MediaJacket: An Integrated Clothing Based Personal Communications System

by

Christian Todd Metcalfe

B.A.S. Computer Science
B.A. Economics
University of Pennsylvania, 1997

Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning, in partial fulfillment of the requirements for the degree of

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Signature of Author: ______________________________
Program in Media Arts and Sciences
August 6, 1999

Certified by: ______________________________
Andrew Lippman
Associate Director
MIT Media Laboratory

Accepted by: ______________________________
Stephen A. Benton
Chairman, Departmental Committee on Graduate Students
MIT Program in Media Arts and Sciences

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ABSTRACT

Recent developments in fabric based conductive embroidered input devices has created the opportunity for the next generation of wearable computing. This thesis presents a preliminary attempt to develop a wearable, multi-purpose, extensible, IP device that uses flexible fabric based circuitry for its user interface.

It integrates a suite of advanced communications devices into a standard PolarTec™ jacket using an embedded personal computer for its controller. Users wear the MediaJacket similarly to normal clothing, and can use a diverse set of applications that include IP telephony, two-way pager-like email, an MP3 audio player, and a contactless “interface pocket” for handling input data streams from external devices.

By embedding advanced electronics into clothing using an RF connection for tetherless internet connectivity, this research aims to reduce the stigma of using technology by creating a more personalized user experience. It is our hope, that as the size and cost of the MediaJacket's components come down, this research will help people better to better integrate technology into their lives.

Thesis Supervisor: Andrew Lippman
Title: Associate Director, MIT Media Laboratory

Thesis Readers

Reader: ______________________________

Professor Alex S. Pentland
Academic Head, Toshiba Professor of Media Arts and Sciences
MIT Program in Media Arts and Sciences

Reader: ______________________________

Professor David J. Farber
Alfred Fitler Moore Professor of Telecommunications
University of Pennsylvania Computer and Information Science

Acknowledgements

> "You can't get out backwards. You've got to go forward to go back. Better press on!" – Willy Wonka

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Two years ago I began my journey as a graduate student at MIT. To say it has been a challenging experience would be a gross understatement, however I have been in awe of the drive, motivation, zeal, and energy with which the MIT community approaches intellectual discovery.

No one has been more influential during my graduate school sojourn than my advisor, Dr. Andrew Lippman. Although our relationship has not always been an easy one, I am grateful to him for accepting me to the program and for turning me on to the marvels of conductive embroidery technology.. Even during times when my head was in the clouds, Andy has been a major force in pushing me to achieve high goals.

I want to thank Prof. Sandy Pentland for serving as a reader of this document, and for introducing me to the marvels of wearable computing. Over the last year I have come to rely on Sandy for his solid advice, compassion, and understanding of the fundamentals of scientific discovery. I consider myself truly fortunate to have worked with him.

Prof. David Farber, who also serves as a reader, has been my valued mentor since I met him as an undergraduate at the University of Pennsylvania. I am grateful to have had Prof. Farber as a resource for this thesis, and want to acknowledge his assistance in offering advice, support, and injecting his unbridled enthusiasm for gadgets into my work.

There are many others that have helped shape, implement, and support my thesis efforts. Maggie Orth and Rehmi Post allowed me to use their "E-broidery" technology as a foundation for the MediaJacket. I consider it an honor to have worked with their technology, and appreciate the openness with which they shared information.

I am grateful to Ben Vigoda for making his tagreader available for me to explore the opportunity to integrate it into a body worn communications system.

Pamela Mukerji's tireless efforts allowed this work to advance the state of art for conductive embroidery. I am tremendously thankful to Pam for her generosity, compassion, sewing skills, and ability to put up with my incessant questions and mistakes.

Peter Russo, who designed the controller board for the fabric keyboard, was an exceptional person to work with and always exceeded my expectations. The keyboard is a testament to his methodical hard work, and I am honored to have had the opportunity to work with him.

Casey Mueller deserves accolades for having done daily battle with the Linux operating system for the MediaJacket. During times of stress I was able to draw upon Casey's dogged determination, and even temper.

Scott Smith helped me to engineer and implement crucial components of the MediaJacket Operating System, and Application Programming Interface. Scott is one of the most gifted programmers I have ever known and, if only through intellectual osmosis, I have greatly benefited form his support during this effort.

Dan Overholt's hardware knowledge and support was instrumental in designing the InterfaceCard for Vigoda's tag reader. Dan reminded me of hardware skills I had long since forgotten, and through example showed me that few problems are unsolvable.

There are many other people who pushed and prodded me towards the graduation line. Heroic efforts were made by and huge thanks are owed to Ed Hammond, Steven Schwartz, Emily Cooper, Matt Reynolds, Dana Kirsch, Matt Lau, Rob Poor, Maria Redin, John Watlington, Nitin Sawhney, Advantech Corporation, and 4Front Technologies.

I could not have done this without the support of my mother and brother. I want them to know how much I love them, and how I have appreciated their encouragement.

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Table of Contents

1. INTRODUCTION 8

1.1 OVERVIEW 8

1.2 SIGNIFICANCE 10

1.3 THESIS STRUCTURE AND ORGANIZATION 12

2. BACKGROUND 15

2.1 TAXONOMY OF WEARABLE COMPUTING 15

2.2 REVIEW OF RELATED WORK 18

2.2.1 Body Worn Fabric Computing 18

2.2.2 Wearable Computing User Interface Techniques 20

2.2.3 Networking 20

3. MEDIAJACKET HARDWARE 23

3.1 OVERVIEW 23

3.1.1 The Brain – Advantech Biscuit PC 24

3.1.2 Fabric Keyboard 25

3.1.3 Interface Pocket 27

3.1.4 Microphone 28

3.2 OUTPUT DEVICES 29

3.2.1 Speakers 29

3.2.2 Display 29

3.3 POWER SOURCE 30

4. MEDIAJACKET SOFTWARE 31

4.1 OVERVIEW 31

4.2 UNDERLYING OPERATING SYSTEM – LINUX 32

4.3 MEDIAJACKET OPERATING SYSTEM - JACKOS 33

4.3.1 JackCommander ... 35
4.4 APPLICATIONS ... 35
4.4.1 Overview ... 35
4.4.2 Interface Pocket ... 36
4.4.3 JackMP3 ... 37
4.4.4 JackPager ... 37
4.4.5 JackTelephony ... 38
4.5 DESKTOP INTERFACE ... 39
5. INTERFACE DESIGN ... 40
5.1 DESIGN CRITERIA ... 40
5.1.1 Fabric Keyboard ... 40
5.1.2 VFD Display/Housing ... 41
5.1.3 Microphone and Speaker Housings ... 41
6. CONCLUSIONS AND FUTURE WORK ... 43
6.1 RESULTS ... 43
6.2 CONCLUSIONS ... 44
6.3 FUTURE WORK ... 44
7. BIBLIOGRAPHY ... 46
8. APPENDIX ... 48
8.1 JACKTELEPHONY GSM CODEC COPYRIGHT NOTICE ... 48
8.2 PRIMER ON BLUETOOTH ... 49

1. Introduction

1.1 Overview

The MediaJacket is an endeavor to weave advanced communications into a garment that can be used during most normal activities. To demonstrate the concept, I have integrated a miniature 586 computer, fabric keyboard[23], display, microphone, capacitive tag reader[39], speakers, batteries, and wireless networking into a standard Polartec™ fleece jacket. In addition, a robust and extensible operating system and Application Programming Interface (API) was developed to complement the MediaJacket's unique hardware, and to extend its functionality into areas previously limited to desktop computing.

