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Marathon Man

by
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But I would specially like to thank Brad Geilfuss, Michael Hawley, and Rob Poor. They took on responsibilities beyond their fair share. A specially big thanks to Jason Hunter, who gave me an inordinate amount of his love, time, patience and support.

All pictures were taken by members of PIA unless otherwise noted.

Abstract

This thesis describes the design and development of the Marathon Man system. The system consists of a personal "black box" recorder worn on a belt that logs time, latitude, longitude, direction, speed, heart rate, temperature and running pace of the wearer. In addition to logging, the system can transmit this information wirelessly to an Internet server. The server stores the information and makes it available to arbitrary Internet applications, like Java applets, which display it.

The goal of this project was to engineer such a system and take it through a number of grueling tests in order to illuminate the practical aspects of the design and its performance in real field situation.

1
Introduction

The Story

On a bright and sunny April morning in Hopkinton, Massachusetts, three MIT scientists were sitting in the grass, watching a large crowd gather along Main Street. Just before 8 a.m. each took out a lumpy white pill and swallowed it with a gulp of water. Standing up, they wove their way through the crowd on to Main Street, and ran the Boston Marathon in the name of science. The pills were radio thermometers. They transmitted core body temperature to a tiny receiver each runner carried in a belt pack. The belt pack was a "black box for humans", capable of logging footsteps, heart rate, and GPS position, as well as body temperature. These vital statistics were to be recorded in a small computer ready to be relayed live to the Internet. The runners, Brad Geilfuss, Craig Wisneski, and Professor Michael Hawley, were the first runners to carry live health monitors during a marathon[1]. Five hours later, all three of them had crossed the finish line. However, only Professor Hawley was still carrying his sensors; the other two had left their recorders behind near mile 20. Much analysis would ensue aiming to understand what had worked, what had not, and what was to follow this five-hour experiment.

Hawley, Wisneski and Geilfuss take their pills before the marathon.

Three months later on the morning of July 13th, the weather in San Francisco was cold and rainy. Geilfuss and Hawley were standing on the Golden Gate bridge in a thick and gray mist, shivering. They were joined by Anil Tiwari, a serious amateur runner from Trimble, Inc.. The sensors and recording system had been redesigned and repackaged after Boston, and were ready for yet another marathon. A film crew from ABC World News Tonight began interviewing them. At the same time, a lone MIT engineer, groggy from an all-night computer hacking session, worked to set up a temporary web site at "Mission Control" just south of Market Street. A little after 7:30 a.m., as the runners began making their way towards San Francisco, he watched as bits from the runners' sensors began to

[1] Apparently, Associates & Ferren attempted to transmit a live heart rate from a runner in the New York Marathon to ABC television in the 1980's, using an infrared beacon and an observer in a helicopter. Unfortunately when the runner discovered he was in the lead, he jettisoned the equipment, and it was trampled by the rest of the pack [2].

blink on to the computer screen. Vital statistics were not only being logged, but also broadcast live to the Internet.

The Concept

Kazuhiko Nishi of ASCII Corporation suggested that it might be interesting to build "black box" flight recorders for cars to capture data at the time of a crash. Digital technology had evolved to the point where a black box for cars is already underway. Every Formula One car has a crash recorder that all information relevant to the car. Pushing Nishi's idea in a different direction, we decided a challenging application would be a personal black box that could relay its information live. Marathon Man began in January of 1997 as a device that would gather data about the location and health of its wearer just as its airborne counterpart records data about a plane's flight plan and status. We proposed to build it and test its capabilities in the Boston Marathon.

This system looked at the heart rate, temperature, cadence and location of three athletes as they ran a marathon. We wanted to record these statistics and relay them live to the Internet. Our goal was to gain an understanding of the engineering necessary to create a personal device capable of large-scale and real-time sensory collection for extended periods of time and under varied conditions. The previous scenarios were the culmination of months of engineering and the first two large-scale tests of the Marathon Man system.

TV cameras film the team preparing the runners for the marathon.

The larger goal of the Black Box Project is to understand the requirements and nuances of complete systems that bring real-time information from the physical world to a virtual realm where it can be collected and used in different applications. Marathon Man gathered vital statistics from three runners while they ran a marathon and relayed the information back to be displayed on the web. Kevin Kelley, of Wired Magazine, points out that although there are currently 500 million processors in PC's around the world, most people are unaware of the over 6 billion somewhat more modest computer chips in objects like cars, appliances, and toys. Furthermore, the computational power in such "things" is increasing at a rate vastly greater than that of conventional computers[1]. The power of everyday objects to perform complex computational tasks is generating a whole new category of "intelligent objects." As these objects attempt to behave in an intelligent manner they will need more and more information about their surrounding. This raises innumerable questions about how to get this information, how to store it, how to manage it, how to share it and how to understand it. Black Box's first project exploring these questions was Marathon Man -- a "personal black box".

This thesis describes the work done on the Marathon Man system from conception to execution in both the Boston and the San Francisco marathons. Chapter 2 describes work done by others relating to the Marathon Man system. Chapter 3 gives an overview of the vision and requirements of the system. Chapter 4 explains the technical specifications of the systems built for the Boston and San Francisco marathons and the reasoning behind the architecture. Chapter 5 discusses the engineering observations made during both marathons. Finally, Chapter 6 provides a wrap up discussion of what was learned, where this research is heading, and future projects based on this system.

2 Background

It need not take much technology to run a marathon. In fact, running shoes are perhaps the most advanced piece of engineering on a runner, and Abebe Bikila won the 1960 Rome Olympic Marathon without them. This thesis documents the first time anyone has run a marathon with substantial live computer monitoring. It is similar to other efforts of scientific instrumentation in that we want to measure certain body signals, but it differs in that we have a more demanding set of capture and transmission requirements.

As we began to design the Marathon Man system for the runners, we discovered a number of components and similar efforts that were relevant to our project. We collaborated with several of these groups. They provided us with technical expertise, advice, and grounding for our work. The following sections discuss each of them.

Wearable Computing

A human being is a particularly intriguing thing to wire with sensors. The notion of cybernetic clothing brings a whole new meaning to the term personal computing. Wearable technology seems to be gaining momentum as an important new field of interest. As evidence of this, cellular phones, pagers and small personal digital assistants have had enormous success in the marketplace. This suggests that computing power and communication devices that accompany us through out the day are reaching a high level of acceptance. Currently there is a burgeoning volume of research on wearable systems. For example, Steve Mann has investigated the benefits of carrying a computer with him at all times and applying its ubiquitous availability for non-traditional tasks [3]. In addition, in the fall of 1997, MIT hosted the first scientific conference on wearable systems and large-scale public symposium to discuss the diffusion of technology into clothing and personal articles [4].

Wearables' research group at the MIT Media Lab. © S. Ogden

BodyNet and PAN

When one begins to look at the mechanics of at computing on and around the body, the problem of internetworking emerges. How might you send the information from your smart shoes to your watch or to your doctor? Olin Shivers at the MIT Laboratory for Computer Science proposed the notion of a *BodyNet.* A BodyNet is a communications medium that utilizes the electromagnetic properties of the human body to communicate information between peripheral devices. Each of the devices shares the medium, much the same way that the different devices in a computer share its data bus [5]. Neil Gershenfeld and his team at the Media Lab have created early forms of this medium, which they describe as "Personal Area Networking" [6]. His team is continuing to explore the speed and bandwidth issues involved in utilizing this medium for personal computer devices. Similarly, Phil Carvey of BBN has been working on an implementation of a radio system that requires two microjoules per transmitted bit and four microjoules per received bit for a network on the body [7].

