Designing interaction: human-machine interface design in medical devices and products

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Abstract

Medical devices and products play a vital role in human life and health. According to several studies, a well-designed human-machine interface (HMI) has the potential to significantly reduce medical accidents, as well as enhance the effectiveness and efficiency of diagnoses. To achieve an optimal medical product design and improve user experience, it is essential that the HMI design incorporates both interface design and human emotion. This article takes into consideration the perspectives of both patients and medical staff to analyze the key factors in human-machine interface design for medical devices and products. These factors encompass safety, effectiveness, and emotion. Additionally, the study delves into how the interactive design between humans and machines strikes a balance between product functionality and the end users' experiences.

Keywords: human-machine interface; medical devices and products; interactive design

1. Introduction

A successful design of medical devices relies on an effective user interface. Medical devices and products often incorporate advanced technology. It is crucial to have a good user interface design to ensure the safe and efficient operation, installation, and maintenance of medical equipment (Sawyer et al. 1996). The quality of human-machine interfaces has become a key factor in distinguishing products and attracting users. Moreover, health and safety are paramount in the design of medical devices. A poorly designed interface can be difficult to use and can pose significant dangers as it significantly increases the chances of errors in equipment operation. Thus, it is essential to consider the impact of medical device design on the ability of healthcare professionals to provide safe and effective patient care (Sawyer et al. 1996).

User experience is a vital aspect of human-machine interaction and plays a pivotal role in designing successful interfaces for medical devices (Harutyunyan and Riehle 2019). In theory, most medical product designers today cater to the needs of a global marketplace, emphasizing the customer's or user's perspective (Wiklund and Wilcox 2005). Therefore, based on extensive technical support, the interface design of medical devices and products should be user-friendly and easy to navigate (Norman 2002). Medical devices are utilized in a variety of settings, including operating rooms, emergency rooms, waiting areas, x-ray rooms, labs, emergency vehicles, intensive care facilities, clinics, and homes. These situations present important considerations that impact the performance of medical devices. Under normal circumstances, performance is

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Influenced by environmental factors such as noise, inadequate lighting, surfaces that produce glare, heat, dirt, improper cleaning agents, electrical interference, humidity, and moisture. Other factors that can negatively affect performance include poorly written procedures, stress, and fatigue.

This study aims to explore the key factors involved in the overall human-machine interactive design of medical device interfaces, and how these factors can enhance functionality and the overall user experience.

2. Human-machine interface design

Human-machine interaction (HMI) plays a crucial role in designing medical device interfaces. The term HMI was previously known as ergonomics, dating back to 1857 according to Jastrzebowski. In the 1970s, Murrell rephrased it as "understanding human-system interactions to optimize human well-being and system performance," as stated in Edholm and Murrell's work in 1973. Ergonomics has been described in various ways, including "cognitive ergonomics," "human-computer interaction," and "user experience design," as illustrated by Kitson, Prpa, and Riecke in 2018.

Norman coined the term User-Centered Design in the 1980s, prioritizing users' needs over changing their existing behaviors, as described in Norman and Draper's study in 1986. Moreover, a framework called "Calm Technology" was developed to seamlessly integrate technology with users without constantly demanding their attention, as outlined in Kitson, Prpa, and Riecke's paper in 2018. Boy argues that human-machine interfaces are rationalized based on relevant attributes and categories that arise from using computerized machines. This definition encompasses four key principles: safety, performance, comfort, and aesthetics, which align with the examination of physical, cognitive, social, and emotional factors, according to Boy's research in 2017.

New HMI technology, such as voice recognition and gesture-based technology, has been incorporated into medical devices, as exemplified by Rautaray, Kumar, and Agrawal in 2012. For instance, the Intel Perceptual Computing Group utilizes a 3D camera and computer screen to enable hand gesture control. This interface enhances computers' perceptiveness by integrating natural human responses with machine interactions.