Today there is a wide range of Personal Data Assistants (PDAs) available to consumers. Many of the devices, such as 3Com's Palm Pilot™, are extensible in that they run third party software, yet are restricted to the small set of functions their hardware support. Due to these constraints, a user may carry multiple devices to satisfy their needs. For example, I, carry a Palm Pilot to keep track of my addresses and schedule, a cell phone for voice communication, a pager for sending and receiving email, and a Diamond RIO for listening to music. This situation has turned the marvels of miniaturization into a burden that necessitates a briefcase and a sturdy belt to transport the plethora of one's personal digital technologies.

I built the MediaJacket in response to the need for an integrated platform that packages a wide assortment of mobile communications and entertainment capabilities into an extensible, lightweight form factor. A jacket is a suitable vehicle for this because it can be naturally worn throughout many activities, and has the space to tastefully encapsulate the various components.

The contactless Interface Pocket serves to enhance overall extensibility by making it as easy to connect to an external device as slipping a credit card into your pocket. Today this entire system fits into a jacket. As technology improves, I hypothesize it will not be long until an undershirt package is practical.

Offering diverse and extensible capabilities in a piece of clothing is an important goal of this project; equally important is the need to balance the comfort, appearance and weight of the system. My desire to keep the technology as transparent as possible has served as a guiding force for selecting the individual components, and engineering their integration. The initial features of the system include the ability to conduct hands-free IP telephony voice calls, send and receive email, listen to MP3 audio files, and to wirelessly connect to external devices using Vigoda's pocket mounted RF tagreader[40].

Working within the jacket form factor, my primary concern was to build a system that can address future needs by being as extensible as possible. To achieve this, I designed a robust Operating System (OS), JackOS, that runs on top of Linux and allow for simplified development of new applications. This extensibility, coupled with the MediaJacket's streamlined input/output (I/O) features, allows for the potential to extend far beyond the niches of current PDAs.

This thesis presents a solution for better integrating technology into every day activities by using a clothing based carrier. Interestingly enough, this work comes at a time when multiple, industry wide, efforts are underway to develop low cost, open standard networking technologies. Bluetooth[5] is one powerful example of a protocol with the promise to greatly expand the reach of digital networks. Even though I have used a costly Freewave modem for this system, technologies such as Bluetooth will unleash a wave of low cost, ubiquitous networking tools that will make the need for omnipresent computing all the more apropos.

1.2 Significance

Over the years both industry and academia have invented a diverse set of wearable computers. A lot of these systems have addressed specific niches[8][28] that generally included on job training, schematic navigation, and assistance with complex record keeping.

The cumbersome and complex nature of the early systems was justified by the enormous gains in productivity they afforded their users. The Navigator 2[19], an augmented reality system worn by US Airforce inspectors, is a bulky hip worn unit that reduced plane inspection time by nearly 20%. Another wearable, Georgia Tech's Fast Educational Performance Support System[21], allows poultry inspectors to use verbal commands to interface with, and add entries to the plant's inspection databases.

Figure 1-1: Twidler input device

The above systems and their counterparts have succeeded because they increased work place efficiency by enabling users to access databases from diverse and desktop unfriendly locations. A few systems, such as Starner, Weaver and Pentland's[36] American Sign Language (ASL) interpreter, have attempted to extend wearable computing to the private sector by creating applications that enhance day to day activities. The appeal of these systems, however, has been limited due to their reliance on vision occluding, head mounted displays, and heavy satchel encased computers.

> "['Wearables'] central processing units are designed to be small and unobtrusive.. Our goal is to offer devices that would be so small and light that they could be worn constantly – much as

> eyeglasses and watches are now – providing access to computing power at all times. Today's smart clothes are not yet inconspicuous… but the coming of continuous computing is not far off."[25]

The task of this thesis is to build a general purpose integrated computer that complements, and minimally hinders, users while they are engaged in other physical pursuits. By packing the device into an object as familiar as a jacket, I have attempted to trickle networked computing into activities not previously considered desirable for online activity. Having strongly benefited from previous wearable computing research, this project attempts to differentiate itself by being streamlined and less cumbersome.

To attempt to reach Pentland's vision for "continuous computing", I have replaced the classic wearable keyboard, the Twidler (shown in Figure 1-1) with the next generation of Orth and Post's fabric keyboard technology. This keyboard is attached to the forearm of the jacket, and uses conductive embroidery[24] to detect when the user *touches* any of the 16 individually sewn keypads. The keyboard is part of an integrated input/output (I/O) assembly that includes a padded florescent display. Despite having fewer key combinations than the Twidler, the fabric keyboard provides a more discrete and less cumbersome experience than any other existing (non-voice) wearable input device. Though it lacks the graphical capabilities of wearable alternatives such as the Private Eye, the VFD liberates the user from the social costs of having a head mounted display occlude their vision.

In the 1960's corporations, government, and academic elite were among the small niche with access to advanced computing resources. Less than two decades following the advent of the Personal Computer (PC)[26] there has been an explosion in the wide scale dissemination of computing technologies – placing computers in our banks, grocery stores, and homes. Dr. Andrew Lippman, of the MIT Media Lab, hypothesizes that:

> "As the price drops, the PC fits into more places; as the use of the WEB increases, the steam still left in the physical interface drives it into new venues."[13]

The MediaJacket's skin close computing, extensible wireless IP interface, fabric keyboard, and voice/data offerings is a suggestion for how to address the need to better integrate technology into people's lives. It is my goal to craft this system into a framework others can build upon to make mobile computing more accessible, less cumbersome, and increasingly omnipresent to the user, yet omniscient to everyone else.

1.3 Thesis Structure and Organization

This thesis is structured into eight sections.

1. Introduction
2. Background
3. MediaJacket Hardware
4. MediaJacket Software
5. Interface Design
6. Conclusions and Future Work
7. Bibliography
8. Appendices

Chapter 2 reviews the background literature, historical precedents, and related projects used as a foundation for the MediaJacket. This chapter covers developments in wearable computing, conductive fabric circuitry, electrostatic tagreaders.

Chapter 3 addresses the overall hardware design for MediaJacket, the challenge to cleanly integrate its components, and the need for continued development. In this chapter I review the hardware components including the custom built conductive fabric keyboard, electrostatic tag reader, electrostatic tag transmitter/data collector, and battery systems. In addition I describe how I integrated the commercial components of the MediaJacket, including the Advantech Biscuit PC, spread spectrum FreeWave RF radio, and Noritake Electronics VFD display.

During the course of designing, and fabricating the MediaJacket I have built upon the work of and collaborated with a number of my colleagues at the MIT Media Lab. In Chapter 3 I also describe the contributions of my hardware collaborators: Maggie Orth, Dan Overholt, Rehmi Post, Steven Schwartz, Ben Vigoda, Casey Mueller, Pamela Mukerji, and Peter Russo.

Chapter 4 examines the underlying Linux Operating System (OS), and the custom built and tailored software that provides the functionality for the MediaJacket. In this chapter I explain the extensible design and nature of JackOS, its corresponding Applications Programming Interface (API), the application launcher, JackCommander, and the host of individual software programs that operate within the JackOS environment.

