A Wearable Vehicle Interface for Augmented Reality in Operating AUVs

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***Abstract* - Running an operation with an Autonomous Underwater Vehicle (AUV) presently requires that the pilots situate themselves, primarily in a sedentary position for extended periods of time, in front of a computer that is in communication with the vehicle. Such an Operations Workstation is likely to be a networked PC that cannot be exposed to the elements, but has access to all of the software necessary for data reduction and visualization. At the MIT AUV Lab we have extensive experience with this mode of operation. In order to overcome the deficiencies in the current paradigm, we have developed a lightweight computing system that is worn by members of the AUV deployment team to investigate the human factors issues associated with immersing a user in a computing environment that is being used to control an underwater robot.**

The Wearable Vehicle Interface (WeVI) is intended for use in the marine environment and fits over a US Coast Guard approved personal flotation device. The WeVI provides for connectivity to the AUV as well as other WeVI suits via Radio Frequency and 802.11b wireless standards. The operator's point-of-view and GPS location may be shared among WeVI suits to promote situational awareness for the entire operations team. Mission control (planning, scripting, and launching), and visualizing datasets is performed through the graphical user interface that is displayed in a user's head-mounted display. Research into particular attributes of the augmented reality provided by such a suit is ongoing and presented in this paper.

I. Motivation

Running an operation with an Autonomous Underwater Vehicle (AUV) presently requires that the pilots situate themselves, primarily in a sedentary position for extended periods of time, in front of a computer that is in communication with the vehicle. Such an *Operations Workstation* is likely to be a networked PC that cannot be exposed to the elements, but has access to all of the software necessary for data reduction and visualization. At the MIT AUV Lab we have extensive experience with this mode of operation. We routinely run operations with, at the very least, two laptop computers – one for control and data visualization, plus one for tracking – as well as a networked server computer for persistent storage.

The deficiencies in this paradigm are numerous: equipment bulk, stagnated information flow about mission characteristics, disparate location of information like vehicle documentation and circuit diagrams, lack of diagnostic tools for AUV malfunction, the need to service the craft within proximity of the fixed control station, increased downtime between missions, no means of conveying situational knowledge except over audio channels, etc. AUV operations would benefit from a new architecture for mission-control, one where running a mission with the AUV is made easier and the following goals are met:

- Operators remain mobile and in communication with the AUV as well as each other
- Rapid information exchange of vital mission statistics is automatically generated and presented in a head-mounted display
- Graphical representations of scenarios and mission content improve understanding of circumstances
- Data visualizations may be shared among users
- Information storage and document retrieval is made easier.

II. Methodology

Wearable computing endeavors have been, until only recently, primarily a hobbyist pursuit. As such, the commercial product line available to the end user is meager [7,8,9], however in the community of users (Borgs) there is extensive knowledge from hands-on experience with a variety of implementations [2].

Specification of components and layout is dependent on one's need in processing power and intended environment use [4,5,6]. As such, outfitting a wearable system with the appropriate sensor suite is application dependent. Deciding where to instrument the body, how these sensors will exchange information, and how much power they consume are all considerations that influence the layout of a wearable computer. The major component-systems of a wearable computer (WC) are: *processor, connectivity, display, interaction, sensors,* and *battery*. This section discusses how we converged on a set of electronics that make up the wearable portion of the WeVI project. It begins with an overview of the components that can be incorporated into a wearable system. Then we will cover the analysis of power consumed, ergonomic considerations, and goals for functionality. Finally, an itemized fiscal budget is presented.

A. Wearable components

Foremost is the choice of processor, as this will usually consume the majority of power for a wearable system. There are numerous microprocessor solutions available on the market, which, as packaged chipsets, contain the computational resources for satisfying the three operational modes for wearable computing: *constancy*, *augmentation* and *mediation* [1]. The difficulty lies in trading off the flexibility afforded by more powerful processors with that of the amount of power they consume, all the while being mindful of the software language and operating systems they support.

