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A Taxonomy for User-Healthcare Robot Interaction

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Abstract— **This paper evaluates existing taxonomies aimed at characterizing the interaction between robots and their users and modifies them for health care applications. The modifications are based on existing robot technologies and user acceptance of robotics. Characterization of the user, or in this case the patient, is a primary focus of the paper, as they present a unique new role as robot users. While therapeutic and monitoring-related applications for robots are still relatively uncommon, we believe they will begin to grow and thus it is important that the spurring relationship between robot and patient is well understood.**

I. Introduction

As the baby-boomer generation in the United States reaches seniority, the demand for both personal- and health care will begin to outpace its supply. At the 2009 TEDMED conference, Colin Angle, CEO of iRobot, mentions that, today, for every person over age 65, there are four people under age 65 capable of caring for that person. By 2030 the ratio of elderly to care givers will become one to one [1]. He predicts that robotics will likely become more prominent in personal health care as a result. As the robotics and health care industries begin to intermingle, unique social and economic obstacles will likely arise in the face of user acceptance of personal health care robots. In order to ensure that robots are introduced into personal health care successfully, it is important to consider the potential users' needs, expectations, and perceptions of robotics. This paper evaluates existing robot taxonomies, but focuses on the unique user-robot interactions between patient and robot. This taxonomy is intended to be a prescriptive tool for robot designers with a well-defined target user.

II. User

In this study, the user is defined as any person who will interact with a functioning robot in any degree and has specific needs and expectations that must be fulfilled.

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A. Primary and Secondary Users

Primary users are defined as those affected directly by the robot with which they interact, generally in a beneficial manner. In other words, a robot's functionality should be tailored to the needs and expectations of its primary user, as this is the user the robot is intended to serve. Secondary users interact with the robot to control, maintain, and supervise it. These users do not necessarily benefit from the robot's functionality, but are vital to its operation, granted the primary user is unable to carry out these additional responsibilities.

B. User Roles

Different users can interact with a robot in different ways, thus inherently assuming a specific role. Additionally, one user can assume a multitude of roles, depending on the robot in question. Drawing from possible roles proposed by Grabowski et al. [2], they can be categorized as a peer, supervisor, commander, or operator. We exclude the "observer" role proposed by Grabowski et al., however, due to its redundancy.

A *peer* interacts with a robot either actively or passively, but does not directly control the robot [2]. Active interaction implies that the user is aware of the robot and willingly decides to interact with it. Passive interaction implies that the robot receives information from the user without the user's conscious input. This role is often associated with a primary user because a peer interacts with a robot in order to receive information, assistance, or entertainment. Thus, a peer is generally, but not necessarily, a beneficiary of the service the robot provides. Any commands presented to the robot by a peer are executed by the robot in a manner it finds to be most appropriate based on its programming or the input of a secondary user assuming the role of commander or operator – the peer does not take part in task execution.

A *commander* programs a robot with specific tasks, functions, and/or objectives [2]. The instructions given to the robot can be very simple, allowing the robot to achieve the objective by its own means (i.e. make decisions based on environmental stimuli), or a highly detailed sequence of actions the robot will perform, potentially in repetition. This type of role is common in manufacturing, for example, where robots are programmed to perform repetitive tasks without any additional human intervention (apart from supervision).

An *operator* essentially acts as surrogate intelligence for a robot [2]. The operator decides what actions the robot performs and instructs it to do so in real-time. This process is most often performed remotely, and is hence called tele-operation. A tele-operated robot requires much attention and a user-interface that provides sufficient sensory information and control to the user.

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A *supervisor* is responsible for monitoring a robot's performance and providing direction only when necessary, i.e. in the event of malfunction, emergency, etc. [2]. A supervisor can be said to assume the role of operator when intervention is required. Robots that require supervisory control tend to exhibit a high capacity for decision making and require a relatively small amount of human intervention. See Table 1 for examples of these roles.