It should be noted that the MediaJacket's brain is a fully functioning 586 PC running Linux, and has standard VGA and keyboard ports. Although it is capable of interfacing with traditional wearable I/O devices, such as HandyKey's Twidler (shown in Figure 1-1) and Thought Technologies Private Eye, this thesis does not deal with those possibilities in order to focus on the customized 'skin close' display and keyboard setup.

Chapter 5 covers the factors that went into the design of the MediaJacket, and ultimately formed the heart of its design requirements. I discuss the overall look and feel I was trying to achieve, and the how I dealt with the limitations of current technology.

In Chapter 6 I review the results of this thesis, address the shortcomings of the work and examine the possibilities for extending the scope and capabilities of the MediaJacket in the future.

Chapter 7 contains the bibliography and list of references I used to research, build and document this thesis.

2. Background

2.1 Taxonomy of Wearable Computing

One of the first documented wearable computers was Thorp and Shannon's[38] 1961 invention for predicting the outcome of the casino game roulette. The twelve transistor system was remarkable in that, compared to the tractor-trailer-sized computers of the day, it fit within a cigarette pack size container. A more powerful, and larger, machine could have enhanced Thorn and Shannon's results, however testing it within the "Mafia riddled 'gaming' industry"[38] dictated that the system had to be as small and covert as possible.

The need for secrecy led them to conduct technical triage to select the features and components that would allow for a concealed system. Despite the non-conventional testing ground, their wearable represented many of the principles that have become staples of work since then; they saw a problem, and found a way to solve it using technology that could be *worn* on the body.

Not too long after Thorp and Shannon's developments, Ivan Sutherland laid the groundwork for both Virtual Reality (VR), and large-scale augmented reality by integrating a display into a helmet[37]. Although his vision could not be fully realized using the technology of the times, it exposed how computing was more than a numeric simulacrum – it was something that could enhance and complement physical experience.

Since these early experiments various researchers have expanded upon the models put forth by Sutherland, Thorp, and Shannon. One group of physicists, who dubbed themselves the

Eudaemons[4], developed a next generation roulette prediction system. Aided by financial incentive, their system attracted a sufficient enough following to prompt the passage of the Nevada Devices Law restricting the use of wearables within Casinos. Whatever the motivations, this early work set the stage for people to accept the use of mobile digital assistants, and to start thinking about new ways to employ them.

Thad Starner[35] and Steve Mann[14] strengthened these ideas by building a series of machines that functioned as "mental prostheses" to assist users with everyday tasks. Mann's system, for example, superimposed computer generated feedback onto the user' vision of the real world. This added metrics to what one saw, warned as a rear-view mirror, and provided apropos digital cues to real life situations. A hallmark of his work was a camera coincident with the wearer's head so that local or remote computing resources could process the same data the user was attending.

Starner concentrated on *in-situ* cognitive enhancement by using a hand-held keyboard and a superimposed display to digitally augment common activities. In his vision, one could use a wearable to recall data pertinent to a situation, or even have it automatically cued by fixed signal beacons[33]. Using this system, one could, for example, simultaneously take class notes while querying related material in the corner of your eye, or repair a car engine while literally viewing its manual *on top of* the work being done.

These notions were foreshadowed by similar work done at Honeywell during the 1970's, and have been replicated across a wide berth of industry and academia. The Honeywell VIMAD was a DARPA funded project intended to provide an augmented view for maintenance and repair tasks. It allowed a worker to use speech cues to trigger the recall of archival documentation that was presented throughout the course of actual repairs. Another wearable system, Carnegie Mellon's Vuman3[6], similarly provides its user access to a vast repository of schematics, and records to complement ongoing repairs. While the physical instantiations of these systems greatly vary, the concepts are similar: use computing, *in-place, in-time, and on-site as an assistant.*

These explorations helped establish the ground rules and parameters for what a wearable computer can, and should do. Some of the primary constraints that were identified include: size, weight, level of comfort, methods of interface, programming techniques for real-time interaction, and options for network connectivity. Whereas early wearable developers were forced to use blunt triage to balance the constraints of weight versus resources, today's systems are sophisticated enough to allow for powerful, lightweight, general purpose computing.

Equally important to proving the technology, the early wearables introduced society to the idea of omnipresent computer assistance. In a *de minimum* sense, the pagers and telephones many wear on their waists are practical embodiments of these ideas. By using pagers and cell phones, we have come to accept information in the course of doing other activities. Once the exclusive tool of niche workers, pagers have become so commonplace that many high school students exchange 'paged' messages the way they once passed class notes.

> "It's not hard to imagine the next step. One tiny chip implanted in your throat to monitor your vocal chords and send a signal, 30 minutes of practice speaking silently (try it, it's easy) and another chip in your ear."[11]

The freedoms afforded by today's mobile computers, coupled with the broadening attractiveness of the Internet, have increased the need to better conform computers to the user. The history of wearable computing is rich with examples of systems that, individually, addressed a plethora of niches. This thesis attempts to go beyond the niche, by building a general purpose communications device that advances the state of art for comfort, usability, and transparency.

2.2 Review of Related Work

There are a number of projects I have drawn upon for the development of the MediaJacket. To complement, and add detail to the above historical precedents, I describe some of the projects that have directly or indirectly influenced my work.

2.2.1 Body Worn Fabric Computing

There is a growing area of work that focuses on techniques for, quite literally, weaving wearable electronics into clothes. This allows a far more fashionable design, and offers the potential to blend computing and communications into our lives in a more desirable manner. For example, the package delivery person, auto rental check-in agent, law enforcement official, or inventory taker commonly have a suite of devices draped to their belt that are integral to their job. The first commercial clothing based wearables will likely help these industries to make their critical peripherals more fashionable, less obtrusive, and increasingly user friendly.

> "The tactile and material properties of what people wear are important to them, and people are reluctant to have wires and hard plastic cases against their bodies. Eventually, whole computers might be made from materials people are comfortable wearing."[24]

In this context, the notion of fashion is not a trivial one. Often, technologies begin with ungainly, but useful implementations that penetrate society as they become more attractive. Ford's cars were initially only available in black, whereas the new Smart Car admits a weekend change of color or trim. The telephone was formerly black and large, yet morphed to fit our décor as people started to have more than one within their home. Similarly, the pocket calculator grew from a device sold by its features to one sold by its look and feel – thus and effort to integrate function in tandem with design is a worthy goal.

The use of conductive threads woven, applied and sewn into garments is one example of work being done to make computing more fashionable, comfortable, and symbiotic with normal physical activities. The additional opportunities afforded by woven electronics allow for the creation of a framework that can interconnect electronics distributed across the body in a flexible, pleasurable way.

Margeret Orth[23] and Rehmi Post[24] have made advances in the technology of embroidering conductive garments and distributing electronic circuitry within them. In 1997, Orth demonstrated a musical jacket that had an integrated cloth keypad sewn onto it. Using a thread originally designed to reduce electrostatic carpet shock, Orth constructed a keyboard that was a compromise between conductivity, wearability, and comfort. Orth and Post, instead of using conventional physical switches, attached each fabric key trace to a PIC processor that measured the change in resistance caused by human touch.

