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What Would You Do with a Hundred MIPS on Your Wrist?

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Abstract

We recently demonstrated high function wrist watch computer prototypes capable of running the Linux operating system, X11 graphics, Bluetooth wireless connectivity and a VGA resolution display. We see technology evolving to the point where in a few years one can expect to have a hundred MIPS or more on one's wrist. We would like to challenge the mobile computing community to think about a couple of questions: Does it make sense to put a hundred MIPS on one's wrist? What would one do with this compute power? Is the watch the right place to put these cycles? How many cycles are really needed? What mobile computing issues does putting these cycles on one's wrist solve? What others does it raise? We offer some of our thinking on these issues to stimulate the thought process.

1.0 Introduction

It is clear that as technology evolves, computers are getting smaller, faster, more capable, cheaper, and more power efficient all at once. Such improvements are visible across the entire spectrum of computing starting from the smallest of microcontrollers to large supercomputers. Technology has now reached a point where we are able to pack a significant amount of compute power into small portable devices. As a case in point, we recently demonstrated a high function *wrist watch computer* prototype, which is capable of running the Linux operating system and X11 graphics [4]. Subsequently we have demonstrated Bluetooth connectivity [5] and a VGA resolution display [3] in a wrist watch.

We embarked on the wrist watch research project for two main reasons. The first was that the wrist watch was a very attractive form factor to put computing into and the second was that the small size of the wrist watch challenged us to push the limits on many different areas of technology. We admit that our research efforts have been more along the lines of "If we build it they will come", than "What can we build to attract them?". Nevertheless, we anticipated correctly that trying to meet these challenges would lead to innovations in a variety of areas such as miniaturization, mechanical packaging, power management, user interface design, application design, etc. Though we have a set of ideas of what we could accomplish with a wrist watch computer, and are in the process of realizing many of them (please see [2] for a discussion of some of the applications), we would like to challenge the Mobile Computing community to come up with other interesting uses and applications.

In order to motivate the need for putting compute power into a wrist watch, we first discuss several problems in the area of mobile computing and how a wrist watch addresses some of these, while raising several other new problems.

2.0 Problems and issues in design of small portable devices

2.1 Size and convenience

One of the significant problems faced by mobile users has ironically been the lack of portability of their *portable* computing devices, i.e., the portable devices have often been bulky, unwieldy, or unnatural to carry along. As we looked at mobile computing, instead of asking "Can we make a certain mobile computer more attractive to carry?" we asked the question "Can we put a computer inside something that many users are already accustomed to carrying?". We reasoned that if we can fit a substantial amount of compute power into a device that the user was already accustomed to carrying, then there was a greater likelihood that the device, and therefore, the compute power will be with the mobile user. The question then, instead of being "Is it useful enough to carry with me?" becomes "It is always with me, can I find an use for it in this context?". Of course, there has to be a sufficient number of useful contexts to make the user want to purchase the device.

2.2 Energy supply

Another major problem that mobile users face with respect their portable computing devices is one of providing adequate energy to run their mobile devices. The most common method of powering these devices is to use batteries. Unless the benefits of the mobile device are high enough to warrant the difficulty of recharging batteries, the

acceptance of the device is questionable. There are two things that one needs to do to solve this problem: one is to make the device so useful that the user is willing to replace or recharge the batteries, and the other is to make it easier to replace or recharge the batteries. One of the main ways of making it easier to replace or recharging the batteries is to ensure that the battery lasts for a long time by doing aggressive power management, making replacement or recharging less frequent. Instead of this being a continuous spectrum there are distinct thresholds that when crossed improve the usefulness of the device significantly. For instance, improving the battery life of a laptop from 1 hour to 2 hours can be very useful, but one can argue that improving the life from 24 hours to 25 hours (or even 48 hours) may not give the same incremental benefit.

A completely different approach to powering computing devices is not to use batteries at all, and instead generate the required energy through other means such as solar energy, or generating energy from the physical movement of the user. For an in-depth analysis of the possibilities of powering wearable computers by harnessing energy expended by the user see [1]. Unfortunately, at the current time, these other means either do not provide sufficient energy capacity or appear to be not as convenient. As a result, batteries still are the preferred method for powering mobile computing devices.

