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A Wearable Personal Assistant for Surgeons – Design, Evaluation, and Future Prospects

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Abstract

In this paper, we present our body-and-mind-centric approach for the design of wearable personal assistants (WPAs) motivated by the fact that such devices are likely to play an increasing role in everyday life. We also report on the utility of such a device for orthopedic surgeons in hospitals. A prototype of the WPA was developed on Google Glass for supporting surgeons in three different scenarios: (1) touch-less interaction with medical images, (2) tele-presence during surgeries, and (3) mobile access to Electronic Patient Records (EPR) during ward rounds. We evaluated the system in a clinical simulation facility and found that while the WPA can be a viable solution for touch-less interaction and remote collaborations during surgeries, using the WPA in the ward rounds might interfere with social interaction between clinicians and patients. Finally, we present our ongoing exploration of gaze and gesture as alternative input modalities for WPAs inspired by the hospital study.

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1. Introduction

Mobility is one of the main characteristics of work in hospitals. Due to the spatial distribution of departments, wards, and offices in clinical settings, clinicians need to move between different departments all the time. Aside from the considerable time that clinicians waste on moving in hospitals, having access to the right information in different situations is a big challenge. The majority of previous work on providing remote access to the patient information have used mobile devices (e.g. PDAs and smartphones). However, most mobile devices do not support interaction on the move, which means the users need to stop, pick up their device, and direct their attention away from the task at hand [1]. This way of interaction often requires the user's full attention and occupies at least one hand which most of the time interferes with the task at hand. Furthermore, interaction with the dominant touchscreen-based mobile devices does not comply with sterility restrictions in hospitals. Emerging wearable computers such as Google Glass provide various hands-free input modalities (e.g. head motion and voice commands) and raise the question as to whether such new computing platforms can address some of the challenges of interaction on the move. What are the potential advantages and limitations of using such devices in hospitals? To answer these questions, we implemented and evaluated a wearable personal assistant (WPA) for orthopedic surgeons [2]. In this article we provide a more detailed look into the design and evaluation of this previously presented prototype. Our WPA supports three specific tasks throughout a workday of surgeons: 1) touch-less interaction with medical images, 2) tele-presence during surgeries, and 3) mobile access to the Electronic Patient Records (EPR) during ward rounds.

2. Wearable Personal Assistants (WPAs)

The idea of designing wearable systems in the shape of "personal assistants" is mainly inspired by earlier studies on intelligent interface agents [3]. Interface agents are intended to (1) observe the user's actions and imitate them, (2) receive user feedback on the systems'

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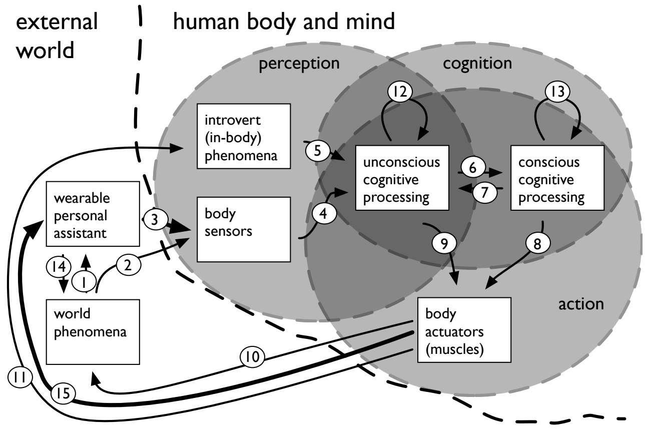

Figure 1. A body-and-mind centric model of how Wearable Personal Assistants fit into the flow of perception, cognition, and action of human agents. [2]

actions, and (3) learn from users feedback. Based on this approach a *personal digital assistant* could help users by handling emails, scheduling meetings, filtering news, or recommending books or music [4]. Thad Starner [5] and Steve Mann [6], two of pioneers in wearable computing, have defined the main characteristics of such wearable assistants in the late '90s. Both Thad Starner and Steve Mann's definitions stress the vision of a wearable assistant supporting users in mobile scenarios and in parallel with real-world activities by providing relevant information to the task at hand through an appropriate modality.

However, apart from the visionary definitions of wearable assistants, very few elaborated and practical approaches towards design and implementation of such systems have been proposed.

3. Our design approach

Since wearable computers are physically closer to the human body more than any other computing device ever has been, and they (in the visions of for instance Thad Starner and Steve Mann) are intended to extend both the user's body and mind, we think it is close at hand to therefore adopt a human body-and-mind centric design approach [2]. To emphasize the tight integration between a single mind, body, and computer we use the term "Wearable Personal Assistant (WPA)" instead of the shorter but more general term "wearable assistant" often used by Thad Starner and others. Fig. 1) illustrates how we see the WPA to be very integrated into the perception-cognition-action loop depicting how the wearer of the system interacts implicitly and explicitly with both the surrounding world and the WPA itself [2].