We were already familiar with the miniature PC/104 industrial computer form factor. Most of these boards make use of the Intel x86 architecture; they run our *Odyssey II* and *III* class AUVs. This made it a natural choice for the WeVI 1.0 prototype. PC/104 is an international industry standard, giving us a wide range of configuration options. The parts are typically ruggedized to withstand temperature extremes, shock, ESD, etc., making them suitable for a field-deployed application such as the WeVI. However, the PC/104 form factor, particularly the stacking requirement of the PC/104 bus, makes it difficult to create a complete system that both has all the desired features, and is slim enough to fit comfortably against the body.

One project that has had some success using PC/104 is Charmed Technology's CharmIT [7]. Our prototype is modeled after this design, with the PC/104 stack in a small aluminum enclosure. This approach yields a fairly bulky design that must be placed carefully on the body to avoid obstructing movement (compare figures 1 and 6).

FIGURE 1
CHARMED TECHNOLOGY'S CHARMIT WEARABLE COMPUTER

Connectivity among devices servicing the processor is also crucial– wired solutions are the dominant choice, however wireless device management is now an option as well. In addressing data flow paths, one must also consider how power will be distributed and perhaps take advantage of a communications bus that also supplies (limited) power like USB. Many human interface devices, including some new, experimental keyboards and mice, are available for the USB bus. Other sensors such as our GPS receiver are restricted to RS232 serial only, or more complex interfaces such as PCMCIA or CompactFlash that require bulky additional I/O on the main computer. USB has yet to become widely accepted in industrial computing, and RS232 serial remains a standard for low-overhead connectivity. Interacting with the system through either keyboard strokes or mouse movement (or both) has different ramifications for building up a software interface. Adapting to limited key throughput and not having the interface device interfere with other mobility is a concern as outlined in section IIC.

The choice of display dictates how you will perceive the operating system running on the processor, and puts limits on how complicated a graphical user interface may be. Resolutions as low as 320x240 with only 8bit color resolution are common, with the state of the art being 640x480 and 24bit color depth. This feature set limits the capabilities of the interface - only a limited amount of information may be legibly displayed on the screen at one time (as compared to state-of-the-art desktop displays with much higher resolution). The nonstandard displays and drivers, and the embedded form factor in general, make it difficult or impossible to support accelerated 3D graphics, so we are restricted to a 2D interface.

For augmented or mediated reality applications, there may be some desire to produce an overlay effect, where computer-generated graphics are combined with the user's natural view; some systems provide for such an effect while others do not [13].

Finally, the display is the item most vulnerable to environmental hazards; it is by far the most challenging part to waterproof, can be difficult to see in bright sunlight, can be caught on protrusions or knocked out of alignment/focus by casual contact. Low screen refresh rates on many devices also appear to cause discomfort for some users.

B.Power Analysis

To fulfill the first operational mode of a wearable computer, *constancy,* an understanding of the power consumed by the electronics was necessary. This power analysis helped dictate battery choice. Table 1 lists a common grouping of electronics that, when worn together, constitute the basis for a wearable computing platform. The expected power consumption of 12.63W was primarily a function of the processor, which is rated at 8W.

TABLE 1
WEVI POWER AND WEIGHT

Part	Power (W)	Weight (g)
PC/104	8	70
GPS	0.58	74.4
Compass/Gyro	0.1	44.8
HUD	0.5	45
Headset	N/A	84
Keyboard	0.1	179.2
Pointing Device	0.1	20
802.11b Card	2.25	40
802.11b Amp	1	104
Marine Band UHF	N/A	1344
LiIon Battery	N/A	1416.8
TOTAL	**12.63**	**3422.2**

C. Ergonomics

The Carnegie Mellon Institute for Complex Engineered Systems [14], in collaboration with the CMU Wearable Group [3], has done a study of "Design for Wearability" [15], exploring methods of adding electronic components to the human body in ways that do not interfere with its normal operation. Guided by their findings, we are attempting to translate this picture of the available real estate on the body into a mechanically and electrically realizable arrangement of parts for the wearable computer. To quote their findings:

"The general areas we have found to be the most unobtrusive for wearable objects are: (a) collar area, (b) rear of the upper arm, (c) forearm, (d) rear, side, and front ribcage, (e) waist and hips, (f) thigh, (g) shin, and (h) top of the foot."