More recent work has employed fabric technology as a means to collect data about the user. For her Ph.D. Thesis, *Sensing, Analyzing, Interpreting, and Responding Musically to Expressive Gestures*[16], Teresa Marrin built a vest that captures the actions of an orchestra conductor and relays a processed version to enhance, or augment a live performance. Whereas Mann used a point of view camera, Marrin has distributed an array of sensors throughout her garment to *capture* and *record* the actions of an orchestral leader. Taken to the farthest extreme, this work could one day permit an entire virtual orchestra to be lead by one person.

Other work currently being conducted by Dr. Andrew Lippman and Pamela Mukerji, attempts to expand the clothing input model by creating a 'sensing shirt' to capture the upper body motion of the user. This system has the promise to provide therapeutic feedback to those who suffer from upper body pain, as well as the potential to help improve the user's golf swing.

2.2.2 Wearable Computing User Interface Techniques

Many different precedents and methodologies have been developed for interacting with wearable computers. Wearables have become so broad that, not surprisingly, a plethora of input and output devices and techniques have emerged.

For systems that offer users digitally augmented views of the world, graphics are of the utmost importance. There is a wide range of choices, from Nintendo's commercial Gameboy VR display, to the custom, DARPA funded, Honeywell body worn display[12].

The specific method for user interface is highly dependent on the wearable application. Incredibly noisy environments, for example, are ill suited for voice communication[29]. Yet a system used to recall a limited set of prints/schematics can make do with a dial[12] for user input. The high variance of input/feedback methods for wearables includes everything from a system that employs an underwear mounted temperature probe[14] to control a room air conditioner, to the use of a swallowed internal body core temperature probe.

2.2.3 Networking

> "A person who carries a watch, pager, cellular phone, personal stereo, personal digital assistant (PDA), and notebook computer is carrying five displays, three keyboards, two speakers, two microphones, and three communications devices. The duplication of the I/O components is in part a result of the

> inability of the devices to exchange data. With proper networking these devices can share I/O, storage, and computational resources."[16]

The wide scale use of personal electronics has created the need to better share resources. As a general purpose machine, the MediaJacket is an attempt to add more functionality to a single device, and does not address the need to bridge existing body worn systems (i.e. watches, phones, etc). For the MediaJacket I use a mix of wires, conductive threads, and Radio Frequency (RF) communications technology encased within clothing. It should be noted that there are alternatives to using a garment as a wiring frame for a set of interconnected devices.

An IBM researcher, T. G. Zimmerman[42], found a way to use the entire human body as a conduit for sharing information between devices. Using a battery powered, electrically isolated, device, Zimmerman capacitively coupled a pico amp displacement current[42] through a human body to a receiver. Using this near-field technology, Zimmerman demonstrated that data could not only be shared across people by touch, but also that a watch face could serve as a display for a hand held cell phone. The system, dubbed Personal Area Networking (PAN), demonstrated that a host of body worn devices could be interconnected without the need for cumbersome wiring, or high power RF transmitters/receivers.

The MediaJacket does not use PAN to communicate between its components, however is capable of using Ben Vigoda's PAN-like touch tag reader[39]. as a means to interface with external devices. The touch tag reader is designed to electrostaticaly couple with EM Microelectronic V4050 RFID tag chips. The original system, which has been modified to receive streaming data, reads a tag when the user *touches* it – an interface method that lends itself particularly well to industries such as package delivery and rental car returns.

In assembling the MediaJacket I have taken the utmost care to reduce the hindrance of wires, and cabling. PAN, and technologies like it, offers the exciting possibility to further streamline body word systems; PAN holds the promise of replacing the need for a soldering iron by allowing consumers to seamlessly integrate displays on and around their person.

3. MediaJacket Hardware

3.1 Overview

The MediaJacket is comprised of a variety of different components I have integrated to form a streamlined communications system. In choosing the components I attempted to minimize the overall complexity, weight, and power consumption.

The system includes a mix of hardware built exclusively for this project, as well items built by collaborators and commercial companies.

Table 3-1: MediaJacket Components (Exterior View)

Item	Description
1	Speakers
2	Microphone
3	Fabric Keypad
4	Noritake Vacuum Florescent Display
5	Interface pocket tag reader

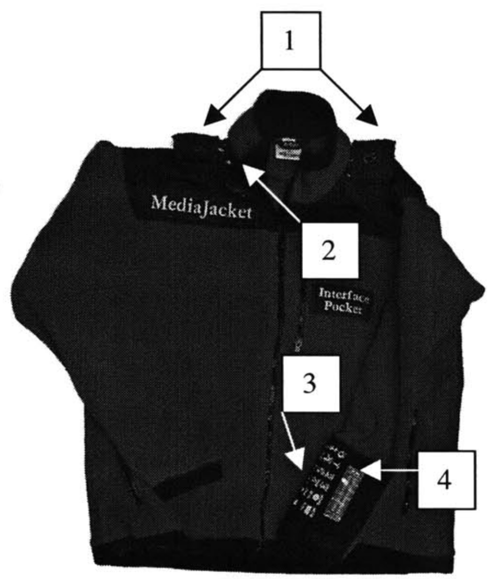

Figure 3-1: MediaJacket Exterior View

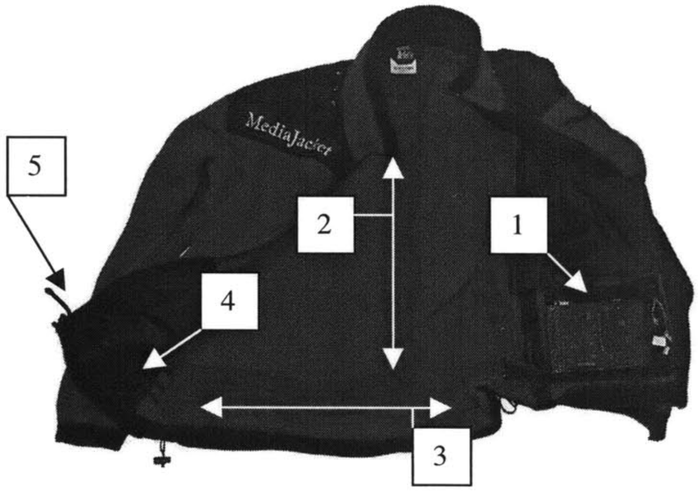

Table 3-2: MediaJacket Components (Exterior View)

Item	Description
1	Advantech Biscuit PC
2	12 VCD power trace
3	5 VDC power trace
4	Insulated organza (conductive fabric)
5	Battery holders (encased)

3.1.1 The Brain – Advantech Biscuit PC

At the heart of the MediaJacket is an embedded Advantech Biscuit PC model#PCM-4825 (shown in Figure: 3-3) . This unit is a commercially available, fully functional PC measuring 145 mm

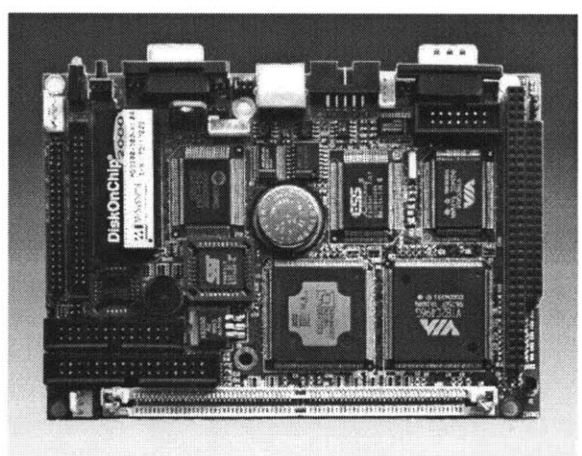

Figure 3-3: Advantech 4825 Biscuit PC

x 102 mm. While there are smaller machines, such as the Jumptec's DIMM-PC, shown in Figure 3-4, the Biscuit PC offers one of the most efficient footprints for a system with integrated audio capabilities .