Increasing the physical size of the batteries is often not an option for mobile computers since this may make the devices larger. The shrinking size of the electronics within allows for more room in the device for the battery and can result in a modest increase of battery life. One of the key challenges in this context is how to get to the point where the battery life is long enough that it is no longer a major factor in deciding whether or not to use the mobile device.

2.3 User interfaces

Designing a user interface that is both easy to use and fits well with the device is a hard problem. The limitations of space to incorporate input devices are rather serious. The input devices need to be large enough that the user can conveniently manipulate them while at the same time be small enough that it makes sense to incorporate them into the limited space available. A common complaint about keyboards on devices any smaller than a laptop computer is that the keys are too small and too close together for many users. An added problem is that many portable devices may have to be used in situations where the user's time and attention are limited. For example, the user may be walking or may be holding a bag in one hand leaving only one hand free to interact with the device. The user may also be in a situation where it is socially unacceptable to speak to a device, or to pull a device out of ones pocket and look at it. So interfaces have to be intuitive to use in such situations.

Visual output is another problem with small devices. The available area for display tends to be rather small and many users may lack the visual acuity to read text presented in small fonts, especially when the lighting conditions are not very good. On the contrary, people seem to be rather comfortable reading the time on a wrist watch when the time is shown in an analog fashion with hour and minute hands even when the watch is quite small, and the hands that are only a few millimeters long. Are there ways to present information on small devices in a manner that is easy to use? What kinds of information can be presented in this manner? How would one present information that is hard to present in a usable manner on a small device?

2.4 Multiple devices

A constant debate in the area of portable devices is whether it is better for a device to do fewer things and do them well or to do as many functions as possible. Proponents of the less functionality per device viewpoint argue that these devices are hard enough to use that adding functionality simply complicates the issue. It is often said that most people tend to use four or five of the dozens of features available on the current cell phones. Also when a vast majority of the population is unable to program the time on their VCRs, how would you expect them to figure out how to use the myriad of features on a highly functional device?

Proponents of the "put everything into one device" viewpoint argue that it is difficult to carry a collection of devices and to keep each and every device's battery charged. Also it may be easier to design and offer services to users if their devices were integrated; for instance if a user had a cell phone with GPS and the user's calendar, the user can conceivably invoke a service to call for a taxi to take him/her to his/her next appointment in a single action which would rely both the user's location and destination to the taxi company.

2.5 Lesser capabilities than non-mobile counterparts

An issue that plagues mobile computing devices is that the capabilities of a mobile device tends to lag those of its non-mobile counterpart (if there is such a counterpart). For instance, desktop computers tend to have faster processors and more memory than laptop computers for comparable price tags. Similarly, the network speeds achievable on a wire-line network connected desktop tend to be higher than a wireless network connected portable. When these differences in capabilities reduce the productivity of the users, the portable device tends to annoy them.

On the flip side, if the capabilities of the portable device are over a certain threshold that the user does not perceive the difference in capabilities in the course of their common tasks, the users may choose to use their portable

devices even in situations where they may have access to a more capable device. We have seen that when users have laptops with a powerful enough processor, enough memory, and a fast enough network (11Mbit 802.11b Wi-Fi) to run commonly used applications, they prefer to use it in their office even though they have a machine on their desk that sits on a network that is an order of magnitude faster (100Mbit ethernet) and perhaps has at least a factor of two larger memory, and a faster CPU. Similarly, some people just use their cellular phones even in their homes instead of wired phones.

While it is true that compute requirements of users tend to grow over time, it also appears that technology is growing even faster, resulting in the crossing of the usability thresholds discussed above. In the course of this evolution of technology, we cross several thresholds where the question one asks changes from "Is it possible to do X?" to questions such as "How quickly can we do X? or How much does it cost to do X?" to ultimately "How did we ever get by without doing X?". Admittedly we are not close to these situations for a variety of applications on many mobile devices, but it is interesting to ask when we will.