PAN transmitter and PAN III RS232-to-body modem.

Affective Computing

Networking in, on, and around a body is a nascent area, which has been driven into existence by the force of many practical needs. As sensors and personal networks mature, it will become possible to measure more interesting nuances in the signals generated by the body. Is the person happy, or sad, or perhaps angry? These questions fall into what Rosalind Picard has termed Affective Computing, a study of the different aspects of the relationships between human emotional states and computing [8]. If the tools we use everyday can sense human emotions, then they can adjust accordingly and thus benefit from the information. The system worn by our marathon runners clearly points in this direction.

Soldier Monitoring

In trying to improve the working and living conditions of its soldiers, the U.S. Army has been researching technology to monitor their soldiers under real conditions. At the moment, soldiers are assessed for fatigue by visual determination of the commanding officers. Unfortunately, commanding officers rarely have sufficient information about the actual state of accurately. To help alleviate this, the Army has developed systems similar to Marathon Man for monitoring soldiers during the course of their training.

An example of this is the Body Core Temperature Monitor (BCTM) developed by BBN for the Defense Advance Research Project Agency (DARPA). It consists of a receiver and a pill developed by the Johns Hopkins University Applied Physics Laboratory in collaboration with NASA's Goddard Space Flight Center. Once the pill is ingested by the subject, it transmits a low-intensity radio-signal to a radio-receiving device that accumulates body temperature statistics.

Muscles and Lost Patients

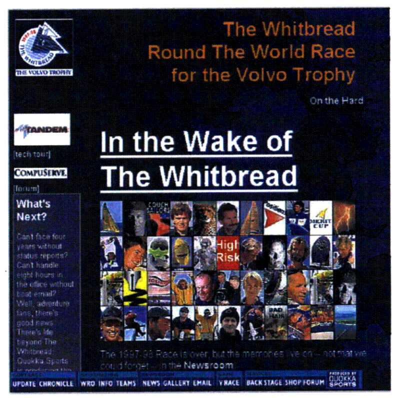
Medical science literature is filled with experiments measuring the many different parameters and signals of the human body. As we geared up for the marathon, we met the design team at the Boston University Neuromuscular Research Center led by Don Gilmore. They were working on measuring muscle fatigue through electromyographic measurements. They looked at the electric signals from the muscles across time and determined when the muscle was fatigued based on the variance in electromagnetic signals [9]. In time it would be very interesting to test these sensors in the real world.

At Draper Laboratories not far from the Media Lab, work was done to combine paging technology with a Global Positioning System receiver. The aim was to track Alzheimer's patients as they moved around in their daily schedules. Such tracking allowed the patients greater freedom in their lives without sacrificing the security of around the clock monitoring. Draper created a simple device that captured GPS coordinates. The device then sent this data through a two-way pager to a medical tracking service [10]. Unfortunately, the research was discontinued because of the high cost of paging and fact that GPS does not work indoors.

Sports Instrumentation

Ever since the discovery of measuring tape and stopwatches people have felt much more in touch with the quantitative aspects of training and competition. Quokka, a San Francisco-based technology company, demonstrates a more ambitious example of sports instrumentation. They seek to link live sensors to athletes and equipment, and make the data from these sensors available through the Internet. Their goal is to bring the analyzed data to the home viewer as a new dimension to already existing sports events. This type of monitoring is similar to, though not quite as public as other efforts such as "helmet cameras" used on quarterbacks and skydivers or the real-time digitally traced hockey puck developed by FOX television [11].

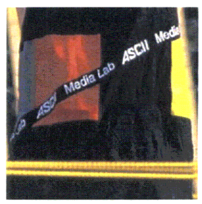
Currently, Quokka is monitoring the Whitbread yacht race by transmitting positional information and other details to their web site[2]. However, yacht racing as a sport avoids many of the more extreme problems inherent in more physical activities like marathon running. It will be interesting to see how their projects develop in comparison to the Marathon Man Project.



Screen shot of the Whitbread home page.

Along the same lines, the BBN team pursuing the temperature monitor work spun off a startup company called Personal Electronic Devices (PED), Inc. PED Inc. is engaged in designing specialized health-monitoring systems for the consumer market place, and is currently working on a select few sensors and actuators which will enable users to monitor vital signs while participating in fitness activities. Their goal is to have devices that are stylish or inconspicuous, wireless and could be worn as apparel, jewelry, and fashion accessories. We worked directly with PED to modify a version of the pill-temperature sensor, and provided the opportunity for PED to test its sensors in-place in a complex recording system.

[2] http://www.whitbread.org/main.html



3 Vision + Requirements

Imagine the following 20 minutes into the future:

Maria is lying down on her couch after her daily run. A bit of analysis is being performed on the data she transmitted while she was running. As she walks over to the refrigerator for a drink, a projection is cast on the door. Position, heart rate, blood pressure, oxygen and sugar level graphs appear as she pours a glass of water. Her heart rate seems not to quite have calmed down from that last minute sprint. The map of her run plainly shows that today she took a little shortcut; she double-backed a little sooner than she should have. The data is clearly projected in front of her, and soon enough, it will be in front of her personal trainer as well, who will not like what he sees. Usually he monitors Maria from the gym while she is running, giving her feedback and motivation, shouting while she climbs the hills. She decides to console herself by looking at her best friend's data. Geeta was always the slacker anyway. She pulls up the data graphs for Geeta, and discovers she is running at the moment. In fact, she is at the very hill Maria decided to skip. A graph appears. It compares both heart rates versus altitude. It does not look good. Geeta has been training for only two weeks and her heart rate is already lower that Maria's. Maria decides that it is time to step up the training.

The description in the paragraph above is one scenario of what a system like Marathon Man could do. The requirements for such physical system include minimal weight and size, ruggedness, self-encapsulation and extensibility. Let us examine each requirement.

Requirements

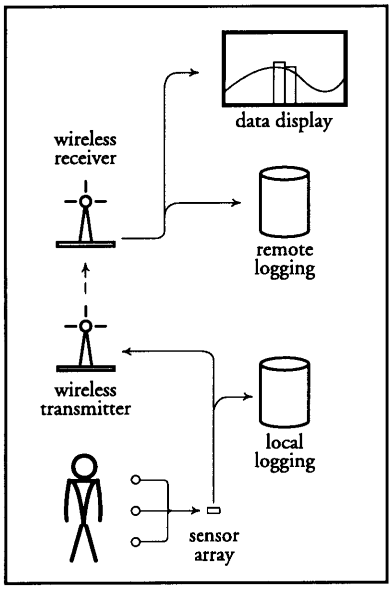
Minimal Weight and Size. Because running a marathon is a physically exhausting endeavor, the system must be as small and light as possible. Ideally, the system should be invisible to the runner. Worn on a belt or a vest, it should automatically start logging vital statistics once the runner puts it on.

Ruggedness. A marathon is hard on the body and anything that goes with it. The system needs to be able to withstand the shock of long distance running.

Self-contained. We want to monitor the running without disrupting it. The runner should not have to interact with the system once it is working. This means that the runner should be able to turn on the system, put it on and complete a marathon without any other input to it. It should be as simple as putting on your shoes, if they are not already included in them.

Extensibility. The Marathon Man system is only an instance of a typical Black Box project, so the base architecture needs to be modular. We want to facilitate the process of adding different sensors, updating or changing the data collection methods, trying different ways of data storage, etc.

4 Technical Specifications



Data flow through the major components of the system.

