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A Study on Smart Dust (MOTE) Technology

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Abstract— **A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The WSN is built of "nodes" - from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. A sensor node, also known as a mote (chiefly in North America), is a node which is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. A mote is a node but a node is not always a mote. We compare and contrast the selected WSN motes under these different headings, highlighting the individual mote's performance under each category.**

Keywords— **Wireless Sensor Networks, Middleware, Mobile Agents, Motes, smart dust.**

I. Introduction

A wireless sensor network consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on. The WSN is built of "nodes" – from a few to several hundreds or even thousands [1], where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of [2]. The motes function within the network and typically fulfill one of two purposes: - either data-logging, processing (and/or transmitting) sensor information from the environment, or acting as a gateway in the adhoc wireless network formed by all the sensors to pass data back to a (usually unique) collection point.Fig1 shows one such network using modes instead of sensor nodes. In this paper, we present a review of several current WSN motes, compared and contrasted under a number of different parameters. These parameters are processor used, expected lifetime, protocols, cost, applications and their pros and cons. These motes are also compared on the basis of total power consumed by different modules of the motes.

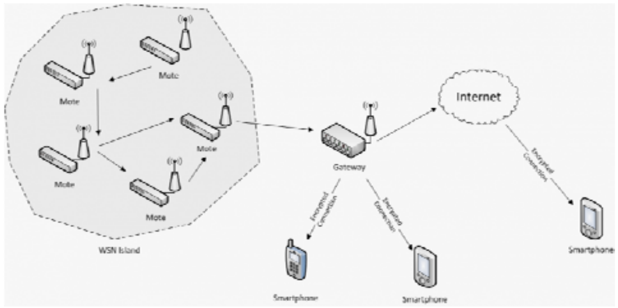


Fig1: use of motes in wireless sensor networks

II. Scope Of The Study

In this section we provide an overview of the motes on which our study is based. The parameters on which these motes are reviewed are divided in five sections in this paper. These are processor and memory, protocols used, cost of motes, power consumption and their applications. The pros and cons of each mote are also listed.

The following motes will be discussed:

- Rene -The Berkley Rene motes were developed in 1999 by CrossBow Technologies.
- MicaZ-It is a third generation mote family from CrossBow Technology used for enabling low power wireless sensor networks.
- IRIS-It is a latest wireless sensor network module from Crossbow Technologies. It includes several improvements over the Mica2 / MicaZ family of products. This mote features several new capabilities that enhance the overall functionalities of sensor network projects.
- SHIMMER-SHIMMER (Sensing Health with Intelligence, Modularity, Mobility, and Experimental Reusability) is a wireless sensor platform designed to support wearable applications. It is currently available from Real Time Ltd.
- TelosB-Wireless sensor modules developed from research carried out at UC Berkeley and currently available in similar form factors from both Sentilla and CrossBow Technology.
- Sun SPOT: - The Sun "Small Programmable Object Technology" (SPOT) is a wireless sensor network mote from Sun Microsystems.
- LOTUS-The Lotus is an advanced wireless sensor node platform. The Lotus platform features several new capabilities that enhance the overall functionality of MEMSIC's wireless sensor networking products.

The fig 2 shows all the above mentioned various kinds of motes.

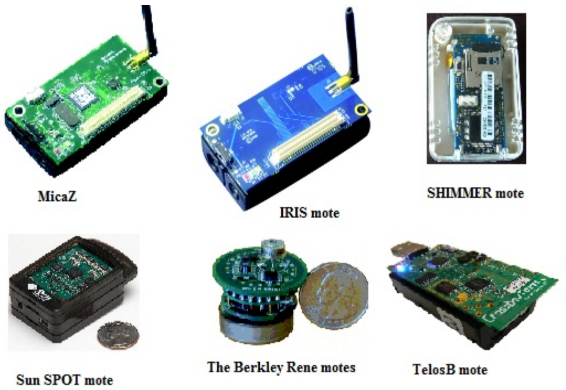


Fig2: Types of motes

III. REVIEW

III.I Processor

Basically the processor is built on the microcontroller which reads sensor data and makes the data ready for transfer. In other words, processor is a core module for the calculation in a wireless sensor node. This part of the node helps to control the task scheduling, to calculate energy, to define communication protocols, to make suitable coordination, for data manipulation and data transfer. The processor is therefore the most important part, Table 1 reviews the microprocessors used for each of the respective motes reviewed [3]. Table 2 provides information on available on-board memory, ADC, power consumption and serial communication of these processors for each mote platform [4] [5] [6].There is a wide variation here in available memory sizes and types
for the different motes, possibly a reflection of their different application spaces [7] [8]. In addition to these on-board memory capabilities, some sensor nodes now also allow the option of saving data to additional external Non-volatile memory.

