A DESIGN APPROACH FOR THE DEVELOPMENT OF A DEDICATED MEALS TRANSPORTER MOBILE ROBOT

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SYNOPSIS

In this paper we present the design of a dedicated meals transporter mobile robot, motivated by the need to increase the quality of the meals transportation service inside hospitals and health care centres (HHCC). This robot has isolated walls and a heating system which keeps meals temperature at acceptable levels to prevent bacteriologic proliferation. The project has been developed within the compass of the Master in Engineering Design, at the Technical University of Lisbon. The product development addressed many knowledge areas such as project management, geometric modeling, ergonomics, mechanical technology and materials, structural and thermal validation, microelectronic, control systems, artificial intelligence and communication networks, some of which are presented in this paper. A prototype was developed to be presented to stakeholders that would be interested in the project.

INTRODUCTION

The meal distribution service is one of the most important aspects inside HHCC and similar health services, namely because the quality of the food strongly influences the patient's recovery. It is also important that patients should have a personalized diet that guarantees an appropriate nutrition. These diets would origin strong benefits to patients, such as better tolerance to the treatments and attenuations in symptoms, promoting the patients' quality of life (Ravasco, 2004). For these reasons, it is common practice to take extreme care not only with the food preparation but also with the transport between kitchen and patients. The later task normally takes between 10 to 30 minutes, with the risk of the meals temperature decreasing below 60ºC, the limit temperature for which bacteriologic proliferation may occur (WHO, 2000).

Having in mind this target market, we analysed this service and proposed a new product to create a more hygienic and efficient meal transport service: a dedicated meals transporter mobile robot - the *i-MERC*. The new concept establishes as the main requirements of the robot that it should include a personalized diets management system and should be able to deliver these diets to patients and return to the washing room with soiled dishes for cleaning (see Fig.1).

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 heating system for hot meal transportation and an area on top to carry thermal bottles with milk, coffee or tea (Carreira, 2005).

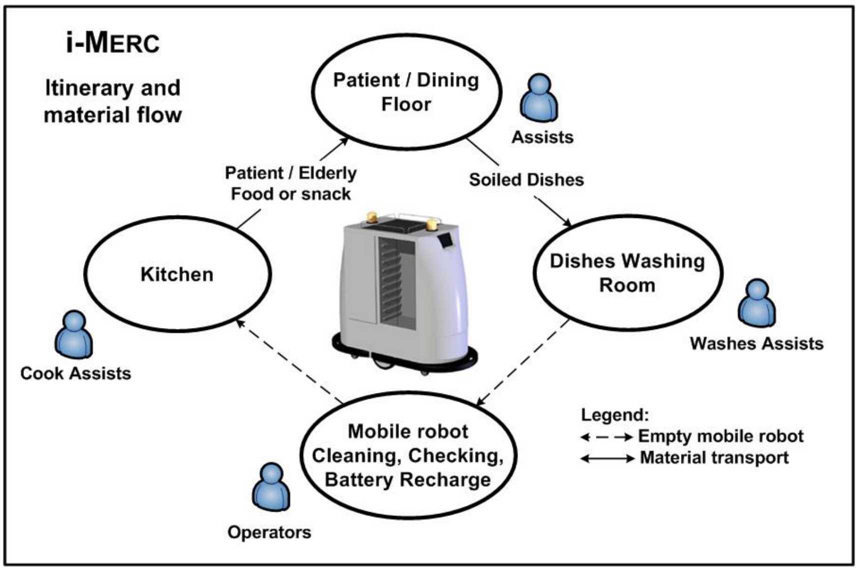

Fig. 1 Itinerary and material flow of the *i-MERC*

DESIGN FOR AN ERGONOMIC INTERACTION

Ergonomics is an important factor during product development, resulting in better human interfaces and reducing the probability of accidents and long term diseases from poor manipulation. Thus, the authors studied the three main areas of ergonomics: security, operational features and maintenance.

