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Speech-Controlled Wearable Computers for Automotive Shop Workers

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ABSTRACT

Vehicle inspection in repair shops is often still based on paper forms. Information Technology (IT) does not yet support the entire inspection process. In this paper, we introduce a small wearable IT device that is controlled by speech and enables service technicians to wirelessly access relevant data and to perform on-site communication. Users can carry this device in a pocket and use a small headset to enter speech and receive audio feedback. This system provides a completely speech-enabled functionality and thus offers a hands-free operation. After showing the applicability of wearable computers in this environment, we developed a proprietary hardware system consisting of a thin-client connected via a Digital Enhanced Cordless Telecommunications (DECT) link to a standard Personal Computer (PC) that runs a speech engine and hosts a database. Several field tests in garages helped us during the evolution of our prototypes where service technicians critiqued the prototypes.

INTRODUCTION

Repair shops use a variety of IT tools for supporting inspection and maintenance processes. Few of them offer a consistent redundancy-free and paperless computing support throughout the entire inspection process. Most service technicians performing inspection-related data collection use paper forms they carry through the inspection facility on a clipboard. At the end of the inspection, these service technicians copy the data from the paper forms back to a computer for further processing.

We developed a small mobile IT device that is controllable by natural speech and enables service technicians to access inspection data, control measurement devices, and communicate with other service technicians and the main office. Users can carry this wearable IT device in a pocket or on a belt and can use a small headset to enter speech and receive audio feedback. We first built a self-contained wearable computer system that only transmits inspection data at the beginning and the end of each inspection. In the final configuration, a remote server provides the processing power and the memory necessary to run the actual inspection application software. This server can simultaneously handle up to 4 clients and could be any standard desktop PC available in the repair shop, even the office computer.

During the design of this device, we interviewed the targeted users, which are ‘real’ service technicians at repair shops actually performing the inspections supported by the first, self-contained prototype of this device. This first prototype was based on commercial off-the-shelf (COTS) hardware and enabled us to perform field tests before the actual implementation of the final design. Thus, we got valuable insights into the requirements for the hardware and software design crucial for the success of the next version of this product.

The functionality provided by this system is completely speech-enabled and thus able to be operated hands-free. This functionality includes: access to centrally entered vehicle and order data; hands-free data collection in the garage environment; remote control and access of measurement devices; communication with other service technicians or repair shop personnel; remote data access; or remote automation control via modem. These functionalities are all directly usable from the mobile unit.

MOTIVATION

Today, computers only indirectly support the visual inspection of vehicles at thousands of inspection facilities. The typical visual inspection is a state or government-mandated vehicle safety inspection conducted at a local inspection site. When beginning the inspection of a specific vehicle, a service technician goes to a computer centrally located in the shop and prints out a list of items on a vehicle that are to be inspected and carries this list on a clipboard to the inspection site. The technician notes his findings on these paper forms, having to stop what he is doing to write down inspection results by hand. After completing the inspection, the service technician transfers the data and possible annotations from a paper form into the centrally located computer using a keyboard. This process is shown in Figure 1a.

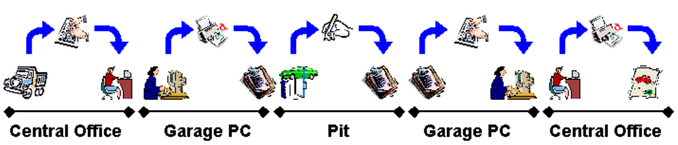

Figure 1a: This figure shows the current inspection process. A series of 5 steps has to be performed which includes three times a manual data entry and a paper-based data collection.

Research on similar applications [1][2][3][4] showed that with the emergence of mobile computing platforms, speech recognition technologies [5], and wireless communication technologies, it is possible to develop a mobile, or wearable computing system [6], referred to as the 'Speech-Controlled Wearable Computer' (SCWC), that aids the service technician in performing his work. As shown in Figure 1b, we envision the SCWC would wirelessly communicate with any central office PC and provide speech-controlled support for the inspection process.

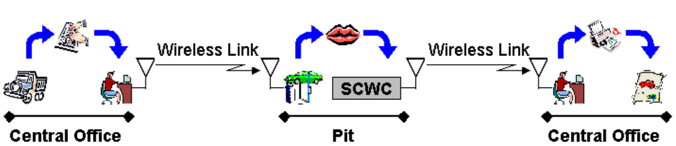

Figure 1b: This figure shows the envisioned inspection process. A series of 3 steps has to be performed, which incorporates full IT support within the garage's office.