TABLE I. EXAMPLES OF USER ROLES

User Role	Example
Peer	Primary user of HealthSense's eNeighbor monitoring system (user is monitored by means of several sensors collecting information).
Commander	Secondary user of HealthSense's eNeighbor robotic monitoring system (personnel on staff ready to react to emergencies – do not interfere otherwise).
Operator	Primary user of the VGo Communication's mobile tele-present communication robot. The user directly controls the robot's movement in real time.
Supervisor	Secondary user of the iRobot's Roomba (programmer of the robot's vacuum sequence – the commander inputs a series of code on which the decision-making process is based).

C. Freedom of Interaction

Salter et al. [3] state that in order to interact with a robot and benefit from its functionality, some freedom of interaction is inherently compromised. Additionally, operating instructions, particularly when there is a specific objective to be achieved, compromise this freedom further because in this case the user is limited to interacting with the robot in such a way as to achieve the objective. As mentioned previously, this limited freedom is inherent and would not greatly hinder the acceptance of the robot. There is another factor that may limit the autonomy of the user, namely a handicap. A user that is deaf, blind, mute, or physically/mentally handicapped in any other way will experience a limited freedom of interaction with a robot that is not designed to meet their special needs. Therefore, it is important to understand and consider the special needs of intended users when designing a user interface, whichever role the user may assume.

D. User Expectations

In order to be a marketable product, a robot must meet the expectations of the consumer, or in this case the potential primary user. The robot must fall within an acceptable price range, have a desired functionality, and be easy enough to use and maintain (depends upon user preference). Additionally, the amount of privacy a user is willing to compromise should be considered – it must maintain a non-overwhelming presence. These metrics can be determined by studying the intended consumer demographic by means of interviews, surveys, and focus groups as well as studying consumer trends. It is important that the expectations of potential users are well understood by a robot designer because without interested consumers, a robot is useless regardless of its functionality and the service it may provide society.

III. ROBOT

With the dimensions of the user characterized, the focus can now turn to the different types of robots. First, however, the main underlying constraint must be defined. Because the focus is the characterization of robots, we must define the term "robot" itself. Drawing on a definition proposed by [4], the following definition was developed:

A robot is a machine that is capable of obtaining information from its environment by means of sensors and manipulating that information into a form that can be utilized by an actuator – locally or remote. Using this definition, we can begin the characterization process.

Fig. 1 visualizes this definition.

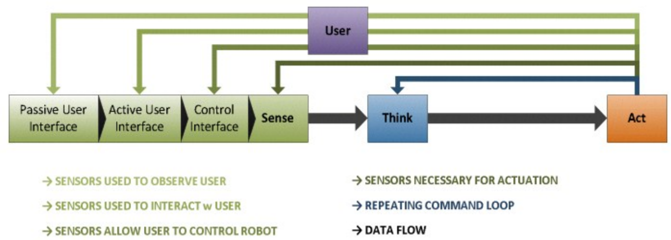

Figure 1. Data flow in a robot.

The first classification criterion to be discussed is the robot's hardware – its sensor(s), processor(s), and actuator(s). Additional dimensions to be discussed include morphology, architecture, and autonomy.

A. Hardware

Unlike Yanco et al., who claim that "it is much more important to consider how the [robotic] system provides decision support in the interface […]" [5] than to consider the input/output devices of a robot as suggested by Agah [6], we believe that is necessary to consider both the input and output devices in our categorization of robotics because a robot's user interface is defined by this hardware.

TABLE II. SENSORS

Sensor Type	Description
Visual	Capable of "seeing" their environment (constituted primarily by cameras - 3D, thermal, infrared, etc.).
Physical	Capable of "feeling" their environment, whether directly or indirectly. Physical stimuli include pressure, motion (acceleration, deceleration, relative direction, relative speed, etc.), position, and temperature.
Auditory	Capable of "hearing" their environment (constituted primarily by microphones).
Chemical	Capable of "tasting" their environment - sampling their environment and detecting the chemical composition of the sample (constituted by biosensors, air samplers, liquid samplers, etc.).

