The Matchbox PC: A Small Wearable Platform

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Abstract

We describe the Matchbox PC, a fully functional PC not much larger than a box of matches yet able to run popular operating systems such as Linux and Windows and to perform most tasks commonly run on desktop PCs. Although our motivating application is wearable computing, we expect many other applications will emerge.

1 Introduction

Recent advances in VLSI and packaging technology have brought the size of general-purpose computers down into a range previously the domain of embedded computers. It is now becoming possible to use general-purpose computers to build systems that were traditionally based on custom hardware and software.

The burgeoning adoption of general-purpose computers in homes and offices is pushing their price/performance ratio down to that of embedded systems. In addition there is a remarkable volume of software available for them. Smailagic et al [1], while objecting to the high costs of off-the-shelf solutions, acknowledge a 30% reduction of software porting. For today's software systems this would seem a gross underestimate. There is much less software for special purpose computers, and it is much more expensive because each such computer has relatively few customers each of whom must shoulder a proportionately greater share of the software development costs.

This software includes tools for creating new applications. For every new embedded system that comes out, not only must software be ported to or written for these new systems but tools must be developed in order to build these new applications. This development is simpler when the target is the same platform as that on which the applications are built. In addition the motivation to provide device drivers for any given platform is greater for platforms in wider use.

This paper describes the Matchbox PC. In summary this is a general-purpose PC, having a 66 MHz 486-SX CPU, 16 megabytes of random access memory, 340 MB hard drive, 10 MB/s ethernet interface, VGA output, keyboard interface, two serial ports, a parallel port, and floppy interface, brought out to a miniature connector. A second connector brings out 64 ISA bus and IDE controller pins for connecting the CF socket and for further expansion such as audio. With the Microdrive installed the dimensions are 2.8" by 1.8" by .8" (4 cubic inches) with a weight of 2.5 oz. We also discuss the challenges in building the Matchbox PC and the motivations behind our design decisions.

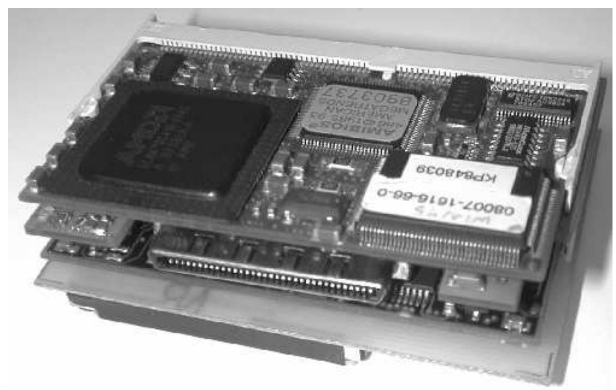

Fig 1. The Matchbox PC

2 Design Rationale

Compressibility Matching as a Design Principle Today's laptops and PDAs package everything in the one case. This has the advantages of portability and convenience, but hinders miniaturization by putting incompressible and compressible components together in the same package. We define the "compressibility" of a component to be how much its volume decreases when "design pressure" is applied by the world's designers over say a year.

Our approach to wearable computing is to segregrate components according to compressibility, allowing components in the same module only if they have a similar degree of compressibility. Our underlying philosophy here makes an analogy with the well-known impedance-matching principle for electronic components, which maximizes efficiency by connecting components of similar impedances.

The least compressible component of a portable device is the battery. Battery size is shrinking much more slowly than any other component of wearable computers.

The keyboard is close behind. The limiting factor for a conventional QWERTY keyboard as used on laptops is the size of the user's hand, itself absolutely incompressible. Typing speed decreases with size of keyboard, and a user accustomed to 60 wpm on a full size keyboard will be hard pressed to achieve 30 wpm on a half-size keyboard.

The display has also resisted compression. The eye is not of itself quite as much an obstacle to display miniaturization as the hand is to keyboard miniaturization, and there has been recent promising progress in miniaturizing displays. Even here however, miniaturization of displays intended to be integrated into the unit (as opposed e.g. to head-mounted displays) has been slower than for the rest of the computer.

Connectors are also incompressible to the extent that they need to adhere not only to electrical but mechanical standards.

