Human Robot Interface Design for Hospital Robot Swarm

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Robots have been traditionally exploited in production engineering to boost productivity and competitiveness in manufacturing systems. More recently, robotics and its related technologies are progressively and substantially entering homes and public places with the scope to improve the quality level of human life and welfare. As this new trend requires robots increasingly capable to collaborate and work closely with people, the design of a suitable Human Robot Interface (HRI) has then become a fundamental issue in robotics, since it can enable efficient and effortless robots-user communication. In this research work, the problem of configuring the most appropriate HRI to be implemented on a robot swarm for hospital care is investigated. With the aim to get a full view of the potential tools offered on the market, the most relevant available HRIs are presented and evaluated by taking into account the specific requirements imposed by the hospital environment and the potential users. The most suitable interface is identified using a Multi-Attribute Decision Making (MADM) method based on the Simple Additive Weight (SAW) aggregation technique coupled with the Linear Scale Transformation Max Method and eventually configured with reference to an application test case concerning the delivery of medicines within the hospital area.

Keywords:

Human Robot Interface, Multimodal Interface, Robot Swarm

1 INTRODUCTION

For many years, robotics has been largely employed in shop-floors since it offers the opportunity to significantly increase productivity and competitiveness of manufacturing industries. Nowadays, this technology is moving out of the industrial environment towards homes and public places. Accordingly, while in the past robots were mainly employed for industrial manufacturing and transportation tasks, to date increasing research and development efforts are dedicated to service and entertainment applications [1].

The trend of many recent research studies on robotic systems has now invested the market where traditional cleaning, transporting and guiding applications in environments like metro stations, hospitals and museums are now increasingly conceived for consumer-targeted robots [2]. The robot systems of the next years will be human assistants, helping people do what they need in a natural and intuitive manner.

As a matter of facts, new social and public service demands have emerged in modern society for which innovative solutions can be effectively found in robotics. An example is represented by the ever-increasing growth of the elderly population and labor shortages in the welfare service. To tackle these problems, numerous researchers are investigating the applicability of intelligent systems and robotic artefacts in assisted-living environments [3] with functionalities related to the support of basic activities: mobility, household maintenance, monitoring and safety preservation, etc. [4].

This article relates to a wider research effort whose main purpose is to overcome the lack of healthcare staff with particular reference to hospitals and healthcare centres. This research work aims at the implementation of a robot swarm that will carry out four major tasks: attendance, recognition, communication and support (for assisting, cleaning and delivery).

Advantages achievable through the implementation of this robot swarm include (but are not limited to) the increase of attention paid to patients by hospital staff; the reduction of human error instances; improved cleanliness of the environment; faster and timelier delivery of medicines. The self-organising robot swarm will efficiently support hospital staff by offering them a convenient manner to request tasks. The robot swarm user will simply need to specify to one of the robots in the swarm the job that should be carried out, without the necessity to program robots or worry about the details of execution. The robot swarm will autonomously decide which robot should carry out the mission and how to perform it.

In order to carry out the specified activities, the swarm robots should be capable of performing diverse tasks in an unstructured dynamic environment such as the hospital ward, not only by operating among humans but also by continuously interacting with them. The main robots requirements are: mobility; advanced perception capabilities; and easy interaction with humans [2].

This article focuses on the latter aspect, i.e. the need of communication/interaction between humans and robots. This is the prerequisite to allow the robots to work proficiently in the same environment and under the command of different users.

To enable efficient and effortless communication, a proper Human Robot Interface (HRI) is fundamental. This HRI should permit the average user to transmit their will to the robot in a simple way and to control and assess the state of the system. Moreover, a well-designed HRI can make the robots more acceptable by all kind of users.

The main purpose of this article is to find the most suitable HRI to be implemented on hospital swarm robots. Even if different devices can be available to hospital staff, the HRI should be unique for every application involving interaction with the swarm robots, and should take care of all the problems related to the usage by several different potential users.

2 AVAILABLE INTERFACE TECHNOLOGIES

The various kinds of HRIs commercially available on the market have all been designed to on the basis of the typical ways of human communication in daily life.

This is because the principal requirements of HRIs or, more generally, all human-machine interfaces (HMIs) is to provide an easy and intuitive human-like interaction.

HRIs designed to make use of all or some of the five senses (particular focus is on vision, hearing and touch interaction), represent relatively simple tools enabling natural communication.

In the following, the most relevant available HRIs are introduced and evaluated.

2.1 Graphical User Interface

A Graphical User Interface (GUI) allows people to interact with a device through direct manipulation of graphical elements. Graphical icons, visual indicators or special graphical elements called „widgets" are used rather than typed commands or text menus. Icons are generally used to display a current state object, process or situation. Compared to text, they permit to save much space and their visibility, accentuated by a particular position on the screen, provides a very easy to use interface. Usually the icons are employed in combination with text and labels to clearly represent the information and the actions available to the user. Besides icons, also symbols, buttons, drop-down lists and menus are employed to allow easy viewing of data [5]. Typical input devices are keyboard and mouse.

