Designing Wearable Personal Assistants for Surgeons:
An Egocentric Approach

A wearable personal assistant prototype based on Google Glass facilitates touchless interaction with x-ray images, allows clinicians to browse electronic patient records (EPRs) while on the move, and supports synchronized ad hoc remote collaboration.

Shahram Jalaliniya and Thomas Pederson
IT University of Copenhagen

Increasingly powerful wearable computers suggest that a tight integration between human and computer is achievable. However, to reach a deep integration that offers timely cognitive support, we need to better understand how humans perceive, think, and act in the world. An ideal wearable intelligent assistant "augments memory, intellect, creativity, communication, and physical senses and abilities."[1] We prefer the term "wearable *personal* assistant" (WPA) to emphasize the tight integration between a single mind, body, and computer.

Human body-and-mind-centric design approaches can complement existing technology-driven efforts (that is, efforts based on available state-of-the-art hardware) in addressing many of the challenges of human-computer systems because, ultimately, the power of these systems depends on the level of integration.[1] Although we can adapt and modify the artificial cognitive architecture (the "computer" system), we cannot change the body and brain of human agents. As system designers, we can only ensure that our WPAs talk to our relatively static biological setup in the way evolution designed it to interpret and act in the world. Our focus here is on human perception, cognition, and action.

How we think we interpret the world around us in everyday life is not how we (our brains) actually do it. In the last few decades, research in cognitive science, perception psychology, and neuropsychology has resulted in some remarkable findings, some of which are still debated:

- About 95 percent of measurable brain activity is unconscious.[2]
- The 5 percent of human conscious cognitive processing (attention) is volatile and easily interrupted by internal unconscious processes or external stimuli.
- Human attention does not multitask.[3]
- By the time external stimuli grasps our attention (if it does), it has already undergone significant filtering and transformation by unconscious processes.[4]
- Human routine actions are often initiated and controlled by unconscious cognitive processes triggered by direct external stimuli, leaving conscious processes out of the loop.

As developers of interactive systems, we should care about these findings, because the

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systems we aim to design are closer to the user's body and mind than classical personal computing devices have ever been. Inspired by these findings, we propose an information flow model that considers the perception, cognition, and action of human agents while (unlike in more classical HCI models) dealing with conscious and unconscious cognition separately. This lets us take a more holistic view of the role of WPAs, making it evident that the explicit interaction between WPAs and users occurs in an information-rich context, in which our brains process much more than we traditionally model as system designers. It also lets us start speculating about functionalities that WPAs could offer that interface directly with the unconscious part of our cognitive processes, something that is undoubtedly still hard to implement in practice, even if successful attempts have indeed been made.[5]

Although this article's main focus is our egocentric approach to the design of WPAs inspired by modern cognitive science, we also discuss our experiences deploying the framework in the hospital domain and our initial WPA prototype for orthopedic surgeons based on the Google Glass platform.

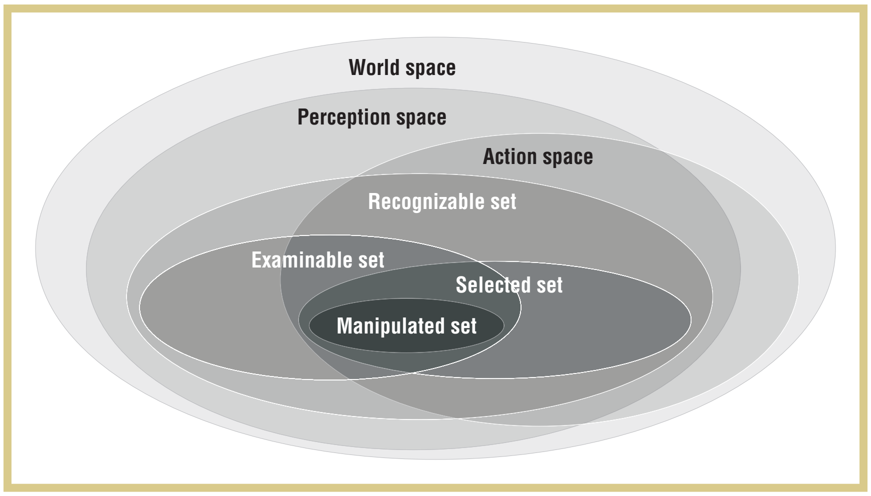


Figure 1. The situative space model (SSM).[9] We developed the SSM to capture what a specific human agent can perceive and not perceive, reach and not reach, at any given moment in time. In particular, the perception space is the space around the agent that can be perceived at each moment. The action space is the space around the agent that is currently accessible to the agent's physical actions.

Egocentric Interaction

Both system designers and users increasingly face a new HCI paradigm that redefines the relationship between the human, computer system, and world: an *egocentric interaction paradigm*.[6] This paradigm extends and modifies the classical user-centered approach in HCI[7] on several points:

- *Situatedness* acknowledges the primacy of the agents' current bodily situation at each point in time in guiding and constraining agents' behavior.
- *Attention to the complete local environment* emphasizes the need to consider the entire environment, not just a single targeted artifact or system.
- The *proximity principle* assumes that proximity plays a fundamental role in determining what can be done, what events signify, and what agents are up to.
- *Changeability* of the environment and of the agents' relationship with the environment takes into account agents' more or less constant body movements, including the head, hands, and sensing organs.
- The *physical-virtual equity principle* pays equal attention to interaction with both virtual (digital) objects (classical HCI) and physical objects (classical ergonomics).

