LOW-COST MINIATURE INTERFACE AND CONTROL SYSTEMS FOR SMART SENSORS, TACTICAL RADIOS, AND COMPUTER NETWORKS

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abstract

Low-cost Commercial-Off-the-Shelf (COTS) hardware and software products can be used to build small control, processor and interface devices suitable for current and future tactical radio systems. For example, the input from video cameras, infrared imagers, acoustic transducers, proximity detectors, laser range finders, and other sensor input can be digitized, compressed, processed and transmitted via SINCGARS radios when a soldier presses a button. Tactical radios could also be connected to ethernet or telephone lines, and a radio could become a field-accessible email address, file server, or message bulletin board. These capabilities can be developed and fielded quickly for a very modest cost.

1. introduction

Miniature, lightweight, and low power smart sensors can be developed and produced quickly and inexpensively due to recent evolution in several key areas of technology. These technology areas include: high-performance miniature PC-compatible computers for commercial embedded applications; highly integrated low-cost sensors and communication equipment; rugged and miniature interface modules and high-capacity storage devices; and industry standards for data compression and transmission.

PC compatible miniature computers & interfaces

The immense popularity of the industry standard "PC" computer has driven private investment into the development of very small, but functionally complete, computer systems for consumer and commercial uses. The ubiquitous "notebook" computer has become a very popular product among students and business people. Credit-card sized "PC Cards" are becoming the interface and portable high-density storage modules of choice. Seiko Epson has recently introduced a credit card sized complete PC computer: CARDIO.

The manufacturers of "embedded PCs" take advantage of the highly integrated parts that are produced for notebook computers. These "embedded PC" processor board products provide the functionality of the classic PC AT "motherboard" and sometimes include video display drivers, drive controllers, and non-volatile storage devices. "Embedded PC" processor boards have become very popular in automated products that are produced in limited quantities The form factor for the current generation of processor boards ranges from notebook-size to credit-card size; processor capabilities range between the Intel 8088 and Pentium products; and the cost varies between US $100 and $2000. Many interface modules are available in the consumer-product "PC Card" form or the industrial "PC/104" and "STD32" forms. Some products offer very low power consumption or very high levels of integration. The manufacturers of these products are located in North America, Europe, and Asia.

sensors

Sensors are becoming smaller and less costly. Video cameras, infrared imaging devices, and laser rangefinders are becoming increasingly smaller, lighter, less expensive, and better performing. New types of acoustic and radar sensors are becoming available.

communications

small and lightweight tactical band radios

The standard tactical band (30-88 MHz) radio for US forces, known as SINCGARS (Single Channel Ground and Airborne Radio System) weighs over 20 pounds (with

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batteries). Handheld radios which can handle moderate data rates via commercial and military standard interfaces are now available. For example, the Racal Communications PRC-139 -- a three pound, tri-band, fixed-frequency mode military radio -- is currently available in a special version with a MIL-STD-188-114 port; it can receive and transmit in a 16 kilobit per second (kbps) synchronous data mode. The Racal Leprechaun Combat Net Radio -- a new model that is promised to have the complete capability of the SINCGARS manpacks in a three pound package -- will be available by mid-1996.

TCIM in PC Card form factor

The standard Tactical Communications Interface Module (TCIM) is available in a PC Card form factor from Magnavox Electronic Systems Company. This modem handles the low level interfacing functions and the complete data transfer between the PC and the tactical radio. Drivers are uploaded into the TCIM immediately before use. Therefore, the protocols can be easily changed without modifications to the host software or the TCIM firmware. Since the TCIM also provides packetizing and forward error correction, little processing power is needed from the host.

ethernet and the popularity of computer networking

Ethernet networks have become as popular in military field activities as they are in business offices. Ultimately, high-speed networks allow the rapid transmission of data from the field to virtually anywhere in the world. Inexpensive PC/Ethernet interfaces are available in all form factors.

2. new opportunities

expanded usage of wireless communications

In 1996, handheld military radios will be able to offer the performance and security of the current manpack radios -- with an order of magnitude decrease in weight and volume and no significant increase in price. This fact will allow more soldiers to carry radios, smart sensors and handheld computers -- thus increasing the capacity for armament and other mission-essential equipment. This increase in the usage of communication technology could result in substantially more effective troops.

image and video data compression

Most military radio communication modes suffer from a lack of bandwidth -- an especially important consideration in HF and tactical band VHF applications. As an example, a SINCGARS radio operating at its highest speed (16kbps half duplex) is likely to achieve a throughput of only 4000 to 8000 bps. This is due to the need for forward error correction (to maintain a minimally acceptable bit error rate) and the requirement of 33% data transitions (for reliable bit synchronization).