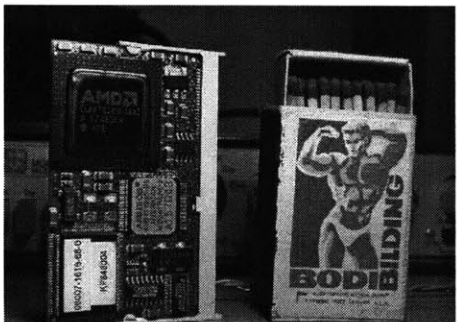

Figure 3-4: Jumptec's DIMM-PC
Photo Courtesy of Vaughan Pratt

The PCM-4825 has a 586-133 MHz microprocessor, 16-bit ESS 1685 Soundblaster™ compatible audio controller, 32-bit SVGA and LCD interfaces, floppy disk and IDE controller, parallel port, standard serial, mouse and keyboard ports. I have also added an M-Systems 144 MB Disk on Chip® DIMM that performs like a regular IDE hard drive, and a 32 MB EDO DRAM SIMM.

The Biscuit PC has standard LCD and SVGA outputs, however I have used one of its serial port's transmit pairs to drive a Noritake Electric Vacuum Florescent Display (VFD) that is mounted on the forearm of the jacket (pictured in Figure 3-11). The PCM-4825 could readily use a Private Eye™ display, however I decided against it due to it's high cost, limited availability, and my strong desire to build a system that does not occlude the user's eye.

3.1.2 Fabric Keyboard

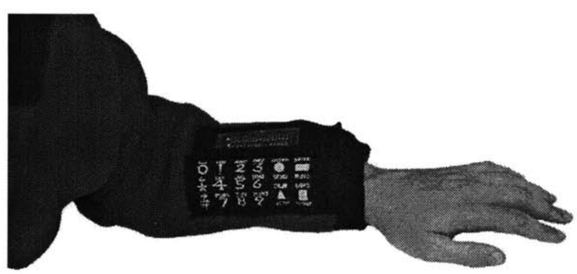

Figure 3-5: Fabric keyboard and VFD display.

The fabric interface keyboard is the result of collaborative efforts with Maggie Orth, Rehmi Post, Pamela Mukerji, and Peter Russo. The keyboard, pictured above in Figure 3-5, operates using resistive capacitive circuitry to detect key strokes.

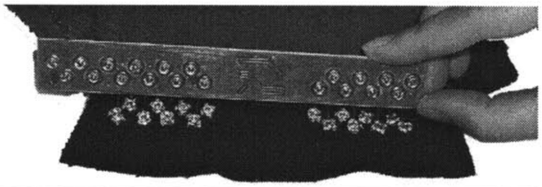

Figure 3-8: Controller board lined up with conductive "docking" snaps.

In a conventional keyboard, key strokes are detected by the completion of an electrical circuit resulting from the physical depression of an actuator (e.g. circuit is completed upon a key press). This technology, developed by Orth and Post, does not use a 'physical' actuator. Instead, each key is a sewn with conductive thread and is connected directly to a pin on a microprocessor. The microprocessor charges its pins (and their respective keys) and monitors the change in resistivity across each circuit. If the microprocessor detects a change in the resistance, it interprets it as a key stroke and accordingly transmits the key press information to the Biscuit PC using the PS/2 protocol to emulate a

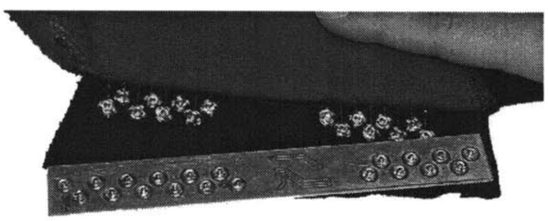

Figure 3-6: Controller board resting atop underside of fabric keyboard.

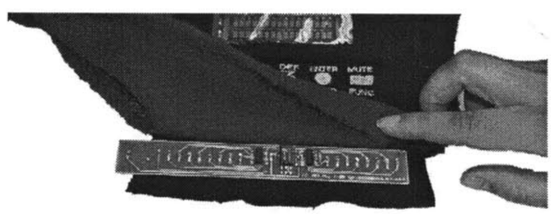

Figure 3-7: Controller board secured to Fabric Keyboard.

standard keyboard.

There are two main components for the fabric keyboard – the keypad, and the controller board. Designed by Peter Russo, the controller board (shown in Figure 1) is a standard circuit board that contains a 16F84 PIC microprocessor with traces that connect its pins to the 16 conductive keypads. To maintain the modularity of the system, and preserve the MediaJacket's "washability", the controller board is attached to the inside of the jacket's sleeve using a set of conductive snaps.

This interface closely resembles its conventional counterparts in that, upon trigger, it announces to another system that an event (or keystroke) has occurred. For a wearable application, however, it is far superior to its plastic counterparts in that it is extremely light weight, malleable, and can be easily washed. To satisfy the need for modularity, the keyboard controller is attached to the jacket using conductive snaps that permit the circuitry to be removed in case the garment needs to be laundered.

3.1.3 Interface Pocket

The Interface Pocket is comprised of a fabric pocket sewn onto of the fleece of the MediaJacket containing Ben Vigoda's Touch Tag Reader[39], and two flexible antennas. The Interface pocket serves as a dynamic "port" for connecting to external devices in a contactless manner, and makes it as easy to connect to external devices as slipping a credit card in one's pocket. The board was originally designed to read EM Microelectronics Company's static V4050 RFID tags, however I constructed a custom PIC controlled Interface Card to stream data to the Tag Reader using the V4050 protocol.

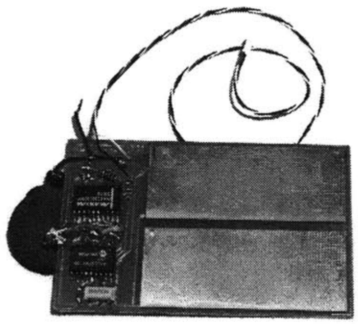

Figure 3-9: Interface card shown with temperature probe

The interface cards are credit card sized custom boards designed to transmit data to the Tag Reader board. The card is powered by a watch-type battery, and contains an analog to digital chipset capable of reading data from external sensors (such as temperature probes). A PIC 16F84 microprocessor parses the data, and translates it into the Manchester encoded format that Vigoda's board expects to receive.

Although the tag reader in the interface pocket is actually designed to receive a static RF ID, we 'trick' it by quickly varying the tag's ID. This feature allows MediaJacket users the possibility of interfacing with devices such as GPS receivers, and various kinds of probes (temperature, soil, hydration). Future applications include use by field workers to monitor environmental conditions and/or use as an interface to GPS navigation devices.