The term "egocentric" signals that it is the body and mind of a specific individual that (literally) acts as the center of reference, so all modeling is anchored to this individual's body and mind in this interaction paradigm. The term is analogously used in psychology and virtual reality to denote the conceptual and spatial frames of reference that humans by necessity rely on when thinking and acting in the world and when collaborating with others.[8]

Action and Perception Instead of Input and Output

In the egocentric interaction paradigm, the modeled individual must be viewed as an agent that can move about in a mixed-reality environment (an environment consisting of both directly accessible everyday "real" entities and virtual/digital objects accessed through mediating digital devices), not as a user performing a dialogue with a computer. Adopting the physical-virtual equity principle, we suggest substituting the concepts of (device) input and output with (human agent) action and perception.

The New "Desktop"

To facilitate the design of egocentric interaction systems such as the WPAs we focus on here, we developed a situative space model (SSM) to capture what a specific human agent can perceive and not perceive, reach and not reach, at any given moment in time (see Figure 1). This model is for the emerging egocentric interaction paradigm what the virtual desktop is for the PC/WIMP (window, icon, menu, pointing device) interaction paradigm: more or less everything of interest to a

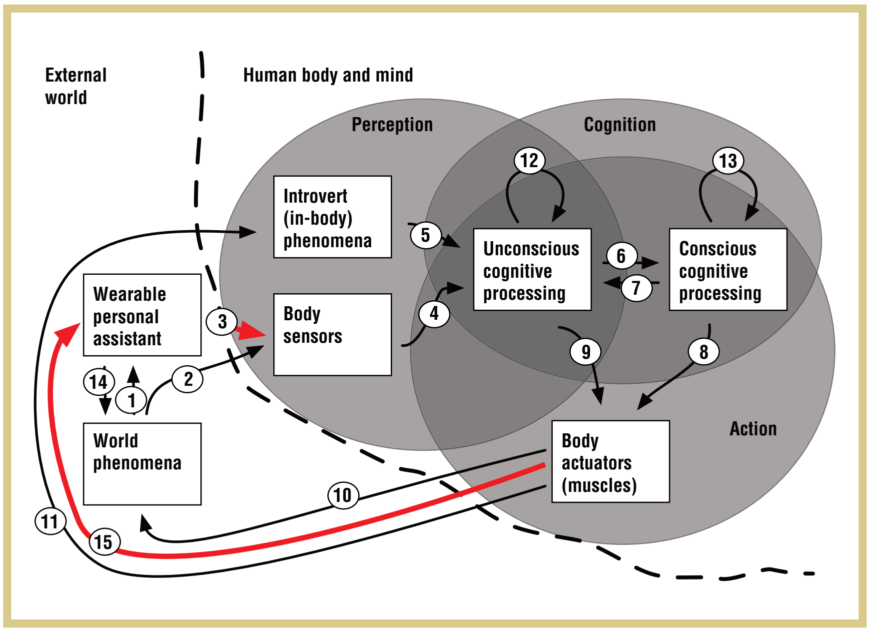


Figure 2. A body-and-mind-centric model of how wearable personal assistants (WPAs) fit into the flow of perception, cognition, and action of human agents. Classical HCI models are typically concerned only with pathway 15-3 (the bold red arrows) and how it relates to conscious cognitive processing. Yet by and large, our perception of the world (pathway 2-4) and our perception of our body state (arrow 5) is beyond our conscious control.

specific human agent is assumed to, and supposed to, happen here. We describe only the perception and action spaces here and point the reader elsewhere for more details.[9]

The *perception space* is the space around the agent that can be perceived at each moment. Like all spaces and sets of the SSM, it is agent-centered, varying continuously with the agent's movements. Different senses have differently shaped perception spaces, with different operating requirements, range, and spatial and directional resolution with regard to the perceived sources of the sense data. Compare vision and hearing, for example.

The *action space* is the space around the agent that is currently accessible to the agent's physical actions. Objects within this space can be directly acted upon. The outer range limit is less dependent on object type than that of the perception space and is basically determined by the agent's physical reach.

Perception-Cognition-Action Loop

Figure 2 shows a simplified model of information flows occurring as the result of a human agent acting in the world. The purpose is not to provide a completely accurate account but a good-enough model for designing future interactive systems.

Perception

By and large, our perception of the world (pathway 2-4 in Figure 2) and our perception of our body state (arrow 5) is beyond our conscious control. However, conscious cognitive processes influence unconscious processes (arrow 7), as in the case when we deliberately address our attention to a certain speaker in a crowd and automatically (thanks to unconscious processing), to some degree, single out the voice we want to hear. We can also consciously and indirectly affect unconscious processing by orienting our body sensors (such as vision) toward phenomena of interest (pathway 8-10-2-4).