The system described in the vision above lends itself to be divided into five major components:

- Data Acquisition
- Local Logging
- Wireless Transmission
- Remote Logging
- Data Display

The measurement of data is done by the data acquisition hardware, which consists of an array of four sensors. One sensor measures GPS satellite information for time, position, speed and direction. The other sensors measure heart rate, temperature and cadence respectively. The data collected by the sensors is stored immediately by the local logging sub-system. Once secured, the transmission module sends the same data to the remote logging server, which takes the incoming data, stores it and indexes it for anyone who needs it. The data display applets take the information from the server and plot the data for visual analysis.

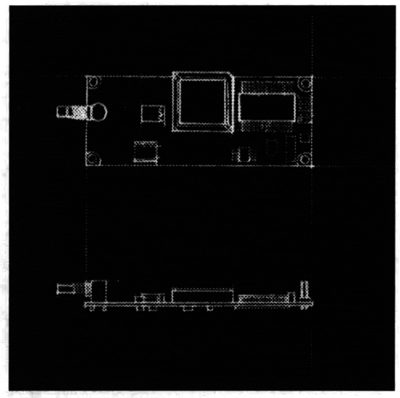
Data Acquisition

The data acquisition hardware is made up of four sensors: a GPS unit, a heart rate monitor, a temperature sensor and a cadence measurement device. The four sensors have four wires: power, ground, ping and data, which are connected to the power and input pins of an IRX board [12]. The IRX continuously listens to the GPS data line for an output sentence. Once it hears the sentence from the receiver, it places the data on the serial line. The IRX then proceeds to query each of the remaining sensors, one at a time, for their current state. Raising the voltage on the ping line starts the querying for the particular sensor. Once the sensor detects the level change, it returns it state data. Each of the sensors' responses are tagged with the respective ID and sent through the serial line following the GPS sentence. Once all the sensors have been queried, the IRX returns to listening for the next GPS sentence.

This architecture effectively emulates a master-slave arrangement with the IRX as the bus master and the GPS as the clock. The GPS receiver acts as the trigger for the querying cycle because we use the clock from the GPS as the time stamp for all the data. This cycle-based querying mode architecture can easily be modified to accommodate additional sensors by simply inserting them in the querying cycle. The following is a more detailed description of each of the components.

Global Positioning System Receiver

The Global Positioning System (GPS) is a collection of satellites owned by the U.S. Government. These geo-synchronous satellites provide worldwide positioning and navigation information by broadcasting their position at all times. GPS receivers listen for these satellites and use their beacon transmission as a reference point to determine precise location, direction and speed.

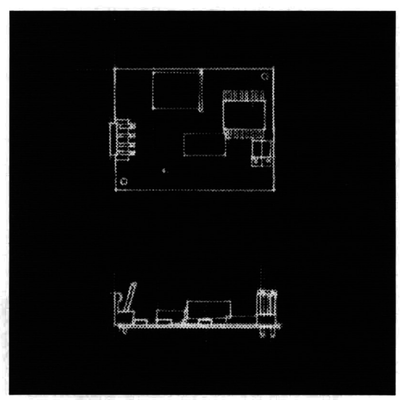


Trimble Lassen SK-8 GPS receiver.

For both marathons we used the Trimble Lassen SK-8 OEM kits. They were the smallest GPS receivers available in the market. The kit consisted of a receiver board and an antenna. The power requirement was 200mA at 5V. The frequency as well as the type of output was configurable. We chose ASCII NMEA $GPGGA and the $GPVTG[3] sentences once every second. The output was sent serially at TTL levels through one of the pins on the board at 4800 baud. This made it simple to connect to one of the pins of the IRX board for reception.

Heart Rate Monitor

To track heart rate data, the Marathon Man system uses Polar's monitoring equipment, which consists of a chest strap and an OEM receiver board. Each heartbeat is an electrical signal sent by the sinoatrial node to the heart muscles. This electrical impulse can be detected on the skin. The Polar chest strap detects the voltage differential generated by this signal and sends a wireless notification to the receiver. The receiver board



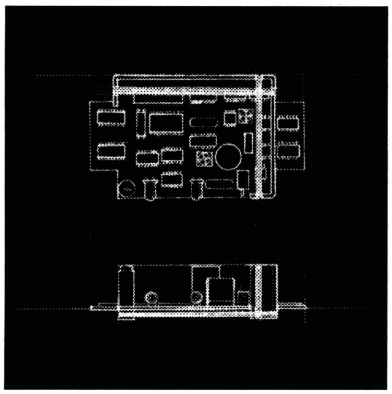
Polar Heart Rate receiver board.

3 The $GPGGA sentence contains UTC of position, latitude, longitude, GPS quality indicator, number of satellites in use, horizontal dilution of precision, antenna altitude, geodial separation in meters, age of differential GPS data and differential reference station. The $GPVTG sentence includes track made good in degrees true, track made good in degrees magnetic, speed over ground in knots and speed over ground in km per hour. Out of these we only use time, position, true direction, and speed in km per hour.

calculates the rate and stores the data until it is polled by the IRX board.

For both marathons we used this chest strap/receiver configuration. The receiver board utilized very little power. The output of the board was configured such that it would return 2 hexadecimal characters for heart rate each time one of the pins on the board was set to high. They were also transmitted at 4800 baud.

Temperature

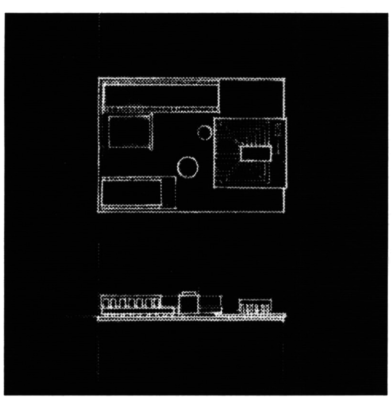


Body Core Temperature Monitor receiver board.

As described in the Background chapter, BBN designed the BCTM unit for DARPA. The BCTM consists of two components: a pill transmitter and a receiver unit. The pill is a small non-toxic radio transmitter that generates a continuous radio signal, whose frequency changes in proportion to the temperature. When the pill is swallowed, these changes in frequency correlate with fluctuations in the core body temperature of its carrier. The receiver sits outside the body, typically on a belt pack and captures the signal. Although the data that comes back from the BCTM is directly proportional to the temperature, it still depends on a calibration number for the pill as well as a calibration number for the receiver.

The BCTM was used for both marathons. The system had to be retrofitted to match our system because the original design stored the data in the receiver, and we wanted to have the information when requested. PED Inc. modified the system such that holding one of the pins high returned the state data. A set of frequency metrics was later used to decode the data and determine actual body temperature.

Cadence



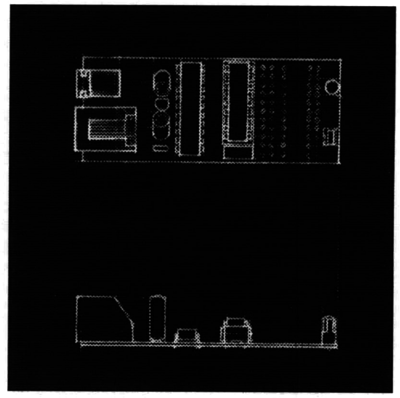
Cadence monitor board.

PED Inc. designed the cadence sensor for the system. The cadence sensor is basically an accelerometer worn on the hip. The downward force of each footstep causes a spike on the accelerometer. Counting the number of spikes that are sufficiently large results in the number of steps. Both marathon systems used the cadence sensor. It is extremely lightweight and uses very little power because of its simple mechanism.