We observed current inspection practices and environments at BOSCH inspection sites in the US and in Germany. During our visits to inspection sites, we found that IT support in garages ends at the office of those facilities. Seeing paper-based inspections and manually transferred data, we saw great potential, similar to that stated in [7], to support service technicians during inspections as they work inside and outside the inspection site by providing them with mobile, wearable hardware and software.

One of the main goals however was to build a system that effectively responds to the needs of the end users instead of forcing them to operate futuristic IT gadgets.

OBJECTIVES

The objectives of this project were to prototype a hardware and software system that could be presented to and actually used by technicians, helping us to evaluate the needs and acceptance of future commercial systems. Therefore we took two different approaches with two different devices. One device is based on a commercially available wearable computer – the Mobile Assistant IV (MA IV) from Xybernaut Corporation, which is also used in industrial projects [8][9]. The other device is a proprietary hardware system developed during this project. The idea was to investigate the relative acceptance of two different systems by service technicians of two approaches: 1) a bigger, more complete system; and 2) a smaller system that provides the same information in a more resource-efficient way (with respect to size, weight and costs). This would enable us to propose a device that can be used for future inspection-related tasks in the automotive industry and similar domains.

APPROACH

Before developing an initial prototype, we had no preliminary specifications on how to implement the software, and no guidance on which hardware to choose. Thus, we visited an inspection site, collected information about the current practices, and started analyzing the performed tasks so as to have a good model of the inspection processes, before compiling software and hardware needs into specifications. Smailagic et al. and Siewiorek et al. performed similar approaches in [10][11]. We developed a solid understanding of this vehicle inspection process from which to evaluate the designed and implemented prototypes.

SPECIFICATION OF FUNCTIONALITY

Based on our initial visits to inspection sites and our understanding of the inspection application, we developed an initial functional specification and set of constraints. The main components of this specification are:

- The technician is to execute different tasks for an inspection and collect data. This information is to be combined into a final report for each vehicle.
- A list of vehicles to be inspected is to be entered or retrieved from another computer in the garage.
- The list of vehicles to be inspected is to be sent by wireless communication to the technician while on

the shop floor, where he can easily select the next vehicle to inspect and receive the appropriate list of vehicle items to be inspected.

- The SCWC is to be carried to the inspection pit either on a belt or in a clothing pocket and support the technician's data collection activities: identifying the items to be inspected, recording evaluations for specific inspection items, and reviewing the inspected and evaluated items.
- Since the technician often needs both hands free during the inspection process, the SCWC is to be controlled using speech recognition. The technician's evaluations for specific vehicle items are to be entered using speech recognition.
- Feedback from the SCWC to the technician, such as the command the system believes has been stated, the inspection item the system believes is to be inspected, or the evaluation the system believes was given, is to be provided acoustically, visually, or in both forms, depending on the technician’s desires.
- The inspection data collected for a specific vehicle is to be quickly, easily and automatically transmitted from the SCWC to the centrally located PC, again using wireless communication, when the technician indicates he has completed the inspection. The data is to be stored locally on the SCWC until the inspection is completed.
- This system is to be developed to support the German “Sicherheitsprüfung” (safety inspection). Hence, the language of the first prototype is to be German. However, this system is intended to be distributed in many other countries with equivalent inspection types, and thus a great variety of languages must be eventually supported.
- The SCWC is to be integrated in the garage-wide network with a centrally located PC (in the following referred to as the “Central PC”) and a central reception where vehicle data are entered.
- The use of the SCWC is to be included in the overall process of the German “Sicherheitsprüfung,” which includes aspects of the inspections that are performed outside the pit and for which data is collected at other locations in the garage network.
- The changes within the existing BOSCH software are to be kept to a minimal level and an error during the use of the system must not have impacts on the software operating on the central PC.

With this set of preliminary constraints we selected the hardware for the first system from commercially available components. In this step, we built a system that fulfilled all requirements and offered full functionality. By offering a full-featured system, we could later derive the actual needs to perform the target application. The proprietary hardware system would then be designed to fulfill the second, smaller set of requirements.

COMMERCIALLY AVAILABLE HARDWARE

We wanted to field-test a head-mounted versus a flat-panel display for acceptability of technicians. We planned the prototype to be connected to a Wireless Local Area Network (WLAN), which led to a requirement for a PCMCIA card slot to connect the wireless network adapter. This feature enabled us to connect to and test with Carnegie Mellon’s campus-wide wireless network before integrating the device in the garage network for a field test using the hardware available in repair shops (see Figure 5a). At the time the project was conducted, the only product we believed met our requirements was the Xybernaut Mobile Assistant IV. The total cost for the system, described in the section “Hardware of Prototype I”, was about $10,000.