Cognition

Human cognition is divided into unconscious and conscious processing (arrows 12 and 13 in Figure 2, respectively). The human agent receives input from sensors capturing in-body phenomena (such as proprioceptive information about limb positions and for maintaining homeostasis) and from sensors capturing information from the external world. No external world or in-body phenomena is subject to conscious cognitive processing before it has been unconsciously processed (pathways 2-4-6 and 5-6, respectively).

Conscious processing is slower than unconscious processing. For instance, muscular reactions to immediate threats are initiated unconsciously (pathway 4-9) long before conscious processes are engaged. We protect our faces with our hands instinctively from approaching projectiles such as hockey pucks even when we are consciously aware of the fully protective shields of transparent material in front of us.

Action

Human action is initiated and controlled by a mix of conscious and unconscious cognitive processes. An example of an activity mostly driven by an unconscious perception-cognition-action loop is walking along a well-known road with no exposure to obstacles (pathways 2-4-9-10 and 11). An example of an activity that uses a combination of conscious and unconscious cognition is attempting to thread a needle, which demands focused visual and tactile conscious attention (pathway 2-4-6-8-10) in parallel with unconscious detailed control of hand, finger, and arm muscles (pathway 5-9-11).

The Wearable Personal Assistant in the Loop

By including unconscious cognitive processing and all perceivable world phenomena (including everyday objects such as coffee cups and footballs), the model in Figure 2 provides a more complete perspective of the context in which a WPA operates than classical HCI models, which are typically concerned only with pathway 15-3 (red arrows in the figure) and how it relates to conscious cognitive processing. It becomes evident that any information generated by a WPA (arrow 3) is just one source of information among many others that hit the unconscious and conscious parts of our brains, which together try to make sense of it all. Heuristics for serving that information in a timely manner, arriving at successful "attention management," is probably best based on knowing what else is hitting the senses in parallel. The context-aware systems community has investigated this for years but often using a system- or device-centered approach. We believe that a human-centric approach toward determining what matters in a given situation (for example, using the SSM in Figure 1) will reveal interesting complementary information.

Note that conceptually, the hardware user interface of a WPA (such as the head-mounted display [HMD], microphone, loudspeaker, and Google Glass touchpad) receives input from the human agent and provides output that the human agent can sense in the shape of world phenomena (arrows 10 and 2). In Figure 2, these information flows are re-represented as separate information flows (arrows 15 and 3) to facilitate the following discussion.

Implicit Input and Output

Although seldom clearly defined in the HCI literature, the distinction between explicit and implicit input and output is useful for discussing some important properties of WPAs[10]:

- *Explicit input* is action intentionally and consciously directed toward the WPA. For example, a human agent navigates the GUI presented on the Google Glass HMD by swiping the touch area (pathway 8-15).
- *Implicit input* is action performed by a human agent without the conscious intention of communicating with the WPA. For example, a human agent acts in the real world (moves about, manipulates objects, and interacts with other human agents), which is partially sensed by the WPA (pathways 8-10-1 and 9-10-1).
- *Explicit output* occurs when a WPA addresses the conscious mind. The WPA creates a change in the agent's perception space (Figure 1) that the human agent cannot avoid consciously perceiving (pathway 3-4-6), thereby inviting the human agent to act (arrows 10, 11, and 15).
- *Implicit output* occurs when a WPA addresses the unconscious mind. The WPA generates a phenomena in the agent's perception space (Figure 1) that reaches the unconscious part of cognition (pathway 3-4) but not the conscious part (pathway 6)—for example, through ambient displays such as the "dangling string"[11]).

By placing actuators and sensors on or very close to the body and keeping them there for large parts of the day, we would argue that the WPA can potentially sense and affect several of the information flows shown in Figure 2 with more precision than more traditional interactive systems (such as PCs and smartphones). This leads to the intriguing idea of future WPAs being able to facilitate the transition from "felt sense" tacit knowledge, generated as the human agent experiences the world, to knowledge that the agent can consciously reflect on and articulate,[12] augmenting human cognition at the core. Space limitations, and our wish to discuss possibilities that are more directly applicable in the near future, make us end this section by mentioning some more concrete potential mechanisms for using implicit input and output in the context of WPAs (all currently explored by the pervasive computing community but not necessarily in the context of designing WPAs).

Situation identification is one such mechanism. By implicitly monitoring body state through pathway 10-1 (for example, body posture, galvanic skin response, and heartbeat), and correlating it with the state of the nearby world (arrow 1), the WPA has a reasonable platform for determining the human agent's current situation.