Safety

The movement of a robot along a certain path could be an easy task to robot designers when moving in a known path. However, it could be an adventure when sharing the same space as persons. Thus, to guarantee a safety movement some features must be implemented:

- Put sensors, in the base and around the robot, specially in the frontal parts, to detect persons and objects along its path;
- Limit the maximum speed of the robot to 0.3 m/s;
- The speed of the robot should decrease when nearing a moving object;
- The robot should be able to detect non-moving objects and round them;
- The frontal bumpers should actuate as an emergency stop when the robot collides with a person or an object;
- The robot must have one or several easily accessible emergency buttons;
- Whenever, the robot moves, it must turn on intermittent lights, on the top and in each side;
- The robot must emit a sound (in a way not to disturb the persons) before arriving to a bend and whenever it encounters an object;
- All electric and electronic components must be electrically isolated and protected from the water;

Operational features

In this item, the team studied the interactions between the users and the robot, to optimize usability. The most relevant features addressed were the overall dimensions, the accessibility, the user posture when interacting with the robot, the effort (energy spent by the user) to operate the robot, the visibility, the noises and sound generated by the robot, and the information exchanged with the robot.

Overall Dimensions

The dimensions of the robot must be appropriate to move inside actual hospitals and health care centres, including rooms, corridors, kitchen and elevators. It was estimated that in the final product concept the robot should not exceed 1,74m length, 0,80m wide and 1,58m tall.

Accessibility

The positions and dimensions of doors must allow users easy access to the different compartments to place and remove the meals (see Fig. 2).

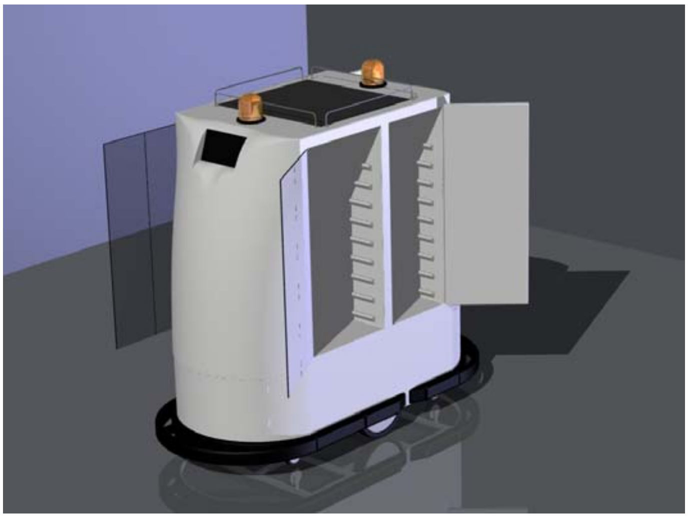

Fig. 2 Accessibilities of the meals compartments

User Posture

The height where trays will be placed should optimize/minimize the user movement. Nevertheless, the robot must carry enough meal trays to be efficient. Thus, the lower tray is placed at 45cm from the floor and the higher tray at 1,40m

Effort to operate the robot

With this robot the users do not need to push or pull, since it is fully automatic.

Visibility

The visibility of a mobile robot becomes a critical problem when it moves among persons, since it must not endanger them along its path. Thus, the choice of colours must allow for a contrast with the environment, especially with the colour of the walls, once that is the background of the robot. Along its movement the robot must switch on intermittent lights and emit sound to alert to its presence.

Noises and sound generated by the robot

The level of noise must be as low as possible, since the high noise level disturbs the patients, and becomes inconvenient to the other persons. However, the absence of noise would also be dangerous when the robot is moving. For this reason, a minimum noise level of 35dB is mandatory, along with some discontinuous alert sound, to signal the robot movement.

Information

The information of the alert tags or in the touch screen must allow easy reading to the users, guaranteeing both safety and usability.

This easy reading feature will be performed with adequate text proprieties: text without ornamentations; written in small characters – could be all caps in alerts and with highlight; the font size of display must be readable at 1m and the alerts at 2m; enough spacing between lines; the contrast of tags and display and the presence of pictograms that allow a fast assimilation of the information.

Maintenance

The robot also must guarantee the safety of maintenance operations for the motors, wheels, batteries, sensors, lights, hardware, etc. For this reason, some items were studied regarding the maintenance of the robot, including accessibility for maintenance, the posture and effort of maintenance operators, and the existence of a book of instructions.

