it can be used in the future to attract partners and stakeholders to the project.

In a near future, we intend to address further the diets manager service, the orientation system of the *i-MERC*, the heating system of the hot compartment, the controller of the robot and the optimization of the structure.

If you are interested in knowing more about the project, please visit http://www.istdesignstudio.net/proj14.

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