2.6 Skill shortage

A more pragmatic issue in designing and building mobile computing devices is that often such devices tend to use proprietary software. A lot of the code running on these devices may be written in low level languages and targeted to proprietary APIs and running on operating systems that are limited in their deployment. As a result, the developers working on building such systems are perceived as having skills that are not portable. This results in the difficulty of finding qualified people to work on such devices and keeping them motivated. Developers may feel that the longer they work with the organization, the less marketable they become outside the organization. In the current environment of critical shortages of qualified developers, a significant fraction of embedded systems companies have had to deal with this problem at some time or the other.

Is this a problem that we are forced to live with, or is there a way of moving these devices to a more open environment, i.e., an environment where the developers feel that they are enhancing their overall skills while they work on such devices and do not feel that they must change jobs in order to remain marketable?

3.0 Details of the wrist watch prototype

The initial wrist watch prototype is 56mm wide x 48mm long x 12.25mm thick and weighs about 44 grams. A picture of the prototype is shown below.

The watch has an ARM processor that can run at speeds up to 74 MHz. When running at 74 MHz it is equivalent in power to a 100 MHz Pentium processor. In order to save battery power, we typically run it at 18 MHz and put the watch in a power saving stand-by mode whenever possible. The watch also has 8MB of Flash memory and 8 MB of DRAM memory. We currently have the standard Linux 2.2 kernel, and X11 graphics running on the watch, with a file system that has the basic Linux and X11 libraries stored in flash memory.

The watch is powered by a rechargeable lithium polymer battery which sits inside the watch case and has a capacity of approximately 230 mWH. When the processor is running at 18 MHz and updating the display, the

average power dissipation is around 60 mW, in idle mode the dissipation is around 25 mW and in standby mode the dissipation is less than 1 mW. At 74 MHz the power dissipation is expected to be around 180mW.

We have prototyped watches with two different kinds of displays. One is a 96x120 pixel monochrome reflective LCD display shown above and another more recent one is a VGA resolution (640x480 pixels) emissive OLED (Organic Light Emitting Diode) display [9] that is shown below. The LCD display is available in the market and is fairly inexpensive. Since the LCD is reflective and we do not provide a back light in the watch, some ambient light is needed to see the display. The OLED display is emissive and is readable in direct sunlight as well. The power consumed by the OLED display is proportional to the number of pixels that are lighted. For just a watch face, 5% or fewer pixels need to be lit. For photographs the number of pixels lit may be as high as 40%.

The watch also has a touch screen and a roller wheel for user input. The wheel can be rolled either clockwise or counter clockwise and also clicked in resulting in three different kinds of input signals that it can generate. There are no other buttons on the watch. We noticed that people often found buttons on wristwatches hard to use; it was hard for users to remember what each button did if there were more than a couple of buttons on a watch, and it was also hard for users to push the correct buttons especially if there were many small buttons that were close to one another.

 Though the touch screen can sense the location of the touch with reasonable precision, for the same reasons why buttons are hard to use, it is difficult for the user to precisely control the location of the touch. Also the watch face is not much bigger than the width of a human finger. As a result we limit applications to differentiating touches at just


the four corners and maybe the center of the touch screen.

In addition the watch also wireless communication capabilities using both an infrared (IRDA) port and a short range Bluetooth radio. The Bluetooth protocol stack, BlueDrekar™, developed by IBM Research, is running on top of Linux.

When the watch is docked on a cradle it can be connected to another computer via a serial connection. The watch also has a buzzer, a speaker and a microphone.

With better integration of components one can expect that the electronics in the watch to become smaller, and perhaps support larger amounts of memory, and a faster processor. Power consumption requirements are also expected to come down with time though not at the same pace as increases in memory capacity or processor speed. Power required for radio communication is expected to decrease significantly in the near term since the current Bluetooth hardware is in its infancy and is bound to improve as designs mature and more players enter the market.
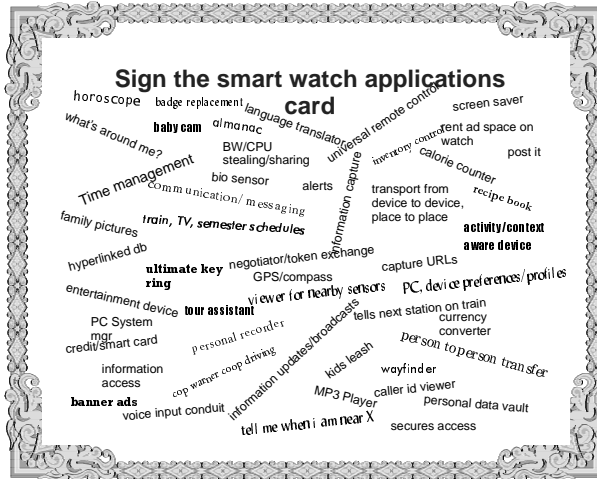
4.0 Applications