2.2 Touch User Interface

A Touch User Interface (TUI) allows the user to employ both the senses of sight and touch to activate functions. It requires a pressure on parts of a graphical surface, replacing the common interaction devices like keyboard and mouse with a touch screen. Actions can be carried out just by interacting with the touch surface: the printed pages act as a template or overlay to a switch array, and the switching sensor holds the connection with a database in order to launch the appropriate application.

TUI icons are used to show what function is activated by interacting with the corresponding part of the printed page. The most common touch screens are Resistive touch screens, usually employed for applications like PDA (Personal Digital Assistant), but also Capacitive touch screens and Dispersive Signal Technology.

2.3 Gaze-based Interface

A Gaze-based Interface employs an eye-tracking system able to detect the visual behaviour of users. Input can be entered by turning the gaze into a pointing device. Gaze controlled systems provide hand- and barrier-free interaction that can be used in a large spectrum of application fields. They could increase the efficiency of human-machine interaction in the near future adding an additional modality besides conventional interaction devices. Applications could be controlled by eyes with a display showing the function and interaction feedback.

2.4 Voice User Interface

A Voice User Interface (VUI) founds interaction with machines on a voice/speech platform to initiate an automated service or process. Since speech is the main mean of communication for humans, a VUI is a natural interaction modality. However, designing a good VUI is very difficult, and can be done in different ways.

In the natural language recognition the system converts words into text, just as if they had been entered via keyboard. In the case of Speaker-dependent system the user has to introduce samples so that it could identify his voice. Speaker-independent system does not require the registration of samples of voice, but can recognize limited vocabularies. There are three types of voice recognition applications: Command system that can recognize a few hundreds of words, Discrete voice recognition that is usually employed for dictation and requires a pause between single words, Continuous voice recognition that understands natural speech without using pauses.

On the other side, to synthesize text into speech Text to speech technology has been significantly improved in recent times, and although it is still not comparable to recorded human voice, it offers an alternative to produce sound messages from text that cannot be known in advance.

A hearing-based interface can also include a sound emission device. Sound is widely used for warnings, alarms, and monitoring status information. The effect of sound on human behavior depends on intensity, pitch or timbre. Some of them will be completely ignored while others are automatically associated to a specific situation or have alarming nature as a siren.

2.5 Multimodal Interface

A Multimodal Interface offers to the user multiple modes of interaction with a system: it typically combines a visual modality like a display, keyboard, and mouse solution with a voice modality such as speech recognition for input, speech synthesis and recorded audio for output. However other modalities may be used [5]. The advantage of multiple modes is increased usability: the weaknesses of one modality are offset by the strengths of another. Multimodal interfaces have the potential to enhance users‘ access to information technologies through an augmentation of the perceptual processes via multiple modalities. Users who have difficulty with one modality could greatly benefit from using an alternative one, or a combination of modalities enabled by a multimodal interface [6].

3 TECHNOLOGY EVALUATION

3.1 Interface Requirements

In order to select the most suitable interface technology for the hospital swarm robots, it is essential to examine the environment in which they will be implemented and the different kinds of users they will encounter.

In a hospital, human-robot interaction can occur in several different scenarios such as wards, patient rooms, staff offices, etc. These environments have very different features: they should be then analysed to identify the environmental constraints (location, accessibility, temperature, noise level, etc.) and the requirements that a HRI should meet to be employed in those locations.

The analysis of the hospital environment has been carried out through interaction with the actual users as well as on the basis of a research performed on internet. The latter offers a wide variety of information, not only in the form of written articles and statements, but also in the form of multimedia files. It is possible, for example, to listen to the characteristic sounds of a hospital environment in different rooms and conditions, such as a corridor rather than a patient room etc. (e.g. on the website www.audiosparx.com many different files related to hospital sounds are available).

On the basis of this research, some considerations can be made. In a corridor, for example, noise level will be much higher than in patient rooms or staff offices. This could influence command understanding and hence compromise the task achievement in case a voice based technology is employed. These issues should be taken into consideration when designing a proper interface.

Also the inclusion of the user's perspective throughout the entire design and development process is central for an effective, efficient, and usable interface [7]. For this reason, it is essential to make a sort of classification of the potential users to consider the needs of any category.

The hospital swarm will interact with four main groups of people, each having different skills and requiring a different functionality from the robot. Supervisors are part of medical staff with the role of monitoring and controlling the overall situation; operators are skilled users able to modify the internal state of the robot, with knowledge of robotic programming and architecture; peers are agents with specific abilities, interacting with the robot at an high level to reach common goals; bystanders are agents that simply co-exist in the same environment of the robot [6].

On the basis of this scenario, the main requirements that a HRI should satisfy can be identified:

Ease of use: The robot needs to interact with the medical staff, but also with patients and visitors. Due to this fact, the interface should be easy to use enough to allow anyone for a simple interaction with the machine.