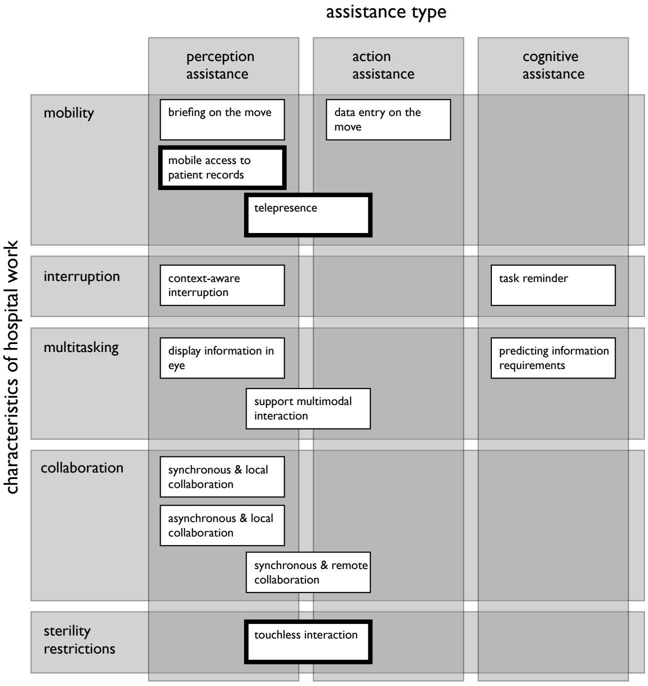

Figure 2. A design framework for Wearable Personal Assistants (WPAs) in hospital settings based on hospital work characteristics elicited through interviews and literature review (left-most column) and assistance mechanisms considered by us as WPA designers (the boxes distributed over the three types of assistance defined by the framework). The three ideas for assistance highlighted in bold were the ones chosen for implementation and evaluation based on a combination of technological feasability offered by the available WPA platform (Google Glass) and expressions of need from interviews with orthopedic surgeons. [2]

In our simplified model of a human agent acting in the world (Fig. 1), the WPA can potentially provide three main types of assistance: (1) action assistance; (2) cognitive assistance; and (3) perception assistance. To design a WPA for orthopedic surgeons, we tried to define the functionalities of the WPA by focusing on these three types of assistance. Moreover, to ensure that the main aspects of the surgeons' work in the hospital is covered in design of the WPA, we developed a conceptual framework in the form of a two-dimension matrix. The rows of the matrix describe the main characteristics of the surgeons' work while the columns explain three types of assistance (see Fig. 2).

After discussing the utility of the initial functionalities derived from the design framework with three orthopedic surgeons in a Danish Hospital, we focused on three of them: (1) touch-less interaction with medical images in surgery room; (2) tele-presence during surgeries; and (3) mobile access to the Electronic Patient Records (EPR) during ward rounds [2]. These three functionalities have bold frames in Fig. 2.

4. Related Work

4.1. Early wearable assistants for clinicians

The first generation of wearable computers for hospital work domain [7–11] comprised a head mounted display (HMD), a microphone and earphone for vocal interaction, a compact processing unit connected to a wireless network, and other peripherals such as wrist-mounted keyboards, trackball mice, and etc. RNPSS [7] was one of the first wearable systems for clinicians. The main goal of this system was to decrease the medical errors of nurses. A similar project [10] was done to support nurses in home care tasks. Supporting physicians in ward rounds was another application for the early wearable assistants [8]. The ward round system supported hand gesture interaction using inertial sensors [8] and conductive textile sensor [12]. These initial prototypes of wearable assistant for clinicians increased hopes for using wearable computers in practice, but due to the technical, social, and usability challenges [13] those system never took off.

4.2. Using Google Glass in healthcare

In [14], an expert surgeon provided guidance to a local surgeon over distance. The guidance was provided through vocal communication and the image of the remote surgeon's hand was superimposed on the live view of the surgical site on the Google Glass HMD. This study showed some problems with battery life, audio and image quality, and difference between camera view and the surgeon view. In another study [15], Google Glass was used to retrieve similar medical cases by sending a picture and relevant keywords to a remote server. In this paper, similar technical issues were reported such as limited battery life, unstable WIFI connection, lack of auto-focus functionality, which decreases the quality of the pictures. Muensterer et al. [16] showed the utility of the Google Glass for hands-free photo and video recordings, hands-free calls, looking up billing codes, and searching for unfamiliar medical terms in a hospital. The feasibility of using Google Glass for monitoring patient's vital signs in the surgeon's eye was investigated by Vorraber et al. [17]. Their study showed that using Google Glass decreases head and neck movements of the surgeon and increases the surgeon's focus on the operation. They reported over-heating problems of the Google Glass in addition to the other technical issues. While previous work has focused on the technical feasibility of using Google Glass in healthcare scenarios, our focus here is on human-computer interaction challenges emerging from using the device as a wearable assistant in hospitals.

In the work presented in this paper we investigate the ecological validity of the WPA design explained in more detail elsewhere [2]by asking real orthopedic surgeons use the WPA in a clinical simulation.