The common applications that a set of people requested on a smart watch are included in figure above. They can be grouped into a few categories.

1. Keeping Time: Basic watch functions. Some examples include
   a. Time, world time and stopwatch, perpetual calendar
   b. Alarms - Hourly, Daily, Event Triggered, Twice Daily, Thrice Daily (reminder for medicines)
   c. Holiday Lists - based on country, religion, etc., downloaded from the Internet each calendar year
2. Managing Time : Personal Information Management (PIM) Functions. Some examples include
   a. calendar schedule, to do, phone/addresses, micro-email
   b. Multi-user calendars - holds calendar of manager, spouse, team members, children, etc.,
3. Point in Time Information: Static cache - Examples include
   a. personal data vault with password protection - possibly credit card numbers, bank account numbers, passport numbers, frequent flier numbers, etc.,
   b. reference information - dictionary, tourist information
   c. download data from web or PC or other watches
4. Just in Time information: Dynamic retrieval - pull, push and demand pull paradigms. Examples include
   a. a calendar that is always up to date
   b. customized information delivery - stock quotes, weather, traffic, ..
   c. directions with maps to hotels, restaurants, theaters, etc., downloaded from the Internet
   d. "Web Serf" - Universal Alert mechanism
      i. your bid on Ebay has been outbid - what do your want to do?
      ii. temp in NY $< 32^O$ F - what do you want to do?
5. Authenticator and controller
   a. Wearer securely gains access to other devices, buildings, rooms.
   b. Personalize, control and interact with other devices
6. Utilities and health monitoring. Examples include
   a. Currency converter and language translator
   b. Calorie counter, pulse monitor
7. Entertainment
   a. Games
   b. Horoscopes

A quick review of the above list indicates that some applications rely on just having the data in the watch. However, even for these applications, the data has to enter the watch from some adjunct device, such as a PC, because the input capabilities on the watch are rather limited. Other applications people want on the watch extend to the network and to information on servers on the Internet.

5.0 Addressing the challenges

As mentioned above, we went with the wrist watch form factor as the familiar device into which we could put compute cycles into since this addressed one of the important challenges raised above, namely, it is small enough to be really portable and is already worn by many people. The wrist watch form factor has opened up an interesting set of questions however.

5.1 Adoption of watch form factor

There is an important difference between a watch and other mobile devices such as a pager or a cell phone. When the pager was introduced in a large scale, it was worn on the belt or carried in the pocket. With the exception of cowboys, policemen, and mechanics, most people did not wear instruments on the waist. So the typical pager user did not have to throw away existing devices on his waist in order to make room for the pager. However, since most people wear a watch already, it is a unique challenge to get them to discard their present watch and switch to new one. Several factors come into play here. People often tend to have more of a sentimental association with their watches compared to other computing devices, and often consider watches to be more of statements of fashion or jewelry than performing specific functions. As a result one can expect a certain degree of reluctance to give up one's favorite watch for another even if the new one is better. For example, many people were reluctant to move from mechanical watches to electronic watches, and many ultimately did so because electronic watches offered better function; namely they were more accurate. Many others did so after electronic watches became cheaper than and as elegant as mechanical ones.

One way to address the fashion issue in the near term is to let fashion and jewelry designers create the cases, bands and ornamentation for the watch and to make the electronics as tiny as possible. A high-contrast high-resolution display can be used to make new fashion statements and also sport traditional watch faces. The ability to change the watch face based on the occasion can be used to advantage as well.

5.2 Parasitic computing

One of the severe limitations of the watch form factor is a small screen and lack of space for input devices. A concept that we refer to as *parasitic computing*, where we use resources that are around the watch, can address some of these limitations.