Effectiveness: The interface should assure an effective interaction between the robot and the user. Effectiveness measures how well a result is achieved.

Efficiency: Efficiency is related to the user efforts to fulfil a task: the more quickly users are allowed to carry out their jobs, the more an HRI is efficient.

Transparency and understandability: Many potential users, especially patients, could be intimidated by the robots technology. Then, it is of crucial importance to make robots behavior fully comprehensible and their intentions clearly apparent for all users. Transparency of the robot's in¬ternal state is then required for assistance within hospital centers. This also allows potential sources of misunderstandings to be immediately detected.

Robustness to errors: Errors will occur in human-robot teamwork just as they do in human-¬human teamwork. This is particularly true when the environment is noisy and the user is unskilled. Successful human-robot cooperation must then rely upon a robust interface.

Hygiene: Hospital swarm robots must satisfy precise hygiene instructions to avoid transmission of infections. Particular attention should be paid to the interface devices, as they are the part of the robot in direct contact with users.

Accessibility: The interface should be accessible to every potential user. In a hospital, this problem is particularly felt since different levels of patient disability can be encountered. The interface should be developed taking into consideration the different degrees of perception and mobility for the patients.

Cost: The development of a new interface should also consider cost issues, which include not only purchase costs – that in some cases can be very significant - but also maintenance needs.

Availability on the market: Availability on the market should be considered since a commonly used device allows for easy and fast purchase, and its maintenance will be simple as necessary skills and spare parts are readily available.

3.2 Interface Evaluation

Evaluation methodology

The problem of selecting the most suitable interface for the swarm robots can be classified as a Multi Attribute Decision Making (MADM) problem, i.e. a problem that involves ranking or evaluating a finite number of alternatives with multiple, often conflicting, attributes.

A powerful methodology to solve this category of decision-making problems is represented by the use of a decision matrix. The latter consists of an array that presents on one axis a list of n alternatives, also called options or solutions, and, on the other axis, a list of m criteria to be weighted dependently on their respective significance for the final decision [8, 9].

In this case, the alternatives are represented by the available interface technologies, evaluated by considering as criteria the interface requirements described above. In order to build the decision matrix, it is fundamental to analyse how each of the existing technologies meets those requirements.

Evaluation of the existing interface technologies

The evaluation of the existing interface technologies with reference to the selected requirements has been carried out on the basis of the expertise of 10 users and 5 developers of interface systems. The following paragraphs summarise the main issues of the analysis.

Graphical User Interface: Transparency and understandability are the major advantages of a GUI, since the shape of the information is always formulated exactly for the robot. Hence, there are no understanding problems and an effective final task achievement, as the error rate is very low. However, if the easy understanding of commands positively influences efficiency by reducing the operator's effort, the interaction process can require a number of actions. Transparency of the robot's internal state is also determinant to improve robustness to errors, as the they are clearly apparent to the user and can be easily identified. The use of graphical icons and visual indicators can enhance the ease of use in giving commands to the robot. Problems regarding the hygiene requirements can be encountered because input is introduced via keyboard or mouse, which are difficult to keep perfectly clean. Accessibility is not allowed for all kinds of patients, in particular for those who have impairments. Moreover, people who are not familiar with ICT (Information and Communication Technology) could require a long time to accept this interface. Finally, availability on the market and cost aspects can be positively evaluated because this technology is very common and doesn't require a large financial effort.

Touch User Interface: A TUI presents characteristics that are very similar to those of a GUI. It offers both effectiveness and efficiency, because the data input path is simple and leaves no space for misunderstandings. As in the GUI technology, this is one of the factors that support the successful achievement of the final result, and guarantee robustness to errors and transparency. Ease of use and acceptability are enhanced since a TUI just requires the touch of the screen icons related to the various functions, which is more intuitive for common users if compared to the use of keypad and mouse. Moreover, using touch screen as combined input/output device is a solution that provides a more hygienic interface than a traditional GUI where input occurs via keyboard or mouse. Touch screens can be easily cleaned at regular intervals to ensure that hygienic requirements are fulfilled. The main disadvantage of this kind of interface concerns its accessibility: patients with disabilities could not be able to interact with the robot as the process requires getting to the touch screen. Availability on the market and cost do not represent problems because this technology is commonly used and doesn't require a large investment.

Voice User Interface: High efficiency and ease of use are assured by a VUI, because language is certainly the simplest and fastest form to provide commands. The possibility to keep hands and eyes free while inputting data or commands allows an easy operation even for people who have vision or limbs limitations, and promotes accessibility. Transparency and understandability are not always ensured as recognition problems are common in spoken communication. This issue also affects effectiveness and robustness to errors, particularly in a noisy environment, where speech interaction is negatively influenced [1]. Hygiene is guaranteed since interaction takes place without any physical contact with the robot. Availability on the market and cost are not the same of a GUI or a TUI, but this technology is still under development and it is becoming progressively more common and cheap.