Sensors allow a robot to collect visual, auditory, physical, and/or chemical data. The various types of sensors are broken up according to the type of information they collect in Table II:

Actuators allow a robot to perform different functions. A robot can produce light and image based visual responses, physical mechatronic responses, sound based auditory responses, and/or chemical responses with the appropriate actuator. Actuators are described in more detail in Table III.

TABLE III. ACTUATORS

Sensor Type	Description
Visual	Capable of displaying images or videos, producing light, etc. by means of screens, projectors, lamps, etc. Visual actuators are often vital parts of a machine's user interface.
Physical	Capable of creating motion or giving tactile or haptic feedback, etc. Motion can be used for transport, as part of the user interface, manipulating the environment, etc.
Auditory	Capable of conveying data to the user using sound, mainly by means of speakers. Auditory actuation can range from single tones to synthesized voices.
Chemical	Release chemicals in order to maintain a certain balance, treat a disease in a human or animal, etc.

A robot's *processor* is equivalent to a human's central nervous system and is defined by its computing hardware, software, and internal data communication methods. The computing hardware is what determines any limitations of the software (data manipulation/interpretation): Stronger processing capability allows more sophisticated software to be operated by the robot. A robot's software can be measured relative to the software currently available. Generally, better software implies a more "intuitive" thought process. The more data manipulation that occurs, the more sophisticated the software. In other words, a robot's processor that is able to manipulate and interpret data in higher quantity, complexity, or in less time would be considered as "highly-capable."

B. Morphology

Morphology is an important consideration because people react significantly differently to different appearances [7]: In Japan, anthropomorphic robots are very popular, whereas in the United States, robots generally assume a functional appearance. Morphological preference is heavily influenced by societal perceptions of robots and the roles they play in our lives. Three categories – anthropomorphic (human-like appearance), zoomorphic (animal-like appearance), and functional (appearance related to function) – are sufficient to characterize robot morphology.

C. Architecture

The architecture of a robot characterizes the manner in which its physical components are organized in space, as well as how a robot interacts with other machines in its environment. Robots may be comprised of localized (components contained within the "body" of robot) or delocalized (one or more components dispersed throughout environment) components and may function individually, as part of a system (where it is co-dependent with on its associated robots), or cooperatively (where it works with other robots as part of a team).

A *localized* robot has all of its components contained in one "being". It does not have to rely on external devices or robots to carry out its function (may rely on user). A robot with this architecture can assume any of the previously mentioned morphologies.

A *delocalized* robot has one or more of its hardware components separate from the main unit, if there is one. The components communicate with each other wirelessly. A robot with this architecture can usually only assume a functional morphology.

An *independent* robot that is capable of accomplishing tasks completely on its own, without the assistance of additional robots or devices. It may, however, rely on a human to carry out its task.

A *robot system* (or *swarm*) is composed of multiple simplistic robots (limitations in at least one hardware component) that depend on each other or another device to complete a task. The separate robots compliments each other in terms of their sensing, processing, and/or actuating capability (i.e. some robots may have sophisticated sensors but limited actuation, and other may have sophisticated actuation but limited sensing capability). In other words, robots within a system are co-dependent, meaning they must cooperate to execute a specific task. In some cases, one component may be shared by the separate robots, i.e. all robots of a system upload and download data from a common server.

A *robot team* is composed of at least two localized robots. The robots must be able to operate individually, but in this architecture they cooperate to accomplish a more complex task.

TABLE IV. DEGREES OF AUTONOMY

Degree	User's Role	Description
Autonomous	Peer	No user intervention required.
Combination	Supervisor	Mix of autonomy and human intervention.
Fixed	Commander	Follows preprogrammed command patterns.
Remote-Controlled	Operator	Robot is controlled remotely with operator on the location of task execution.
Wizard-of-Oz	Operator	Robot is controlled remotely with operator away from location of task execution.