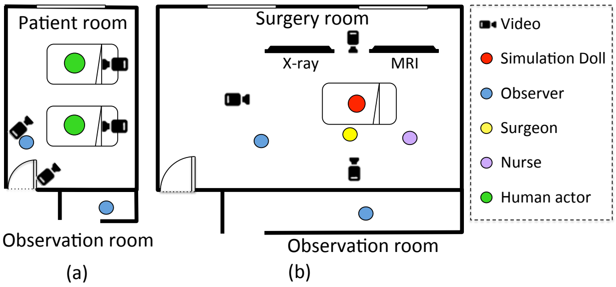

Figure 3. a) The simulation setup for the ward round scenario. The room is equipped with hidden cameras, microphones, and an observation room behind a one-way mirror. b) The simulation surgery room for touch-less interaction and tele-presence scenarios is equipped with surgical equipments, a simulation doll connected to a monitor displaying simulated vital signs, and two large screens for displaying X-rays and Magnetic Resonance Images (MRIs).

5. Method

Since deploying the WPA in a real clinical setting needs legal approval, we evaluated the WPA in a clinical simulation facility. Such simulations is common and have been proven efficient in the medical work domain [18]. Our simulation facility includes different hospital departments from patient wards to surgery rooms. We set up the facility for the above-mentioned three scenarios. The touch-less interaction and tele-presence scenarios were played out in the surgery room (see Fig. 3b), and for the mobile access to the EPR scenario we set up a patient room with two beds (see Fig. 3a).

5.1. Participants

During a full day simulation, two orthopedic surgeons, a senior nurse, and two human actors (to play the role of patients) participated in the study. Since surgeons are extremely busy and hard to recruit for such studies we could manage to find only two surgeons.

This is a big limitation for finding statistical significance; therefore, we only rely on qualitative findings from interviews and observations. The entire simulation was recorded using video cameras, note taking, photographing, and observations behind a one-way mirror. After welcoming the participants, a brief introduction was delivered on the purpose of the study and the scenarios. Both surgeons performed all three scenarios. Before starting each scenario, the surgeons were briefly trained on how to use the WPA. Each training session took about 30 minutes. After each scenario, the surgeons were asked to complete a structured questionnaire polling their experiences

Figure 4. A surgeon (right) uses the Google Glass-based WPA prototype for touch-less interaction with X-rays and MRIs shown on the big display (left) without the need to involve the nurse (in the background) which otherwise typically would be necessary.

completing the task and using the system. The result of questionnaires is represented in Fig. 7. Immediately after the questionnaire the surgeons were interviewed to get deeper insights into their experience of using the WPA.

5.2. Scenario-based evaluation

We took a scenario-based approach in evaluation of the WPA. The scenarios were defined based on a previous study [2]. Scenarios included: 1) Touch-less interaction, 2) Tele-presence, and 3) Mobile access to the EPR in ward rounds. These three scenarios are part of a bigger scenario which starts with a patient getting an orthopedic surgery. Before the surgery, the surgeon needs to review the medical images of the patient. The WPA helps the surgeon find relevant medical images and adjust the view through touch-less modalities. During the surgery, the surgeon needs another experienced surgeon's opinion about the surgery. The WPA helps the local surgeon to have a tele-presence session with the remote colleague. After surgery, the patient is moved to the ward, and the surgeon visits the patient in the ward. The WPA enables the surgeon to see the patient electronic records on the go and review the new medical images after the surgery.

5.3. Preparing data for the study

Since all three scenarios are related to each other, for this study we needed real medical cases. We selected two cases with the help of our medical partner. We anonymized the data and assigned fictional names to the selected cases. Two human actors (university colleagues) played the role of patients during the ward round scenario. We also used real pictures of the surgical site taken during real surgeries. The pictures were printed and attached to the simulation doll to create a more realistic setting (see Fig. 4).

6. Scenario 1: touchless interaction

In the surgery room, the surgical team including a surgeon and a nurse, are about to start the surgery. Before starting the surgery, the surgeon looks at X-rays and MRIs. But his/her hands are sterile and s/he cannot touch the mouse or keyboard. Therefore, the surgeon uses the WPA for browsing X-rays and MRIs on two different screens in the operation room through voice commands and head movements. The surgeon might need to zoom in, rotate, or navigate through the medical images until s/he finds a good view. The surgeon can also take a snapshot of the screens and see the content on the HMD.

Table 1. Input modalities for each module of the Wearable Personal Assistant.

System module	Commands to the WPA	Voice	Head	Touch
Touchless interaction	Wake up the Glass		×	
	(De)activate the X-ray/MRI system	×		
	Switching X-rays (next/previous)	×		
	Positioning X-rays on the screen		×	
	Changing MRI views	×		
	Change the depth of the MRI views		×	
	Take snapshot of X-rays/MRI views	×		
Tele-precense	Wake up the Glass		×	
	(De)activate the tele-precense system	×		
	Take a picture	×		
	Select a picture for sharing	×		
	Call a clinician	×		
	End call	×		
EPR	Wake up the Glass		×	×
	(De)activate the EPR system	×		×
	Select a patient record	×		×
	Switch X-rays	×		×
	Zoom in/out X-rays	×		×
	Rotate X-rays	×		×
	Navigate through X-rays		×	
	Browse EPR pages	×		×

6.1. Apparatus

We used Google Glass to implement the WPA since Google Glass provided at least two touch-less input modalities: voice commands and head movements. Moreover, the relatively unobtrusive form factor of Google Glass and the fact that it only covers a small part of the user's field of view made it the best available option for applications where having a good view over the real-world is crucial. We developed a simple image browser for displaying the X-rays in the surgery room. To visualize MRIs and X-ray scans, we modified Invesalius, an open-source medical imaging system [1].