Gaze-Based Interface: HRI based on gaze seems the most innovative and complex technology. It imposes several strict conditions to the environment to allow the interaction process. User's visual attention is absolutely necessary to carry out interaction, but the hospital chaotic atmosphere, noisy corridors and patients' rooms may not guarantee this fundamental requisite and the robot understanding of data input provided through eyes movements. In this case, gaze-based interface may not be very effective and robust to errors. Ease of use is not ensured because every user should know the right movements and position to perform for giving commands to the robot. This limit also reflects on transparency and understandability: not all patients could interact with the robot, this function should be rather performed by an expert. Nevertheless, the use of this technology would ensure high hygiene and accessibility. Finally, availability on the market is limited and cost is high since this technology is still under development.

Multimodal: A multimodal interface combines the characteristics of different interaction modalities. To date, the most common multimodal interfaces available on the market are basically composed of a visual interface (like a GUI or TUI) combined with a voice interface. In this configuration, effectiveness, robustness to errors and transparency are enhanced because each single technology positively contributes to the achievement of these requirements. Efficiency and ease of use are assured because the user can choose between different input/output modalities (e.g. a word that may be quite difficult to type, could be easier to say). In addition, multimodal interfaces offer broad accessibility: a well-designed multimodal application can be used by people with a wide variety of impairments. Visually impaired users can rely on the voice modality with some keypad input. Hearing impaired users can rely on the visual modality with some speech input. Hygiene is preserved since the voice modality can be used when there is risk of infections by contact. The cost of a multimodal interface can vary a lot depending on the combined technologies and is usually higher than for single interfaces.

Decision matrix construction

Through the previous analysis, scores (called performance ratings, x_{ij}) were assigned to the different available technologies according to how well they fulfil each of the identified requirements. Moreover, a weight was attached to each requirement to set its relative priority (the sum of the weights is equal to 1).

Two processes are usually required to obtain the overall preference value for each alternative: normalization and aggregation [10]. Normalization is first used to transform performance ratings to a compatible unit scale. Aggregation is then used to combine normalized performance ratings and attribute weights to obtain the overall preference value for each alternative. On this basis, the overall ranking of alternatives is achieved.

The selection of the most appropriate normalization and aggregation techniques depends on the specific problem to deal with. Research studies suggest that in decision problems where the attributes measurement units have different ranges and there are a small number of alternatives to be ranked, the Simple Additive Weight (SAW) aggregation method coupled with the Linear Scale Transformation Max Method for values normalization are particularly suitable [10].

The Linear Scale Transformation Max Method performs normalization by dividing the performance ratings of each attribute by the maximum performance rating among alternatives for that attribute.

For benefit attributes, like in this case, the normalized value r_{ij} , for each performance rating x_{ij} is obtained by:

$$r_{ij} = \frac{x_{ij}}{x_i^{max}} \qquad (1)$$

Where x_i^{max} is the maximum performance rating among alternatives for attribute i = 1, 2, …, m. Through this method, ratings are transformed in a linear way.

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To aggregate the data, the SAW method, also known as the weighted sum method, is probably the best known and most widely used MADM technique. The basic logic of the SAW method is to obtain a weighted sum of the performance ratings of each alternative over all attributes. The overall preference value of each alternative is obtained by:

$$V_j = \sum_{i=1}^{m} w_i r_{ij} \qquad j = 1,2,\ldots,n \quad (2)$$

where V_j is the value function of alternative j , w_i is the weight of requirement i, and rij is the normalized performance rating. This means that weighted ratings have been obtained by multiplying each option's normalized rating by the corresponding weight and summed to achieve an overall preference value for each alternative.

The resulting decision matrix is shown in Table 1 where, under each alternative, two columns are reported: the first for normalized performance ratings (r_{ij}) and the second for weighted ratings ($w_i r_{ij}$).

The option with the highest overall preference value has been emphasized in bold since it represents the solution suggested by the matrix.

4 INTERFACE DESIGN

4.1 Interface Selection

According to the decision matrix, a multimodal interface appears to be the most suitable HRI for the hospital swarm robots. The high overall preference value achieved by this type of HRI is based on the fact that, particularly if combining visual and voice technologies, it

Table 1:
Decision Matrix for HRI Technology Alternatives.

