Design and Implementation of a Mobile Device for Outdoor Augmented Reality in the ARCHEOGUIDE Project

Tim Gleue, Patrick Dähne

ZGDV – Computer Graphics Center
Rundeturmstrasse 6
64283 Darmstadt, Germany
{tim.gleue, patrick.daehne}@zgdv.de

Abstract

This paper presents the design and implementation issues associated with the development of a mobile device for the ARCHEOGUIDE project. We describe general and application specific design goals as well as the technical requirements the implementation is based upon. Since speed is crucial for an interactive application we provide a survey of mobile and wearable computing equipment especially considering performance aspects. A detailed overview of available hardware components follows. We describe the decisions made during prototype development and present the final result – a mobile unit for outdoor Augmented Reality tours in cultural-heritage sites. Finally we discuss the experiences we made using the system during a first trials phase at ancient Olympia in Greece.

1 Introduction

The ARCHEOGUIDE (Augmented Reality-based Cultural HEritage On-site GUIDE) project aims at providing visitors of cultural-heritage sites with archaeological information in an innovative and compelling new way. Instead of rebuilding historical remains and thus interfering with archaeological research Augmented Reality (AR) techniques are used to present virtual reconstructions of the artifacts in the real environment. Visitors equipped with a small mobile computer and a display unit (e.g. a head-mounted display) are able to experience the real site while appreciating visualizations of the virtual reconstructions integrated seamlessly into the natural field of view (see Figure 1).

Therefore the mobile device permanently tracks the visitor's position on the site. By additionally determining the viewing direction the ARCHEOGUIDE system is able to compute the current view of the reconstructed objects. The rendered images are finally shown in the display unit, yielding an augmented view of the real world adapting to the user's movements in real-time.

Since the impression of the augmentation mainly depends on the quality of the fusion of virtual and real images, i.e. the exact placement and projection of the models into the user's field of view, determining position and orientation – the pose – is the crucial task to be performed by the mobile device besides visualization of the virtual objects. However, tracking the user's pose is not trivial, i.e. it requires extensive computation and high-quality input data. That's why the choice of suitable hardware components for a reliable mobile AR system is elementary and needs thorough consideration.

Figure 1. Augmented view of the Hera temple in ancient Olympia, Greece

The next section gives a brief overview of related work in the field of mobile computers for AR systems. In section 3 we present the initial requirements analysis carried out for the ARCHEOGUIDE mobile unit. The main part, which covers the implementation issues in greater detail and discusses the choices we made during prototype development, is contained in section 4. Section 5 deals with the results of the initial evaluation of the device in a real site under true working conditions. Finally we conclude with a short outlook in section 6.

2 Related work

Augmented Reality systems have been studied extensively in the recent years. A central question to these systems is the determination of the user's position and orientation. Various tracking methods that yield reliable data to correctly superimpose the correct aspect of the virtual objects into the user's field of

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view have been proposed. Especially hybrid tracking methods rely on a variety of sensors like gyroscopes and electronic compasses that have to be integrated in such an AR system. Consequently much work has been dedicated to the special issues of such devices, e.g. [1] and [17]. Also, mobile outdoor applications greatly extending the field of applications in a natural way have been studied, e.g. in [3], [6], and [8]. In a mobile scenario the choice of suitable hardware requires special consideration. Although wearable computers have gained a lot of interest in the research community (see e.g. [4], [9], and [17]), most AR applications demand for especially designed devices. In this sense, our work proceeds in the direction already pointed out by [4] in that it focuses on off-the-shelf hardware freely available instead of custom designed components.

3 Requirements analysis

Since the ARCHEOGUIDE mobile unit (MU) is supposed to be carried around by visitors roaming freely on the site it must be designed to be small, lightweight, and easy to handle, even for unskilled user. Thus, it has to be an intuitive to use wearable or portable device. Moreover it must be robust enough to withstand rough outdoor conditions keeping the efforts and costs for maintenance as small as possible.