Perhaps the most difficult compromise to be made is that of interaction with the computer, vs. interaction with the environment. Existing human interface devices (HID) are primarily meant to be used at a desk, with the computer itself as the focus of the user's attention. In our fieldwork, the AUV team member must be much more concerned with his surroundings; the environment on the deck of a ship is likely to feature any number of hazards to the unaware. Hands must remain relatively free to allow the user to steady himself against sudden motions of the boat, or to grab or fend off vehicles, lines, hooks, etc. (Similarly, loose cabling must be kept to an absolute minimum to prevent its being snagged on any number of such objects). This has pushed us away from the "traditional" solution for the hobbyist wearable designer, the handheld chording keyboard, which must be actively gripped and fully occupies one hand. This approach is simply inappropriate for our operating environment, and might be supplanted by a more suitable technology like the WristPC keyboard from L3 Systems (figure 2).

We are actively exploring ways to adapt or redesign existing HIDs to keep hands free. Work is in progress on a novel pointing device which straps in place onto the hand, staying out of the way when actively gripping an object but otherwise available for input. Similarly we are experimenting with keyboard placement, as well as the number of keys necessary for our software interface; a simple chorded interface mounted to the forearm of the non-dominant hand, or keypads on the forward surface of the upper thighs, are possibilities in line with the DFW guidelines described above.

FIGURE 2
WEARABLE KEYBOARD FROM L3 SYSTEMS

The other major concern is weight. Assuming that all parts of the wearable computer can be kept within the "safe zones" of the body, the problem becomes one of comfort - where is the most comfortable place to stow the heaviest components? Our initial trials suggest that the hips and trunk best support batteries and computer, either on a hip belt or weight belt style mount that wraps around the lower body. It is particularly important to keep weight off the head as this quickly becomes tiring. A GPS patch antenna fits well on the upper back or shoulder, while the main computer itself sits fairly comfortably on one or, ideally both sides of the chest. We are concerned with leaving room for a PFD, as well as leaving room for the user to stand, sit, climb, hang over gunwales of a small craft, etc.

Even without a battery, the operator would already be carrying over 2kg worth of equipment (Table 1). The majority of this weight comes from the marine band UHF radio worn to remain in radio contact (easily removable, and does not draw off the main power bus), and when not considered, reduces the total weight of the WC system to only 661.4g (1.47lb) – 2.08kg (4.64lb) with Li-Ion battery.

D. Goals

With an understanding of the power issue and an idea for how we wanted the WC to be worn, a set of goals that pertain to the *physical* nature of the WC was established. Among these was trying to maximize the battery life to accommodate at least an 8-hour shift on a cruise and to make the entire suit waterproof to handle the harsh ocean environment in which we operate the AUVs [12]. The total system weight is a primary concern and with a factor of two safety should be kept below 5kg (11lb) [16] and the mass distributed in such a manner as to avoid inhibiting dexterity and range of motion. It was deemed possible to incorporate a broad range of functionality for less than US $6.6K.

TABLE 2
SUMMARY OF WC PHYSICAL CHARACTERISTICS

- 8 hr continuous operation
- Cost less than $6.6K
- Weigh less than 5kg
- Waterproof to 1m

The next design consideration was the range of *functionality* necessary to make this a useful tool for AUV operators. To do this, we compared different operational scenarios from our past AUV deployments and scrutinized the deficient aspects of mission planning, launch and recovery, vehicle maintenance and troubleshooting, team member communication, and data visualization. This analysis led to two distinct data flow paths that needed to be addressed: operator to operator (op-op) and operator to AUV (op-AUV). The functionality requirements for each pathway will be met by integrating the appropriate wearable sensors with a software system to facilitate information sharing. The architecture for sharing sensor and vehicle data among the WeVI operators is encapsulated within the graphical user interface (GUI) written in the Java programming language described in section IIIB.