APPLICATION SOFTWARE

To add the functionality defined in the functional specification to the initial prototype, we had to develop the speech-controlled inspection software. This inspection software was specified to fit into the BOSCH repair shop software application family. We developed the Graphical User Interface (GUI) of the first prototype to be very similar to the existing BOSCH applications (see Figure 2). By doing so we felt that the application would be easily used by technicians already familiar with BOSCH software. In the final prototype, which is a thin client (the mobile device has only a minimal hardware configuration), the GUI is replaced with a text-only display (see Figure 3) that provides only the essential information needed to support the interactions between the service technicians and the mobile device during inspections.

Figure 2: GUI of the first prototype, which fits into the BOSCH application family.

The development of the software included several tasks. First, we had to integrate the speech-control. For this, we used two different Software Development Kits (SDK) from Lernout & Hauspie: “ASR 1500”, a telephony, multi-client Speech Recognition System (SRS), and “ASR 1600”, the SDK for speech-controlled multimedia applications. Second, we realized the wireless connection to the existing garage network and the data exchange with BOSCH's inspection software. Finally we developed a database containing all necessary inspection data and speech vocabulary.

Figure 3: Text-based display of Prototype II

PRELIMINARY FIELD TESTS

Throughout the development process of this prototype, our goal was to evaluate the functionality and usability of the system and get response from end users as soon as possible. Therefore, we conducted several performance tests, presentations at BOSCH, and surveys with technicians who perform vehicle inspections. Those technicians are real inspectors doing performance tests in their actual working environment – the garages they work in. Thus, we gained insight about how these service technicians would interact with the system, how they like working with the system, and how the system performs within the noisy garage environment. Through this interaction we got valuable feedback, such as biases against carrying an IT device through the pit, the objection to the head-worn display (HWD) because of usability concerns, or the wish for a specific vocabulary. Those field tests and presentations throughout the design and implementation process of the first generation helped us to clearly define the needs and restrictions to include into the specifications for the second-generation prototype.

CRITIQUING AND REDESIGN

Diverse BOSCH departments and the service technicians critiqued the completed prototype based on the Xybernaut MA IV before we set up the functional requirements for the final device, using BOSCH-developed hardware, and worked on the specifications for this device.

The second-generation device evolved as a thin client concept in response to the technicians' desire for a smaller, less expensive speech-controlled device. Based on this feedback, we explored the possibility of building a device without local memory, processing power, or an expensive display that could still support speech-controlled interaction. Thus we went from a self-contained wearable computer to a thin client concept, which uses remote processing and remote memory resources.

PROTOTYPE I: THE COMMERCIAL HARDWARE

As described in the previous section the first part of the project involved building a software and hardware system based on commercially available components.

Hardware of Prototype I

The first prototype was based on a Xybernaut MA IV (Figure 6 and Figure 7). We chose the highest available configuration of the MA IV: 160 MB of RAM, Pentium MMX 233 MHz and 4.1 GB harddrive. We also decided to test the flat-panel and the head-worn displays. After evaluating a self-contained version of the software we additionally purchased wireless LAN equipment consisting of a Lucent WaveLAN access point and PCMCIA cards to integrate the MA IV in the garage's existing wired Ethernet network.

SOFTWARE OF PROTOTYPE I

We tried to adapt the graphical user interface from Bosch's inspection software to keep irritations from an unfamiliar user interface at a minimum. Obviously, we had to adjust this interface to better suit the needs of a mobile, wearable system. For example, we used a larger font (see Figure 2). Since we had additional input/output interfaces we had to enable the user to make use of and profit from those improvements. The ideal SCWC interface would be one that is fully adaptable and able to respond to the user's behavior and the capabilities of the IT environment, such as the presence of a graphical display or a text-only display.

Lernout & Hauspie's speech recognition SDK, ASR 1600 allows developers to include speech control using languages like C++, Java and Microsoft Visual Basic. Since we used Visual Basic for prototyping the systems, we could test this software and simultaneously be open to change the development environment for future projects. We chose ASR 1600 because it is a speaker-independent SRS that also supports English and German, the two languages we had to support for this project.