Consider the amount of data required to transmit a single image made of 512 X 512 8-bit pixels. Using the communication system described above, 4 to 8 minutes would be required for the transmission of each image. Obviously this is impractical. Therefore, efficient compression algorithms are needed to enable timely transmission of image data over tactical military radio links.

An immediately available solution is JPEG: a compression standard for still images that was developed during the 1980's. It is widely used in commercial applications, although it has seen only limited usage in military applications. Using JPEG-style compression algorithms, images of high subjective quality can be recovered from images compressed at a ratio of 10 to 15:1. This represents an order of magnitude decrease -- from minutes to seconds -- in the time required for the transmission of images over current low bandwidth data links. The JPEG compression software is readily available from many sources in the form of C library functions or source code. A 486 PC processor can perform the compression and decompression at a speed adequate for low-bandwidth communications applications. Alternatively, the JPEG processing load can be done by specialized modules, available in PC Card and PC/104 forms, that combine framegrabbing and JPEG compression; this approach would allow the host processor to perform communications and control functions.

Current compression technology research is focused on fractal and wavelet algorithms that show promise for high quality recovered still images compressed at 50 to 100:1. Video compression algorithms offer even higher compression ratios by taking advantage of the temporal redundancy found in sequences of images. Evolving standards for video compression over low bandwidth data links include H.263 and MPEG IV.

cost and speed of application development

Readily available PC programmers and users can develop applications for "embedded PCs"; expensive specialists in microcontrollers, special operating systems, and digital hardware are not needed. Since "embedded PCs" are virtually equivalent to industry standard desktop computers, most commercial "PC" software can be used without modification. Custom software can be written by experienced "PC" programmers using commercial software development tools. Therefore, industry-standard embedded computers provide the potential for the *lowest possible development costs* presently available in the industry.

Conventional military products require many man-years of effort and several calendar years to complete. In contrast, this combination of off-the-shelf hardware and software enables the development of useful field-worthy products with man-months of effort within a single calendar year.

3. smart sensor applications

description of smart sensor

Our "smart sensor" hardware model is shown in Figure 1. Since these computers and the interfaces are standardized, systems can be built as required from the available building blocks.

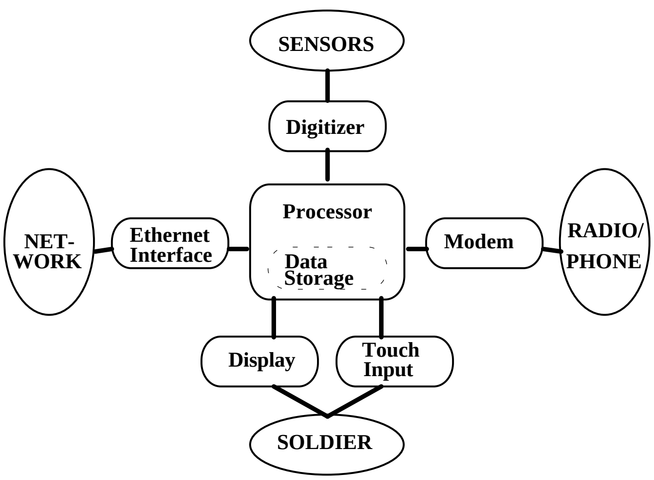

Figure 1

The software model is shown in Figure 2. This model uses a standard operating system, such as Microsoft DOS. Since solid state storage devices that emulate hard disks are available, software can be developed on another platform and simply copied onto the "embedded PC's" solid-state drive. Essential memory resident device driver software is included with the operating system and supplied by the manufacturers of interface cards. Some special purpose drivers and "C" library functions are available as "off-the-shelf" products from a number of suppliers. The only "custom" software that is usually required is at the highest and most portable level. Therefore, for most applications, the "C" language is the most cost-effective choice.

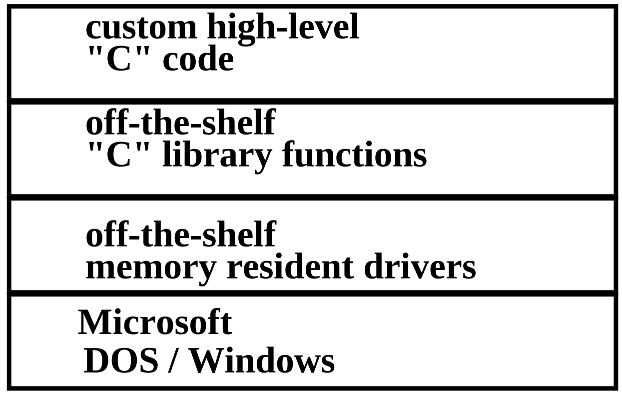

Figure 2

The following are examples of systems we have developed and tested. They illustrate the potential of the technology described above.

example 1: soldier's remote imaging system

An example of a soldier's remote imaging system is shown in Figure 3. A framegrabber digitizes the image received from the camera; the CPU performs JPEG data compression and uploads the compressed data into the TCIM; and the TCIM packetizes the data and sends it through the tactical radio using a standard protocol. If the camera was fixed on a mount, then the system could be used to monitor motion in a surveillance application; images would only be sent whenever motion was detected. The surveillance system could be powered from the batteries of a manpack radio, and it would reduce the radio battery life by less than ten percent. If the camera was mounted upon the soldier's helmet, then a stream of images -- separated in time by five to ten seconds -- could be sent to another location.