For example, the small display of the watch could be compensated by a larger display available on a PC or a nearby projector. The watch would enlist the services of the larger display to present its data. Similarly, the PC or kiosk nearby could be connected to the Internet by a high speed connection. The watch could request use of the PC's Internet connection and retrieve data from the Internet through the PC.

The CPU on the PC may also be used to perform some complex calculations that the watch is not capable of doing and then send the results to the watch. An example that fits this description would be voice recognition where some part of the voice recognition work could be done on a remotely and the text of the utterance passed back to the watch.

An external keyboard could be connected over Bluetooth or IrDA to the watch to alleviate the input problem.

The watch could have a USB port connection. In this case the data on the watch will just appear as an additional drive on another PC when the watch is attached to the USB port on the PC. The user may then edit the data on the watch using his PC.

Parasitic computing could be multi-tiered as well. For example, the user may have a watch with Bluetooth wireless capability but may also have a hand held device with both Bluetooth and 802.11b wireless connectivity. In this case the user's request for data from the web may first be relayed to the hand held device via Bluetooth and then sent to a machine connected to the Internet via the hand held device using the 802.11b connection.

In order to make parasitic computing somewhat simpler, the user may carry a parasitic computing enabler (PCE). The PCE could provide some functions such as web page transcoding, communication protocol converters, ports and interfaces to connect to external devices. For example the PCE may have a couple of compact flash slots, SD card interface, USB connector, built in ethernet, wireless 802.11b and Bluetooth capabilities, data buffers, graffiti pad, keyboard and mouse connectors, etc.

Of course, with a PCE, or a Bluetooth-802.11b hand held, we are now back to the situation where the user is carrying an additional gadget, which is something we were seeking to avoid. If the other device can simplify the creation of the infrastructure and also be made easy and natural to carry, that may be acceptable.

In some situations the use of these external resources would be free. However, it is conceivable that the user will have to pay a small fee for each of these services in public places. The cost of these services could be dependent on a variety of things, such as the importance of the task, the relative availability of the resources in the vicinity, etc., and could even be negotiated using electronic tenders and bidding schemes.

5.3 Operating System

We hope to address the skills issue by running Linux a standard desktop operating system on the watch, maintaining the same kernel APIs, and libraries. Developers could work on a Linux desktop with the same set of tools they would otherwise use and hopefully not have to learn any proprietary APIs.

5.4 Energy supply

Efficient power management is critical on a watch since available energy is limited owing to the limited space available for the battery. Also there is a psychological barrier that one has to overcome with respect to rechargeable batteries in watches. Users are accustomed to conventional watches (which usually provide nothing more than basic time keeping functions) running for years on a single battery and generally tend to replace the watches rather than replace the battery within the watch, let alone consider recharging a watch. Though people used to wind their mechanical watches in the past in order to provide it the energy to run, recent watches tend to be either self winding or run off batteries.

The available energy will be limited if we stick with similar battery designs where the battery fits inside the watch case. However, there is the potential for placing the batteries outside the case, perhaps on the band which would result in a substantial increase in battery capacity since there is now a lot more space for the battery. Placing the battery externally may also ease the pain of recharging, since it is easier to swap a fully charged battery for a drained battery, and put the drained battery on a charger.

Current emphasis on processor design is on providing an increasing number of MIPS keeping the rest of the variables (e.g. power) constant. At the high end there are indications that this trend may not be the right one. A two year old desktop computer is still adequate for many of the applications. The user perceives no increase in speed for applications such as e-mail, web browsing, etc., and since newer applications such as video conferencing have not taken off, sales of newer faster systems have not grown significantly. In the case of processors for small devices, though increasing the MIPS may be useful, it may be even better to concentrate on decreasing the power requirements while keeping the MIPS constant.