In general, the implicit benefit of wearing a computer is the always-on computational power (*constancy)* that is the basis for *augmentation* (of the senses, memory, etc). Harnessing this aspect, we plan on investigating how the information from the WeVI sensors can be exploited to promote new perceptive capabilities for vehicle operators, in addition to having traditional information flow to and from the vehicle like mission data, new mission files, and vehicle status. We also plan on using the hard drive capacity (30GB) of the WeVI to augment operator memory so that digitized vehicle documentation can be accessed quickly and is searchable.

With respect to inter-operator communication (op-op), the major deficiencies we found were the inability to project situational information over a radio link, and the need to grasp a radio for communication. We had no good way to let one member of the team know precisely what the other was seeing or doing. Furthermore, on large research vessels, the time wasted in walking from the operations station to where the AUV is being worked on to troubleshoot can be considerable. We needed a way to project information about the AUV so that a group of engineers located remotely could process situational information and offer insight more efficiently. Thus, in an effort to blend the experiences of the individual engineers operating the AUV, a head-mounted video camera will provide point of view (POV) perspective for each team member. To understand the orientation and direction the camera is facing, a miniature compass/tilt sensor will be affixed next to the camera. Additionally, each member will be outfitted with a radio and a headset for hands-free audio communication.

For the operator to AUV (op-AUV) data path, one such goal is the ability to sense the AUV on an artificial horizon projected into the computer display. This can be accomplished if the location of the AUV and the operator are known simultaneously and referenced to the operator POV. Since we use a vehicle tracking system that provides us with global position of the AUV, the WeVI will need a means of localizing its operator (when outside) and we plan on doing this with a GPS unit strapped to the shoulder of the operator.

TABLE 3
SUMMARY OF WC FUNCTIONALITY

- Team member inter communication
- Team member localization
- Team member POV
- Software
    - GUI
    - Track AUV on horizon with GPS
    - Mission planning and execution
    - Log file extraction
    - Data visualization
    - Diagnostic evaluation of AUV
    - Digitized archiving of documentation and circuit diagrams
    - Vehicle status indicator

E. Fiscal Budget

An extensive survey of prospective electronics was conducted with the budget outlined in section D in order to limit the range of cost for the WC. Refer to table 4 for the listing of parts and their associated costs.

TABLE 4
PART LISTING AND PRICING

Part	Mfg	Function	Price
SV-3 display, VGA input, 6bit color	MicroOptical	Computer display	$995
MOPSLcd6+	Kontron	PC104 CPU	$450
PRV-1016X-02	Parvus	PCMCIA Adapter	$199
USB Hub	MicroCenter	Connectivity	$15
Power Distribution I	Parvus	PC104 power supply	$250
MPEG1000	AMP Ltd	MPEG Framegrabber	$570

Aironet 350 PCMCIA [AIR-LMC352]	Cisco	Wireless ethernet card	$159
HA2401-AGC1000	Hyperlink Tech	802.11 amplifier	$300
1/4 wave omni	MIT AUV Lab	802.11 antenna	$5
TravelStar 30GB	IBM	Hard disk	$120
V3214	Marshall	Head mounted camera	$599
GPS-25 LVS	Garmin	GPS Receiver	$118
GA27C	Garmin	GPS antenna	$80
New Eagle Tac Ops	New Eagle	Headset	$200
Trackpoint mouse	MIT AUV Lab	Pointing Device	$10
Virtually Indestructible Keyboard	GrandTec	Rugged keyboard	$40
BB2590 battery and charger	UltraLife	Li-ion pack 110Wh	$695
Construction Materials	Various	Plastic, cases, rigging	$350
	TOTAL		**$5,155**

III. WeVI 1.0

A. Wearable Layout

The wearable computer portion of the WeVI project is depicted in figure 3. All of the components are integrated into a tactical-operations vest and hat except the battery, which is worn around the waist on a nylon belt, and the display, which is worn on the head and fixed to glasses (figure 4). The PC/104 computer was inserted into an aluminum housing, and both the RS232 serial ports and VGA D-sub connector were drawn out and bolted to this housing with 4.45cm (1.75") standoffs. Both the computer and the 4-port USB hub fit into a velcro-strapped pouch (figure 6). A close up of the head-mounted V3214 Camera, and the TCM-50 is shown in figure 5.