Apart from these mere general, application-driven requirements more technical ones must be taken into account, too. The most important one is processing power, because user tracking and object visualization have to be accomplished in real-time. The system should at least be able to update the augmented view of the real world 10 to 15 times per second, which strongly affects the choice of the central processing unit (CPU) and optional hardware accelerators.

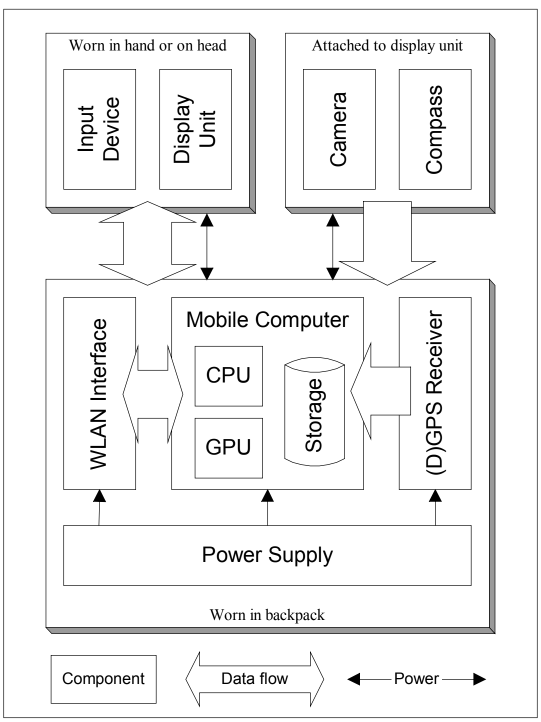


Figure 2. System diagram

Furthermore connectivity is another major issue, as many peripheral devices need to be attached to the main module. First of all, a display unit such as a head-mounted display (HMD) or a portable liquid-crystal display (LCD) of reasonable resolution is required. It is used to present the augmented images of the reconstructions as well as the system's user-interface. In order to interact with the ARCHEOGUIDE system a mobile input-device has to be provided. A touch-screen integrates best with a portable LCD solution but using a HMD makes it necessary to have an extra device, which is easy to use outdoors.

Position and orientation tracking is facilitated by a camera and an electronic compass both mounted to the display unit, capturing and measuring the user's current field of view. Additionally a (D)GPS receiver determines the visitor's position on-site delivering rough initial estimates to the tracking software.

Although ARCHEOGUIDE units are self-contained, i.e. all the data presented to the visitor is stored locally on the MU, a wireless network (WLAN) interface is required. It allows communicating with other units, e.g. to synchronize certain presentations for groups, and with a centralized site-server distributing updated datasets and keeping track of the individual units on-site.

General	Technical
Small and lightweight	High processing power
Wearable or portable	Opt. hardware accelerators
Robust and outdoor usable	Peripheral interfaces
Easy to handle	Low power consumption
Low price	Long running time

Table 1. Mobile unit design goals

Evidently the MU's main module does not only need to provide suitable interfaces to all of these peripheral devices but also power to drive them. So special care must be taken regarding the power consumption of the various components as well as the power supply included in the MU, since additional batteries produce extra weight. In the end, the ARCHEOGUIDE system should at least allow tours of two hours without recharging or exchanging batteries.

Table 1 summarizes the applicable design goals. Obviously some of them are contradictory, so that a reasonable trade off between them has to be found.

4 Implementation

To meet the above design goals and to keep the price of a single MU as low as possible, we chose to rely solely on currently available commercial-off-the-shelf (COTS) components. Figure 2 shows the system structure of the ARCHEOGUIDE mobile unit. In the following sections the illustrated components are discussed in more detail and the choices we made are presented. The evaluation of the final system follows in section 5.

4.1 Computer

The MU's core consists of the portable computer and its power supply. Although originally not designed for lightweight portable environments, we decided to use Microsoft's Windows operating system family on Intel compatible processors. Virtually all off-the-shelf devices are shipped with suitable driver software already, dramatically reducing the effort to integrate them into the system. On the other hand, fixing the system type in such a way, strongly limits the choice of appropriate computers. We compared different currently available wearable, mobile and portable devices (cf. Appendix A) especially considering their hardware properties: processing power offered for tracking and rendering, types and number of interfaces already built-in or at least optionally available, required power supply and potential running-time, as well as weight and size, which ultimately determine the user's convenience using the system.