5.5 Single-purpose/multi-purpose device

The personal computer is generally considered to be a very complicated device. The primary reason for this is because it can do many things. On the other hand, an egg beater is a simpler device to use because it does only one task. These devices represent two ends of the spectrum. The eggbeater is a commodity product with very low profit margins. Some aspects of the personal computer business are quite profitable. However, we feel there is a middle ground where device could be more versatile but not overwhelmingly complex. There are some points to examine here. It seems different people use different sets of applications on their personal computer due to their different interests and personalities. Likewise, though there are several applications available for a Palm Pilot™, many people may just download four or five of these. Moreover, the five functions you use may be different from the five functions I use. So a way to keep the device complexity down may be to determine the applications a user needs at the current time and location and have them available when they are needed. Even this could prove difficult, maybe the first step is to design watches for specific professions and activities. For example we may design watches for doctors, nurses, spectators at a game, classroom students, visitors to a museum, visitors to a theme park etc. Such designs should begin by studying what these people do and what goes on in a typical day in their life.

Doctor's watch: A doctor's watch may show the list of patients that need to be visited in their hospital rooms. If the doctor is running late, the order of visits for the patients may be modified somewhat depending on the criticality of the patient. Another potential use is to show the patient's case history as soon as she enters the patient's room. The doctor could renew or enter the medicine prescription in the watch and the system would then relay it to the pharmacy and the nurse station. The pharmacy's ordering system in turn could use this information to stock up more of this medication if needed.

Nurse's watch: A nurse's watch could have a list of drugs that need to be administered to the patients he is responsible for. A list of common drug interactions could also be provided. He may also be able to enter a request for the attending doctor to come visit the patient.

Couch potato's watch: The couch potato's watch would be a universal remote control and have the TV guide in the watch. In addition it could have built in functions to order pizza and beer with just a few clicks.

Student's watch: A student's watch could be used to hold the class, exam and holiday schedule for the semester in the watch. It can also be used as a location device to determine where their friends are.

Spectator's watch: In a stadium equipped for wireless connectivity, the watch could be used to show the current score and also give some details about a player's statistics. Scores from other games in the league could also be broadcast in the stadium that could be picked up by the watch.

Art museum visitor's watch: One problem during a visit to an art museum is that paintings need to be viewed at a distance to get the complete picture, however, to read the caption for the painting, we need the go close to the painting. This problem of having to walk back and forth, away and towards the picture, can be solved with the watch. When the person is viewing a painting, the painter's name, style of painting and the date it was created could be displayed on the watch. If the viewer likes the painting, he can bookmark the painting and when he goes to the museum store he can determine if a print or a replica of that piece of work by lesser known artists is available for sale.

*Theme Park Visitor's watch***:** Visitors to a theme park could each be provided a smart watch for the day. They would use this watch to keep track of the family members' whereabouts, reserve positions for rides and be notified when their turn arrives. In addition the watch could take the planning confusion out for the user by automatically suggesting for example a two hour program, a four hour program and a day long program for the visitor. The watch could also display the expected wait for each ride.

In terms of added functionality, one could imagine integrating a pager into the watch; watch pagers are already available on the market [7]. Health monitoring sensors (pulse rate, temperature, etc.) could be integrated into the watch; again watches with such sensors are currently available on the market [6]. Watches with MP3 players and cameras, [8] and GPS [10] have also appeared on the market. The watch may also be enhanced to include security information used for access control, authentication, and conducting transactions. The watch is a preferred location to keep security information because it is personal and harder to lose than many other things that people carry such as wallets or key chains.

Again these enhancements need to be balanced with the requirements of keeping the device simple and easy to use.

6.0 Open challenges

What other form factors are suitable for a mobile computing device? Would it make sense to put computing power in a ring? What about hearing aids, false teeth, wallets, shoes, key chains? What are the trade offs in terms of ease of use, size, power, etc. What would the applications be for these form factors? What can we do with compute cycles on these different gadgets? What interesting applications can be built around it to help the mobile professional?

One question that is asked often is whether the watch should just be a viewer and let all the intelligence lie in some adjunct device. While it seems a clean way to keep the watch simple and elegant, this means that all data to the watch has to be sent wirelessly and this could place a heavy drain on the watch battery. One argument for keeping a reasonable level of compute power in the watch is to permit it to provide simpler interfaces (perhaps voice based interfaces) and also run security algorithms. A powerful CPU could also be used to perform on the fly decompression of data and thereby reduce the amount of data transferred wirelessly, thereby reducing the overall power consumption. Over time we expect the power consumed by the system to be dominated by the wireless subsystem because of the physical requirements of wireless reception and transmission is unlikely to fall at the same rate as the power consumed by the CPU and the display. It appears that having a fair amount of compute power in the watch is justified because of the true wearability of the watch and it is feasible to have it in there.