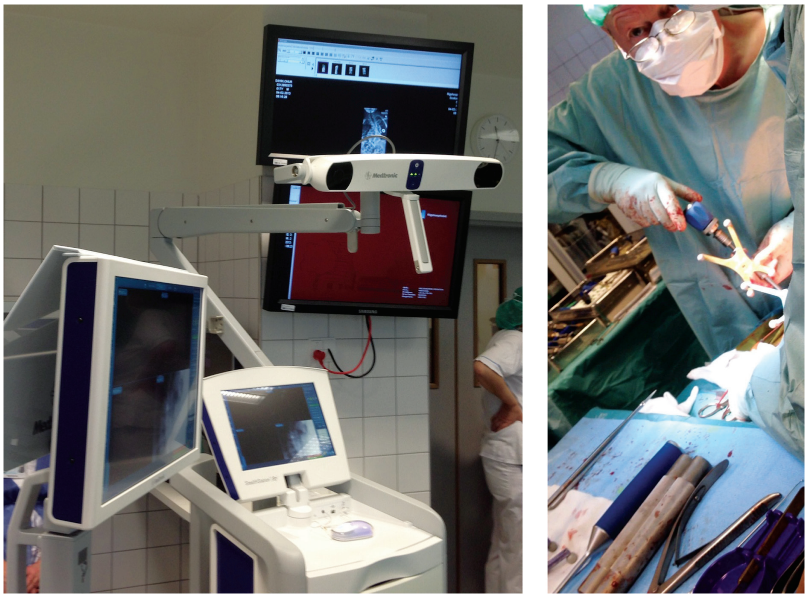
Another mechanism is *subliminal cueing*. Certain phenomena measured best close to the body (for example, eye movements, facial expressions, and electromyography [EMG]) can provide important insights into ongoing conscious and unconscious cognitive processing. They can therefore help determine the intensity level and type of stimuli that could be used for subliminal cueing,[13] and for the WPA to subliminally direct the human agent's gaze in a certain direction (pathway 3-4-9).

Finally, work has also been done in *mediated reality*. If the WPA is sufficiently integrated into the visual perception flow, beyond Google Glass see-through and partially covering monocular HMDs and toward Steve Mann's EyeTap vision,[14] the WPA could act both as a filter and highlighter. In this way, it could directly alter the perception of the surrounding world (arrow 2) so as to facilitate tasks. Naturally, security and ethics become important topics if development leads us in this direction.

A WPA for Orthopedic Surgeons

Healthcare is a highly collaborative work domain, and even single-user hospital systems, such as electronic patient record (EPR) systems, are used for coordination and collaboration. Moreover, because of the spatial distribution of departments, wards, meeting rooms, and offices, clinicians move around a lot. Their mobile yet collaborative work style forces them to use pagers, mobile phones, and other devices to communicate, which can interrupt and interfere with ongoing activities.[15]

However, previous attempts to develop WPAs for clinicians have faced several



(a) (b)

Figure 3. Design framework for a WPA prototype for surgeon assistance: (a) the navigation system and several large screens to monitor medical images in the operating room, and (b) surgeons look at the screens while operating on the patient.

technical and human-related challenges.[16] Emerging unobtrusive eyewear computers such as Google Glass raise hope for solving some of the technical issues. Furthermore, we believe that our egocentric design approach demystifies some of the human-related complexities by defining the concept of a WPA based on human needs for different kinds of assistance. We are currently developing a WPA for orthopedic surgeons to support them throughout their workday based on our egocentric design approach.

To understand the healthcare work domain, we conducted an ethnographic study in Rigshospital in Copenhagen. As part of the ethnographic study, we shadowed an on-call orthopedic surgeon during a workday. Our initial observations showed that surgeons have among the highest mobility in the hospital. Moreover, we observed several orthopedic surgeons in different types of orthopedic surgeries.

A typical surgeon's workday starts with a daily or weekly meeting with other surgeons. During these meetings, surgeons discuss general topics such as administrative issues and special patient cases. After regular meetings, all surgeons meet in radiology conference rooms to review patients' latest x-rays, MRIs, and CT scans; the medical images are presented on several large screens. During the radiology meetings, surgeons discuss important cases and make notes in special notebooks. Afterward, surgeons booked for different types of orthopedic surgeries go to the operating rooms (or theaters). Operating rooms are prepared based on the type of surgery planned because each type requires particular medical infrastructures. For example, some complex orthopedic surgeries require a navigation system to monitor a 3D model of the surgical site and the position of the operation instruments. Several screens in the operating room allow surgeons to monitor patient records, x-rays, MRIs, and CT scans (Figure 3a).

Because computers and their peripherals are difficult to sterilize during a surgery, an assistant or nurse operates the mouse and keyboard for surgeons. We observed a complex orthopedic surgery (scoliosis surgery) in which the surgical team used the navigation system to increase accuracy of the operation. In surgeries using the navigation system, a CT scan of the patient is displayed on a large screen, while the navigation system tracks the positions of surgical tools in relation to the patient's coordinate systems. Thus, the surgeon needs to look at the screen and at the same time use the surgical tools to operate (see Figure 3b). In such situations, the surgeon needs to frequently switch visual focus between the surgical site and the screen. During some complex surgeries, the surgeon might call an experienced colleague to help. In such cases, the experienced surgeon provides guidance either over the phone or in person.

In trauma cases, the acute department calls the on-call orthopedic surgeon, and the surgeon must go to the acute department immediately. The acute department sends a short text message to the surgeon giving a brief history of the patient. The surgeon reads the message before arriving at the acute department. In trauma cases, a group of clinicians from different departments work together to save the patient from life-threatening injuries.