2.1 Human-human interaction and human-machine interaction

Haberland (1999) clearly distinguishes between human-human interaction and human-machine interaction. He argues that human-human interaction can be considered symmetrical through analytical conception, while human-machine interaction cannot. The key difference lies in the types of constraints that shape communication in each scenario. In human-human interaction, societal conditions determine the degrees of freedom allowed, forming the "fabric of society". However, in human-machine interaction, societal conditions are overridden and partially obscured by technical constraints, which are man-made and grounded in practicality.

The excessive focus on these technical constraints has long misled researchers into believing that the main goal is to overcome meaningless and dysfunctional technological limitations in order to make human-machine interaction more natural. Nonetheless, naturalness does not truly exist even in basic face-to-face interactions. Ignoring this fact is a result of believing in the fallacy of naturalness. Cognitive Technology has highlighted the significant impact of the models incorporated in technological tools, which, similar to human minds, shape the mind of the creator. It is crucial, therefore, to identify and understand the other constraints under which these systems operate (Haberland 1999).

2.2. Human-machine interface design in medical devices

The human-machine interface (HMI) serves as the means of conveying patient information for the use of medical devices. The primary focus is on the design of the display and control components to ensure they are reasonable and convenient for operation. The design should also effectively prevent incorrect usage and meet the physiological needs of the human body (Feldman et al. 2008; Hines 2009). Unlike human-machine interaction, HMI refers to the layer that separates a human operator from the machine itself (Kumar 2005). It is categorized as computer hardware, encompassing all physical parts of a computer. Unlike software, which contains data and operates on it, users directly interact with physical hardware.

The traditional human-machine interface of medical devices serves as a conduit for the exchange of input and output information between humans and machines. Its main focus is on the product's functionality. Users can navigate the product interface through various operations, ranging from basic physical interactions with keyboards to more complex cognitive interfaces. An ideal human-machine interface design not only achieves functionality but also enhances the efficiency of end users while creating a joyful and emotionally satisfying experience.

3. HMI and interface design

In the general concept of "human-machine interaction," the term "human" pertains to the person operating a device or product, while the term "machine" encompasses the device or product itself. The objective of HMI is to develop designs that take into account ergonomic considerations, such as user-friendliness, efficiency, and usability. The end users are generally regarded as static, as they have full control over the machine in various scenarios, including programming and design (Hoc 2000). Nevertheless, Hoc (2000) argues that modern machines not only process information but also navigate dynamic situations, which users do not have complete control over and can be influenced by numerous uncertain factors.

When designing medical devices, safety and effectiveness are of utmost importance. According to Sawyer et al. (1996), achieving this requires considering the interaction between the operating environment, user capabilities, stress levels, and device design during the manufacturing process. Research also shows that human factors play a significant role in the design of medical devices. These factors encompass physical and sensory capacities, perceptual and cognitive abilities, as well as expectancies and mental models.

Physical and sensory capacities, including vision, hearing, manual dexterity, strength, and reach, are fundamental to consider in design (Sawyer et al. 1996). Various design factors, such as legibility and discriminability of displayed symbols, audibility and distinctiveness of alarms, strength required for connections, and reachability of controls, can influence human performance (Sawyer et al. 1996).

Perception refers to the ability to detect, identify, and recognize sensory input based on psychological theories. Understanding human limitations and strengths is crucial in ensuring safety in medical device design. Moreover, the arrangement of controls, keypads, displays, information presentation, and alarms during the design process is also vital.

Cognition, on the other hand, involves higher-level mental phenomena such as memory, information processing, use of rules and strategies, hypothesis formation, and problem-solving (Sawyer et al. 1996). Computerized devices often overwhelm users with multiple hierarchical pathways and a vast amount of information, exceeding their memory limits. Therefore, it is important to consider the cognitive abilities of users during the design process.

In designing medical devices, it is essential to take into account people's established habits and conventions. Designs should align with existing conventions in the general population and adhere to standards and conventions within the medical community. For instance, the color red is typically used to signify danger, while the color green typically represents good health. Designs that conflict with people's conventions can lead to errors or mistakes.