What next after time, basic PIM, and games, as far as the wrist watch is concerned? Is videoconferencing more useful in the mobile scenario? People may use this in emergency situations where the problem to be solved may be more important than not revealing a bad hair day? What is the killer application? Is there a killer application? Is the killer application time and location dependent? On demand software? Will the applications be sent to the device on demand? What is the role of XML in this space? Should special mark up languages be defined for controlling home appliances?

Are there other technologies for powering these gadgets? There appears to be orders of magnitude differences between battery energy density and chemicals and food/gasoline. The typical energy densities of rechargeable batteries are of the order of 0.4 Kilo Joules per gram, while that of explosive materials that are reasonably safe to handle are of the order of 4 KJ/g and that of oil or fat is approximately 40 KJ/g. Are there newer energy technologies waiting to be discovered?

Do you want to think of the watch as a general purpose computing device or a special purpose single function device (with possibly different functions for different people). The role played by market forces could be significant. For example, companies that build special purpose devices may be able to bring them to the market sooner than companies that build more general purpose devices. Will the speed to market play a significant role only in the near

future or for a long time? Another point to consider is the buying habits of people. Many people have a limit for how much they will spend on an impulse buy or for a gift.

No single dominant player has emerged in the mobile computing space. Is this because the devices are more special purpose than multipurpose? For example while several million Palm Pilots™ and Visors™ have been sold, devices such as the RIM™ two way pager and the Motorola PageWriter™ that focus on delivering e-mail on the go have about 400K and 900K subscribers respectively and the numbers are growing. An interesting question is also whether the same users are replacing their Palm Pilots™ when newer versions appear or is the population of users really growing?

Can voice based interfaces solve the challenge of input for these devices? Should the PCE take the role of providing additional interfaces?

If Tolstoy were alive today he would perhaps ask these two questions "How much storage does a man need?" "How much compute power does a man need?"

7.0 Conclusions

At IBM Research we have built a wrist watch sized computer to study the above interesting issues. At present only a few prototypes are available and the demand for these prototypes has far exceeded our expectations. Clearly this interest indicates that many researchers want to examine the above issues as well. At present we are examining the possibility of building more prototypes to ease this shortage. We are also looking at possible collaboration opportunities with universities once we have many units.

8.0 References

[1]   Human-Powered Wearable Computing. IBM Systems Journal 35(3/4): 618-629 (1996), Thad Starner

[2]   Application Design for a Smart Watch with a High Resolution Display, Proceedings of the Fourth International Symposium on Wearable Computers (ISWC'00), Chandra Narayanaswami and M.T. Raghunath

[3]   eMagin and IBM to Demonstrate New OLED Display at the Consumer Electronics Show http://biz.yahoo.com/prnews/010105/nv_emagin_.html, Jan 5 2001

[4]   Linux on a wrist watch, http://www.research.ibm.com/WearableComputing/factsheet.html, Aug 7, 2000

[5]   Bluetooth developers conference keynote. http://207.94.167.208/keynoteIbm.cfm#2

[6]   Heart rate monitor. http://www.heartratemonitor.co.uk/

[7]   Timex Beepwear™ http://www.beepwear.com/html/index.html

[8]   Casio Wrist Watch Camera WQV-1™, Casio WMP-1V™ Wrist Audio Player, Casio PC-UNITE BZX-20™ and BZX-20D™ Wrist-type Wearable PIM Data Viewers http://www.casio-usa.com/corporate/index.cfm?act=10&ID=734 &CFID=496231&CFTOKEN=31158399#WristCamera

[9]   Direct view active matrix VGA OLED-on-crystalline-silicon display, J. Sanford and E. Schlig, Document under preparation

[10] Casio Satellite Navi Watch™ http://www.casio.co.jp/English/gpsw_e/top.html