Visiting patients in the ward is also part of the daily routine. Surgeons make their ward rounds together with a nurse, moving from patient to patient. The surgeon makes a diagnosis and prescribes treatment facilitated by the nurse, who has general knowledge of the patients and can provide an overview of their current conditions. Before ward rounds, the surgeon needs to review the patient records and recent medical images of the patients on a computer in his or her office. After ward rounds, the surgeon reports results from the rounds using a Dictaphone. Later, administrative personnel transcribe the recorded voice for the EPR system.

Because of clinicians' high mobility, they usually bump into each other in corridors, wards, and other parts of the hospital. In these ad hoc collaborative situations, they might talk about a particular patient or medical task. They might then move to one physician's office to look at a patient's medical information. In some cases, they go to the ward to visit a particular patient and discuss appropriate treatments.

WPAs in Hospitals: Design Framework

Based on the egocentric design approach and the ethnographic study, we developed a WPA design framework for supporting clinicians—in particular, surgeons (see Figure 4). The main characteristics of hospital work are the core elements of the framework, represented by the five rows in Figure 4, while the columns correspond to the three kinds of assistance defined by deploying our egocentric design approach. The boxes within present our initial 12 ideas for our healthcare WPA, which we briefly discuss here.

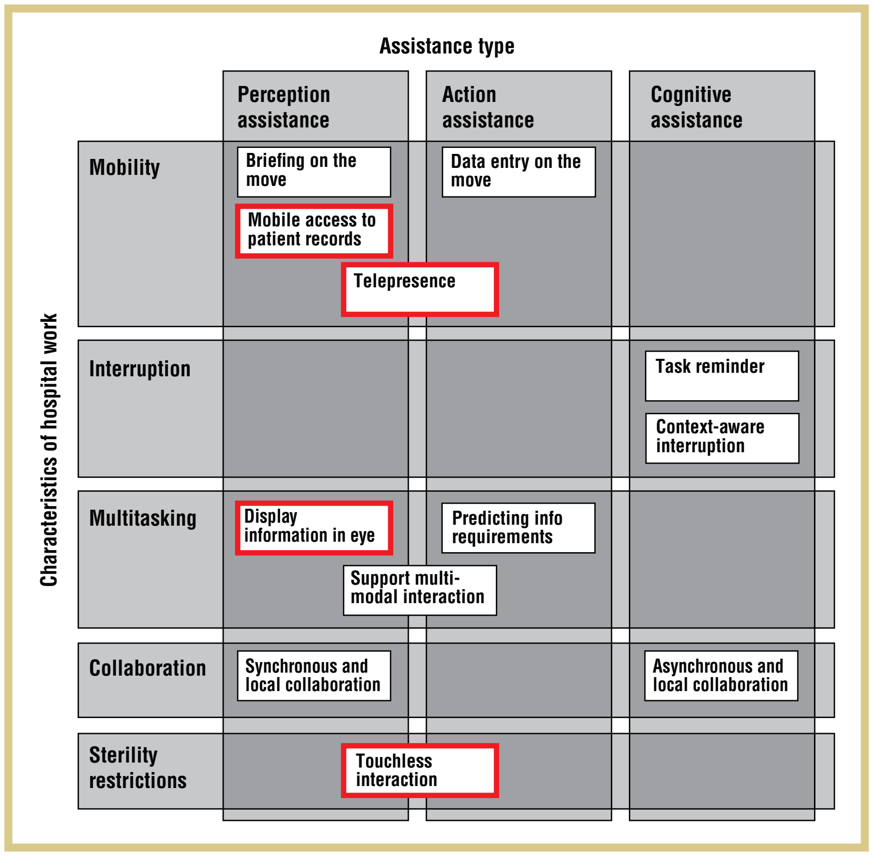


Figure 4. A design framework for WPAs in hospital settings. The rows present the main characteristics of hospital work, while the columns correspond to the three kinds of assistance defined by deploying our egocentric design approach. The boxes within present our initial 12 ideas for our healthcare WPA, while those in bold red were implemented in an initial Google Glass prototype based on feedback from surgeons.

Perception Assistance

Perception assistance includes both augmenting the world by adding needed information to the perception space and simplifying the world by filtering out potentially distracting or irrelevant phenomena from the perception space.

Briefing on the move. To utilize time on the move, the WPA provides information relevant to the situation that the surgeon will soon be entering. For example, surgeons called to the acute department get important health status information about the emergency patient from the WPA.

Mobile access to patient records. The main reason for mobility in hospitals is the need to be in different physical places, to get in contact with a particular person, or to access knowledge and shared resources. A WPA connected wirelessly to the EPR system facilitates information and knowledge sharing and can potentially be further simplified by automatic retrieval based on location (history) of the clinicians (for example, data for the patient nearest the clinician's current location), or bookmarked x-ray images for a surgeon attending a radiology conference.

Telepresence. Although digital resources can be easily shared through mobile devices, sharing physical resources, people, and tacit knowledge is still a challenge. WPAs could help share tacit knowledge among clinicians by offering ad hoc telepresence sessions between a remote specialist and local clinicians.