All three systems were connected to a dedicated local WIFI network. We used UDP protocol for communication between Google Glass and other two medical systems. The WPA app on the Glass accepts both voice commands and head movements for interaction. Voice modality is used for discrete commands such as activating/deactivating the interaction, switching between X-rays, zooming in/out X-rays, changing the views in MRIs between (sagittal, coronal, and axial). While head motion is used for continuous commands such as adjusting the position of the X-rays on the screen. In the latter case, we used the user's head similar to a mouse where the vertical and horizontal head movements are translated into the vertical and horizontal movements of the pointer displayed on the HMD. We defined some command areas in the GUI of the Google Glass. By moving and keeping the pointer in each area, the WPA sends an appropriate command to the X-ray and MRI systems. As soon as the pointer exits from the selected area the WPA stops sending commands. Table 1 shows the modalities used for sending commands to the WPA.

6.2. Procedure

After briefing the participants and setting up the surgery room, the surgeons played out the scenario one after the other such that surgeon P1 performed scenario 1 after which surgeon P2 performed the same scenario, and so on. First the nurse gave a brief explanation about the patient to the surgeon. Then the surgeon activated the stationary X-ray system through the WPA to find an X-ray and adjust the scale and position of it on the large display. To find a good view the surgeon used either voice commands or head movements as shown in Table 1. After finding the appropriate view, the surgeon took a snapshot of the stationary X-ray which made it come up on the HMD. This snapshot helps the surgeon to examine the X-ray image during the surgery without having to change the head orientation towards the large display. Each surgeon repeated the scenario for both patients. Since the second patient had also some MRIs, in the second surgery, the surgeons used the WPA for interaction with both X-rays and MRI systems. To interact with the MRI system, the surgeon needed to activate three different views (sagittal, coronal, axial)

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[1] http://svn.softwarepublico.gov.br/trac/invesalius/

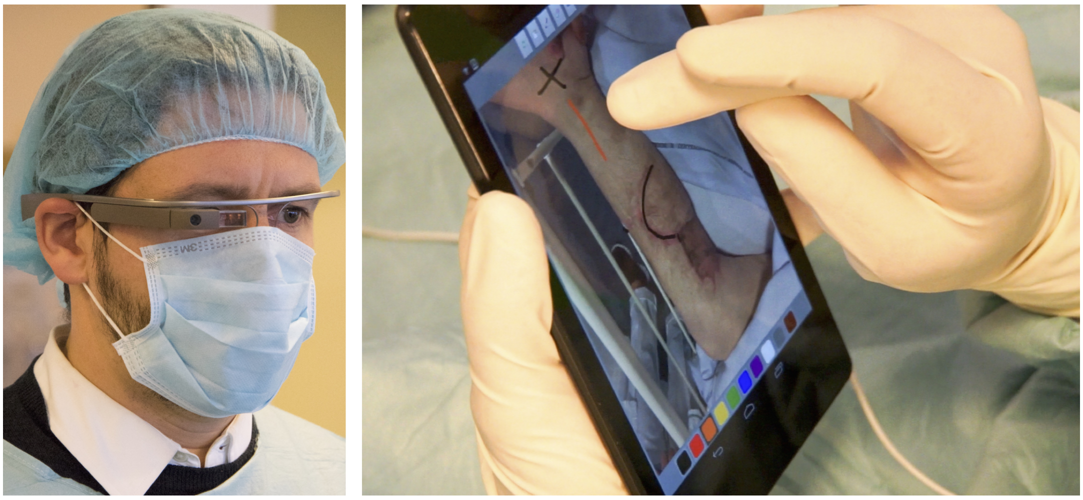


Figure 5. A remote surgeon (right picture) uses a tablet computer to provide guidance to the local surgeon (left picture). The local surgeon sees the visual guidance on the WPA Head-Mounted Display in real-time.

through voice commands and adjust the image to an appropriate depth perspective using head gestures.

6.3. Results

Interview: After having played out the scenario, we asked the surgeons about the pros and cons of the WPA for touch-less interaction compared to the current indirect interaction (asking a nurse to control a computer mouse as proxies for surgeons). Participant 1 (P1) indicated the higher speed of interaction using the WPA; however, he believes that it might take more time for older surgeons to learn how to use the WPA. P2 thinks the direct interaction through the WPA can be a big advantage and saves time of surgeons in the surgery room because sometimes it is very hard to explain to a nurse the view that the surgeon is looking for. However, interaction with X-rays by head movements is not easy since the user needs to look through the HMD to see the pointer and at the same time look at the X-rays or MRIs on the large screens which demands frequently switching between the HMD and the large screens.

We also asked whether they prefer voice commands or head movements for interaction with X-rays and MRIs. P1 thinks the voice commands are more convenient for interaction with X-rays where the user usually needs to provide a few commands while in the MRI case the head movements can be more beneficial since finding the right depth view among a lot of slices can be frustrating by voice commands. P2 prefers voice commands since interaction through head movements was challenging for him due to the need for switching frequently between the HMD and the large screens.