The survey shows that due to the massive performance requirements for real-time tracking and visualization on the one hand and the high connectivity needed to attach all the peripherals on the other hand, the only reasonable choice is a generic laptop computer, although weight and size are still far from optimal. Instead of a small belt-worn system, we now get a slightly larger unit carried around in a backpack (see Figure 4).

a) Generic laptop b) Sony VAIO

c) Saintsong ESPRESSO d) Cell PLUG-N-RUN

e) Xybernaut MA IV f) ViA II PC

Figure 3. Portable and wearable computers

However all specially designed and readily available wearable computers either lack interfaces that are absolutely necessary (or supply them through a port-replicator/docking station rendering their compactness obsolete) or fail to have a CPU powerful enough for the ARCHEOGUIDE context. Since computing power is crucial, the choice between the large amount of generic laptops can be further narrowed down by demanding an additional state-of-the-art 3D graphics accelerator to relieve the CPU from the load of performing two compute intensive jobs.

Currently only NVIDIA offers a special mobile, i.e. low-power, version of its well-known GeForce2 chip [10] that allows high-quality 3D graphics on standard laptops. At the time being Dell [6] and Toshiba [18] are the only manufacturers integrating this chip within their Inspiron and Satellite series, respectively.

For our MU we chose the Dell Inspiron8000 equipped with a 1GHz Intel Pentium III processor and NVIDIA's GeForce2Go graphics accelerator. Previous tests of Inspiron series laptops had also proven that their second battery slot allows extremely long running-times and that their design was compact as well as robust enough for mobile outdoor-use. Furthermore the Inspiron8000 provides a wide variety of built-in interfaces for external devices such as USB, IEE1394/FireWire, VGA, PCMCIA/CardBus, etc. Hence no extra port replicators were needed, keeping size and weight of the overall system low.

4.2 Display unit

The display unit serves as the mobile unit's main output device. It is used to present the user-interface, the multimedia data about the site as well as the augmented virtual reconstructions of the historical artifacts. Two alternative solutions were considered for the ARCHEOGUIDE unit: a small, portable LCD similar to a Palmtop device (see Figure 5a and b) and a typical HMD as in many AR systems (see Figure 5c and d).

The main advantage of the LCD solution is its intuitive and flexible way of use since LCD panels with an optional touch sensor are quite common today and appear in a lot of applications, like cell phones, PDAs, and WebPads. Moreover HMDs are often uncomfortable to wear and raise security issues, especially when used while walking on sites with uneven ground. Nevertheless we decided to use a HMD since most LCDs suffer from extremely low contrast in outdoor environments with bright sunlight, rendering the display almost unreadable.