At the top level our design for a wearable PC matches compressibilities by moving the main incompressibles, namely power, screen, keyboard, and standard connectors, to other modules.

What remains has turned out to have compressed a lot in the last couple of years. The inclusion of incompressible components in essentially all portable computers to date has tended to obscure the extent of this shrinkage. Without them one can have a considerably smaller machine.

Choice of platform We chose the x86 platform for three reasons. First, the platform has a wide variety of software available for it. Second, the insatiable demand for PC's of all sizes and shapes has served as a driver for many different types of design improvements over the years. Third, there are large numbers of programmers, hardware designers, and users familiar with the general layout and principles of operation of the PC.

An oft-cited drawback of the x86 is its prehistoric architecture, rooted in Intel's early-1970's 4004, 8008, and 8080 microprocessors. Its imminent demise has been predicted on this basis since the emergence in the mid-1980's of RISC processors such as SPARC and MIPS. However careful design in response to the pressure of market forces has led to impressive x86 performance gains allowing it to keep pace comfortably with the rest of the pack.

Power is at least as big a concern in the wearable industry as performance. Today the x86 does not look as good on paper as say the StrongARM, which has been carefully designed for minimal power, a factor in its adoption for Compaq's Itsy wearable computer [2]. However market forces have have been at work here too, driving down the power requirements of x86's, and it seems plausible to us that the emerging wearables marketplace will accelerate this trend and that the power/performance tradeoff for the x86 will improve as dramatically in the near future as its performance has in the recent past.

3 Matchbox PC Design

The basic Matchbox PC is composed of three boards that snap together. The DIMM-PC module on top measures 2.8" by 1.8" and is a single-board computer designed by JUMPtec (www.jumptec.de). It has an AMD 486-SX 66MHz CPU [3], 16 MB of RAM and a 16 MB flash drive on board. Two serial ports, a parallel port, keyboard, a floppy drive interface, and 5 pins of an IDE interface are brought out to the pins on one side, while an ISA bus interface is brought out on the other side. The board fits into a 144-pin SO-DIMM socket intended originally for notebook memory.

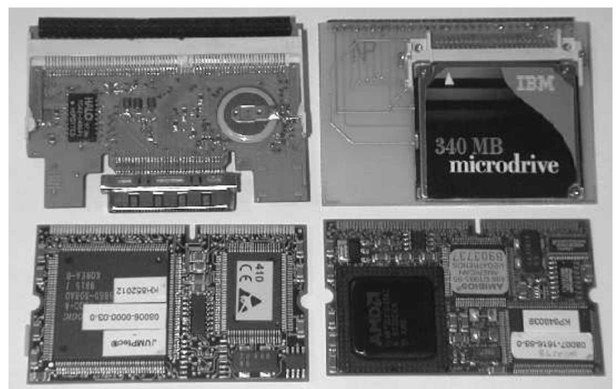

Fig 2. Main board, CF board, DIMM-IO, DIMM-PC

The JUMPtec DIMM-IO module underneath, also in SO-DIMM format, provides a VGA graphics controller with 512KB of graphics memory, a 10 Mb/s ethernet controller, and two more serial ports. The onboard VGA controller is capable of supporting CRT resolutions of 800×600 with 256 colors or 1024×768 with 16 colors. It can also support an STN or TFT flat panel display. The ethernet controller is a Crystal Lan CS8900 ISA controller capable of half- or full-duplex operations at up to 10 MB/s.

Our contribution is the interface or main board in between. It measures 2.8" by 1.8" and contains two 144-pin DIMM sockets, a 68-pin female VHDCI connector, a single-row, 32-pin receptacle, and a Compact Flash connector. The board also has some discrete components including line drivers for the serial ports, termination for the parallel port and keyboard, ethernet transformer, ethernet LEDs, and a clock battery. The VHDCI connector brings out power, ground, keyboard, VGA, ethernet, two serial ports, a parallel port, reset, and floppy. The interface board uses vias to connect the 72-pins of the ISA bus on the CPU board, mounted on one side of the board, to the respective pins on the IO board, which is mounted on the other side of the board.