Accessibility for Maintenance

The accessibility study had to combine the exterior design of the robot, the structural design of the chassis, components' layout and operators' postures. Considering that the main components with greater maintenance will be placed inside the base of the robot (the chassis), two frontal and two lateral access points had to be created to allow access for maintenance and repair purposes (see Fig. 3).

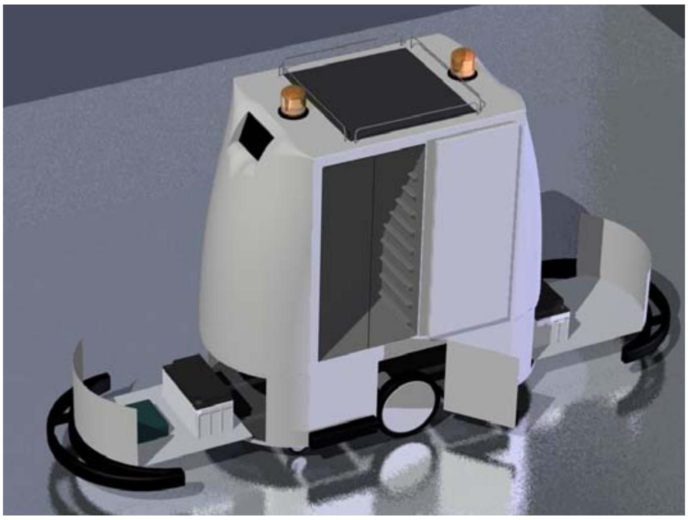

Fig. 3 Accessibilities to the maintenance operations

Posture and Effort of Maintenance Operators

As was referred about accessibilities, the access points were studied to optimize the operators' postures. Thus, the heavier components were placed at the two front and rear drawers, sliding out of the robot chassis for maintenance. The lateral access points allow easy access to motors, gears and encoders of the wheels.

The effort needed by the operators will also be reduced by the front and rear drawers.

To perform maintenance operations on the wheels, the robot must be lifted by an elevator allowing good postures and low human effort.

Book of Instructions

Due to the innovative nature of this product, it must have a perfectly clear book of instructions, in a language that is accessible to nurses and other support staff, relying mostly on graphics. Extremely technical language should be avoided, and troubleshooting guidance should be simple: for problems requiring technical expertise, specialized maintenance shall be called upon.

DESIGN FOR A HEALTHY MEAL TRANSPORTATION

The challenge of the design of a compartment to transport the meals between the kitchen and the rooms is in its capacity to keep the meal temperature above 60ºC and with a high impact resistance. Thus, this compartment was designed to be composed by sandwich panels combining a high thermal isolation and impact resistance. These panels are composed of a core with 40mm of thickness of polyurethane (PU) covered by thermoformed polypropylene (PP) sheets of 5mm thickness and thermal conductivity of, respectively, K_{PU}=4x10^{2} *W/(m.K)* and K_{PP}=10^{-1} *W/(m.K)*.

However, 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 temperatures rise above 70ºC. To guarantee even further the quality of the meals' distribution in case of damage of the heating system, the robot has a security system which sends information to the user and does not allow the opening of the doors for distributing meals to the patients when the temperature of the hot compartment drops below to 60ºC.

A thermal simulation of 1 hour of delivery work, where it was assumed that the environment is at 20ºC, the temperature of the hot compartment is controlled to be between 65ºC and 70ºC and the doors are opened 15 seconds in each minute, showed that the heating system had consumed 47,1Wh of energy and it was possible to keep the meal above 60ºC (see Fig. 4), preventing the risk of bacteriologic proliferation and increasing the quality of the service.