Display information in eye. During surgery, the surgical team needs to monitor important information on a display. For example, during some orthopedic surgeries, it is necessary to take periodic x-rays of the patient (fluoroscopy). Fluoroscopic surgeries force the surgeon to frequently switch focus between the surgical site and the screen. The WPA can display this information directly to the surgeon's eyes, letting the surgeon maintain focus on the patient, reducing surgery time and avoiding complications from x-ray exposure.

Support for multimodal interaction. The WPA facilitates parallel activities by providing appropriate input and output modalities according to action and perception restrictions of the situation in which clinicians perform medical tasks, as captured by the SSM (Figure 1). For instance, when the user is performing a visual task, the WPA could switch automatically or manually to aural modality for displaying helpful information.

> We selected three scenarios for further implementation: mobile access to patient records, telepresence, and touchless interaction and display information in the eye.

Synchronous and local collaboration. In synchronous and local collaborative scenarios, WPAs can increase awareness among team members. For example, during a surgery, the attention point of a surgeon on the surgical site, tracked by a gaze tracker, could be shared with the surgical team.

Cognitive Assistance

Many ideas for perception assistance ultimately target cognitive assistance. Hence, there is some overlap in the assistance mechanisms targeting perception and cognition. What we list here are support mechanisms that aim to affect cognitive processes more directly.

Context-aware interruption. As a continuously running device that stays with clinicians at all times, a WPA could determine current context and determine whether or not its wearer is interruptible in a given situation.

Task reminder. To mitigate the risk of a clinician forgetting a task that was interrupted, the WPA could remind the user about the (state of) the interrupted tasks after interruption.

Asynchronous and local collaboration. Many medical tasks are coordinated through asynchronous collaboration. For example, clinicians update the time schedules of personnel on whiteboards, enter descriptions of medical tasks performed on patients during a work shift into computer systems, and so on. Ubiquitous WPAs would allow for binding virtual objects to physical objects, locations, or situations.

Action Assistance

The main focus of action assistance is to make the surrounding environment easier to manipulate by providing information relevant to the task at hand through appropriate modalities.

Predicting information requirements. The WPA would be able to recognize clinicians' activities and allow them to access relevant information quickly, without sacrificing their connection to the patient or the procedure at hand.

Data entry on the move. In a clinical setting, everything needs to be properly recorded, for legal reasons and to ensure continuity of care. For instance, after visiting a patient in the ward, clinicians should record diagnosis results and decisions. The WPA could support data entry on the move by automatically recording the visited patient's ID and the date, time, and author (WPA user).

Touchless interaction. As noted earlier, in most operating rooms, several computers and large displays monitor different medical information before and during surgery, and because of sterility restrictions, input devices are handled by an assistant or a nurse instructed by the surgeon. This can sometimes cause misunderstandings and delays. A WPA could act as an interface between stationary computers and the surgeon through touchless modalities such as speech, body gestures, and gaze.

A WPA Prototype for Selected Scenarios

We interviewed three orthopedic surgeons to evaluate the utility of the 12 ideas in practice. First, we explained the ideas to the surgeons and asked them to rank the usefulness of each idea using a 5-point Likert scale. Next, we discussed the ideas in more detail with open questions about the situation in which the proposed idea could play a role, how frequently these situations occur, what information is needed in each situation, and what specific restrictions and requirements (such as sterility) should be observed. Based on the results of the interview study, we selected three main scenarios for further implementation: mobile access to patient records, telepresence, and touchless interaction and display information in the eye.

Because of Google Glass's unobtrusiveness, its support of various input channels, such as voice commands, head motion, and touchpad. Consequently, we developed the WPA prototype on the Google Glass platform. The first prototype supports three selected scenarios.

Mobile Access to Patient Records

According to the interviewed surgeons, mobile access to patient records through the WPA provides valuable support in situations such as making ward rounds, working in the operating room, performing ad hoc collaborations. However, each situation requires the WPA to provide different interaction modalities. For example, the WPA should support touchless interaction in the operating room because of the sterility restrictions, whereas during ward rounds, surgeons can use a Google Glass touchpad to provide input to the device. In fact, support for multimodal interaction is a crucial characteristic for the WPA to provide mobile access to the patient records. But different strategies could be applied to support multimodalities; the interaction modalities can be switched automatically or manually in different situations.

To compare the effect of automatic and manual switching between modalities on user performance, we conducted a lab experiment in which we asked participants to complete a physical task (a hotwire game, as illustrated in Figure 5a) while simultaneously answering simple math questions either displayed on the HMD or played through the headset.[18] Participants answered the visual questions through head gestures, and the aural questions using audio modality (speech). We measured participants' performance based on the speed and error rate in the hotwire task. The results of the experiment show that performance was higher when participants answered the questions using the audio modality than when they used visual and gesture-based modalities, probably because the auditory modality interferes less with the motorically and visually demanding hotwire task. Furthermore, the participants' performance was higher when the modalities were switched automatically than when they were switched manually, but manual switching was preferred because of the higher controllability.

Based on findings from this experiment, we implemented redundant input channels for the WPA and let users choose appropriate modalities manually in different situations. The main steps for mobile access of the patient records on the Google Glass application are as follows.