3.1.4 Microphone

The MediaJacket uses an Optimus "Tie Clip Microphone" that is imbedded into the jacket's collar. The Optimus is a broadcast quality microphone, and contains an electric element microphone. The element is powered by using a 9 volt battery, and is connected directly to the Biscuit PC's sound input using a three conductor shielded audio cable. The lack of shielding afforded by the organza was determined to contribute to background noise.

3.2 Output Devices

3.2.1 Speakers

Figure 3-10: Philips Vienna speakers

Two Philips Vienna speakers provide the MediaJacket's audio feedback. The speakers are similar to the ones used by Nitin Sawhney for his Nomadic Radio Project[29] and provide a highly directional dynamic sound output. Notably, the directional aspect of these speakers affords a degree of privacy to be retained by the user; making these speakers a worthy choice for the telephony application.

3.2.2 Display

Figure 3-11: Noritake Vacuum Florescent

The sole text display for the MediaJacket is a Noritake T-Series compact VFD. This VFD is 2 lines by 16 characters, and offers exceptional brightness and clarity. The display is connected to the Biscuit PC via the Biscuit PCs COM2 serial transmit pair.

The VFD, shown in Figure 3-11, is integrated into the MediaJacket's sleeve, and is housed in a custom rubberized and fabric housing.

The VFD operates on 5 Volts, 100 miliAmps and is enclosed in an insulated housing to prevent electrical interference from the user. A Maxim-232 was added inline between the computer's COM port and the display to convert the computer's RS232 (+/- 12 volts) signals to TTL levels (+/- 5 volts).

3.3 Power Source

The Media Jacket uses two Sony, NP-F730, camcorder style, lithium battery packs. The batteries are connected to the system via custom battery clips, designed by Post and Starner using a mold fabricated on the 3D printer at the MIT Media Lab's Physics and Media Group.

The batteries are wired in series, and connect to a main power bus that runs along the inside of the jacket. All of the MediaJacket components require either 12 volts DC or 5 volts DC. There are two Datel power regulators that are connected to the main power bus, and serve to stabilize and provide the correct voltage to the various electronics. The Datel units accept a voltage range of 7.6 volts to 5 volts, and convert it to 5 volts or 12 volts, respectively.

Due to the dangers associated with charging Lithium batteries, the power configuration does not allow for the batteries to be charged while in the jacket.

4. MediaJacket Software

4.1 Overview

The Biscuit PC is a fully functional personal computer, and is capable of running a variety of PC based operating systems including: Windows 95/98, NT, DOS, and Linux. The open source Linux operating system was selected because it offers the best reliability, cost, modularity, and is the friendliest development platform.

The MediaJacket's soundcard and wireless modem are standard devices, however the inputs and outputs for the system are not. To enable the non-standard I/O, JackOS and JackCommander, a custom built environment and application navigator (respectively), were written to operate on top of Linux and in between the individual MediaJacket applications.

These applications were developed in collaboration with Scott Smith, and were authored in C++ using shared dynamic linked libraries. An extensive Application Programming Interface (API) was constructed to enable this work and to simplify future development for the MediaJacket platform. This system, in many ways, parallels 3Com's PalmOS model in that the API foundation frees application developers from having to deal with the intricacies of the MediaJacket hardware. Instead of having to know how big the display is, or what protocol it speaks, they need only call the display function – the rest is handled by the OS. This modular structure enhances the ability to upgrade components, because it minimizes the number of places hardware specific code needs to be updated.

The following diagram illustrates the relationship between the applications, JackOS, and the Finder-like JackCommander, and Linux.

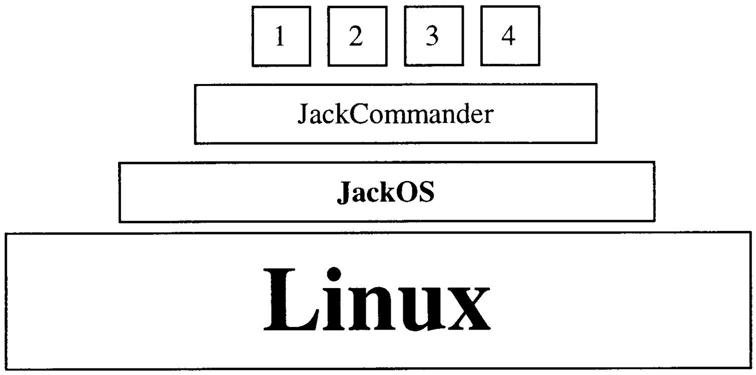

Figure 4-1: MediaJacket software hierarchy. 1,2,3,4 represent applications such as JackPager.

To illustrate these relationships I offer the following example:

1. The user is at a prompt and is deciding what to do
2. JackCommander is running and displays the date, and time of day. The user then decides to launch JackMP3 by using the fabric keyboard.
3. Upon selection, JackCommander is backgrounded (note, priorities are further explained in section: 4.3) and JackMP3 takes control of available system resources.
4. JackMP3 then makes direct calls to the JackOS API functions, such as:

Table 4-1: API examples

C++ Equivalent	JackOS Translation/(API Function call)	Explanation
char getchar();	char keyboard::getkey();	gets a character from the keyboard

Like Linux, JackOS is multithreaded and supports the prioritization of processes and resource allocation.

4.2 Underlying Operating System – Linux

As already mentioned, the MediaJacket system uses the open source, free-ware Linux operating system. This operating system has greatly aided this project, and its flexibility has extended the scope of this work.

The MediaJacket is running the Debian distribution of Linux, and was installed on the 144mb DiskOnChip 2000 storage device and, with the exception of using 4Front Technologies' Open Sound System™[1], is running standard Debian Linux drivers and installation packages.

4.3 MediaJacket Operating System - JackOS

JackOS is a core program that controls access to the MediaJacket's resources including: sound card, VFD, fabric keyboard, interface pocket, and the underlying Linux operating system. JackOS acts as an intermediary between the MediaJacket applications and Linux, and serves the pivotal role of communicating with the specialized MediaJacket hardware. Since the display and keyboard are non-standard, JackOS is the gatekeeper for applications to access system resources.

All processes running under JackOS appear, to the Linux operating system, as if they are merely part of the JackOS processes. In other words the individual applications, such as JackTelephony, do not spawn their own process under Linux, and instead create new, or operate within existing, JackOS processes.

Although JackOS is multithreaded, it must keep the user within the bounds of the MediaJacket hardware. JackTelephony and JackMP3, for example, share a sound card and speakers. To minimize the interruption caused by the shared resources, JackOS hierarchically prioritizes sub applications. Each application, on a scale of 0 to 5 (0=highest priority, 5=lowest) specifies a priority for the display, keyboard, and sound card (shown in Tables: 4-2, 4-3, and 4-4). This system permits applications to smoothly share limited resources, and to reduce the impact of hardware collisions on the user.