In terms of thinking and cognitive processes, individuals tend to develop abstract concepts regarding complex phenomena. These mental models should be taken into consideration when designing. However, some studies suggest that there are two aspects to the "human-machine interaction" in medical devices: an active end user and an uninvolved end user. The active end user includes health care and medical staff, while the uninvolved users are the patients. The medical device or product serves as the machine in this scenario. In this perspective, the patient is not actively involved in the operational process and is treated as an object. However, the design of the medical device still impacts the patient through factors like its external appearance, human-machine interface, and color. The medical staff is responsible for receiving the output and input information of the medical device while maintaining operational control.

3.1 The interface between patients and machines

Most medical devices are utilized by medical professionals who have specific expertise in the field. Although they may not have direct interaction with patients, these devices are employed on the patients' bodies, potentially causing fears related to the machine's interface presentation. These apprehensions may be influenced by factors such as the machine's shape, size, color, material, graphic display, and auditory features. Consequently, there is a need for comprehensive assessment of how end users comprehend the operation of medical monitoring and treatment devices. This matter of understanding is intricate because end users vary in their ability to mentally integrate and conceptualize data that are subject to change over time.

The design of the interface between patients and medical devices should take into account three key aspects: modeling, color, and safety. Given that patients are often in a fragile physical state, it is possible for them to experience apprehension and distress regarding medical devices and facilities. Therefore, incorporating their needs into the design process will aid in mitigating emotional reactions of fear and anxiety.

3.1.1 Modelling

Firstly, patients should feel safe to help alleviate their psychological fear and anxiety. Therefore, the design of the medical device should focus on achieving a "smooth transition," which means integrating the device seamlessly into the user's daily life. The designer accomplishes this by incorporating curved surface features and round chambers to create a smooth and vibrant form. Secondly, the interface design elements should have a symmetrical form achieved through the arrangement of points, lines, and surfaces. The layout of interface elements should be organized with low density to provide patients with a sense of stability and comfort.

3.1.2 Color

In the design of human-machine interfaces for medical devices, color is a key element. The main body color should be neutral, such as white or gray. Bright colors can draw the patient's attention to the product itself, which may increase fear or aversion to the product. Additionally, the color scheme of the interface should be simple and cohesive. The active parts of the interface, common operation keys, and other features should use vibrant colors to enhance the recognition of interface elements, while also providing an aesthetic appeal.

3.1.3 Safety

The interface design of medical devices should be kept simple. There should be no inclusion of unnecessary shapes in the design of medical devices and products. Unstable product design has the potential to cause harm to the patient.

3.2 The interface between medical staff and machine

The design of the human-machine interface for medical equipment requires medical staff to operate with accuracy, efficiency, and comfort. Typically, medical devices include a control panel, which is typically situated at the center of the equipment, where the medical staff can physically be positioned. The machine control panel houses the controller used to operate the medical device. Furthermore, these operation panels typically consist of a control section and a display section. To achieve a seamless user experience, three primary aspects must be addressed when designing medical devices.

3.2.1 The control parts

Many medical devices possess sizable consoles. When multiple controllers are present concurrently, the functional keys on the console must be arranged in accordance with design principles, such as size, interaction, and user-centered design. Currently, significant issues in controlling certain parts of medical devices can perplex individuals, leading to difficulties and operational mistakes. The designer should take into account the users' capability to swiftly and accurately discern controls, switches, and displays; access and precisely adjust controls; accurately read displays; and connect controls with their corresponding displays (Sawyer et al. 1996).

The problems existing in the control keys of medical devices can be solved from three aspects: firstly, the combination of keys ensures that each key controls a specific function. If a key controls more than one function, it may simplify the mechanical operation structure to some extent, but it leads to functional confusion. Additionally, placing important controllers in the most advantageous operating position and setting constraints on where keys and operators are located can be beneficial. However, these constraints are limited to a certain extent. Similar or related functions can also be placed in adjacent locations. The order of the control keys should prioritize usability.

Secondly, the matching problem can be addressed by aligning the keys on the medical device interface with the corresponding contents on the display screen, such as symbols, directions, colors, etc.

Thirdly, the tactile sensation experienced when pressing the keys is important. Keys should be designed to enhance the touch experience and facilitate comfortable and easy operation. Designers should avoid using smooth film switching that makes it impossible for fingernails to completely touch the key and lacks tactile feedback.