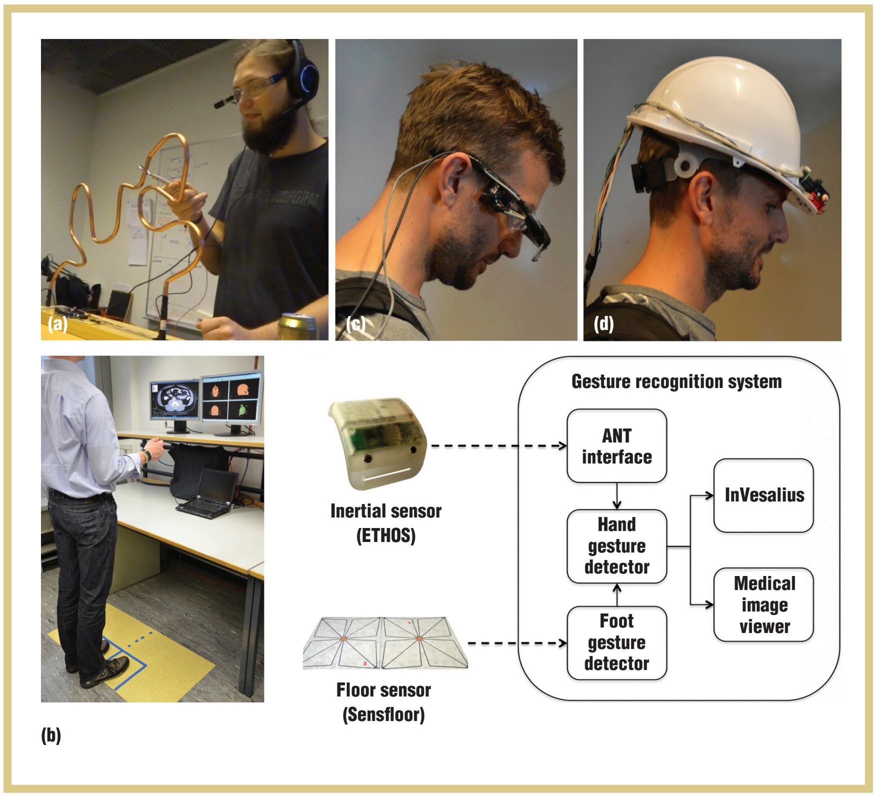


Figure 5. Early experiments informing the design of the WPA prototype: (a) a participant completing the Hotwire task[18]; (b) a participant touchlessly interacting with medical images on the screens,[19] (c) a head-mounted display for teleguidance applications[17]; and (d) a wearable laser pointer.

Find the records. To find and retrieve a patient's health records, the system provides two main channels: voice and QR code. Users can filter the patient list by saying the patient's name or social security number. They can also find the patient's records by reading the patient's QR code using the front-view camera of Google Glass. The latter method is faster and more accurate when the QR code is available.

Switch between textual data and medical images. Patient records are distributed in several pages (cards) on the Google Glass. Because of the display size in Google Glass, the textual part of the patient records is shortened. However, medical images (x-rays, CT scans, and so on) are the most important part for orthopedic surgeons. Users can switch between cards using voice commands (such as "Ok Glass," "next," or "previous") or performing swipe gestures (swipe left and swipe right) on the Google Glass touchpad.

Interact with medical images. Users can zoom in or out, rotate, and navigate through a zoomed-in view of the medical images using voice commands or touch gestures on the touchpad (tap for zooming in, long press for zooming out, and swipe up for rotation). To navigate through an enlarged image in real-time, the Google Glass head tracker sensor is used, allowing the user to quickly scan over the complete image by moving his or her head (Figure 6).

Touchless Interaction

We studied the utility of touchless interaction techniques in the operating room in a lab experiment (Figure 5b).[19] Based on the experiment's promising results, we designed a touchless interaction module for the WPA that enables surgeons to provide touchless input to other computers in the operating room using voice commands and head gestures.