Table 4-2: **Priorities (sorted by Keyboard Priority)**

Keyboard Priority	Display	Sound	Application	Function
1	1	1	JackTelephony	Talking
1	1	1	JackTelephony	Ringing
1	0	n/a	Interface Pocket	Transmitting
2	2	2	JackTelephony	Dialing
3	3	4	JackPager	All
4	4	3	JackMP3	All
5	5	n/a	JackCommander	All

Table 4-3: **Priorities (sorted by Display Priority)**

Keyboard Priority	Display	Sound	Application	Function
1	0	n/a	Interface Pocket	Transmitting
1	1	1	JackTelephony	Talking
1	1	1	JackTelephony	Ringing
2	2	2	JackTelephony	Dialing
3	3	4	JackPager	All
4	4	3	JackMP3	All
5	5	n/a	JackCommander	All

Table 4-4: **Priorities (sorted by Sound Priority)**

Keyboard Priority	Display	Sound	Application	Function
1	0	n/a	Interface Pocket	Transmitting
1	1	1	JackTelephony	Talking
1	1	1	JackTelephony	Ringing
2	2	2	JackTelephony	Dialing
3	3	4	JackPager	All
4	4	3	JackMP3	All
5	5	n/a	JackCommander	All

To further illustrate this point, here are three scenarios:

Scenario 1: User running JackPager when JackTelephony receives a call.

The user is typing an email using JackPager, when the JackTelephony application receives a call. By the priorities listed in Tables 4-2, 4-3, and 4-4, you can see that JackTelephony::Ringing (read as the Ringing function within the JackTelephony application) has higher keyboard, display, and sound priorities than the JackPager. As a result, the pager application will be backgrounded, and all keyboard, display, and sound functions are brought to the foreground and control of JackTelephony.

Scenario 2: User listening to JackMP3 and launches JackPager

In this scenario the user is running JackMP3 and is interacting with the keyboard and display to queue desired songs. The user then launches JackPager to send and/or read email. In accordance with the stated priorities, JackMP3 will give up control of the display and keyboard, but will retain control of the sound card so that the user can listen to music while typing/reading email.

Scenario 3: User Listening to JackMP3 and manually launches JackTelephony

The user is listening to JackMP3 and interacting with the application to queue songs. Upon launching JackTelephony, all system resources (as stated in the priority lists) are given to JackTelephony. To save system resources, JackMP3 then saves its state to disk (including queue lists, etc), and releases all system I/O resources.

4.3.1 JackCommander

JackCommander, by default, runs in the foreground when no other applications are running. It contains the menus for the system, and displays pertinent information such as time, date, and available applications. This program is, in many ways, similar to the Apple Macintosh Finder, or Microsoft Windows 3.11 Program Manager.

From within JackCommander users can launch other applications, shut down the system, and manipulate system settings. JackCommander is the first program launched on startup, and is the means by which the user launches all other applications.

4.4 Applications

4.4.1 Overview

There are four applications that have been written, or custom adapted for use in the MediaJacket system. They are:

Interface Pocket
JackMP3
JackPager
JackTelephony

4.4.2 Interface Pocket

When the Interface Pocket is actively transmitting, the computer receives the data, parses it into plain ASCII text, and mails the data (with a time stamp) to a preset address. This allows the demonstration of the feature, and is indicative of what it would for a field worker to use the system to collect data. On the receiving end we parse the files using procmail to append data to a text file that can be viewed over the internet using a web browser.

To activate this feature, the user need only insert an Interface Card into the Interface Pocket. This automatically triggers the system to begin receiving the streaming data, and transmit it to the world. If the network connection is down, the emails with the interface pocket data are queued for future delivery.

4.4.3 JackMP3

Figure 4-2: JackMP3 player welcome screen

JackMP3 is a command line Unix MP3 player written by Scott Smith that has been adapted for use within the JackOS environment. The decoding algorithms used in JackMP3 were written and are copyrighted by Tomislav Uzelac.

Smith's player is capable of receiving streaming MP3 audio feeds, as well as playing files from the local DiskOnChip2000™ storage system – at this time JackMP3 includes support for local playback. To simplify retrieval I have grouped the music by genre and artist. For example:

Folder	Folder	File/Song
Rap	Beastie_Boys	Remoteontrol.mp3
Jazz	Cole_Porter*	Blackmagic.mp3

* Author's favorite dog.

4.4.4 JackPager

Figure 4-3: JackPager welcome screen

The Linux box is running the open source Sendmail program to process and handle all email to and from the system. While it would be possible to have multiple, discrete users for the purposes of this project there is only one user that can be reached by emailing the following address:

thesis@mediajacket.media.mit.edu

A custom built application was written that allows for the use of the MediaJacket fabric keyboard and VFD to read, and write emails.

4.4.5 JackTelephony

Jack Telephony is a custom built telephony application that utilizes industry and world standard GSM compression algorithms. The codecs are freely available, and were written and copyrighted 1992 by Jutta Degener and Carsten Bormann.

Figure 4-4: JackTelephony welcome screen

JackTelephony uses 4Front Technology's Open Sound driver to communicate with the Yamaha OPL3-SA2 sound card in a full duplex manner. Full duplex, or the ability to simultaneously transmit and receive, is an extremely important requirement because people are accustomed to their regular full-duplex telephone calls.

JackTelephony samples at 8 kHz, and compresses down to 1550 bytes/second before transmitting the data to the recipient. Assuming a good network connection (local connect), the overall lag time due to compression and the cost of transmission is approximately 1/8 – 1/4 of a second.

As there is not yet a standard for IP telephony, JackTelephony allows users to receive calls from and place calls to other JackTelephony users. To call someone, the user needs to know the IP address of the machine they are calling. The address book permits simplified dialing by allowing the user to correlate names with IP addresses.

4.5 Desktop Interface

Largely for development and debugging purposes, JackOS, through a command line flag, can be switched to operate on a standard desktop system. Whether run on a desktop system or the MediaJacket, JackOS has the same feature set, however uses the conventional desktop monitor and keyboard.

Until another MediaJacket is built, the Desktop interface is used to communicate with the prototype MediaJacket system.

5. Interface Design

5.1 Design Criteria

The MediaJacket was created to showcase the potential for merging advanced communications and media systems into a clothing based, skin close, non-obtrusive vehicle. The goal to make the system as user friendly and unobtrusive as possible has served as the underlying motivation for the design and integration of the many MediaJacket hardware and software components.

Although my budget was not unlimited, I was not constrained by the conventional cost, or suitability tests I would have faced in the commercial sector. As such, working with my collaborators, I was able to select the components that maximized the MediaJackets functionality, comfort, and non-obtrusiveness.

5.1.1 Fabric Keyboard

The conductive Fabric Keyboard was designed in collaboration with Pamela Mukerji and Peter r Russo and is based on Maggie Orth and Rehmi Post's Musical Jacket Fabric Keyboard (shown right). By redesigning the whole system, we sought to extend their work by making a number of unique improvements. Chief among them we significantly reduced the controller board's footprint, added insulation to the conductive traces, and utilized conductive snap fasteners to allow for simplified removal (as shown in Figure 3-8).

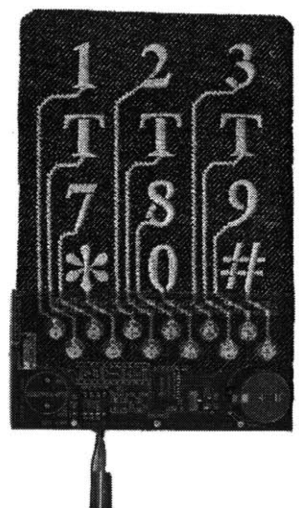

Figure 5-1: Orth and Post's Musical Jacket keypad[23]

The keyboard is permanently sewn on top of the fleece of the jacket's left forearm and is part of an integrated housing that holds both the keyboard and VFD. In keeping with the jacket's color scheme, a felt like black material and similar sewing stitch to mount the unit.