The last question was about the snapshot function. Both P1 and P2 indicated that the snapshot functionality can be extremely useful when the surgeon needs a reference X-ray or MRI to monitor the state of the surgical site during the surgery. In such cases, the surgeon needs to frequently turn his/her head towards the screen. To have a snapshot of such reference images in the HMD, saves surgeons' time and energy for the surgery.

Observations: Both surgeons quickly learned how to use the voice commands for interaction through the WPA; however, P1 felt more comfortable with head-based interaction compared to P2. When P2 wanted to adjust the position of the X-rays in the screen by head movements, he lost the control of the system because he had problems with looking at both the HMD (to control the pointer) and the large screen (to see the X-rays) at the same time. The same problem happened when P2 wanted to adjust the MRI depth view.

7. Scenario 2: tele-presence

After adjusting the medical images on the screen (in the previous scenario) during the surgery, the surgeon encounters a complex situation and needs help from an expert colleague. The surgeon uses the WPA to start a tele-presence session with the remote colleague. The local surgeon takes a picture of the surgical site and calls the remote surgeon using the Glass. The remote surgeon answers the call. Then the local surgeon explains the situation and shares the taken picture with the remote surgeon. The remote surgeon provides some voice guidance while at the same time marking the shared photo on his tablet (Fig. 5-right). The local surgeon sees the content provided by the remote surgeon on the Glass and also hears the voice of the remote surgeon in real-time (Fig. 5-left) in real-time.

7.1. Apparatus

We developed a tele-presence app on the Google Glass for the local surgeon while for the remote surgeon, we developed an Android application on an Asus Nexus 7 tablet. The audio communication is done over WIFI connection using UDP protocol. Due to the limitations in processing resources of the Google Glass and to avoid registration challenges in an augmented reality user interface, the Glass application shares a still picture (instead of video) of the local side, and the remote person is able to draw sketches on top of the shared image using the Android application on the tablet. The sketches are superimposed over the shared image in real-time on the Google Glass HMD of the local user.

7.2. Procedure

In the tele-presence simulation, we ran the scenario twice, and during each time one of the surgeons played the role of a remote expert and the other surgeon played the role a local surgeon. In the second run, the surgeons swapped their role and the surgery case was also changed from patient 1 to the patient 2. Before starting each run, we attached the printed image of the surgical site on the simulation doll. The remote surgeon sat on a chair in the hallway outside of the surgery room. After activating the Google Glass by head nudge gesture, the local surgeon opens the tele-presence application by voice command and takes a picture of the surgical site. Then the local surgeon calls the remote colleague by saying his/her name from a list on the HMD. The remote surgeon receives and accepts the call. As soon as the call is accepted the audio communication is possible and the taken picture is displayed on both sides. The local surgeon explains the situation and asks for the remote surgeon's opinion. The remote surgeon provides vocal and visual guidance by marking the shared image of the surgical site using different colors on his tablet device, markings that show up immediately in the Google Glass display carried by the local surgeon.

7.3. Results

Interview: After having played out the scenario, we asked the surgeons what other content they would like to share in a tele-presence session. P1 believes sharing still images of the surgical site (like our implementation) is very useful for orthopedic surgeries while live videos can be useful in emergency cases. Also sharing medical images such as X-rays or MRIs can be valuable in cases where a junior surgeon needs an approval from a senior surgeon. Currently the senior surgeon needs to come personally to the surgery room and have a look at the X-rays or the junior surgeon sends the X-ray using a smartphone. P2 thinks the quality of the image on the HMD is not good enough for complex surgeries with a lot of soft tissues. He suggested to add a zoom-in functionality to overcome the limited resolution of the HMD.

Observations: The communication between the two surgeons was smooth. There was about half a second delay in the audio communication due to the WIFI-based communication. But the surgeons got used to it after a while. Also during the tele-presence scenario, when the local surgeon was talking to the remote surgeon, Google Glass detected the "Ok Glass" command by mistake and the surgeon needed to deactivate the voice command and continue the session.

8. Scenario 3: Mobile access to Patient Records

It is one day after the surgeries. Patients are lying down in the bed in the ward. The surgeons should visit two patients who got surgery. The surgeons use the WPA to review the new X-rays and the latest state of the patients while walking to the ward together with a nurse. The surgeon searches for the patient records on the Glass by saying the patients name. After finding the patient records, the surgeon reads the updated EPR and looks at the recent X-rays and MRIs on the Glass. The surgeon zooms in/out, rotate, and navigate through the medical images. The nurse reports the latest state of the patient (last blood test, etc.) to the surgeon. The nurse answers the questions that the surgeon might ask during the ward round. The surgeon visits the patients and asks some questions about their pain, etc. Also the surgeon might need to use the EPR system for answering patients' questions. After visiting the patients, the surgeon prescribes the next treatments and the nurse writes down the prescriptions.

8.1. Apparatus

For this scenario, we only needed an EPR app on the Google Glass. Since in the ward round, the clinicians' hands do not necessarily need to be sterilized, the EPR app supports also touch-based interaction on the Google Glass side touchpad. Table 1 shows the ways surgeons can interact with the EPR app. We used different touch-gestures for interaction with text pages and medical images: swipe front/back for browsing EPR and X-rays, short tap for zoom in, long tap for zoom out, swipe up for 90 ° rotation, and swipe up to exit from an active card to the previous menu. Since it was not possible to connect the Google Glass to the EPR in the hospital, the patients data was hard-coded into the EPR app.