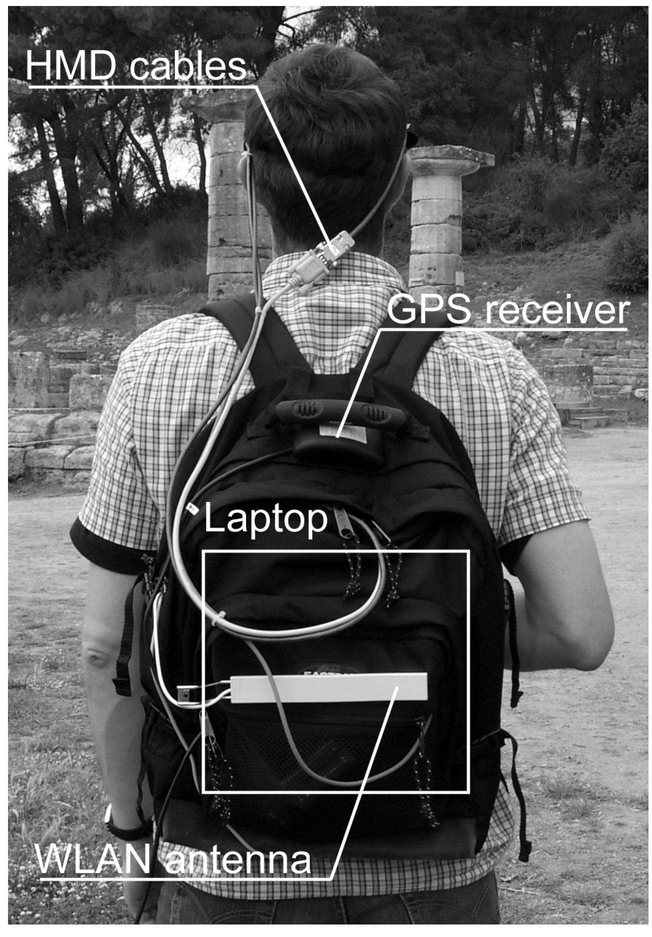


Figure 4. Mobile unit's main module in backpack

There are two types of HMDs applicable for AR. One type uses a see-through scheme with the overlay images displayed "between" the real scene and the user's eye. Thus superimposition of the real and the virtual image takes place in the user's eye, allowing also real stereo views if both eyes are fed with separate images. The other type has a closed back as in VR applications displaying a readily mixed image comprised of the background and the virtual objects. In this scheme true stereopsis is harder to obtain, but on the other hand no extra calibration of the HMD with respect to the user's eyes is required. The AR system simply provides the display unit with a readily mixed background image comprised of the real view an the virtual objects, which is then shown to the user.

We decided to use the second approach, for the sake of easy handling. It allows the HMD to be worn and removed from the user's head during a tour without performing any extra calibration steps. This increases usability of the MU and meets perfectly with the initial design-goals.

Two different kinds of HMDs were used for the MU. A conventional Sony Glasstron [14] worn on the head and a binocular-like but also Glasstron-based n-Vision VB-30 [11], carried by a band around the user's neck. Both devices have a camera (see Section 4.3) and an electronic compass (see Section 4.4) attached, to capture and measure the user's current view and viewing direction for tracking, respectively.

4.3 Camera

The determination of the user's exact position and orientation parameters, the so-called pose, is based on a video-tracking algorithm that analyzes the user's current view for special features. That is why a camera has to be attached to the display unit, permanently capturing the field-of-view and transferring the image sequence to the MU's main module.

The more images the system can process the more accurate the user's pose can be extracted. Consequently there are two primary requirements for a suitable camera: the image quality and the maximum frame-rate it is able to capture. Moreover the camera must be able to capture color images because the image sequence is not only used for tracking but also as the background image in the display unit (see Section 4.2).

a) Palmtop computer

b) WebPad

c) Sony Glasstron

d) n-Vision VB-30

Figure 5. Possible display unit solutions

Like frame-rate image quality, i.e. pixel resolution and color depth, is mainly determined by the interface used to link the camera with the CPU. Basically there are three alternative interface types, again considering only off-the-shelf components: Universal Serial Bus (USB), IEEE1394/FireWire, and analog-to-digital converters – so called frame grabbers.

USB cameras are highly available and widespread (mainly as Webcams) and besides their low price they're reasonably small and very flexible to use, because USB allows connecting and disconnecting devices without restarting the whole system. However, since bandwidth on USB is limited to 12MBit/s image size, color depth and maximal frame-rate are restricted to a color image of 320x240 pixels at roughly 15fps. Alternatively attaching the camera through a IEEE1394 interface allows to increase image quality and frame-rate dramatically since it offers bandwidth up to 400MBit/s. But currently IEEE1394 cameras are not as common as their USB counterparts and are significantly larger and more expensive due to the complex interfacing technology. The third alternative, using a conventional analog camera and a suitable analog-to-digital converter (frame-grabber) to gain digital image sequences, offers the largest amount of freedom to choose between image-quality and frame-rate and also the widest variety of cameras. Yet, frame-grabbers usually use a direct interfacing technology (e.g. PCI) to link to the computer backplane, which is not available on mobile computers and laptops. Only a few models exist, which connect to laptops through a PCMCIA/CardBus slot.