The single-row connector along the back of the board receives a fourth board which contains the Compact Flash drive. The Compact Flash board contains a surface-mount Compact Flash adapter and the necessary routing of signals from the main board. The 68-pin VHDCI connector at the front of the board connects to a docking station containing standard sockets for the keyboard, serial ports, parallel port, floppy, ethernet, and power.

4 History

Web Server Our first application was to create a small web server (http://wearables.stanford.edu). This design consists of just the JUMPtec DIMM PC board described above. It weighs 20 grams and is only slightly higher and wider than a box of matches but one third as thick, measuring 2.8" by 1.8" by .2" for a volume of about a cubic inch.

The 16 MB of flash memory stores a subset of Linux, along with ssh and the Apache server daemon at first, later superseded by Boa. Connection to the internet is via PLIP, a point-to-point network protocol utilizing the Jumptec's parallel port and running at about 33 kilobytes/second.

Despite its small size, the web server has been very stable. It first went online on January 22nd, 1999, and except for four brief downtimes has been up solidly for six months, up to the time of writing. Operating system maintenance and web page revisions are made with the system remaining online.

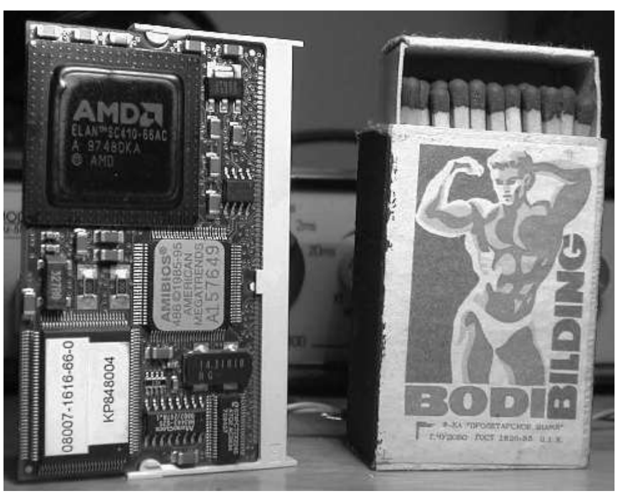

Fig 3. Web server and matchbox.

Diskless PC Despite not being a complete PC, the web server provided a nice example of the embedded x86 technology. Our next step was to design a printed circuit board connecting the CPU and IO modules and bringing out signals for power, ground, a serial port, keyboard, VGA, and ethernet. The installation of Linux on the 16MB partition then gave us a full-functioning PC.

Complete PC While this design inched closer to what we wanted, it still was not what we considered a PC; namely, it could not run any of Windows 95 or the bulk of Linux. Therefore, our next board interfaced to a Compact Flash. We chose Compact Flash for several reasons. First, we believe the price/performance of Compact Flash cards will continue to improve as they are finding their ways into digital camera market as well as PDA market. Second, the Compact Flash standard provides a true IDE mode which allows it to act like a PC hard drive. To configure a Compact Flash unit in true IDE mode, we simply routed the appropriate signals from the IDE and ISA on the PC to the Compact Flash adapter. No extra circuitry was required. Finally, at the time of deciding what type of hard drive to add, IBM offered to lend us their Microdrive hard drive [4], providing a 340MB rotary drive in a Type II Compact Flash form.

The question then arose as to where to put the CF slot. Our first idea was to mount the DIMM-PC and DIMM-IO modules on separate boards with the CF drive in between, creating a safe haven for it. The drawback was that the ISA bus connecting the CPU and IO boards, which consisted simply of 73 vias in the one-board design, was now going to be much trickier, especially with the CF card in the way. In the end we kept the one-board approach and mounted the Compact Flash drive above the PC module board, wired to the ISA bus via a small vertical board at the back. We made this unit operational just barely in time for CeBIT'99 in Hanover, where we exhibited it courtesy of JUMPtec, who kindly made space available in their booth.

Current Design Our latest design enhances both robustness and ease of assembly. For the former we went to a 4-layer board, reducing the noise on the ground and power signals. We also replaced the delicate PCMCIA-style connector with a more sturdy, shielded VHDCI connector. And we made the Compact Flash board removable in order to simplify assembly, and also to allow those who are satisfied with just the internal 16MB hard drive to remove the Compact Flash board for reduced size. Alternatively one may replace the Compact Flash board with a board equipped with an IDE connector permitting a regular hard drive to be attached. We are currently experimenting with an ES1869-based sound card of our own design that mounts in this slot.