D. Autonomy

A robot's autonomy is defined as its ability to make decisions and carry out tasks without human intervention. This metric is similar to Yanco et al.'s category in which autonomy is related to the amount of intervention required – they state that autonomy and intervention are inversely proportional. It is redundant to consider both individually – a low level of autonomy, for example, clearly implies a high level of intervention. Instead, Salter et al.'s [3] metrics for robot autonomy (Autonomous, Combination, Fixed, Remote-Controlled, and Wizard-of-Oz) are adapted for this taxonomy. The categories are described in Table IV. It is important to note that there is overlap between the different degrees of autonomy and that they are generally associated with specific user roles.

IV. User-Robot Interaction

There are numerous ways in which a user can communicate his/her will to a robot, but the user's intentions can be summarized as either controlling or non-controlling.

A. Controlling Interaction

A controlling interaction consists of either causing the robot to engage a certain pre-programmed command sequence or controlling the actuators directly and is most common to robotics today, mainly in manufacturing. There are several ways in which a user may control a robot. To characterize these different methods, Yanco et al.'s space-time taxonomy [7] is adapted. As the name implies, the taxonomy categorizes interaction by the location and time in which the communication occurs relative to task execution. The user can interact with a robot either in real-time or in advance, and either locally or remotely. Real-time interaction can be broken down further into the categories direct control and supervisory control.

The first and most simple method of robot control to be discussed is *real-time direct control*. Here, the user assumes the role of operator and directly controls the robot via its control-interface (a control-interface simply being an extension of the user-interface intended for controlling interactions). The operator communicates the desired functions to the robot and they are carried out immediately. Depending on the robot, it can either perform the exact function requested by the operator or augment the command using software to improve or correct it.

Real-time supervisory control requires a user assuming the role of supervisor to monitor the robot's performance. The supervisor only interacts with the robot, which in this case is capable of functioning nearly completely on its own, in the event of a malfunction or mistake. When the supervisor does interact and commands the robot to perform a certain function, the robot reacts immediately in order to correct any issues.

In *pre-programmed control*, a commander inputs a series of commands into the robot via its control interface before task execution. The robot will execute these commands, often repetitively, at a later time. At the time of task execution, supervisory control is often engaged.

B. Non-controlling Interaction

The way in which a user interacts with a robot depends on the robot's application, sensors, and actuators as well as any disabilities the user may have. A user can interact with a robot by speech, hand gestures, facial expressions, and tactile input (i.e. pressing a button, flipping a switch, etc.) among others. Conversely, a robot can communicate with its user in equally as many ways: A robot can alert the user with lights and/or noise, synthesize speech and even appearance, provide haptic feedback, or physically interact with the user. This is beneficial because the variety of possible interactions allows robot designers to cater to any special needs their intended users may have. For example, a robot may be capable of recognizing and understanding human speech in order to communicate successfully with a blind user. Direct interaction such as this can be termed *active interaction*, meaning the user is aware and willing to communicate with the robot.

A user may not always be aware that he/she is interacting with a robot, however. Interactions in which a robot is aware of the user's status, but the user is not aware of the interaction, are termed *passive interaction*. Such interactions are uncommon and are associated with very specific types of robots, namely those intended to monitor or survey a user(s), and will become more common as robots become introduced into health care as patient monitoring tools.. These types of robots may also be effective in applications related to security, market research, etc.

V. Conclusion

This taxonomy is intended to be applied in situations where the target users will interact with a robot for the sake of therapy or being monitored for health purposes. Recognizing this unique new user role can help a robot designer understand the users' preferred method and extent of interaction with a robot, which in turn translates into specific user requirements for said robot as far as the dimensions described in Section III are concerned. Future work on this taxonomy should focus on creating a more in-depth characterization process for the user and relate this information to the various dimensions of a robot. Considering the users' (patients') needs is vital in designing personal health care robots because they are strictly serving these users. A personal health care robot that is not accepted by its target users is a failure.

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