TABLE 1 : Microprocessor Used

Mote Platform	Processor	Bus
Rene	AT90LS8535	8 bit
MicaZ	ATMega128L	8 bit
IRIS	ATMega1281	8 bit
SHIMMER	MSP430	16 bit
TelosB	MSP430	16 bit
SunSPOT	AT91RM920T	32 bit
LOTUS	NXPLPC1758	32bit

TABLE 2 : Microprocessor Specifications

Processor	Flash	RAM	EEPROM	ADC	Serial Communication	Current Drawn	
						Active	Sleep
AT90LS8535	8K	0.5K	0.5K	10 bit	UART	6.4mA	<5µA
ATMega128L	128K	4K	512K	10 bit	UART	8mA	<15µA
ATMega1281	128K	8K	4K	10 bit	UART	8mA	8 µA
MSP430	48K	10K	None	12 bit	UART	1.8mA	5.1 µA
MSP430	48K	10K	1M	12 bit	UART	1.8mA	5.1 µA
AT91RM920T	4M	512K	None	12 bit	USART	25mA	.5mA
NXPLPC1758	512K	64K	2K	12 bit	USB	50mA	A

III.II Pros And Cons:

Pros and cons of the reviewed 7 motes are listed in table 3.

TABLE 3 : Pros and Cons

Mote Platform	Pros	Cons
Rene	Simple hardware allows easy software optimization	Software intensive
MicaZ	Supported by Mote Works sensor platform for ad-hoc mesh networking	Hardware intensive
IRIS	Increased transmission rate than MicaZ (up to 3 times)	No Sensor capabilities
SHIMMER	Optional Bluetooth & microSD card	Limited set of form factors
TelosB	External Flash	Hardware intensive
SunSPOT	Both Hardware & software are open source	Expensive
LOTUS	Backward compatible with MEMSIC's MDA & MTS range of sensor data acquisition boards	Additional hardware has to be connected for longer range

IV PROTOCOLS & COST

The IEEE 802.15.4[9] protocol has been adopted as a communication standard for low data rate, low power consumption and low cost Wireless Sensor Networks. This protocol is quite flexible for a wide range of applications if appropriate tuning of its parameters is carried out. Most of the mote platforms use this standard for communication between the motes. Rene, IRIS, TelosB, SunSPOT and LOTUS are all IEEE 802.15.4 compliant motes. MicaZ is IEEE 802.15.4/Zigbee compliant and SHIMMER is both IEEE 802.15.4 and Bluetooth compliant, RENE mote uses 2.4GHz, 868MHz or 916MHz frequency band. IRIS and TelosB use 2405 to 2480 MHz band and MicaZ, SHIMMER TelosB and SunSPOT use 2400 to 2483.5 MHz band for communication. This band is called ISM band [10] [11]. For the 7 sensor motes reviewed, current pricing information for each mote is as shown in table 4.

TABLE 4 : Cost per Node

Mote Platform	Cost(US $)
Rene	100
MicaZ	99
IRIS	115
SHIMMER	269
TelosB	99/139
SunSPOT	750
LOTUS	300

V POWER CONSUMPTION

For the 7 separate sensor nodes in this paper, power supply options are as follows:-

Rene:-These sensor nodes are typically powered from an external battery pack containing 2 AA batteries. The cells use an operating voltage of 2.7V. Total active power consumed is 24mW.

MicaZ: - The MicaZ sensor nodes use the same physical battery configuration as the TelosB boards i.e. 2 AA batteries in an attached battery pack. Voltage requirement is minimum 2.5V and total active power is 33mW.

IRIS: - IRIS uses 2 AA batteries similar to MicaZ. AA cells may be used in the operating range of 2.7 to 3.3V DC.

SHIMMER: - the SHIMMER mote is typically powered by a 250mAh battery. Supported configurations include Lithium- Ion/Lithium-Poly cell chemistry and lithium coin cells or alkaline batteries. The SHIMMER design also includes a Texas Instruments BQ-24080 Smart Li Charger for battery management.