Following our original architecture, the sensor returns the number of steps taken when one of the pins is held high.

IRX

The IRX board, designed by Rob Poor at the Media Lab, is a multi-purpose housing for a PIC 16C84 micro controller. It powers the chip, synchronizes its operations with a time crystal, and exposes the chips I/O pins for easier incorporation into larger devices. In addition, the IRX has logic for performing serial I/O operations. The PIC 16C84 is an EEPROM micro-controller with 14K of ROM and 36 bytes of data storage memory. It has 13 I/O pins, which take in TTL level logic.



IRX board

The IRX board was used as an arbitrator to collect the data of all of the sensors and serialize it for logging and transmission. The PIC 16C84 was adequate for this task; it had enough processing power to perform the synchronization and encoding operations and its light weight did not encumber the rest of the system. The program written for this task loops continually while listening on the pin assigned to the GPS. The ASCII sentence from the GPS consists of about 80 characters when all information is present. When the IRX hears this sentence, it starts to pass the characters to the serial output. This is necessary because the PIC does not have enough memory to store the whole sentence. Once the sentence has been fully transmitted, the querying cycle starts for the rest of the sensors. For each sensor, the IRX holds the ping pin high for a short amount of time. Then it listens on the return pin of the current sensor for the answer. The IRX takes the return data and concatenates it with the sensor's tag. The tags are "PR" for the heart rate, "CA" for cadence and "BT" for the temperature. The new tagged data item is then sent through the serial line to the logger.

Local Logging and Transmission

Logging and transmission of the collected data required more sophisticated hardware and software than could be provided by the IRX board and its PIC microprocessor. The local logging sub-system required about 2Mb of storage space for the data[4]. The transmission system required that the data be sent over a wireless communications network. These functions were combined and handled by a general purpose CPU running on a palmtop computer.

The IRX board output is fed to the palmtop via its serial communications port. A custom written software sub-system interprets and stores the output. The sub-system takes the encoded data from the serial line and parses it, discarding the ID tags and compressing the remaining data. The compressed data is then saved to a file. Once the data is secured locally, a copy of it is transmitted through the wireless network link to the main server. This module is designed to do as little conversion as possible. It simply serves as a pipe between the sensors and the server.

Although the palmtop is a complete CPU, the functionality we used was minimal and could have been built into a micro-controller more powerful than the 16C84. However, utilizing the palmtops at this stage allowed us to assemble the system faster and use more conventional market driven products for the wireless network link for modularity. The palmtop computers running a conventional operating system permitted a number of different wireless network and software configurations; this allowed us to determine which architectures worked best without having to reconstruct the entire system each time. On the other hand, we could not use the palmtop to replace the IRX and act as a bus controller because it only had one serial port. It needed a "data funnel," namely the IRX board to serialize the sensor data.

Local Logger

The data logger for the Boston Marathon was a HP 200LX palmtop computer running the DOS operating system. For the San Francisco Marathon, we updated our platform to a Compaq 120 palmtop computer running the Windows CE operating system. Both

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[4] We estimated our runners would at most take 6 hours to finish the marathon. The system sent out state data each second. The data sentence consisted at most of 100 characters. Thus $6*60*60*100 \approx 2MB$.

machines had a serial port, a PCMCIA slot and enough memory for all the data.

The software was the same for both marathons. First written for the HP in C, it was ported to the CE machine for the San Francisco marathon. Essentially, it read the serial port for data. The program took the incoming GPS sentence for the time of day, the latitude, the longitude, the direction and the speed and put each item in a buffer. It then waited for the data from the rest of the sensors. As each tagged item came in, the program placed the new data in the buffer. When the next GPS sentence came in, the buffer was turned into an ASCII string containing the newly acquired information. To create the string each buffer was compared to the previous buffer value. If they were the same, no value was written, otherwise the new value was added to the string. This comparison was done as a rudimentary form of compression. Once the string was finished, it was written to a file.

samp	hp time	UTC	Latitude	Longitude	mph	hr	temp
06120	11:55:35	17:33.51	N042.16.946	W071.22.508	1.02	132	466.1
06121	11:55:36	17:33.51	N042.16.946	W071.22.508	1.02	90	466.1
06122	11:55:37	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06123	11:55:38	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06124	11:55:39	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06125	11:55:40	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06126	11:55:41	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06127	11:55:42	17:33.51	N042.16.946	W071.22.508	1.02	90	466.3
06128	11:55:43	17:33.51	N042.16.946	W071.22.508	1.02	90	466.3
06129	11:55:44	17:33.51	N042.16.946	W071.22.508	1.02	90	466.3
06130	11:55:45	17:33.51	N042.16.946	W071.22.508	1.02	90	466.3
06131	11:55:46	17:33.51	N042.16.946	W071.22.508	1.02	90	466.3
06132	11:55:47	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06133	11:55:48	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06134	11:55:49	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06135	11:55:50	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06136	11:55:51	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06137	11:55:52	17:33.51	N042.16.946	W071.22.508	1.02	90	466.1
06138	11:55:53	17:33.51	N042.16.946	W071.22.508	1.02	90	466.1
06139	11:55:54	17:33.51	N042.16.946	W071.22.508	1.02	90	466.1
06140	11:55:55	17:33.51	N042.16.946	W071.22.508	1.02	90	466.1
06141	11:55:56	17:33.51	N042.16.946	W071.22.508	1.02	90	466.1
06142	11:55:57	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06143	11:55:58	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06144	11:55:59	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06145	11:56:00	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06146	11:56:01	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06147	11:56:02	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06148	11:56:03	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2
06149	11:56:04	17:33.51	N042.16.946	W071.22.508	1.02	90	466.2

Part of Hawley's data from the Boston Marathon.

Wireless Transmission Link

For the Boston Marathon, we planned for the HP palmtops to connect to the main server through a Motorola Montana cellular modem utilizing Motorola StarTac cellular phones as a communication medium. For the San Francisco marathon, we switched to Motorola CDPD modems.

The communications program for the Boston marathon basically opened the modem port and dialed to the Media Lab server. It then attempted to log in and open a socket connection with the remote logging server. For the San Francisco marathon the communication system was further simplified. It had only to open a socket to the server. Because they were designed for data transmission, turning on the CDPD modem connection gave us instant access to full TCP/IP services. The software system became more robust using the CDPD modem because it was easier to detect a dropped socket or dead connection, and because the Windows CE operating system had commercially available drivers for them.

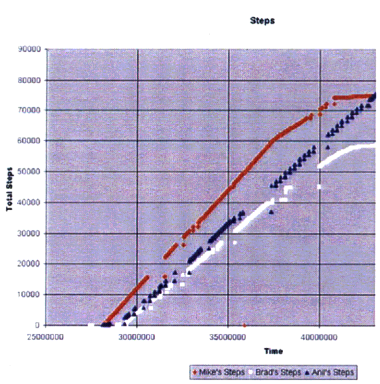
Remote Logging and Data Display

The server is mainly a database for data received from the runners via the wireless link. It indexes and archives what it receives. In addition, the server provides a display client interface to allow the display applets to retrieve the latest data for delivery to the user. The client side consists of an applet, which receives the user's query preferences and relays that information to the server. The server then correlates the appropriate values and the current time and returns the relevant information to the applet.

The goal of this aspect of the project was to make it possible to see, hear, and generally know about our runners in real time on the Internet. To this end, applets were created, which took data from the server and allowed users to select visualization of the following: GPS coordinates, temperature, heart rate, number of steps, direction or speed. The applets updated the data points at intervals of 5 minutes.