Figure 4 shows the 3 tiers of the application software. We separated the input and output for visual and audio feedback from the control part. The database tier stores both the inspection data and the speech data, which enables the exchange of the underlying inspection with only exchanging the database.

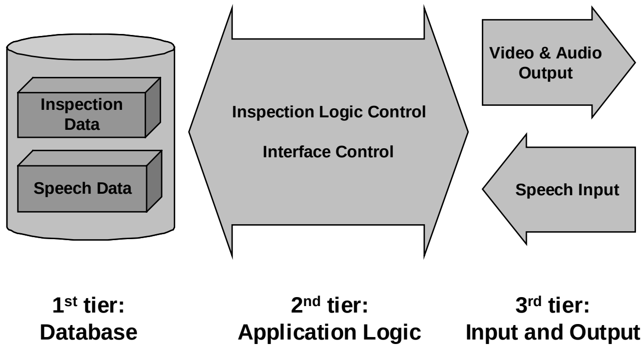

Figure 4: This figure shows the three tiers of the software architecture. The Control Tier sits between the input / output components and the data structure for the inspection data and the speech data.

While performing an inspection, the application guides the user through the different levels of the inspection indicating where the service technician found defects and which parts are yet to be inspected. In defining those levels, we could restrict the active vocabulary to well below 100 phrases per level. This structure of different levels had two effects: It reduced the number of items to be simultaneously shown on the display; and it increased the recognition rate due to a smaller number of possible results (i.e. recognizable phrases).

PROTOTYPE I: RESULTS OF TESTING

The field tests of this first prototype demonstrated a reasonably good acceptance by the participating technicians. In subsequent interviews, they indicated that they liked the idea of getting assistance during work but were mostly dissatisfied by the size and the weight of the Xybernaut system. Since these service technicians have to move within the pit and sometimes need to crawl into the wheel cases of trucks, they were also concerned about damaging the system or being restricted in their movement. On the hardware side, they expressed the desire to have less cabling and an easier attachment of the wearable system. The technicians rejected the head-worn display and expressed preference for the flat-panel display. They expressed a desire for a small preferably arm-worn display even without a graphical user interface.

The performance of the speech recognition system (ASR 1600 from Lernout & Hauspie) was very good in moderate conditions and acceptable even in difficult conditions, such as noisy garage environments with a running truck engine. We estimate a recognition rate around 95% under noisy conditions and around 98% with less background noise.

Finally there were some financial concerns: one service technician expected the price for the system to be about 5,000 DM (US$ 2,500) and imagined that this would be too expensive to economically operate the system in smaller garages where the frequency of vehicle inspection is not very high. He felt an acceptable retail price would be less than 1,000 DM (US $500).

PROTOTYPE II: PROPRIETARY SYSTEM

In the second part of the project, we compiled new specifications for a revised device, built a second prototype hardware from scratch and changed the software to suit the new system while reusing most of the code from the first generation of prototypes.

The main design objectives for the second-generation hardware platform we developed were significant reductions in hardware cost, size, and weight. Consequently, we abandoned the concept of the mobile unit being a self-contained computer. In the second generation system, the speech-recognition engine and the application reside on a remote server, to which a streamlined client is connected via a wireless link that provides the necessary bandwidth and communication range for repair shop applications (see Figure 5b). This system concept makes use of existing infrastructure to the largest extent possible. Any personal computer in the repair shop could be the server. Hence, additional investments for the repair shop are minimized, as the repair shop would only need to acquire the mobile units and one base station. One base station can simultaneously manage up to 4 mobile units.

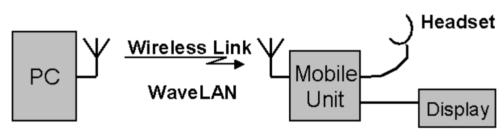

Figure 5a: This figure shows the hardware architecture of the self-contained Xybernaut MA IV connected to a PC within the garage's network via a wireless WaveLAN.

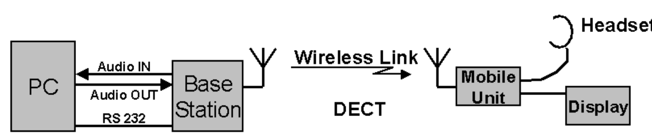

Figure 5b: This figure shows the hardware architecture of the thin client connected to the office PC via a data and speech channel.

The body-worn unit consists of the mobile base unit (which fits in a pocket), an arm-mounted display, and a headset. The mobile base unit comprises a DECT chipset and some peripheral circuitry, rechargeable batteries, and connectors for the display and headset (see Figure 5b).