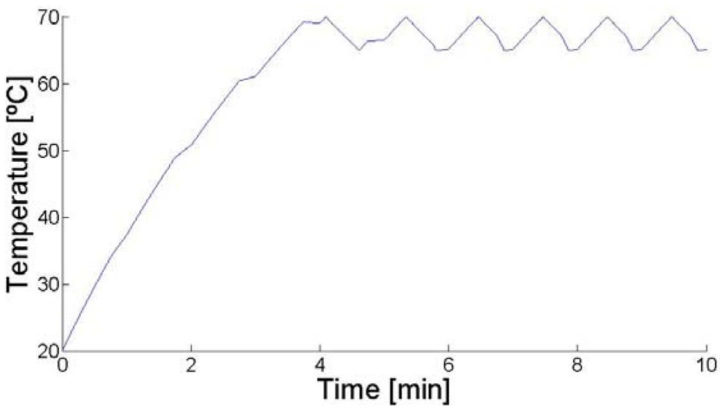

Fig. 4 Temperature inside the hot compartment

DESIGN OF THE STRUCTURAL CHASSIS

The base of the robot – the chassis – is composed of a square tubular structure covered by metal sheets, both of stainless steel. The team chose this material due to its high impact and static strength and its resistance to aggressive cleaning products. The later property is especially important, since the robot must be cleaned and washed after every meal, and the use of aggressive cleaning products is very widespread.

The chassis is responsible for supporting the weight of the meals compartment and the meals of the patients. However, as it's possible to see in Fig. 5, its shape is limited by the shape and dimensions of the access points to the components which were designed to optimize the maintenance's operations.

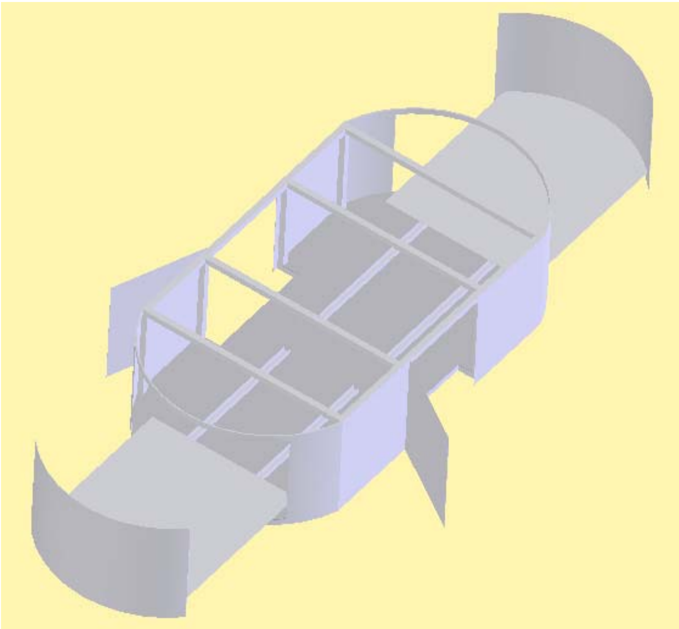

Fig. 5 Design of the robot's chassis

PROTOTYPING

During the product development the team built three prototypes to assess the following concerns:

- Analyze shapes and dimensions;
- Visualize aesthetics and design;
- Analyze the human-robot interactions, using 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.

1st Prototype

After the shape definition through the design of some sketches and the first 3D virtual modelling the team built a first prototype with paper cardboard sheets and polyurethane panels (see Fig. 6) to analyse the shapes and dimensions.

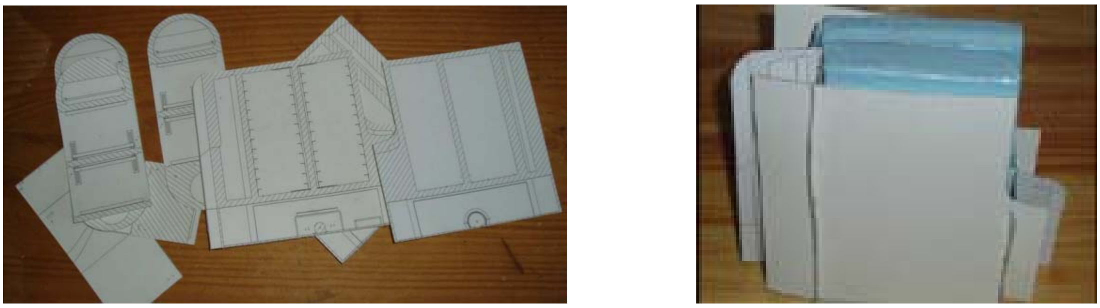

Fig. 6 The 1st prototype

This model had contemplated 4 spaces for trays with meals and another space for the pot of soup. However the team abandoned this shape after a visit to some hospitals' kitchens because they concluded that dieticians were having serious concerns with the temperature of the meals dropping below 60ºC. To partially solve this problem, it's usual in these services to use meals trolleys with two separate areas for the cold and the hot food. The visits also allowed concluding that the compartment to the pot of soup was needless, since the soup was brought in individual isothermal recipients.