For the ARCHEOGUIDE mobile unit we decided to use as well USB as IEEE1394 cameras, mainly because of their ease of handling and the low price. Both types of interfaces are already built into off-the-shelf laptops and require no extra cards or adaptors apart from the power supply, which in turn can either be implemented as an extra battery or taken directly from the computer's backplane.

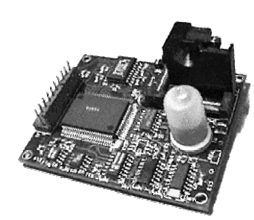
4.4 GPS and Compass

For a first rough estimate of the user's position and orientation we use conventional tracking sensors, i.e. differential GPS for the position and an electronic compass for the orientation. Alternatively, inertial sensors or gyroscopes could be used but the drawback of these sensors is that their errors tend to sum up over time, so calibration would be necessary during the visitor's tour restricting his ability to roam freely. In contrast GPS and compass show a constant error, which can be precalibrated during the installation of the system.

Usually GPS receivers provide the current longitude, latitude and altitude. Because this spherical coordinate system is quite unhandy to determine the position of a visitor in a relatively small area, these values are converted to Cartesian UTM coordinates based on meters.

To further improve the accuracy of the position values, we use differential GPS, where a base station of exactly known location computes the current error introduced through atmospheric effects, for example, and distributes differential correction data via the wireless network. The GPS receiver attached to the mobile unit uses these values to adjust its position computation process. Since the use of differential correction data increases accuracy from about 5m to about 0.5m the ability to process correction data was one of the most important requirements for a suitable GPS receiver.

a) Garmin GPS 35-LVS



b) PNI TCM2-50

Figure 6. GPS and electronic compass modules

Apart from the accuracy issues connecting the GPS receiver to the MU is another part worth considering in detail. Almost all available receivers use the standard protocols NMEA 0183 and RTCM 104 for position and correction data, respectively, thus allowing to easily exchange products of different manufacturers. Having the choice between PCMCIA/CardBus cards, which need no separate power supply but require an external antenna to be placed outside the backpack, and the prevalent models connected via the serial port, we chose the serial Garmin GPS 35-LVS [8] because of its compact, robust housing and the fact that PCMCIA slots are scarce in most suitable computers (see Table 4 in Appendix A). Although serial ports are still available, USB connections ought to be preferred because they are easier to replicate and more flexible to handle. However, receivers connected via USB are virtually not in the market at the time being. Yet, a variety of USB-to-Serial adaptors are.

Like GPS receivers most electronic compasses are attached via serial ports and communicate using the NMEA protocol. For ARCHEOGUIDE we chose the TCM2-50 [13] compass module from PNI, because of its electronic gimbaling, its tilt-compensation up to ±50°, and its extremely low power-consumption. Besides the compass heading, this compass also measures pitch and roll angles, which are valuable additional information to the tracking process since they reflect the rotation of the user's head if the compass is mounted directly to the HMD, like in our case.

4.5 Interaction

User interfaces of classical desktop systems consist of windows and menus that are operated by using keyboards and pointing devices like mice. Obviously, this kind of user interaction is not appropriate for a mobile unit equipped with a HMD. Although the user can see the interface at any time directly inside his field of view wearing the display on his head, he is not able to type text on a keyboard or operate a mouse when walking around. Besides these ergonomic issues we also had to keep in mind that the typical user of the ARCHEOGUIDE system is not used to operate graphical user-interfaces. Most of the visitors of historic sites are not even familiar with computers.

Our solution to this dilemma is the creation of an extremely simple user interface similar to on-screen-menus of television sets, camcorders, or game consoles. Menu items are brightly colored and correspond to a small set of similarly colored buttons on the input device. The distinctive color-scheme and the small amount of active elements makes it possible to operate the device even blindfolded.