DECT was selected as wireless link protocol because of its communication range, small roundtrip delay, high-quality voice transmission (using adaptive differential pulse code modulation), its ability of one base station to communicate with multiple mobile units, and its built-in dynamic channel selection and allocation. Our design is based on a proprietary DECT chipset for parallel transmission of voice and data on separate channels. The DECT chipsets used for our prototype system were designed by the Fraunhofer Institute for Integrated Circuits.

We learned from the initial field tests with the Xybernaut Mobile Assistant that the service technicians found its VGA display was too bulky, and wanted to have a non-graphic text interface that would only display a list of those inspection items that could be selected at a particular instant. Service technicians made reference to mobile phone displays as examples of the desired display. We used a 160 by 160 pixel display (see Figure 3). With a font size of 8 x 12, we are able to display 12 lines of text with 20 characters per line. The data rate for transmitting the text to be displayed from the remote server to the display controller is 57.6 kbps. This data rate ensures an appropriate display refresh time.

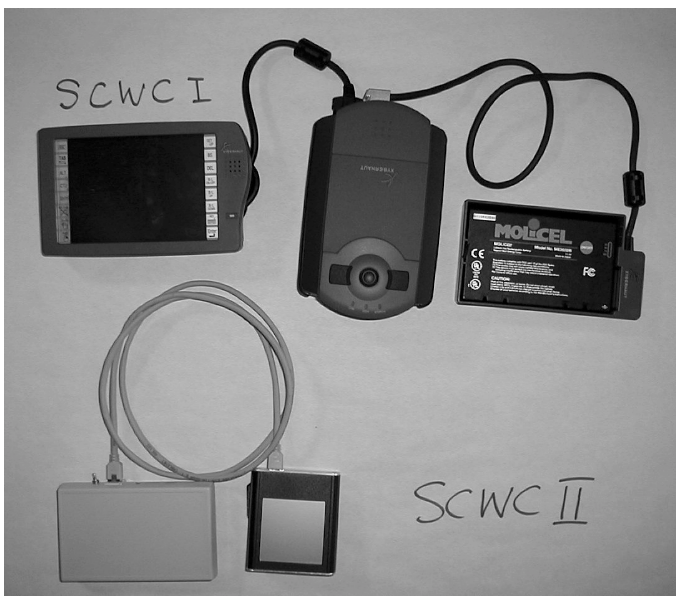

Figure 6: This figure shows both prototypes, the Xybernaut MA IV above, and the proprietary prototype below.

PROTOTYPE II: REVISED SOFTWARE

For the hardware described in the previous section, we had to change the software to suit a client/server environment. Based on the modular concept of the software architecture and the fact that we developed a self-contained application for the Xybernaut platform, we were able to keep most of the code. We added a module that enabled the application to be controlled by one or more remote thin clients. We had a very short development time for the software addition, which enabled us to keep up with the realization of the second-generation hardware, which was prototyped within only 6 weeks.

Another positive factor contributing to the short redesign time was the availability of a multi-client telephony version of the ASR speech recognition development kit, the ASR 1500. We had to change to this SRS because we used a DECT voice channel with limited bandwidth and we wanted to support multiple clients.

The module that needed most of the work was the video output since we downgraded our display according to the needs of the user to a text-based 12x20 characters display. To accommodate this reduced display, we enabled the list box of the GUI of generation 1 (see Figure 2) to communicate via the serial port and display itself on the new text-only display. By only having to transmit the text description of the list items, we kept the data traffic on the wireless link low enough to provide a fast display refresh rate. To allow the voice and data transmissions, we had to enable the application to initially connect to the mobile unit via the serial port and set up a DECT voice and data connection. As soon as this connection exists, it is transparent for the client/server application and the remote clients act like remote speech and control units. Thus, this transparent DECT connection allows the new mobile hardware to communicate with a slightly modified version of the application developed for the first prototype generation.

COMPARISON OF PROTOTYPES

The second-generation platform is a thin client and thus restricted in the functionality it can support (see Figures 5a and 5b). The Xybernaut MA IV, on the other hand, provides more general-purpose functionality but is larger, heavier, and more costly than the second-generation hardware platform we developed (see Table 1). For the vehicle inspection application, the functionality provided by our hardware platform is sufficient and the hardware is much lighter and cheaper. We are aware of the fact that there are applications that require local resources and a self-contained system, but in an inspection environment, in which a computer could be located within an accessible area, we think that the thin client has clear advantages.