2nd Prototype

After the visits at hospitals, the team had reformulated the organization of the compartments eliminating the compartment for the pot of soup and creating four separated areas: two larger areas for trays with cold meals and two smaller areas for the dishes with hot meals.

The team restarted the design process drawing some sketches, building another 3D model and another physical prototype. This prototype (see Fig. 7) was built with k-line and balsam wood to analyze the new layout of the compartments and the access to the lower structural base.

Fig. 7 The 2nd prototype

Thus, after a discussion over this prototype, the team decided to redesign once again the compartments layout because with this configuration the two heated compartments were offset from each other, causing great heat lost through the walls. With this prototype, the team had also abandoned the idea to build a sliding tray support wall to adapt to different size of trays because this system would be difficult to clean, and a HHCC always has a unique tray size.

To maintain the concept to allow different sizes of trays, the team analyzed some trays and decided to build larger compartments and use anti-slide PVC plates to support the smaller trays.

3rd Prototype

This was the last prototype built, with PVC plates, to analyse user's interactions and to demonstrate a real itinerary of the mobile robot inside a HHCC, to attract potential partners or stakeholders to the project.

This prototype (see Fig. 8) has servomotors and LEDs that indicate when the *i-MERC* is moving or is communicating with the computer server. The control of the movement is accomplished by a simple 8 bit microcontroller installed in the base of the prototype.

Fig. 8 The 3rd prototype

This prototype has two programs which were created and downloaded to the microcontroller to demonstrate the service concept. The first program demonstrates several small movements and the LEDs signalling 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.

PRODUCT CONCEPT

Theses studies due to the design of the robot, mainly in the definition of the shape, dimensions, access and the positions of compartments and components (see Fig. 9).

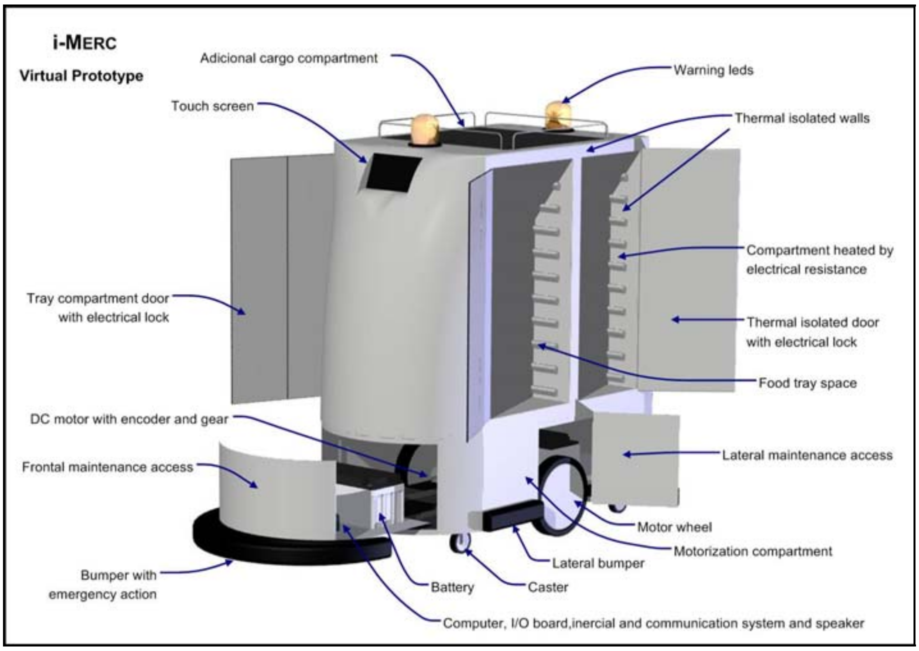

Fig. 9 Virtual prototype and concept product of the *i-MERC*

However, the applied materials and the applied mechanical technology couldn't separate from the design process (see Fig. 10). Thus, the selection of PU panels applied between PP thermoformed sheets should become the robot construction shipper due them applied technology.