Server Software

Our approach to server design varied greatly between the Boston and San Francisco marathons. The differences were a function of how much of the data formatting was done on the server side, and how much was done on the client side. For Boston, the server received the data, averaged it in five-minute intervals, and wrote these cumulative samples to a file. The applet then read and graphed the data. However, for San Francisco we moved the responsibility for formatting the graphical data to the server side. Instead of providing a graphing applet, the server received the data, saved it to a master log file and created graphs at 5-minute intervals. These graphs were provided because we learned in Boston that having each applet request data is too server and applet intensive.



Graph of steps vs. time for the three runners in San Francisco.

Display Applets

As described above, the applets for the Boston marathon received the values for every variable every five minutes from the start of the race until the race's marathon had simpler applets that merely displayed the appropriate pre-drawn graphs.

For the San Francisco marathon, two new applets were added. The first one, a messaging applet allowed anyone logged into the site to send messages to each runner. The messages are also routed to a file for annotation purposes. All messages were time stamped before being stored. The second set of applets was a new applet/servlet combination. It allowed users to listen in to voice snippets made from the runners' phones during the race. We wanted to add comments from the public as well as sound bites from the runners.

Connections

For the Boston marathon the connections between the IRX board and all the components consisted of 4 wires with 4-pin plastic headers on each end. They were soldered onto the IRX board. Each sensor had a matching header, and four wires (power, ground, ping, and data). This setup allowed us to switch the components if they needed to be replaced. Having learned from the Boston marathon that wires are easily disconnected, for the San Francisco marathon all the wires were soldered directly from the IRX to the component completely forgoing the headers.

Batteries

The power requirements for the system in both marathons were about 300 mA at 9 volts for the data acquisition hardware. We used three 3V Panasonic Lithium A batteries in series. The batteries had a specification of 1800 mAh, which meant our system could run for 6 hours. The batteries for the palmtop machines were standard NiCd batteries, which did not need changing during the marathons. The CDPD modem for the San Francisco marathon also used three 3V Panasonic Lithium A batteries. The batteries had to be specially designed for the modem because the original batteries would only last for 30 minutes.

Other Project Elements

Packaging

For packaging in the Boston marathon, we used hip pouches for the equipment. All the components were placed in one pouch and padded with bubble wrap so as to soften the impact on the circuit boards. In the San Francisco race, we worked with the U.S. Army Research Institute of Environmental Medicine (USARIEM). They graciously offered to construct a belt made out of neoprene. The belt had custom designed compartments for each component distributed evenly around the waist. The palmtop sat in the small of the runner's back while the receivers sat in the front, away from each other.

Cellular Phone Link

For both marathons, all runners were equipped with earpieces and microphones connected to cellular phones. They were able to receive calls from relatives, friends, the support crew, and interviewers. One of the runners, Craig, noted that this was the best feature of them all. It made running far less lonely.

Support Team

The support team for both marathons consisted of a Mission Control room and a pit stop crew. Mission Control was the room with the server and a person to staff it at all times in case of emergencies. The Media Lab was host to Mission Control for the Boston Marathon, and Construct, a web design firm, was the host for the San Francisco marathon. In addition, during the actual races, we had a 4-person pit-stop crew assembled. The crew was divided into two pairs, which manned two stops each spaced evenly across the route. For both marathons, the systems were self-sufficient. The stops were mainly for checks on the state of the hardware and the runners.

Other Alternatives

Other alternatives for the implementation of Marathon Man were explored at the beginning of the project. We looked at VIA computers, which are portable computers that handle a full-scale operating system. We discarded this possibility because of their very high price tag. We wanted to be able to produce many of these systems in the future for different kinds of places and different kinds of situations.

For the Boston Marathon, we implemented a second alternative. We created two belts as described above and a third more experimental, system. One of the runners carried a PC104 computer instead of the palmtop computer. Unlike the HP palmtops, it used a Sierra CDPD modem, ran the Linux OS, and had a 700MB hard drive. Its hardware apparently worked fine, however, due to a mistake in the setup the morning of the race, it was unable to log any data. In addition, it gave the runner who carried it a painful bruise. The PC104 computer was not significantly heavier, but it took up more space than the palmtops. It had sharper edges, which were difficult to pad. Although we speculate that the system would have worked, the PC104 system was dropped from the San Francisco race because we had the same functionality with the smaller palmtop machines.

5 Observations

This section describes a series of observations from the experiences of the two races. These observations from the Boston Marathon led to many of the redesigns and improvements that ultimately led to the success of the San Francisco race.

Boston Marathon

Looking at the sensors' state and data from Boston taught us a lot of things about soldering, wiring, crazy glue and electromagnetic waves. The GPS data from Boston marked the route as expected. We anticipated a little more deviation since we did not use differential GPS. Nonetheless, it followed the course with great accuracy. The cadence sensors told us we had taken around 70,000 steps for each runner. However, neither the heart rate sensors nor the temperature sensors returned anything useful. Analyzing the state of the systems when they returned from the marathon, we found that the most common problem was flaky or dead connections between the sensors and the IRX board. The intense shaking of the equipment during the marathon jarred the plastic header connections. We had tried to anticipate this during the construction phase. To ensure that the connections would not come loose we used Crazy Glue to hold the headers to the boards. However, we found that when the metal pins are covered with Crazy Glue, they were not reliably conductive anymore, effectively defeating our attempts to avoid disconnection. Some of the heart rate and temperature sensors were well connected but failed to gather data. Because they depended on radio transmission, we speculate that the electromagnetic radiation given off by the HP palmtops interfered with their reception. We only speculate because none of these symptoms surfaced during component testing or in our later efforts to identify the cause of failure.

Hawley double-checks the software in the palmtops before Boston.

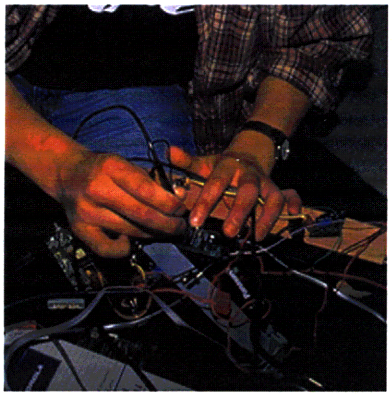
Wireless transmission did not function properly during the marathon due to two main problems. The first involved an unanticipated incompatibility with different versions of the palmtop hardware. During development of the project the software for managing the wireless connection had been written and tested on the HP Palmtop Model 100. However, the Marathon

Man system ended up using the newer HP Model 200 because its increased memory was needed for data logging during the race. We did not test the HP 200's because we did not receive them in time. HP guaranteed the two machines' architectures to be identical, but this information was erroneous. The wireless connection software failed to function properly on the newer model machines despite our best efforts to understand the difference. The second problem involved an unusual conflict between the cellular modem and their companion cellular phones. The modem had a sudden draw of power immediately before it was about to dial. However, this increased power demand reduced the power being delivered to the phone. This caused the cellular phone to turn itself off. To continue the dialing process one would have to manually turn the phone on again: an impossible requirement for the runners.

Due to the loss of the wireless network, we were unable to test the server in real time during the Boston marathon. This failure created many complaints from people at home whose browsers stalled when attempting to access the server software. Nevertheless, after the marathon had completed, the data was taken home for analysis. The log files were spooled to simulate the running of the marathon. The data stream illustrated that the client interface was unbalanced toward the server side. Because the client applets attempted to perform their own data calculations and graphs it was necessary for the server to deliver the relevant data to all registered applets. As the number of clients increased, the server became overburdened trying to update all the applets with the new values. This led to the server side redesign used in the San Francisco race, which pre-computed the graphs rather than updating the values of each applet every 5 minutes.