The digital components in this system fit within a package with the dimensions of 150mm X 100mm X 40mm and cost approximately US $4500.

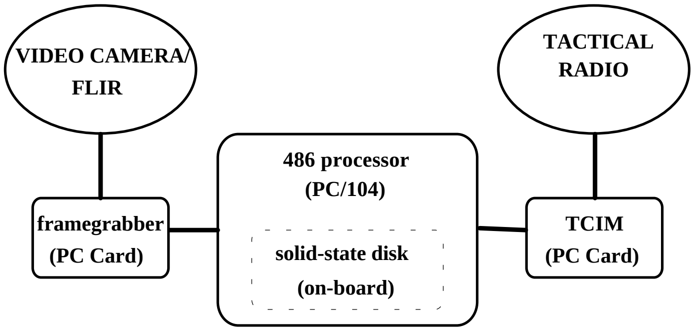

Figure 3

example 2: mobile visual data reception system

The data sent by the solider could be received with the system shown in Figure 4. The data is received by the radio; read by the TCIM; downloaded to the notebook computer; and decompressed, formatted, and displayed by the computer. Since the TCIM fits into a PC Card slot of the notebook computer, the total size and weight are equivalent to the size and weight of the notebook computer. The combination of a suitable computer and TCIM would currently cost about US $5000.

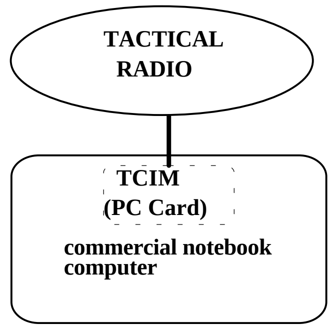

Figure 4

example 3: tactical radio to ethernet interface

Figure 5 shows a tactical radio to ethernet interface. This small battery-operated system could be located at a base site or set on top of a nearby hill for optimum radio performance.

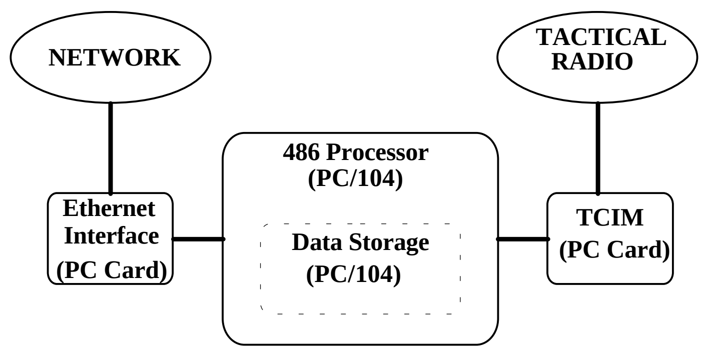

Figure 5

The following is a list of some possible applications:

a) Field Message Receiver: Incoming messages from a tactical radio network would be stored on-board and downloaded as needed via the network. Alternatively, the incoming messages could be sent directly to the appropriate address via email.

b) Field Message Transmitter: Outgoing email messages or data from the network would be transmitted to the field via tactical radio.

c) Field Bulletin Board: Messages from the network are stored on-board, and soldiers can query the unit and download current information. If the messages do not change rapidly, they could be stored on-board, and the network connection would be unnecessary.

This system could be packaged with the dimensions of 150mm X 100mm X 60mm, and the hardware cost would be about US $5000.

variations upon above examples

Many permutations can be developed from the above examples. For example, multiple radio channels could be used in addition to or as a replacement for the network connection; a user interface could be added in the form of a small LCD display and keypad; batteries could be built into the system enclosure; and multiple processors could be employed to support multiple tasks or users. In addition to usage as a stand alone package, the sensor/processor system can be integrated into a helmet, field pack, robotic vehicle, or missile.

4. conclusion

Miniature computer hardware and "PC" software products have been developed in the commercial marketplace to the point where they can be effectively adapted into military solutions at low cost. Soldiers would not be burdened by the weight or size of these devices. Further, the sophistication of the software is such that these devices can be operated with the ease of a radio or camera. Since the software can be quickly developed by "PC" programmers, the development costs for any given application is the lowest currently possible. Although the durability is less than that of conventional military products, the difference in cost outweighs this factor in many circumstances. Therefore, we urge the consideration of commercial "embedded PC" technology in the design of future tactical sensor and communications equipment.

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