5 Externals

Connectors In order to keep the basic machine small we brought out all IO pins to a miniature connector. In the early prototypes we used a female 68-pin PCMCIA connector, then replaced this by two 50-pin female compactflash connectors in order to bring out LCD as well. In the latest design we have gone back to 68 pins, giving up LCD for the time being, but with a considerably more robust VHDCI connector as used with miniature SCSI equipment.

The keyboard, VGA, serial and parallel ports, ethernet, and floppy all adhere to the electrical standards for PC's at the PC's VHDCI connector. To achieve this we put all bypass and impedance components on the main board, with the expander board serving only to bring the connector pins out to standard PC connectors.

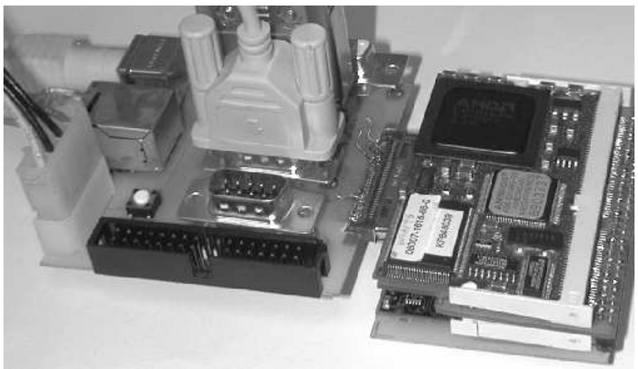

Fig 4. Full-sized port expander attached to the PC

Our goal here has been to allow more than one mode of access to the board. One mode is with a port expander, which we have built, which simply brings the wires out to physically standard connectors. As is evident from Figure 4 these dwarf the Matchbox PC, but allow it to be used like any normal PC using standard external devices and power source, and even with a video projector, which we have taken advantage of for a number of talks.

A quite different mode, one that we have not yet built but that is on our agenda of what to implement next, permits use as a wearable. In this mode a miniature display, keyboard, pointing device, etc. are wired directly to the male connector. By avoiding bulky standard connectors the devices themselves are the limiting factor for miniaturization. At the Society for Information Display's recent exhibit, Toshiba demonstrated a 120-micron pixel 4" diagonal 640×480 display which would be a good match to the size of the Matchbox PC. This mode is compatible with a battery either integral to the unit, say as a suitably sized camcorder battery, or detached and distributed say around the waist in a belt pack.

Power The system performs reliably over a range of 4.8 to 5.2 volts, dissipating 2.0 watts normally and 4.0 watts peak under Linux. (Windows draws more power than Linux, reducible with a program such as CPUIdle.) This gives users considerable flexibility in choosing their source of 5 volts. Obvious candidates are a 5 volt "wall-wart" for AC use, a 12-5 volt DC-DC converter with a car battery, etc. A simple battery would be 4 AA Nicads in series (e.g. a standard 4.8 volt "toy car battery"). NiMH or Li-Ion batteries provide longer life; for example a 7.2 volt camcorder battery (Sony offers a wide range of ampere-hour capacities) can be used with a plain 7805 voltage regulator, or with a more efficient DC-DC converter. The apocryphal suit-case battery should of course run the PC for several weeks.

Ethernet In the prototypes of the Matchbox PC we connected the ethernet module directly to twisted pair cable, which appears adequate for short runs but puts the ethernet chip on the DIMM-IO module at risk of transients or excessive DC levels. For the current version we located an ethernet transformer small enough to fit in the unit, providing the recommended isolation from stray voltages.

Acknowledgments

We would like to thank IBM for the loan of a Microdrive at a time when they were in scarce supply even within IBM. We would also like to thank Matthias Huber and Jumptec for their continued technical support and for space in their CeBIT'99 booth to exhibit the Matchbox PC.

Further photos of this and previous versions of the Matchbox PC may be found on the web at wearables.stanford.edu.

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