Requirements	Weight	GUI		TUI		Gaze		VUI		Multimodal	
		rij	Wi rij	rij	Wi rij	rij	Wi rij	rij	Wi rij	rij	Wi rij
Effectiveness	0.14	1.00	0.14	1.00	0.14	0.56	0.08	0.67	0.10	1.00	0.14
Robustness	0.14	0.90	0.13	0.90	0.13	0.30	0.04	0.60	0.09	1.00	0.14
Ease of use	0.14	0.75	0.11	0.87	0.12	0.50	0.07	1.00	0.14	1.00	0.14
Accessibility	0.14	0.56	0.08	0.56	0.08	0.56	0.08	0.89	0.13	1.00	0.14
Hygiene	0.14	0.40	0.06	0.60	0.09	1.00	0.14	1.00	0.14	0.80	0.11
Efficiency	0.10	0.75	0.07	0.87	0.08	0.62	0.06	1.00	0.10	1.00	0.10
Transparency & Understandability	0.10	1.00	0.10	1.00	0.10	0.22	0.02	0.78	0.07	0.89	0.08
Availability on the market	0.05	1.00	0.05	0.90	0.04	0.20	0.01	0.70	0.03	0.60	0.03
Cost	0.05	1.00	0.05	0.90	0.04	0.30	0.01	0.60	0.03	0.45	0.02
OVERALL PREFERENCE VALUE		-	0.79	-	0.82	-	0.51	-	0.83	-	0.90

is potentially very robust, effective and efficient, and can be employed by all user groups. Going into further details, some considerations about the specific multimodal HRI for the swarm robots are reported below.

As regards the visual modality, a TUI is preferable to a simple GUI since touch screens as input/output devices provide a more hygienic and intuitive interface compared to keyboard and mouse. A suitable size of user interface elements, proper contrasts, legible texts, suitable colour coding, and non-reflective displays are essential. Controls and displays should be large enough to allow interaction even in case of low coordination, and should have easily recognisable icons. The interaction surface should be wide enough to allow easy viewing even when the user needs a digital keyboard to input any additional data. Symbols on the keyboard should be of suitable size for an easy introduction of data using fingers, in order to perform operations faster. This implies that the touch screen located on robots should be mounted on a Laptop rather than on a PDA, as the first one is easier to use even by inexpert users such as patients or visitors.

As regards the voice modality, a VUI including a microphone to instruct the robot via speech could be used. Sound emission from the robot would be helpful to report any danger, alarm or warning, while further information could be provided by a speaker system.

Sounds should be used to a limited extent to avoid alarming people, especially patients, if not necessary. Acoustic feedback should be used in specific cases, such as the announcement of a robots arrival or an emergency.

Once identified the type of interface technology to implement on the swarm robots, the design process can proceed by defining how the software interface should be configured.

4.2 Interface Software Configuration

With the aim to configure the best interface software, it is helpful to define the so-called interaction patterns for the specific hospital application, as they represent useful tools to translate requirements into explicit software solutions. Interaction patterns are generally defined as artefacts which explicitly represent the recurring communication or interaction: they can be physical or abstract instruments such as devices, processes or configurations having the purpose to allow communication and fundamental to perform it [11].

In user interfaces design, interaction patterns focus on solutions to problems encountered by end-users when interacting with a system, with the aim to improve usability. Therefore, as a basis for the development of the interface module for the hospital swarm robots, investigation have been carried out to identify the possible interactions and interaction patterns between humans and robots [12].

Identification of patterns can be realised starting from investigation and social interaction with the potential user community, as a powerful source of information on current activities and problems that need to be solved.

Feedback results must then be classified and organised by fitting them into interaction patterns. During this process, all the scenarios are described in logical steps and the following interaction pattern elements are identified [11]:

- Problem: Problems are related to the usage of the system: they represent the issues relevant to the user or any other stakeholder who is interested in usability.
- Usability Principle: Interaction patterns usually employ a ‚principle' on which the solutions are based. Usability principles can be grouped according to user problem categories as: Visibility for user guidance, grouping, and incremental revealing; Affordance for metaphors; Natural Mapping for compatibility; Constraints for minimizing actions and self-explanation; Conceptual Models for compatibility and adaptability; Feedback for immediate feedback and transparency; Safety for error prevention and correction; Flexibility for explicit control.
- Context: The context is focused on the user and describes the framework of the interaction in terms of user, tasks and environment.
- Solution: The solution consists of the description of the system's structure and behaviour, and must be clearly described without introducing new problems.
- Rationale: The rationale provides a description of how the pattern works, and its benefits. It illustrates the deep structure and key mechanisms that lie under the surface of the system, and includes an argumentation for the impact on usability.

The identification of these elements helps in generating a description of the interaction patterns, thus representing an effective starting point for decision making on the development of the software interaction module.

Hence efforts have been made to logically decompose the hospital scenarios into detailed steps; i.e. goad directed task analysis [13] and identify the interaction patterns required for fulfilling the tasks [11].

4.3 Application Test Case

One of the main activities of the hospital swarm robots (the prototype is shown in Figure 1-2) concerns the delivery of medicines from the pharmacy department to a nurse in a particular ward. This has been chosen as application test case scenario to show how the interface module can be designed.