In such a simple case, an ordinary gamepad used to control computer games and game consoles will do perfectly as the input device. Again the question of linking the device to the main unit must be considered. Even though a variety of devices exists that are connected through special controller ports or the serial port, we chose to connect the device via USB. As already stated above, USB offers the most flexible handling since ports can be easily replicated and devices plugged and unplugged without restarting the system, which strongly increases robustness and improves handling as well as maintenance significantly.

5 Evaluation

The ARCHEOGUIDE mobile unit consisting of the laptop computer carried in a backpack, GPS receiver and WLAN antenna fixed on its outside, and a HMD with a camera and an electronic compass attached was tested on-site in ancient Olympia, Greece (see Table 2 and Figure 7).

Due to limitations of the video-tracking module [13] we had to limit the user's freedom to move around and be able to see augmented views from anywhere on the site. Instead of free roaming and also for the sake of testing usability and acceptance of the system, we decided to lead the visitor through a guided tour. Depending on the position on-site, different multimedia presentations, i.e. audio and video clips as well as 3D animations are played back. At seven especially marked points during the tour, the user is instructed to wear the HMD. From this instant on he is able to move freely in a perimeter of some meters and have a panoramic view of the nearby temples and the respective virtual reconstructions (see Figure 1).

The components' compact design rendered wearing and using the unit intuitive and comfortable even for long periods, although weight and size of the fully equipped backpack are still far from the desired optimum of a truly mobile or wearable system (see Table 3). However, starting and maintaining the running system inside the backpack is still an expert's job and requires extensive technical skills. The decision to use as much hot-pluggable devices (e.g. through USB) as possible allowed replacing single components easily without further interference reducing the need to stop or restart the whole mobile unit.

Main module		
	Device	**Port**
Computer	Dell Inspiron8000, Intel Pentium III 1GHz, 128 MB RAM, NVIDIA GeForce2 Go, 32 MB VRAM	-
WLAN Interface	Lucent ORiNOCO, IEEE802.11b, 11Mb/s, DSSS	PCMCIA
(D)GPS Receiver	Garmin GPS 35-LVS via two Serial-to-USB adaptors for NMEA 0183 and RTCM 104 data	USB
Power supply	All: two internal 56Wh Li ION batteries	-
Display unit I		
	Device	**Port**
HMD	Sony Glasstron LDI-D100BE	VGA
Camera	ADS PYRO 1394WebCam, 1/4" sensor, 320x240 pixels, 30fps, via IEEE1394-to-PCMCIA adaptor	PCMCIA
Compass	PNI TCM2-50	Serial
Power supply	HMD: int. 10.8Wh Li ION battery Camera: ext. 2Wh NiMh battery Compass: ext. 9V battery	-
Display unit II		
	Device	**Port**
HMD	n-Vision VB-30 (Sony LDI-100B)	VGA
Camera	TerraTec TerraCAM USBPro, 1/3" sensor, 320x240 pixels, 15fps	USB
Power supply	HMD: int. 10.8Wh Li ION battery	-

Table 2. System overview

Using a HMD as the display unit turned out to be the right choice although the security and convenience issues remained unchanged, especially for first-time users. But on the other hand the display remained readable with good contrast, even during recurring phases of extremely bright sunlight. An LCD solution tested in parallel clearly showed its limitations in the outdoor environment.

Yet, interacting with the system through an additional externally attached input device – instead of a touch-screen as with the LCD solution – turned out to be not very convenient and ergonomic. Since most people use their hands to support the HMD on their head, operating the gamepad we used as an input device required releasing the HMD and vice versa. Here the binocular-like n-Vision VB-30 HMD proved to be superior to the Sony Glasstron because it had two buttons on top, which could be used for interaction.

The overall system performance was quite satisfactory, yielding 15 to 20 augmented frames per second for a time of almost 1.5 hours with a second battery pack installed in the computer. Since the unit's peak performance was approximately equal to the maximal frame-rate the cameras were able to capture, using low-cost USB and IEEE1394 devices did not affect the overall quality of the tracking. However, larger images would have increased the quality of the visualization, because the captured image sequence also served as the background of the visualizations (see Section 4.3).