8.2. Procedure

In the ward round simulation, each surgeon performed the ward round scenario once where both patients

Figure 6. A surgeon uses the Wearable Personal Assistant to browse electronic patient records and X-rays in the ward round scenario.

(human actors) lying in the patient bed (Fig. 3-a) were visited. A nurse accompanied the surgeon during the ward round and provided necessary information. The surgeons used the WPA to see the recent EPR and X-rays while talking to the patients (see Fig. 6). They tried both voice commands and touch gestures to interact with the WPA. The patients also asked some questions about the result of the surgery.

8.3. Results

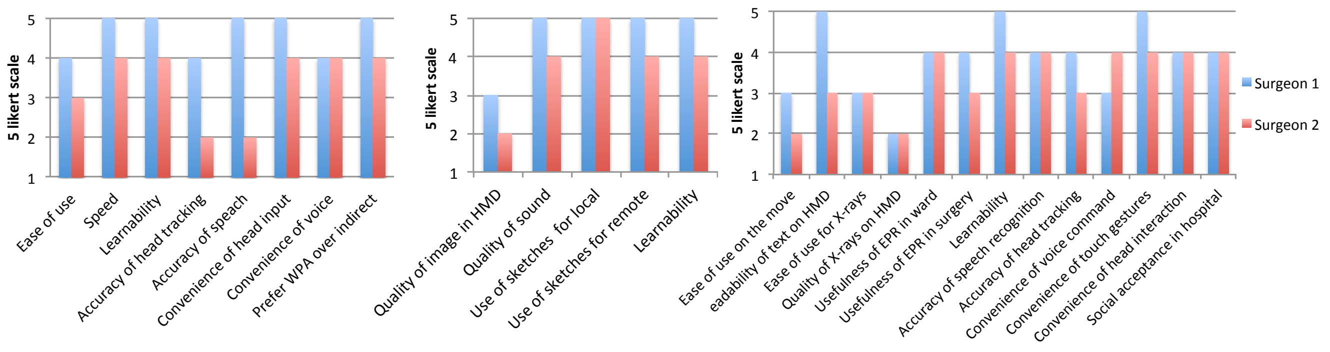
Interview: After having played out the scenario, the surgeons were asked about the pros and cons of the EPR module during ward rounds. P1 mentioned that the most obvious advantage of using the EPR on the Glass is to reduce unnecessary moving between a stationary computer and the ward to check the EPR. However, P2 thinks the small screen in Google Glass makes it hard for the surgeon to read the EPR texts, while a stationary computer is more convenient for such intensive readings. P1 also mentioned that getting an overview of the EPR is much faster using a desktop computer since in Glass the text is distributed over several pages. The other question was about the content that surgeons might need to have access to during a ward round in addition to the EPR and medical images. P2 mentioned that the main information the doctors need during a ward round is lab results that can also be provided on the Glass. However, due to the small size of the HMD in Google Glass, the lab results should be visualized in a way that the interesting results (important abnormal values) are highlighted, and the surgeon can get what s/he wants at a glance. P2 indicated that aside from the medical data, patients usually ask a lot of practical questions about e.g. when they can leave the hospital, when they have their next appointment, etc. The WPA should also provide such practical information to the surgeon.

We also asked about the modality they prefer to use during ward rounds. P1 mentioned that he prefers touch gestures since the voice commands interfere with communication with the patient. P2 said *"I also prefer touch gestures because the head movements look bizarre!"*. All participants (two surgeons, a nurse, and two patients) were asked about the social acceptance of the Google Glass. P2 said: *"Some people might think wearing such a [smart] glasses is arrogant since you are not present with the patient"*. The nurse mentioned that sometimes the surgeon was looking at the HMD but she thought the surgeon is looking at her. Moreover, the patients mentioned that they did not feel good when the surgeon was trying to interact with the Google Glass instead of talking to them.

Observations: During the ward round, P1 spent more time for interaction with the WPA compared to P2 and sometimes there was a long silence until the surgeon read the EPR on the Google Glass. The reason was that P2 was familiar with the medical cases used in the simulation while both cases were new for P1.

9. Discussion

Our study indicates that using the WPA for touch-less interaction with medical images could save surgeons time and energy that can be used for the actual surgery intervention. In part, this is because by using the WPA for touch-less interaction, there is no need for a dedicated nurse to control the mouse for surgeons. However, we noticed some limitations in both voice commands and head movements for touch-less interaction. Using voice commands is a relatively reliable modality but due to the slow speed of the discrete voice commands in our implementation, it



(a) Usability of touch-less interaction

(b) Usability of tele-presence

(c) Usability of EPR

Figure 7. Perceived usability of a) the touch-less interaction module of the Wearable Personal Assistant (WPA), b) the tele-presence module of the WPA, and c) the Electronic Patient Record module of the WPA.

was not an appropriate modality for providing a lot of commands within a short time. In contrast to the voice commands, the head movements were useful for continuous interaction; however, due to the perceptual gap between the image on the large screens and the pointer on the HMD, it was hard to use head movements like a mouse, to control the pointer on the HMD. The lowest scores in Fig. 7a can be attributed to the inaccuracy of the head tracking, in particular for P2. This reveals the challenge of using a head pointer on the HMD for touch-less interaction.