At the time of writing, a basic configuration of the Xybernaut MA IV system is priced at $7,000. Using the second-generation thin client, we can provide the functionality requested by the service technicians with an estimated manufacturing cost of $200-$250.

Compared with the first generation hardware, we also achieved a 75.8 % reduction in size (mobile base unit incl. batt.); 81.3 % reduction in weight (mobile base unit incl. batt.); and 100 % increase in operating hours per battery charge.

Property	Xybernaut MA IV	SCWC Prop. HW
Weight of mobile base	795g (without external battery pack)	318g (batteries included / built-in)
Size mobile unit [LxHxW]	190x63x117mm^3	146x29x92mm^3
Weight of battery pack	450g	included in mobile base unit
Size of battery pack [LxHxW]	136x19x81mm^3	included in mobile base unit
Weight of display	280g	168g
Size of display housing	190x41x119mm^3	91x24x82mm^3
Resolution of display	640x480 pixel VGA	160x160 pixel Monochrome
User Interface	Graphical User Interface	Text-based (12x20 characters)
Battery Life (per charge cycle)	4-6 hrs	10-12 hrs

Table 1: This property comparison of the two prototype generations shows the advantages of the proprietary hardware for the developed application.

BENEFITS

We envision a great potential for these devices in the automotive and similar industries. With the elimination of paper-based data collection and a consistent IT support throughout the inspection and maintenance facilities, we see timesavings and a higher data quality for those tasks. Through the support and guidance of such an IT system that can be worn during the whole shift, the worker will be freed of carrying manuals or approaching centrally located PC terminals to look up information, contacting hotlines or ordering parts.

Figure 7: Service technician using the Xybernaut MA IV in front of the shop floor PC running the inspection software

To date, the savings of using a self-contained system such as the Xybernaut MA IV can only be achieved in tasks that are highly time-critical, need multimedia capabilities, and that are performed in moderate environmental conditions. Additionally, for smaller businesses the costs for such systems are still too high to justify their use economically. With the emergence of more unobtrusive and cheaper versions of wearable computers in the future, those problems could be overcome.

The thin client system described in this paper provides clear advantages over the fully self-contained system for certain applications, such as the described safety inspection application. For tasks where only a limited graphical feedback is needed and where data transmission could be reduced to a minimum, a DECT client/server system is an appropriate, affordable system that can be integrated into existing computing environments with little interference with this environment.

CONCLUSION

The goal of the project was to design an IT system that supports inspections in garages. Therefore, we had specific environmental and workflow constraints. We wanted to support service technicians without bothering them with overwhelming technology. Therefore, we created an initial functional prototype using commercially available hardware and software to show to potential users and get feedback on their opinions about the concept. This enabled us to save a large amount of effort in designing and prototyping a system from scratch for testing purposes. Using these prototypes, we could more successfully extract the user’s needs by having them evaluate an existing device. Given this more refined specification, we could design and build a thin client based on DECT technology, and we specialized that device to fulfill the needs of service technicians. We will continue to research and develop this thin client concept.

On the software side we could use most of the code for the second-generation device that was written for the first generation device. Although we had a major change in the concept - from a self-contained mobile unit with wireless data exchange using a WLAN environment to a thin client concept connected via a wireless data and voice channel based on the DECT technology – the software was designed as a modular, 3-tiered architecture that could be easily modified to support the changes in the hardware. Based on the success we had in evolving the software from generation 1 to generation 2, we will further research these modular, multi-tier software architecture concepts to determine how best to support the evolving hardware and desired functionality for mobile computer applications.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

COTS:
Commercial off-the-shelf; non-proprietary products that are commercially available

DECT:
Digital Enhanced Cordless Telecommunications

FPD:
Flat-Panel Display

GUI:
Graphical User Interface

Headset:
A combination of a microphone and a headphone

HWD:
Head-Worn Display

IT:
Information Technology

PC:
Personal Computer

PCMCIA:
Personal Computer Memory Card International Association; term for credit card-sized card that offers additional features to portable computing devices (PCMCIA cards) that fit in the appropriate slots (PCMCIA slot)

SDK:
Software Development Kit

SCWC:
Speech-Controlled Wearable Computer

Sicherheitsprüfung [German]:
Safety Inspection

SRS:
Speech-Recognition System

Thin Client:
Client side of a client/server system that has minimal system configuration regarding processor power, memory, or storage capacity

WLAN:
Wireless Local Area Network