There are two communications busses: RS232 and USB. Conditioned power is supplied by the 90W power supply of the PC/104; 12V and 5V are available from a terminal strip that devices are presently hard-wired to. The 110W-h LiIon battery supplies the PC/104 with 12V-16V through a molex connector for easy removal and charging. For off-suit connectivity, 100Mbit Ethernet may be plugged directly into the PC/104's RJ-45 port or a wireless connection can be established using the 802.11b PCMCIA card.

It should be noted that this version of the WC does not meet all of the design goals mentioned in section IID. The jacket is not weather resistant, nor have any of the cables been coated and immersion tested. We have used this iteration to understand how the electronics sit (or hang) and fill up the available space on a human body.

FIGURE 3
WEARABLE COMPUTER LAYOUT

FIGURE 4
MICROOPTICAL DISPLAY AND GLASSES

FIGURE 5
CLOSE UP OF HEAD MOUNTED SENSORS

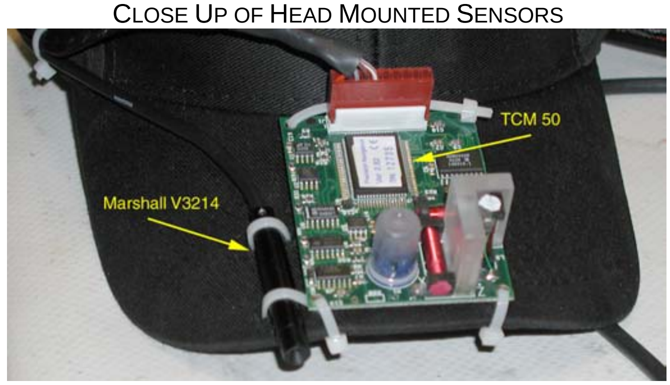


FIGURE 6
PC/104 BOX AND JUNCTION PLATE

B. Software

The WeVI graphical user interface (WeG) is a modular, data-channel driven collaborative computing environment designed to facilitate data sharing between operators and promote awareness among the engineering team about the AUV. It is an extensible architecture that is written in the Java programming language to ensure platform independence. The present version has been tested on both Windows and Linux. Built using Java's Shared Data Toolkit (JSDT) 2.0 [17], and elements of the Java Media Framework [18], the WeG provides a virtual session (i.e., a group of objects associated with some common communications pattern) where data is broadcast over *channels* similar to networked television programming.

Qualified users of the system (there is a means for checking session security clearance) may join a session where information they are interested in subscribing to is being broadcast. Session information and available channel content such as the video stream from a particular WeVI suit, is presented to the user in a hierarchical data tree (figure 7). Users are not restricted to needing a wearable computer to hook into a data channel, and may join or leave channels as they please.

The core components of the architecture are the *WeVIContentUser* and the *WeVIContentProvider,* software objects that provide functionality for either using or providing data. A WeVIContentUser is used in conjunction with a *WeVIContentRenderer* to display information that is produced by one of several *WeVIDataServers,* which itself uses a WeVIContentProvider's functionality for making data available in a session. Presently, WeVIDataServers serve up streaming data from a serial port (e.g. GPS, compass/tilt), video capture device (e.g. video camera), or a TCP/IP Socket. There is a coupling between the rendering and data being served. Ostensibly, all data is represented as bytes in the session, however a particular WeVIContentRenderer must exist to display a given type of data. For instance, the content renderer that presents GPS data currently only displays the GPS string of latitude and longitude, whereas the renderer that presents the compass/tilt sensor has a more elaborate display (figure 8). The system is designed so that a programmer can easily extend the functionality of WeVIContentRenderer and display data however they need to.