San Francisco Marathon

The San Francisco marathon was far more successful. The belts started transmitting data about fifteen minutes before the race started. The server logged the data and within five minutes graphs were available for display on the web. The GPS sensors transmitted their location intermittently, which was expected for reception in city streets. The cadence sensors logged the number of steps taken as a function of time and the temperature sensors worked moderately well. Anil's temperature sensor sent data just as expected. Brad's temperature monitor sent out data but it showed abnormal aberrations. His temperature appeared to be 50 degrees Celsius. We believe the receiver never identified the pill signal, which could have been caused by a pill with a weak battery. This would have caused the receiver to pick up background noise as the temperature. Mike's temperature sensor on the other hand did not send any data. This was caused by a broken connection between the board and the sensor on the day of the marathon. The only items that were not recorded at all were the heart rate values. The sensors were working, but a bug in the logging software killed their values for both logging and transmission. Although the system suffered a couple of drawbacks at the last minute, overall, it was extremely successful.



Lau tests the equipment for San Francisco.

Data Sets

Because our main goal was to learn how to build a black box system, we did not gather enough data to make any significant physiological assessments. Looking at the data individually, we saw what we expected to see for both marathons. The GPS data clearly outlined the courses. It came in and out as the runners went underneath trees or narrow streets. However, there are a couple of examples where the data did surprise us. In San Francisco, the temperature data from Anil showed downward spikes in his temperature. It took a second look to realize that the spikes coincided with the spots where he took drinks of water. Watching the live data from San Francisco, we also saw an aberration in the cadence measurements received from Professor Hawley. His graph of strides versus time showed a change in slope at around mile 13. It coincided with the place where he injured his foot. In contrast, Brad and Anil's stride graphs showed perfectly smooth slopes.

Time scale

In both marathons, we had a team of about ten people working on the project. The original idea was conceived in December 1996 with the Boston marathon in April of 1997. By January 1997, research was underway as to what sort of architecture the system might need. Once the project was clearly defined in terms of components, we divided the tasks. It was not until February that we began building hardware and software. A working prototype was expected in two months, three weeks before the Boston Marathon. Although the interfaces between the components were well specified, we kept falling behind in schedule for full integration testing. A week before the race we had only tested the parts running separately. Full integration of the system did not happened until the day of the marathon. The main problem was underestimating the actual time needed for making the system robust.

Geilfuss and the author analyze the data after a test run.

For the Boston marathon we had tested all the components separately to our satisfaction. Having immutable dates really focused the implementation of the system, however, the short time line did not allow enough time for integration testing. Most of the problems we encountered in Boston could have been avoided by it. For the San Francisco marathon, we understood what the flaws were. In the three months between the marathons, we reconstructed the belt and restructured the server software. Because for San Francisco we had the basic design completed, we had time to put all the system together and test it.

Media Coverage

As our project gained momentum, we began to get more and more questions from television and newspaper crews who were intrigued by our endeavor. The first people to contact us were the team from the New York Times TV branch. They are a new division who has started a show in the fall of 1997 and was doing a segment on GPS. They felt our research was interesting and sent a cameraman to see us. They filmed our beginning meetings, early experiments, accompanied us on both the Boston and San Francisco marathon. Tech Talk, an MIT campus newspaper, interviewed us before the Boston marathon and published a follow-up article. The day before the Boston race, we had a two-minute segment on the Channel 5 local news show. As the Boston marathon approached, NESN and MSNBC became interested. NESN interviewed Hawley at the beginning of the race. MSNBC interviewed him over the phone as the race progressed. In San Francisco, ABC World News Tonight filmed us testing and training a few days before, and accompanied us through out the day of the race.

TV crews followed our progress in San Francisco.

All the publicity this project received was an interesting catalyst for many different things. The benefits of reaching a large audience are stunning. Because the project is based on things people are familiar with like heart rate, temperature and location, the imagination of the general public is sparked. We met many people who heard of the project and not only understood the premises, but were also able to give new perspectives and different ideas. By the end of both marathons, we had used up a fair share of Warhol's 15-minute allotment.

Internet

- http://espnet.sportszone.com/gen/features/00191784.html
- http://web.mit.edu/newsoffice/tt/1997/apr16/43532.html
- http://web.mit.edu/newsoffice/tt/1997/apr30/43565.html
- http://www.mot.com/MIMS/ISG/Products/pcmcia/marathon.html

Television

- New York Times Television
- NECN
- MSNBC
- WCVB ABC Channel 5, Boston
- ABC World News Tonight

Newspapers

- MIT Tech Talk – April 16, 1997
- MIT Tech Talk - April 30, 1997

6 Conclusion

We have come a long way in understanding the work that needs to be done to accomplish our original vision. The Marathon Man project has given us insights to what might happen when personal black box recorders are as small and common as wristwatches. But it has raised as many questions as it has answered.

Future Work

Sensor Hardware Architecture

The Marathon Man system was a first step towards placing sensors on things around us. However, not everything has a heartbeat; nor do all things need to know how fast they are moving. Different sensors are needed for different applications. We must understand what sensors are appropriate for which objects and how can the sensor package be incorporated into a wide range of them.

We need a toolkit of components that are as easy to assemble as LEGO bricks. On one hand, a good designer can lay out chips and boards to do the sensing for any specific task, but each component has its own quirky interface. On the other hand, where network architectures do exist, such as USB or MIDI, they depend on large components to drive them. There is no good high-level component architecture for assembling sensors. To this end, we want to develop an extensible architecture to accommodate sensors in varying configurations.

Communications Systems

In the course of our project, we came to understand the state of wireless technology. RF networking is an essential component for intra-body sensors, but there are no real solutions available yet. Phil Carvey's work on BodyNet at BBN and Robert Poor's work on Hyphos [13] at the Media Lab may be a step in this direction. Poor's low power, high density, distributed network infrastructure holds promise for outfitting sensors with communication. Similarly, Carvey's work on low power radio transmission and reception could be a good option.

Power Management

Batteries are a limitation. If sensors are to prevail in the environment around us, we cannot have sensors that need battery changes. Developing hardware that uses minimal power is a first step. Once this is achieved, alternatives to batteries like solar or parasitic power become feasible.

Human Factors

After the first marathon, the system was totally repackaged. Awkward shapes and bulging packs are unacceptable if sensors appear in many aspects of life. Pedometers should be in shoes, a positioning system on your watch, a temperature sensor on your clothes, a heart rate monitor on your jewelry. Its is essential to develop systems that enhance your lifestyle rather than intrude into it.

Data Gathering

We must better understand the range and breadth of sensory data that can be effectively captured in real time. New sensors will increase significantly the volume of data flow and require new solutions to the management, categorization, and cataloging issues for this river of data. Because the data stream from Marathon Man was relatively small, these topics were not an issue but need to be investigated.

Data Display

An opportunity that was left unexplored in Marathon Man was data display. Marathon Man used applets embedded in Web pages to display graphs of incoming data, offering a relatively primitive view of the data. However, more intuitive ways of presenting information from a black box recorder must be designed. Current displays neglect many of the sensory powers of the human body, or the organizational properties of the human brain.