In order to clearly analyze the activities that need to be performed, and identify the interaction patterns, this scenario has been divided in the following different tasks, each consisting of a number of points:

1. Nurse makes a request for medicines to pharmacy department;

2. Pharmacist receives the request, and prepares the packet;

3. Pharmacist calls for delivery robot;

4. Swarm system identifies delivery robot and redirects it to pharmacy department;

5. Delivery robot notifies pharmacist of its arrival;

6. Pharmacist identifies himself to the robot;

7. Pharmacist places medicines in the delivery box and instructs the robot on the delivery task, using an order number; robot extracts other information from the central system on the final destination of delivery;

8. Robot navigates to the destination ward, notifies of its arrival and uses the order number to give information on delivery;

9. Nurse identifies herself to the robot;

10. Delivery box opens, nurse takes the medicines, and closes the delivery box;

11. Robot senses the box closure and returns to its base.

In this paper, the first phase of the medicines delivery robot swarm mission, comprising the first five tasks (from nurses' request for medicines to robot arrival at pharmacist's), is analysed in details in order to identify the relevant interaction pattern elements and show how the multimodal interface could be configured.

Task 1: Nurse makes an initial request for medicines to Pharmacy department

Figure 1:
Robot prototype.

Figure 2:
iWARD Robot Swarm.

Figure 3:
GUI/TUI for order selection: only one option can be selected from a list of available actions.

Figure 4:
GUI/TUI for order details entering: the fields are labelled and do not allow incorrect data input.

The following interaction pattern elements can be specified:

Problem: The nurse needs some medicines for a patient: thus, she has to send a request to the pharmacy department through a proper interface.

Usability Principle: Natural mapping is considered to create a clear relationship between what the user wants to do and the procedure for doing it. Constraints reduce the number of ways to perform the task and the amount of knowledge necessary to do it, Visibility guides the user during the procedure. Flexibility allows the user to change his mind and modify input parameters. Feedback provides for immediate awareness and transparency, Safety for error prevention and correction.

Context: The nurse has to order some medicines to the pharmacy department by using a proper interface: the application should allow her to know the available functionalities at any point during use. Using the GUI/TUI, she should be able to select the "order delivery" option from a list of available ones, and to enter the order details in terms of medicines, related quantities and ward number for delivery destination. During this interaction, functions that have undesired effects or require in vain the use of shared resources could be accidentally activated.

Solutions: Within GUI/TUI interface, the nurse should be allowed to select a single option at a time from a list of available actions. A menu must show all the functions that are accessible in the current context and make them reachable in one action. While entering the medicine details, it is essential to avoid incorrect data: fields for each data element of the structure should be labelled and well recognisable, and the nurse should select the appropriate data from a list of items to assure the correct syntax. Then, the input order should be verified to prevent errors. Thus, the interface should require reconfirming the desired order to avoid wrong and unnecessary actions. Moreover, the user must be given the possibility to change the order details by going back to the previous screen shot. At the end, the application should provide a feedback to confirm order acceptance.

Rationale: User guidance, realised by providing a list of data to select from or sample data, reduces errors and increases interaction performance. Providing a fixed layout for similar input fields helps in having a consistent interaction with the system, thus increasing interaction speed. Adding a shield or warning reduces errors and increases safety and effectiveness, since two repetitive mistakes instead of one become necessary to activate a wrong function. However, the shield additional layer requires further user actions and longer procedure time.

Interaction patterns: The identified interaction patterns for this task are list options or contextual menus (for constraints), unambiguous format (for user guidance), shield (for safety and flexibility), and feedback patterns (for transparency).

GUI/TUI based configuration for this task is shown in the form of screen shots for the nurse in figures 3-6.

Task 2: Pharmacist receives the request and prepares the order

The following interaction pattern elements can be recognized:

Problem: As the nurse confirms the delivery order, the pharmacist should be notified of the new order. Then, he accepts it or modifies it on the basis of his inventory, and places it in the order queue.

Usability Principle: Natural mapping is needed to link the objective of the user and the action required to achieve it. Constraints reduce the number of ways to perform the task by guiding the user. Flexibility allows the user to modify some order parameters.

Context: The pharmacist needs to be notified of the new order. Then, he can decide whether to accept the received order or modify it on the basis of medicines inventory. To do this, he should be able to check the order details and suggest possible alterations. After pharmacist's acceptance, a message must be sent to the requesting nurse to notify that the order has been successfully placed or modified.

Solutions: The user should be provided with a suitable GUI/TUI allowing to visualize the order details by selection of the corresponding option: then, he must be given the possibility to select only one of these two actions: change the order details, by suggesting proper alterations, or accept the order as is, with few actions. At the end, by choosing to forward the order, an appropriate message must be communicated to the requesting nurse.

Rationale: The options list gives the user an immediate overview of all possible actions, increasing performance speed and reducing errors. By selecting the "proceed" button, a pharmacy order feedback is generated toward the nurse, improving awareness and transparency.

Interaction patterns: Interaction patterns that can be used for this task are list options, command area for entering commands/actions, shield and feedback.

GUI/TUI based interaction for this task is shown in figures 7-8.