The surgeon can interact with two systems: a 3D medical imaging system

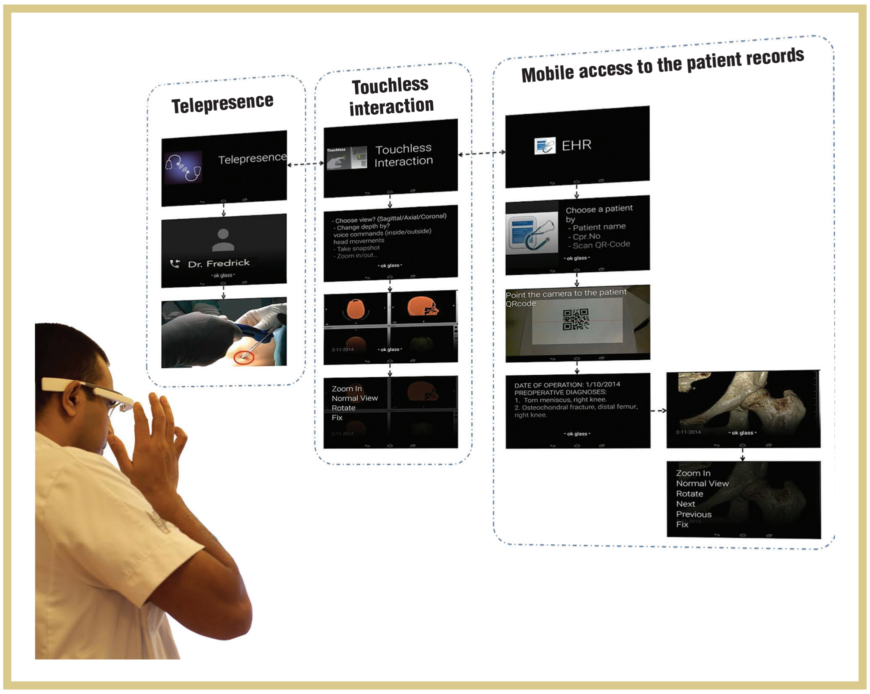


Figure 6. Screenshots of the main cards (pages) of three applications. Users can switch between cards using voice commands (such as "Ok Glass," "next," or "previous") or performing swipe gestures on the Google Glass touchpad. To navigate through an enlarged image in real-time, the Google Glass head tracker sensor is used, allowing the user to quickly scan over the complete image by moving his or her head.

(InVesalius) or a 2D image viewer to review x-rays and other 2D images. The surgeon can switch between 2D images, zoom in or out, and navigate through an enlarged image on the stationery screen via voice commands and head gestures through the WPA. To interact with the 3D imaging system, the user should first choose the desired view (Axial, Sagittal, or Coronal). The surgeon can adjust the view of different slices of the 3D model continuously by vertical movements of the head. To send commands using head movements, we divided the Google Glass screen into three areas distributed vertically. The user's vertical head movement is mapped to the position of a pointer on the screen. When the pointer enters the top area, the depth view of the 3D model increases, whereas crossing the lower border with the pointer decreases the depth. The same method is used to navigate through an enlarged x-ray on the screen, in which the screen is divided into five areas: up, down, left, right, and middle. By moving the pointer from the middle to the four other areas on the Google Glass screen, the enlarged image moves in the same direction on the big screen.

In addition to supporting touchless interaction, this module allows users to take a snapshot from the stationery screens and display it in surgeon's Google Glass HMD (see Figure 6).

Telepresence

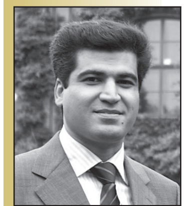
The three surgeons we interviewed noted that, during complex surgeries, the surgeon might need help from an expert colleague. In such situations, the surgeon asks the expert colleague to personally help in the operating room or to provide guidance through a phone call. To enhance the effectiveness of collaborations over the phone, the WPA's telepresence module is designed to share a still image taken by the local surgeon with a remote expert. The remote expert can use a mobile application to see the shared image and provide guidance through vocal communication and also by adding sketches on the still image. The graphical content provided by the remote expert is superimposed on the local surgeon's HMD in real time.

Our comparative study on a remote pointing scenario using a laser pointer and HMD technologies (Figures 5c and 5d) revealed the challenge of stabilizing content provided by the remote expert on the local side when there is a live video stream between local and remote sides.[17] Thus, we used still image and vocal communication in the telepresence module. In addition, because of the technical limitations of Google Glass, the experienced quality of the live video stream is lower than still images, which makes still images the better choice. The feedback from two surgeons who tried the telepresence system also showed that in orthopedic surgeries, sharing still images is more useful than live streams. However, sharing live video can of course be useful in other situations.[20]

At the time of this writing, we just finished an empirical evaluation of the system at the ITX hospital simulation facilities in Copenhagen involving two orthopedic surgeons who tried the WPA in two scenarios: surgery and ward rounds. Preliminary results confirm the WPA's utility and practicality in realistic settings. However, the surgeons and patients reflected on some social challenges in the ward rounds scenario. Our future plan is to improve interaction aspects of the WPA to address the social challenges and other minor issues.

From a theoretical perspective, we hope to help extend current context-awareness research to better explore more powerful future personal assistance systems. Our proposed egocentric design approach, which includes unconscious cognitive processing as part of the system design, is well-grounded in modern cognitive science but poses huge challenges for us as engineers. We believe that the pervasive computing community will take on this challenge with increasing success as body-worn technology and the modeling of human cognition continue to improve.

the AUTHORS



Shahram Jalaliniya is a PhD fellow at the IT University of Copenhagen, where he is a member of the Pervasive Interaction Technology (PIT) Lab. His research interests include wearable computing, HCI, pervasive computing, and multimodal interaction. Jalaliniya has a master's degrees in information systems from Lund University and in software and technology from the IT University of Copenhagen. He is a member of IEEE. Contact him at jsha@itu.dk.

Thomas Pederson is an associate professor at the IT University of Copenhagen, where he is a member of the Pervasive Interaction Technology (PIT) Lab and the Interaction Design Group. His research interests include HCI, context-aware systems, and pervasive/ubiquitous computing. Pederson has a PhD in computing science from Umeå University, Sweden. He is a member of the ACM. Contact him at tped@itu.dk.

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