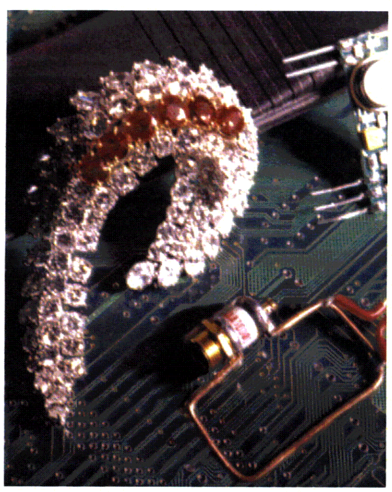
It is imperative that interactions that "feel" right are investigated. Professor John Maeda and graduate student Matthew Grenby are investigating different alternatives for expressing large amounts of data through compression of information into carefully designed spaces [14]. Along the same lines, work done by Professor Hiroshi Ishii and Brygg Ullmer on Tangible Bits allows users to interact with a data space through physical objects [15].

Data Understanding

The medical and sports training applications shown here hint at broader social consequences. In light of this research, we can now appreciate that there are essentially no online medical peripherals. Suddenly, it is not hard to imagine appliances like bathroom scales that transmit your weight to your household home page, in a form that your doctor or trainer could access. What does it mean to know one's precise weight or body temperature on a continuous basis? A new field of physiological science is waiting to be enabled by systems like those in this thesis. Capturing and analyzing vital statistics over an extended period of time is of extraordinary value. Data analysis gives us the capability to understand small subtleties of our surroundings, the departures from our daily routines.

Spin-offs

While working on the Marathon project, we came across many people who were very interested in our work. They provided us with feedback as to where our research was useful in a real context as well as to where it could go. The following is a list of some undertakings that have been spawned from the Marathon Man project. They address some of the issues we mentioned above.



HeartThrob brooch in its electronic splendor. ©W. Chappell

In conjunction with Harry Winston Inc., we created a system that lights a ruby brooch in synchronization with the wearer's heart beat. In addition, it transmits heart rate data to a computer. As digital technology begins to dissolve into the objects around us, there is no reason why sensors should require special probes or electrodes. The brooch is an illustration of how this technology can become part of our lives without intruding upon them.

The Tandemonium project builds on the ideas developed during Marathon Man. Tandemonium involves equipping a tandem bike with an array of sensors to record performance such as speed, heart rates, position, strain, temperature, audio and video. Collected data will then be made into an interactive salient still for others to experience the bike ride as it happens [16]. One of the most important goals of Tandemonium will be the creation of a robust and scalable architecture for gathering large amounts of sensor data as well as a software platform that can deal with the incoming information. The bike offers a rich test bed for data collection because it does not have the weight constraints of the Marathon Man system. The planned culmination of the project is a trip across the country to take place June of 1998.

Tandem bike team in front of the Washington monument.

Because of the Marathon Man trials, USARIEM became interested in our project. They felt our systems would be useful in monitoring soldiers as they underwent training exercises. In a collaborative effort, an Army team of researchers and our group created seven systems, which were used for physiological studies of soldiers undergoing different training situations. Early results from the study show a detailed picture of the physiological state of the soldiers [17].

The author outfits a soldier during trial in Fort Benning, Georgia.

Communications satellite systems are currently being deployed by companies like Motorola and Teledesic. They are designed to create global telecommunication networks that function everywhere on Earth. We would like to build a small black box device that uses these networks to send information from any point in the world to another. Imagine a child in a remote country recording pictures, sounds, and bits from daily life for the world to see. Having access to such information could bring about a host of unexpected changes; much like television did when it broadcast images of presidential debates and wars fought in distant lands.

Finally, we have teamed up with the 1998 American Everest Expedition and doctors from the NASA-Yale Space Center to look at different types of data streams coming down from the mountain. For May 1998, we are developing the following items for the expedition:

Bio/Geo Packs: an array of vital sign monitors will be worn by the climbers to capture and transmit their health statistics as well as environmental data during their ascent.

Datacam: still and video cameras will be augmented with sensors so that contextual data (GPS, altitude, temperature, barometric pressure, compass) are recorded with every still or video frame. Each image will be anchored to a real time and place on earth.

Everest Summit Probe: sensors that measure temperature, humidity, pressure, light level and wind speed and a camera will be placed in the summit and South Col. Climate data will be continually recorded and transmitted via satellite a few times a day for a year.

This will allow us to push two very important aspects: the engineering challenges of vigorous activities and the telecommunication requirements of extreme environments.

A Final Word

Internet growth is immense and will continue apace. The black box prototypes described in this thesis essentially are a mix of sensors in a data flow architecture that makes it equally easy to do local recording or remote transmission anywhere in the Internet. Pieces of the Black Box vision can be seen in other efforts like research in online automobiles, or in early consumer products like heart rate monitors. It can be seen in today's glimmer of things like "web" cameras and online coke machines. But the potential of a scalable, networked sensor architecture is enormous. Whether the result is a pair of jogging shoes that give you training tips, a diamond pin that lets you wear your heart on the worldwide sleeve, or a satellite health monitor connecting patient and doctor, the work done here helps illuminate the revolutionary impact these systems will have as they become embedded in objects around us.

7 Appendix

http://espnet.sportszone.com/gen/features/00191784.html

Venerable marathon gets wired

By Dave Ruden

ESPNET SportsZone

Michael Hawley has always been willing to stretch the boundaries for the good of his profession.

But until this past January, Hawley, an associate professor of Media Arts and Sciences at the Massachusetts Institute of Technology, never realized "stretching the boundaries" might entail running 26.2 miles.

Hawley and two students -- Bradley Geilfuss and Craig Wisneski -- will be running in Monday's Boston Marathon. While the rest of the field will be concerned with personal bests, Hawley and his team will be on a scientific mission: They will be equipped with cutting-edge microelectronic monitoring devices that will measure their vital signs as well as indicate their location on the grueling course.

Hawley's motto might as well be, "Anything for the good of science."

"I never thought I'd ever do anything like this ... not until (this past) January," said the 35-year-old Hawley with a chuckle. "I was talking with a friend of mine from Japan, Kay Nishi, and he wanted to come up with a black box recorder that you could put in your car. We figured with technology, you could put a black box into almost anything. Even pedestrians. From there it evolved into this project with the Boston Marathon, and we just hit the ground running."

Mission control

The equipment Hawley's team will be wearing includes a Global Positioning System sensor, a one-by-two inch board that serves as a satellite to track their location; EMG (electromyography) apparatus, which will monitor long-term lactic acid buildup, which results in muscle fatigue; as well as accelerometers on their sneakers that chart their footsteps.

Before the race, each runner will also swallow a pill that contains a radio transmitter to chart body temperature.

The trio will also run with tiny cellular phones to communicate with the seven people who will make up the "mission control team" at MIT.

All this equipment will be connected to a computer linked to the Internet, so those interested can monitor the runners' vital signs and progress -- "or they can just call us on our phones," joked Hawley.

"This is just the first step in a long road," Hawley said. "Digital technology is going into everything. People just think of computers as big black boxes, but why can't they also be Mont Blanc pens or Victoria Secret lingerie? Today you step on a bathroom scale to measure your weight. In a few years, you will be able to measure calories and input with a device on your refrigerator, and measure output with a device in your bathroom."

Marathon Man

Hawley hopes what has become the Black Boxes Project will eventually lead to wearable technology people will use to monitor their inner workings.

Health monitor fashion?

"Someday high-tech and high-fashion will collide," Hawley predicted. "You will have health monitor jewelry designed by Harry Winston, shoes by Nike and watches by Swatch. You will be able to know more about yourself three times a day than your doctor does once every blue moon."