Main module	
Component	**Weight [g]**
Computer (without batteries)	3500
WLAN Interface	70
(D)GPS Receiver	220
Batteries	840
Backpack (incl. cables, adaptors, etc.)	1500
Total weight	**6,130**
Display unit I	
Component	**Weight [g]**
HMD (incl. controller)	440
Camera (incl. PCMCIA adaptor)	200
Compass (incl. HMD attachment)	100
Batteries	420
Total weight	**1,160**
Display unit II	
Component	**Weight [g]**
HMD (incl. controller and camera)	580
Camera (included in HMD)	-
Battery	90
Total weight	**670**

Table 3. System weight

6 Conclusions

The work presented here proved that it is in fact possible to implement a powerful mobile device for outdoor Augmented Reality applications with standard off-the-shelf components.

Nevertheless we had to make compromises. Currently it is impossible to reach all design-goals (intuitive, robust, powerful and light-weight, to name the most important ones) simultaneously. We decided to optimize for computing power instead of weight, mobility and robustness, since performance is crucial for an interactive system like ARCHEOGUIDE. After showing that such a system is feasible and already capable of reaching interactive frame-rates, reduction of weight and size as well as simplification of handling are the obvious next steps. We therefore plan to further integrate all the different devices, especially the computer and its power supply, and to improve the components' interconnections.

For the second prototype expected during summer 2002, weight and size will be further reduced and handling will be simplified. To overcome the stated interaction difficulties and ergonomic weaknesses we work on an improved input device. First experiments using the VB-30 and its integrated buttons clearly show the trend already known from highly integrated devices such as photo cameras and camcorders. In addition more sophisticated and intuitive interaction techniques, especially speech and gesture recognition, will be available in the future.

Figure 7. The ARCHEOGUIDE mobile unit in action

7 Acknowledgements

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A Survey

	Generic Laptop	**Sony VAIO PCG-C1XS**	**Saintsong ESPRESSO**	**Cell PLUG-N-RUN**	**Xybernaut MA IV**	**ViA II PC**
CPU model, speed	Intel PentiumIII, > 800MHz	Intel Pentium II, 400MHz	Intel Pentium III, 500MHz	Intel Pentium III, 500MHz	Intel PentiumMMX 233MHz	Transmeta Crusoe 5600, 600MHz
Graphics accelerator	NVIDIA GeForce2 Go	NeoMagic MagicMedia 256AV	Intel i810 built-in	Chips & Technologies 69030	NeoMagic MagicGraph 128ZV	*unknown*
Video RAM	16 MB	2.5MB	4MB	4MB	1MB	*unknown*
Resolution (max.)	1280x1024	1024x768	1280x1024	1280x1024	800x600	800x600
Memory (max.)	> 64MB	128MB	256MB	512MB	160MB	128MB
Video	VGA, S-Video	VGA	VGA, S-Video	VGA, LCD	VGA	VGA, LCD
USB	2	1	2	2	1	1
IEEE1394/FireWire	1	1	-	-	-	-
PCMCIA/CardBus	2	1	-	2	2	2
Audio in / out	✓ / ✓	✓ / ✓	✓ / ✓	- / -	✓ / ✓	✓ / ✓
Serial	1	-	1 (port-replicator)	2	1 (port-replicator)	1
PS/2	2	-	2	1	2 (port-replicator)	2
Power supply	Li ION battery (56Wh)	Li ION battery	external (15V DC)	external (5 – 12V DC)	Li ION battery	Li ION battery (50Wh)
Running time [h]	~ 2.5	~ 1.5	~ 4	~ 4	4-6	*unknown*
Weight [g]	~ 4000	1200	460 (w/o batteries)	400 (w/o case)	1245	1225
Dimensions [mm^3]	320 x 280 x 45	247 x 153 x 29	150 x 106 x 32	76 x 127 x 18	117 x 190 x 63	248 x 76 x 32