Apart from the perceived low quality of the images shown on the HMD which was mentioned in both the questionnaire (Fig. 7-b) and the complementary interviews, the WPA was successfully used in the tele-presence scenario. As both surgeons mentioned, the tele-presence scenario was the best application for our WPA implementation. However, in this scenario we observed the problem of overlap between human to human conversation and voice commands directed towards the system. This indicates a need for other touch-less input modalities (e.g. gaze) to avoid overlap between the input modality (voice commands) and surgeons' conversation. The most challenging scenario turned out to be the mobile access to the health records in the context of ward rounds which revealed the social problems of using Google Glass in parallel with human to human interactions. Apart from the social problems, the small HMD of the Google Glass turned out to be a limitation for intensive text reading which is in line with the concept of microinteractions [19] that recommends the fact that interactions with the device should not exceed 4 seconds. To achieve such fast interactions, the WPA would need to prepare the information for the surgeons in such a way that the surgeon can get the information at a glance with basically no demand for information navigation.

The three scenarios in this paper made use of three different types of interaction. (1) The touch-less interaction scenario defined the WPA as an *interface between the user and other computers*. In this type of scenarios, the human agent interacts with two different computers in parallel. (2) In the tele-presence scenario, the WPA plays the role of an *interface between two human agents* where the user interacts with another human agent through the WPA and there is no parallel interaction. (3) In the ward round scenario, the user interacts with another human agent (the patient) and with the WPA *in parallel*. If we look at the results of the questionnaires and interviews, we can conclude that the WPA got the best scores in the tele-presence scenario where there was no parallel interaction, and the user interacts sequentially with the WPA and the other human agent (the remote colleague). In the touch-less interaction scenario, the usability of the WPA is assessed by the participants as average. In this scenario, the user interacts with two computers in parallel: the WPA and X-ray/MRI systems. The most challenging scenario was the ward round where the user had to interact in parallel with the WPA and a human agent.

10. Exploring novel input modalities for Wearable Personal Assistants

In this section we present our ongoing exploration of alternative interaction modalities for WPAs, inspired by the findings from the empirical study presented and discussed earlier.

10.1. Magic Pointing: Implicit use of gaze for interaction with WPAs

Since WPAs are supposed to be used on the move and in parallel with real-world tasks, utilising eye movements as a touch-less input modality coul be

Figure 8. In the EyeGrip interaction technique, the scrolling content on the Head-Mounted Display stops automatically when a particular object attracts more visual attention [20].

a big advantage. We investigated the performance and usability of eye movements for pointing towards graphical user interfaces on a head-mounted displays (HMD) compared to head pointing (translating head movements to the pointer position) and a trackball mouse [21]. Our study revealed the higher speed of eye pointing compared to the other pointing modalities while, however, the inaccuracy of gaze tracking on the small HMD led to lower usability of the eye pointing technique. To mitigate the negative effect of inaccuracy of the gaze tracking, we decided to combine head and eye movements for a target acquisition task. We extended the old idea of the MAGIC (Manual And Gaze Input Cascaded)-pointing [22] for eyewear computers [23]. Our MAGIC pointing method utilizes eye movements implicitly for moving the cursor as close as possible to the target where the cursor can be controlled by head movements for fine-grained adjustments. Our comparative study between MAGIC pointing and head pointing showed that the proposed MAGIC approach benefits from both the speed of eye pointing and the accuracy of head pointing. In addition, the MAGIC method decreases the amplitude of head-movements and thus the ergonomic problems when head pointing over long distances.

10.2. EyeGrip: Interfacing with unconscious cognition

Gaze-based pointing on HMDs, in an attempt to mimic mouse-based pointing in classic graphical user interfaces, might at first seem a viable touch-less input modality for WPAs. However, the need for fast interaction techniques possible to be used on the move (microinteractions [19]) and current limitations of wearable devices (in our case, the small screen of Google Glass) calls for interaction paradigms beyond precise control of a pointer on a display. For instance, Google implemented a card-based interaction concept due to the relatively small size of the screen in Google Glass. A drawback is that the user needs to frequently scroll among different *cards* even to select a menu item. This results in long menu navigation stints for applications that use a lot of cards. In an attempt to simplify card selection, we invented EyeGrip [24], a calibration-free interaction technique that helps the user to intuitively stop a sequence of moving visual contents (e.g. cards) displayed on the HMD. The key idea behind EyeGrip is the fact that during a visual search task while we look at the scrolling content, our eyes perform a combination of saccadic and smooth pursuit eye movements which is called Optokinetic Nystagmus (OKN) eye movements. During OKN eye movements, it is very likely that more interesting contents for us particularly attract more visual attention and create a longer smooth pursuit. By tracking eye movements in the same direction of the moving visual field, the system can detect these longer smooth pursuits and react immediately by e.g. stop scrolling and bringing back that interesting content in front of the user's eye (Fig. 8). Our EyeGrip mechanism is an example of how interfacing with unconscious processes in the human brain, in this case monitored through involuntary eye movements, can improve interaction with computer systems. We believe more powerful mechanisms will emerge by taking this approach and that is the reason why we have included "unconscious cognitive processing" in our body-and-mind centric model of future Human-Computer Interaction (path 3-4-9-15 in Fig. 1).