Overall, there are three fundamental elements for designing controls in medical devices and products. Lastly, the layout design of control parts significantly impacts the user's ability to successfully perform functions and influences the information collected during device operation.

3.2.2 Display panel

The primary function of the display panel is to present information or convert other data into a format that medical staff can comprehend. The interface design of the display panel encompasses indicator lights, panel color combinations, and panel display components.

(1) Indicator light

The indicator light serves as a carrier for visual signal feedback information, transmitting important information to users. Its purpose is to captivate user attention. For instance, the color of medical monitors should contrast significantly with that of the dashboard, enabling medical staff to effortlessly and precisely read data from the device. The pointer's shape should be succinct and easily readable. The width of the pointer tip should match that of the small-scale mark to enhance data speed and accuracy through this design.

(2) The color configuration of the panel

In the color selection of the display for various controllers and instruments, each color represents a specific meaning. Generally, indicator lights are available in red, yellow, green, blue, or white colors. The choice of these colors should be in harmony with the overall color of the medical devices. These design principles are implemented to achieve visual harmony.

(3) Panel display element

The software interface for medical devices displays graphics, symbols, words, or dynamic pictures using digital display devices. Graphics, text, and symbols act as carriers on the display panel, allowing medical staff to accurately perceive and understand key information. As a result, the display panel emphasizes the visual balance of the interface. Additionally, the background color and display font, along with color contrast, enhance the overall display effect.

(4) Additional issues

There are numerous details to consider in interface design. For instance, it is important to avoid printing grey font on a white background or directly onto white plastic material. This can result in low readability, which in turn affects the backlight. The display interface should utilize a clear and legible font, steering clear of overly intricate or weak options like italics.

3.2.3 Interactivity

Interactivity plays a vital role in human-computer interaction, serving as an integral part of computer systems through the user interface. It encompasses the transfer and exchange of information between humans and computers. The purpose of interactivity is to facilitate the translation of information from its internal form to a format that users can comprehend, all while concealing the underlying intricate technology behind a simple and user-friendly interface. This simplification of human operation ultimately enhances the interaction between humans and machines. Interface design tackles the exchange of information between humans and machines. Since there are numerous definitions, this study defines interactivity as "a form of action that occurs when two or more objects have an impact, sometimes necessitating a distinction between the two" (Preece et al. 1994).

In the past, human-machine interaction design required keyboards and mice. Later, touch-screen technology was used for interface design as a more convenient way of interaction.

Now, voice interaction has emerged as a technology for information acquisition between humans and machines. Machines can recognize simple words or specific sounds and respond accordingly. A voice interactive device can interact with a user through voice. The technology incorporates a voice input unit that records and recognizes voices uttered by an end user (Arriany and Musbah, 2016).

In the design of medical devices, end users can interact with a medical device through body gestures, words, or voice tone. Therefore, this article suggests that voice recognition technology could be explored in medical device interface design. Table 1 presents the key factors in designing an effective medical device. These factors in the design of patient and machine interaction can also be applied by the medical staff and machine.

Table 1. The medical device interface design

Patient and machine	Medical staff and machine
Modelling	Control Part
Color	Display Panel
Safety	Interactivity (Voice Recognition Technology)

In addition, other interactive technologies also possess the potential to enhance interactivity in HMI interface design. Wearable transmitting devices should be explored in medical device interface design. For instance, such technology detects physiological signals like photoplethysmograph (PPG), galvanic skin response (GSR), and skin temperature (SKT) for physiological monitoring. It is crucial in detecting implicit communication cues associated with emotions and affective expressions, enabling affective computing (Hoc 2000).

4. Conclusion

Medical devices and products are crucial, as they greatly impact human life. Good human-machine interface (HMI) design plays a key role in minimizing medical accidents, improving the efficiency and effectiveness of medical devices, and enhancing the user experience for end users. However, HMI design for medical devices entails more than the conventional aspects such as safety, modeling, and color. This article suggests that incorporating interactive technology can facilitate communication between the machine and the end users, including medical staff and patients. Voice recognition technology is an example of such innovative technology that holds promise for future development. This study offers suggestions for further research in medical device interface design.

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