Task 3: Pharmacist requests for delivery robot

The following interaction pattern elements can be listed:

Problem: The pharmacist needs to call a delivery robot by either directly interacting with it or asking another robot to call it. A suitable mode must be provided to make the call.

Usability Principle: Natural mapping is important to create a clear relationship between what the user wants to do and the procedure for doing it. Constraints reduce the number of ways to perform a task and the amount of knowledge necessary to do it, making it easier to figure out how to operate. Feedback allows for immediate awareness and transparency, and Safety for error prevention and correction.

Context: The pharmacist needs to call a delivery robot to come to the pharmacy department: the application typically contains many functionalities and the user needs to know them at any point during use. Using the GUI/TUI, he should be able to select the delivery option from a list of available ones, while for voice based interaction he should give commands consisting of vocabulary that the robot understands. During this interaction, functions that have undesired effects or require in vain the use of shared resources could be accidentally activated.

Solutions: Within GUI/TUI based interaction, the pharmacist should be allowed to select a single option at a time from a list of available ones. A menu must show all the functions that are accessible in the current context and make them reachable in one action. Then, the selected option should be verified to prevent errors. For voice based interaction, the pharmacist should be allowed to give voice commands to the robot, with a fixed set of vocabulary that the robot understands. Open ended or ambiguous prompts that could rouse a very large number of responses should be avoided, preferring prompts that explicitly or implicitly provide the user with a list of options. As it is quite common for a speech recognition system to misunderstand a com-

Figure 5:
GUI/TUI for action taken in ordering medicines: flexibility is provided by the possibility to modify the order details.

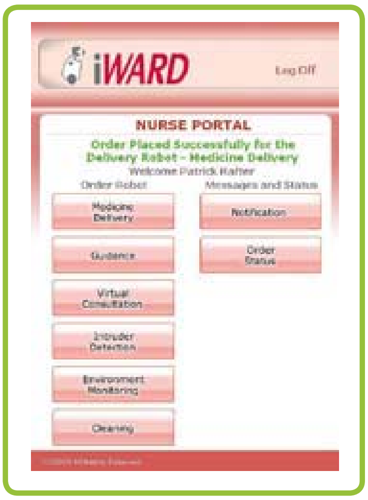


Figure 6:
GUI/TUI for feedback: user is informed that the entered request has been accepted.

Figure 7: GUI/TUI for selection of orders to be processed: only one option (order) can be selected at a time.

Figure 8: GUI/TUI for action selection: user can choose to check the availability, accept or modify the order before proceeding, i.e. ordering the delivery robot.

Figure 9: GUI/TUI screen shot for action confirmation.

mand, it is important to confirm what was recognized. Thus, the robot should ask the pharmacist to reconfirm the required action, in order to avoid errors, and then it should provide a feedback to confirm the request acceptance. In VUI as in UI, the user is warned before proceeding with the task and is given the chance to abort it: adding such a shield as an extra protection layer to the function prevents the user from making mistakes.

Rationale: The menu of functions gives the user an immediate overview of all the available functionalities. Adding a shield or warning in GUI/TUI and feedback confirmation in VUI contributes to reduce errors and increases safety and effectiveness, since wrong functions need to be confirmed twice before being activated. However, the extra layer requires additional user actions and longer performance time.

Figure 10: GUI/TUI screen shot for robots current state.

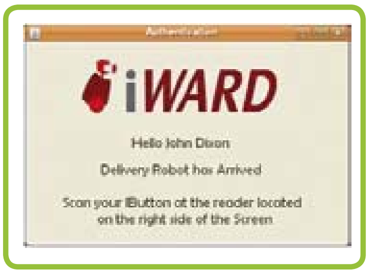


Figure 11: GUI/TUI screen shot for robot arrival notification and user authentication.

Interaction patterns: For GUI/TUI based interaction, list options or contextual menus, shield and/or warning could be used, whereas for VUI, useful interaction patterns are commands and feedbacks.

Using the selected interaction patterns, a GUI/TUI based interface for this task can be configured as shown in figures 8-9 in the form of interface screen shots.

The VUI based interface can be configured to support a speech interaction with the following dialogue:

Pharmacist: “Call a delivery robot”.

Robot: “Do you want to call a delivery robot? Respond by saying YES or NO”.

Pharmacist: “YES”.

Robot: “Request accepted and now calling a delivery robot”.

Task 4: Swarm system identifies delivery robot and redirects it to pharmacy department

This task deals with intra swarm communication; therefore, it is based on machine-machine message protocol. Since human users are not involved, analysing this task is not useful in order to identify the interaction patterns of the HRI.

Task 5: Delivery robot notifies pharmacist of its arrival

The following interaction pattern elements can be listed:

Problem: When the delivery robot arrives at the pharmacy department, the pharmacist needs to be informed of its arrival.

Usability Principle: Feedback is required to provide user awareness through visibility and auditory notification.