10.3. GlassGaze & EyeDroid: Towards a truly wearable gaze tracker

Our studies on utilizing eye movements for interaction with smart glasses, have revealed a great potential for eye gaze as a touch-less input modality for WPAs. However, in addition to the classical challenges of eye-based interaction such as inaccuracy, calibration drift, and the Midas touch problem, integrating eye

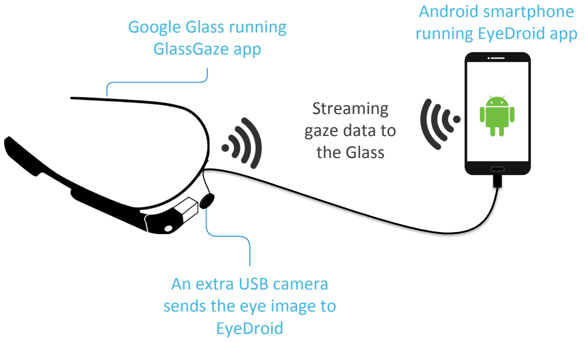


Figure 9. A schematic view of the GlassGaze/EyeDroid system architecture.

trackers with WPAs is associated with technological complexities. The most important technological challenges include (1) building an unobtrusive hardware platform with minimum coverage of the user's field of view and (2) optimizing eye tracking algorithms for wearable computers that exhibit limited image processing resources. To address both of these issues we developed the GlassGaze [25] hardware and software platform for Google Glass together with EyeDroid [26] eye tracking system for Android smart phones (see Fig. 9). The combination of GlassGaze and EyeDroid adds eye-tracking capability to the Google Glass with a relatively high accuracy of 0.5 ° [26]. This modified version of the Google Glass can become a better platform for the orthopedic surgeon WPA because it provides a completely new touch-less modality that can be used to provide input to the WPA. Moreover, the EyeGrip method could be a very fast alternative to touch gestures and voice commands for selecting a menu item or even find medical images without touching the touch-pad of Google Glass.

10.4. Gesture-based interaction with WPAs

Even though the most popular application for gestural control systems is computer gaming, the possibility of touch-less interaction makes gestural input a viable modality for interaction in sterile environments (e.g. [27–29]) and interaction with wearable computers (e.g [30–32]) because the gesture-based interaction leaves users' hands free for performing real-world tasks. In general, body gestures can be detected in different ways from using wearable sensors to environmental sensors. Since the WPA is envisioned to support the user on the move, we tend to favour wearable solutions such as intertial sensors or cameras whenever possible. Since most state of the art smart glasses (e.g. Google Glass) are equipped with a front-view camera, this camera can be used for hand gesture recognition purposes. We developed a hand-gesture recognition system for interaction with electronic patient records on the Google Glass platform [33]. To analyze the captured images we used openCV [2] on the Google Glass but the maximum performance of the openCV was 4-5 frames/second which is is to low for real-time gesture recognition. We also implemented the system on the M100 Vuzix smart glass [3] (Fig. 10). Using the M100 smart glass the performance of the openCV reached up to 10 frames/second which is good enough for some applications. Our gesture recognition method detects 9 different hand gestures and the index finger as a pointer with a precision of 96.91% and a recall of 89.52%. However, the heavy image processing needed for real-time gesture recognition caused a lot of heat in the device which made it shut down every 3-4 minutes.

Figure 10. An illustration of our prototype where a fictive nurse is looking at the electronic patient records through a Vuzix M100 smart glass device and interacts with CT Scans using hand gestures.

11. Conclusions

In this paper, we discussed our body-and-mind-centric approach to design a wearable personal assistant (WPA) for surgeons motivated by the fact that such systems will likely play a role in an increasing set of everyday activities for certain target groups. We empirically investigated the usability and added value of a such a WPA prototype specifically designed for orthopedic surgeons in three commonly occuring everyday scenarios: (1) touch-less interaction with X-rays and MRIs, (2) tele-presence consultancy during surgeries, and (3) mobile access to the Electronic Patient Records (EPR) during ward rounds. Our empirical study in a clinical simulation facility with real surgeons revealed the potential strength and challenges of using the WPA in these scenarios. While the WPA can

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[2] www.opencv.org
[3] www.vuzix.com

be a viable solution for tele-presence and touch-less interaction in surgery rooms, we found that using the WPA in ward rounds interferes with social interaction between clinicians and patients. We speculate that some of the challenges of interaction with the WPA in our empirical study can likely be solved by designing novel input modalities and interaction techniques. Hence, we reported on some of our recent studies on gaze and hand gesture input techniques that turned out to be two promising touch-less modalities for future WPAs, if the limited computation power of current wearable devices (e.g. Google Glass) can be accounted for somehow in the design. We showed how this challenge can be addressed by assigning gaze tracking and gesture recognition to other mobile devices with stronger processing resources (in our case a smartphone). Finally, we briefly also presented our MAGIC pointing and EyeGrip solutions that make an implicit use of gaze to improve interaction with WPAs.

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