5.1.2 VFD Display/Housing

The Noritake Electric T-series vacuum florescent display was chosen for its appealing blue-green hue, clear lettering, power efficiency, and simplified serial interface. The board is integrated into the cloth keyboard, and rests in a custom built rubberized housing that has Velcro and snap enclosure for securing the unit to the jacket.

Although the PolarTec™ fleece provides insulation, a layer of cotton was added between the VFD and fleece to further reduce the chance of electrical interference with the user. The VFD is attached to the transmit pair of the Biscuit PC's COM2 port, and is wired to the 5 volt branch of the MediaJacket's main power bus.

To protect the unit from scrapes and liquid (as shown in Figure 3-5) a clear protective layer was added to shield the VFD.

5.1.3 Microphone and Speaker Housings

Both the microphone and speaker assemblies are encased in fabric pouches that are attached to the MediaJacket using the similar fasteners to the ones used to connect the controller board to the fabric keyboard.

Both the speaker and microphone are encased in black fabric, which blends in with the surrounding fabric near it. This was a deliberate attempt to draw attention away from the components.

The speakers (as shown in Figure: 3-10) rest atop the users shoulders, and are angled slightly inward to focus the direction of the speakers towards the ears. The conductive snaps used to fasten the speakers to the shoulders also serve as a conductive bridge for the speakers signal and power.

The microphone is similarly attached to the lapel, and is pointed towards the users mouth in an attempt to focus the input on the user, and to reduce the chance of picking up background noise.

6. Conclusions and Future Work

6.1 Results

This thesis presents an integrated, extensible, communications and entertainment system within a comfortable, non-obtrusive fabric vehicle.

To achieve this I enhanced several existing conductive embroidery techniques, designed and integrated various pieces of software and hardware, and engineered an extensible operating system that allows for simplified future software development. Using JackOS as a foundation, this thesis presents the following three applications:

Full duplex telephony
Pager
MP3 audio player

These applications are each in and of themselves useful, and together demonstrate the myriad of benefits of the MediaJacket platform. In accordance with the original vision of this thesis, users are able to make voice calls, send/receive emails, and/or listen to music while they are doing *something else.*

A lot of the success of the MediaJacket is due to the solid foundation of previous research it is built on. The work done at Carnegie Mellon, the MIT Media Lab, and Georgia Tech (to name a few) has not only served as an inspiration for this author, but has also provided the material from which I have drawn upon to make better system.

The InterfacePocket proved problematic for integration into the jacket. The RF signals it uses to "broadcast" to the InterfaceCard created substantial interference for the MediaJacket's sound and power systems. The InterfaceCard results were promising in that I was able to stream data to Vigoda's tag reader in a contactless manner. Although it is disappointing that the TagReader could not be integrated into the jacket, I feel confident future research will unearth a way to reduce the interface and marry the two technologies.

6.2 Conclusions

Overall the MediaJacket, as a sleek, comfortable wearable communications device proves to be a promising addition to the expanding field of personal, body-worn, computing. The MediaJacket's basic offerings, telephony, email, and music, are not new, or novel. However, where the system succeeds, is by blending these applications into a form factor not previously executed.

By building upon existing work, this thesis presents a model for how one can think about clothing and advanced computing. As the machines grow ever smaller, it will not be long before the MediaJacket setup appears antiquated, and unsophisticated. In building the MediaJacket it has never been my intention to invent a lasting technology. Instead, by drawing upon existing work, and through exercise of artistic license it is my goal to demonstrate ways to address the coming wave of ubiquitous networks. Personal computing will, indeed, become increasingly personal as the net plays an ever increasing role in our lives. In my mind, clothing is an excellent way to make computing more personal, less cumbersome, and more fashionable – the MediaJacket is, I hope, a step in that direction.

6.3 Future Work

The MediaJacket succeeds in packing a plethora of components into an appealing form factor, however falls short of addressing ways to improve many of those existing devices. Chief among the areas that demand future research and improvement is the MediaJacket's conventionally limited battery and power system. Power has, and will continue to be a monumental task for our planet – so it is not surprising this thesis fails to find a solution. Promising research, however, is being conducted in the field of renewable fuel cell technologies and increased battery efficiencies. For a true wearable system to succeed, advances in power generation, efficiency and storage will have to go beyond linear development.

The Biscuit PC served its purpose, however its processor limitations resulted in restricting the reach (and appeal) of JackTelephony. Moore's Law predicts increased performance will be in our future, however continued vigilance is needed to help computing transition from the desktop to the undershirt. There will eventually be a day when few could fathom how you could get by without omnipresent personal computing – what we do moving forward will shape the nature of that future.

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8. Appendix

8.1 JackTelephony GSM Codec Copyright Notice

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Berlin, 15.09.1992

Jutta Degener

Carsten Bormann

8.2 Primer on Bluetooth

Technology Overview

The technology is an open specification for wireless communication of data and voice. It is based on a low-cost short-range radio link, built into a 9 x 9 mm microchip, facilitating protected ad hoc connections for stationary and mobile communication environments.

Codename: Bluetooth.

A Global Specification for Wireless Connectivity.

Bluetooth technology allows for the replacement of the many proprietary cables that connect one device to another with one universal short-range radio link. For instance, Bluetooth radio technology built into both the cellular telephone and the laptop would replace the cumbersome cable used today to connect a laptop to a cellular telephone. Printers, PDA's, desktops, fax machines, keyboards, joysticks and virtually any other digital device can be part of the Bluetooth system. But beyond untethering devices by replacing the cables, Bluetooth radio technology provides a universal bridge to existing data networks, a peripheral interface, and a mechanism to form small private ad hoc groupings of connected devices away from fixed network frastructures. Designed to operate in a noisy radio frequency environment, the Bluetooth radio uses a fast acknowledgement and frequency hopping scheme to make the link robust. Bluetooth radio modules avoid interference from other signals by hopping to a new frequency after transmitting or receiving a packet. Compared with other systems operating in the same frequency band, the Bluetooth radio typically hops faster and uses shorter packets. This makes the Bluetooth radio more robust than other systems. Short packages and fast hopping also limit the impact of domestic and professional microwave ovens. Use of Forward Error Correction (FEC) limits the impact of random noise on long-distance links. The encoding is optimized for an uncoordinated environment.

Bluetooth radios operate in the unlicensed ISM band at 2.4 GHz. A frequency hop transceiver is applied to combat interference and fading. A shaped, binary FM modulation is applied to minimize transceiver complexity. The gross data rate is 1Mb/s. A Time-Division Duplex scheme is used for full-duplex transmission.

The Bluetooth baseband protocol is a combination of circuit and packet switching. Slots can be reserved for synchronous packets. Each packet is transmitted in a different hop frequency. A packet nominally covers a single slot, but can be extended to cover up to five slots. Bluetooth can support an asynchronous data channel, up to three simultaneous synchronous voice channels, or a channel which simultaneously supports asynchronous data and synchronous voice. Each voice channel supports 64 kb/s synchronous (voice) link. The asynchronous channel can support an asymmetric link of maximally 721 kb/s in either direction while permitting 57.6 kb/s in the return direction, or a 432.6 kb/s symmetric link.