Context: The pharmacist should be notified as soon as possible of delivery robot’s arrival, so that he can address the robot at once. Announcement should be made in both GUI/TUI and VUI modes in order to easily capture pharmacist attention.

Solution: In GUI/TUI mode, the pharmacist should be notified through a flashing message on the screen, while in VUI mode he could be alerted through sound. In both cases, the next action to be performed should be suggested by the robot.

Rationale: The message/feedback alerts the pharmacist about the robot’s arrival, increasing user awareness and performance speed.

Interaction patterns: For GUI/TUI based interaction, Warning/Message and Hint patterns (suggesting the next action to perform) can be used to improve user awareness and operation transparency, while for voice based interaction sound notification at regular intervals could be effective.

GUI/TUI based interaction for this task is shown in the screen shot of figure 10-11.

Voice based interaction could be realised by notifying pharmacist of robots arrival:

System/Robot: "Delivery robot has arrived"

System/Robot: "Please authenticate yourself before fulfilling the delivery request".

UI for voice based interaction for all the tasks (1-5) mentioned above is shown in the figure 12.

Figure 12:

UI for SIP phone VUI on PDA.

5 CONCLUSIONS

The problem of designing the most suitable HRI to be developed with reference to a robot swarm for hospital care tasks is studied. The currently available interface technologies are illustrated and analysed on the basis of the requirements related to the hospital environment and the particular users. A multimodal solution is proposed as most appropriate interface and implemented with special focus on medicine delivery applications.

6 ACKNOWLEDGEMENTS

This work was carried out with support from the iWARD research project, funded by the European Commission within the 6th Framework Programme. Thanks are extended to all partners of the iWARD consortium.

7 REFERENCES

[1] Fai, Y. C., Amin, S. H. M., Fisal, N., Su, E.L.M., 2005, Development and Evaluation of Various Modes of Human Robot Interface for Mobile Robot, Int. Conf. on Mechatronics Technology - ICMT2005, Kuala Lumpur, 6-8 Dec.

[2] Suomela, J., Saarinen, J., Halme, A., Harmo, P., 2004, Online interactive building of presence. Field and Service Robotics: Recent Advances in Research and Applications, Springer-Verlag.

[3] Yoshizaki, M., Kuno, Y., Nakamura, A., 2002, Mutual Assistance between Speech and Vision for Human-Robot Interface, IEEE/RSJ Int. Conf. on Intelligent Robots and Systems, Lausanne, Switzerland, 30 Sept. - 5 Oct., Vol. 2: 1308–1313.

[4] Heerink, M., Kröse, B. J. A., Wielinga, B.J., Evers, V., 2006, Human-Robot User Studies in Eldercare: Lessons Learned.

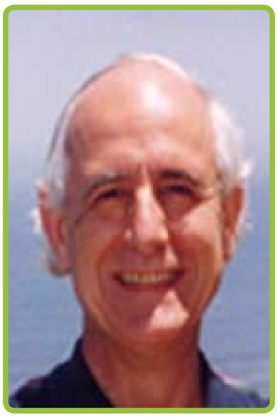
[5] Häbe, D., Beinhauer W., Badiyani S., 2007, iWARD Tech. Rept. on existing/developed technologies for HMI and MMI technologies and protocols.

[6] Vitense, H. S., Jacko, J. A., Emery, V. K., 2002, Multimodal Feedback: Establishing a Performance Baseline for Improved Access by Individuals with Visual Impairments, 5th ACM Conf. on Assistive Technology - ASSETS '02, Edinburgh, 10-12 July: 49-56.

[7] Adams, J. A., 2002, Critical Considerations for HRI Development, AAAI Fall Symp. on Human-Robot Interaction, Cape Cod, MA, Nov.: 1-8.

[8] Berry, A. C., 2006, Development of a Multimodal HRI, 28th Annual University-Wide Research Symp., Tennessee State University, 3-6 Apr.

[9] Tague, N. R., 2004, The Quality Toolbox, Second Edition, ASQ Quality Press.



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[10] Chakraborty, S., Yeh, C. H., 2007, A Simulation Based Comparative Study of Normalization Procedures in Multi-attribute Decision Making, 6th WSEAS Int. Conf. on Artificial Intelligence, Knowledge Engineering and Data Bases, Corfu Island, Greece, 16-19 Feb.: 102–109.

[11] Welie M. and Traetteberg H., 2000, Interaction Patterns in User Interface, The Proc. of 7th Pattern Languages of Program Conference, Allerton Park Monticello, Illinois, USA, 13-16 Aug.

[12] Badiyani, S., Raja, V., Häbe, D., 2007, Documentation/Report on Specifications of Interaction and Interaction Patterns to be used in iWARD Robots.

[13] Adams J. A., 2005, Human-Robot Interaction Design: Understanding User Needs and Requirements, Proc of the 2005 Human Factors and Ergonomics Society 49th Annual Meeting, Florida, USA, 26-30 Sep.

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