While Hawley seems confident about the scientific aspects of his project, he doesn't overestimate his athleticism. "I am not a runner at all," he said. "First, my basic body type -- 6-foot-1, 195-pounds -- is against it. I don't look like those skinny guys. Plus, I live in Boston. The weather in January, February and March is not conducive to training. When I started to train, I was in Grand Rapids, Mich., on Jan. 7. There was six inches of snow and it was 15 degrees. I thought, 'Do I really want to do this?' "

Perhaps the biggest surprise to Hawley is the attention his project has attracted. ABC News, the New York Times, MSNBC and New England Cable News have already come calling.

"I didn't go into this for any publicity at all, and now my phone won't stop ringing," he said. "It's gotten a little crazy."

Hawley's life is likely to get crazier come Monday, but he seems calm amid the chaos. Just as he hopes to one day bridge the gap between technology and fashion, he first must narrow the chasm separating sport and science.

"People thought I was crazy a couple of months ago, but now they're taking it in stride and think it's a nice project," he said. "The way I see it, we have three runners and a lot of technology. At least one of the runners should finish, and if we're lucky maybe all three. Hopefully, some of the technology will work, and if we're lucky maybe all of it will. Everything's coming together really quickly and everyone on the team's excited. We hope to learn something from it.

"And one of the nice things about it is, since we're using cellular phones, we can do this anywhere. I hear there's a nice marathon in Honolulu at the end of the year."

http://web.mit.edu/newsoffice/tt/1997/apr16/43532.html

MIT runners to be wired for Boston Marathon

By Alice C. Waugh

News Office

Associate professor Michael Hawley of the Media Lab will be a "live wire" as he runs in the Boston Marathon for the first time next Monday. He and two of his students will be wearing several of his lab's new microelectronic monitoring devices--both on and inside their bodies.

Four small devices will act as "personal flight recorders" during the race, transmitting data on the runners' vital signs and position that will be uploaded directly to the Internet, said Professor Hawley, the Alex Dreyfoos Jr. Career Development Professor of Media Arts and Sciences.

Joining him on the 26-mile run will be Bradley Geilfuss, a graduate student in architecture, and UROP student Craig Wisneski, a senior in brain and cognitive sciences. Other nonrunning members of the team are graduate student Maria S. Redin, senior Matthew Lau and junior Oliver Roup, all of electrical engineering and computer science.

Mr. Geilfuss will also wear an electromyography (EMG) sensor attached to his body with a glue developed for NASA astronauts by Dr. Carl DeLuca and colleagues at Boston University's Neuromuscular Research Center. The sensor will track frequency shifts in the EMG during long-term lactic acid buildup, which results in muscle fatigue.

Among the devices that all three runners will carry is a plastic-sealed battery and radio transmitter the size of a vitamin pill. Each runner will swallow one before starting to run. "It's halfway between an oral thermometer and the other kind," he quipped.

The capsule, developed by Tom Blackadar and colleagues at Bolt, Baranek and Newman, transmits pulses at a known frequency. The received frequency of the pulses changes in proportion to fluctuations in the transmitter's surrounding temperature, so colleagues can monitor the runners for rising body temperature during the race--often a sign of dehydration.

The trio will also wear accelerometers in their shoelaces that will count their footsteps, and thin plastic straps around their chests to measure pulse rate ("more of a `bro' than a bra," Professor Hawley said), modeled on a heart monitor made by the Finnish company Polar.

There will also be a GPS (Global Positioning System) sensor plus a 1-by-2-inch board in a pouch that together will continually log the vital statistics. That device was originally developed by Draper Laboratories to track the whereabouts of Alzheimer's patients. The ensemble will be topped off with an antenna and Motorola's smallest cellular phone plus earbud, so Professor Hawley and his students can have constant voice as well as data contact. Finally, there are batteries--"too many batteries," he said. "It would be nice if your shoes generated all the power for the electronics. Maybe next year."

Marathon Man

As well as conveying data to colleagues, the devices will send the information to a computer linked to the Internet, so anyone with World Wide Web access can monitor the runners' Marathon progress--"and my mother can watch in real time while I collapse from a heart attack at Wellesley," Professor Hawley joked. The URL will be http://ttt.media.mit.edu/pia/marathonman.

Humor aside, the researchers hope the experiment will yield valuable information for their Black Boxes research project, which grew out of the Media Lab's Things That Think initiative. The project aims to develop many forms of wearable monitoring technology. "When your clothes know more about you three times a day than your doctor does once in a blue moon, the world changes," Professor Hawley said.

Researchers in this area are also working on scalable readers for pedestrians, cars, cameras and other venues. Such devices could some day take information from the Internet and the immediate surroundings, then pass it on according to the user's interests and location. "You could be out on a Sunday drive and your car might say, `Psst, there's a hot antique sale if you take a left at the next intersection,'" he said.

The Black Boxes project is funded by Kay Nishi, CEO of ASCII Corp. in Japan. Special equipment for the Marathon run was donated by Media Lab sponsors Motorola and Trimble Navigation.

http://web.mit.edu/newsoffice/tt/1997/apr30/43565.html

Media Lab devices were up and running in Marathon

By Sarah Wright

News Office

Twenty-six miles in the Boston Marathon is a long way to go in the name of science.

But a trio from the Media Lab went the distance last week, carrying a cluster of microelectronic monitoring devices that they had developed to measure their vital signs and transmit data to be uploaded to the Internet as they ran (MIT Tech Talk, April 16).

The Media Lab's "live wires" were Associate Professor Michael Hawley, the Alex Dreyfoos Jr. Career Development Professor of Media Arts and Sciences, and two of his students, Bradley Geilfuss, a graduate student in architecture, and UROP student Craig Wisneski, a senior in brain and cognitive science. They all finished the course in just under five hours.

"The day after a marathon is painful. Going down stairs is an ordeal. Three days later I was still walking like I'd just got off a horse. But a week later, I'm fine," Professor Hawley said.

Four small devices acted as "personal flight recorders" during the race. One, a vitamin-size capsule containing a sealed battery and radio transmitter to transmit data on body temperature, had to be swallowed before the race. The trio also wore accelerometers in their shoelaces to count their footsteps, heart rate monitors on thin straps around their chests, and GPS (Global Positioning System) sensor in fanny packs.

Professor Hawley reported some "funny ironies" about the monitoring devices.

"A lot of technology goes right out the window when it comes time to perform. Craig's gear provided a working telnet link--folks at mission control could `telnet' right to his butt--but for some strange reason, the data gathering did not work. Brad's system and mine recorded all the data just fine--that was our primary goal--but our live data link didn't work. Also, our backup uploading plan--meet a pit crew every few miles so they could upload the bits--didn't work. It was too hard for them to access the course."

The team was "pleasantly surprised that the data logging did work," Professor Hawley said. "There were a few loose wires--Brad's heart rate monitor came loose and my pedometer broke--not odd considering the pounding our prototypes took. Swallowing the pills was not a problem, but the radio receivers were flaky. The GPS position logger worked fine, and the StarTAC phones were a blast. Several folks phoned the runners during the race. I was interviewed live by half a dozen sources."

Finally, though, the loftier goals of science took a back seat to just finishing the race. Both students dropped their gear "around mile 20," said Professor Hawley, who carried his to the end.

"The lovely thing about a marathon is that you don't need any gear to run it. You don't even need shoes; Abebe Bikila won it barefoot in Rome in 1960," he said.

Marathon Man

Besides, "the joy of running the race is what you remember--the cold water, sweet oranges, the crowd cheering you on for 26 miles, rounding the corner for the finish line," said Professor Hawley.

Would he run the marathon again? "Maybe. A nice long bike ride might be easier on the joints."

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