FIGURE 7
WEG SESSION MANAGEMENT FRAME

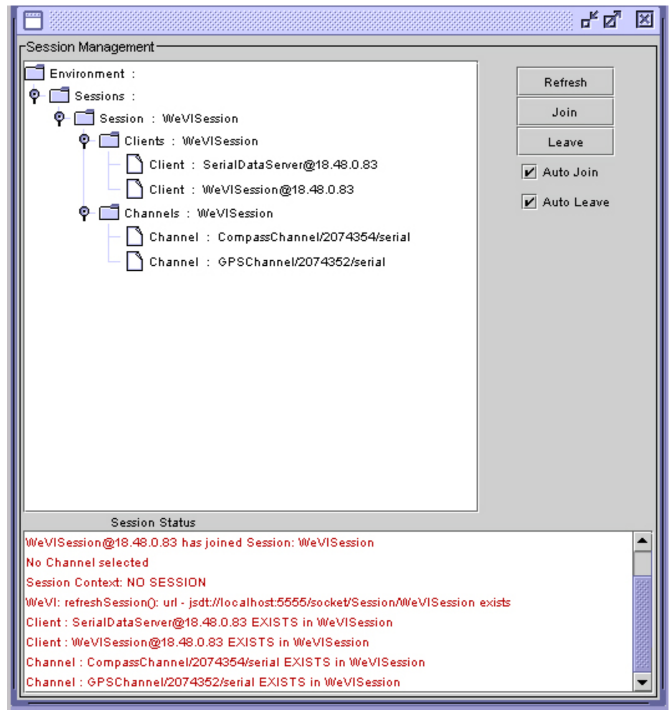
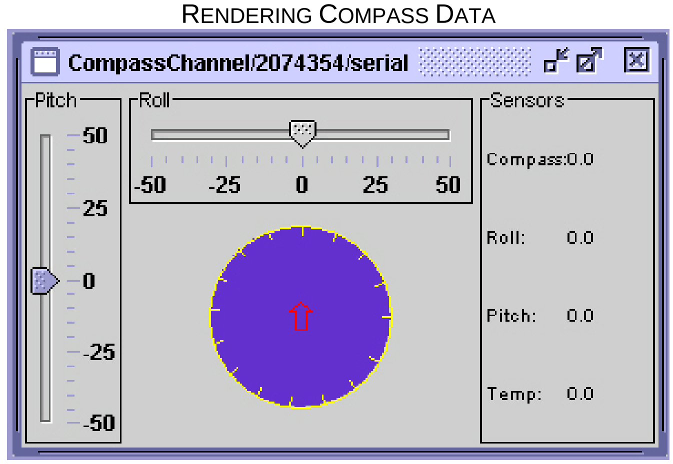


FIGURE 8
RENDERING COMPASS DATA



The WeG has proven to be an effective means of disseminating sensor data from a WeVI suit to multiple interested parties, and has also been used to broadcast vehicle data from the Lab's Autonomous Surface Craft (ASC). In April 2003, video from a small camera situated on the ASC as well as sensor data was used to monitor vehicle performance and presented in real-time on several different workstations simultaneously, thus proving the efficacy of the WeG architecture and validating the choice of the JSDT as the backbone for message handling. There is, however, a need to further benchmark the capabilities of the WeG and qualify performance with different network settings. Additionally, work on incorporating the mission planning and data visualization components is ongoing.

IV. Conclusions

The MIT AUV Lab has developed a novel wearable computing system designed to assist in the operation of autonomous underwater vehicles. This first version of a vehicle interface that is worn by the vehicle operator has been used to successfully monitor the sensor output of our autonomous surface craft in real-time. Operators may share POV, and GPS location information within the WeVI environment through the WeG user interface. The numerous facets of wearable computing and how it pertains to operating an AUV will be investigated with the WeVI platform. Important milestones that remain include waterproofing the system, reducing equipment bulk, and improving the human interface device.

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