The base of the robot will be built in stainless tubular welding structure covered with stainless steel sheets. Although, this is being an expensive material, its corrosion and mechanical resistance, associated to easy shapes, which could easily be built in steel, become the stainless steel one of the better materials to be applied.

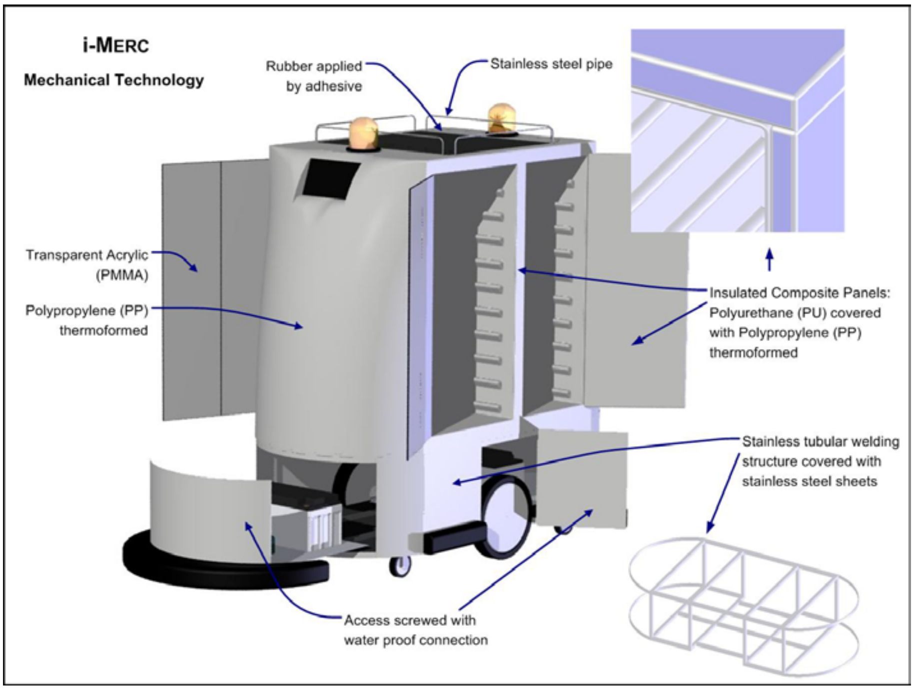

Fig. 10 Materials and Mechanical Technology applied in *i-MERC*

RESULTS

The product development process addressed various knowledge areas such as project management, geometric modeling, ergonomics, mechanical technology and materials, structural and thermal validation, microelectronic, control system, artificial intelligence and communication networks.

The ergonomics study allows analyze many problems about robot and person's safety, and aids the team in the definition of a set of specifications such dimensions, shapes, accesses, noise, emergency actions, sensors and lights positions.

The design of the meals compartment structure produced the definition of the positions of the hot and the cold compartments, its dimensions, shapes and materials. The walls composed of panels of Polypropylene (PP) and Polyurethane (PU) and the implementation of an automatic heating system results in a good solution to keep the temperature above the 60ºC, preventing the risk of bacteriologic proliferation and increasing the quality of the service.

The construction of prototypes had a great contribution along the product development, once allowed the team analyzed the human interactions and the heat propagation through the walls. Theses analysis allowed redesign the project some times due to a better, safe and optimized product.

CONCLUSIONS

The work developed in this project introduced a new and innovative product and service concept, which may greatly improve the meals logistic service in HHCC. A set of problems in different knowledge areas, that must be carefully resolved during the design stage, were addressed in this work. In some areas, some preliminary studies were carried out, to define the materials that should be applied. For more information about the project, visit http://www.istdesignstudio.net/proj14.

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