TelosB: - TelosB boards are typically powered from an external battery pack containing 2 AA batteries. AA cells may be used in the operating range of 2.1 to 3.6V DC, however the voltage must be at least 2.7V when programming the microcontroller flash or external flash. Total active power is 3mW.

Sun SPOT: - Sun SPOT motes are powered from an integrated rechargeable onboard battery. The SunSPOT mote PCB typically uses a 3.7V rechargeable 750 mAh lithium-ion battery, nominally operating with a 30 uA deep sleep mode.

LOTUS: - These sensor nodes are typically powered from an external battery pack containing 2 AA batteries. AA cells may be used in the operating range of 2.7 to 3.3V DC. Of the 7 motes considered here, only 2 use rechargeable battery packs, the SHIMMER mote and the Sun SPOT mote. The SHIMMER is supplied with a rechargeable 250mAh battery while the more processor and power intensive SunSPOT typically uses a 750mAh Li-Ion battery.

VI APPLICATIONS

The recent advance in Micro-electro-mechanical system (MEMS) and wireless approach promises advantage over the traditional sensing methods in many ways: large- scale, densely deployment not only extends the spatial coverage and achieves higher resolution, but also increases the fault-tolerance and robustness of the system, the ad-hoc nature make it even more attractive in military applications and other risk-associated applications, such as habitat monitoring and environmental observation. Rene motes are used for asset monitoring, climate control and surveillance. MicaZ ,LOTUS and IRIS motes have applications in indoor building monitoring and security, acoustic, video, vibration and other high speed sensor data and large scale sensor and large scale sensor networks (1000+ points).LOTUS motes are also used for condition based maintenance and industrial monitoring and analysis. TelosB provides a platform for low power research development and other wireless sensor network experimentation. SHIMMER motes have medical applications and used in sensing speed of vehicles say vehicle tracking. SunSPOT motes have military applications and are used in swarm intelligence and rocket launch monitoring.

VI.I The In-Motes EYE Application

Last year more than 2 million motorists were caught speeding on camera, raising £120m a year in revenue for so-called 'Safety Camera Partnerships' comprising police, magistrate councils and road safety groups. Speed cam-eras have boomed on British roads from a handful a decade ago to 3 300 fixed sites and 3 400 mobile devices today. In October 2006 a massive flaw in a new generation of speed cameras was reported by Daily Mail [11] allowing motorists to avoid speeding fines in some of the busiest UK motorways by simply changing lanes. The Home Office admitted in public that drivers could avoid being caught the by hi-tech 'SPECS' cameras,**Figure 3** which calculate a car's average speed over a long distance.

The cameras were designed to catch motorists who simply slow down in front of a camera, case of the Gatso speed cameras, and then drive above the speed limit until they reach the next one. The loophole in the software is located when a motorist changes lanes as it is unable to calculate if the average speed is above the limits due to the fact that the fixed points of measurement need to be in a straight line. Although the software was designed to improve the road safety, by measuring a driver's average speed between two fixed points which can be many miles apart the loophole meant that drivers may actually in-crease the risk of accidents by continually switching lanes. Since then, an update of the software took place to correct this problem but as Mr. Collins, a Home Office representative stated recently "There are configurations when (a speeding vehicle) would not be picked up, if it's gone from lane one to lane three between cameras."

Figure 3. The SPEC road cameras with the problematic software.

VI.II The RoboMote Application

The ability of a sensor node to move itself or to otherwise influence its location will be critical in sensor networks. The possibility of combining computation, sensing, communication and actuation to not only passively monitor the environment (like static sensor networks) We believe that augmenting static sensor networks with few mobile nodes immensely benefits the functionality of the sensor network and helps solve many of the design problems of static sensor networks. RoboMotes are small (less than $0.00005m^3$) inexpensive (less than $150 each) mobile robots. Each robot features a wireless network interface (the "Mote" part), two speed and direction controlled wheels with optical encoders for odometery; a solar cell for "always on" networks; a compass for direction; and bump sensors and infra-red sensors for obstacle avoidance. RoboMotes sit at the intersection of robotics, ad-hoc networking, and distributed artificial intelligence. They allow research that has previously been either too costly, required too much space, or been technologically out of reach. Because the RoboMote platform itself is small and inexpensive, it is now practical to implement much larger robot networks. The primary motivation for a RoboMote network is research in always on dynamic self re-configurable sensor networks. Figure 4 shows the robomote used in various applications.

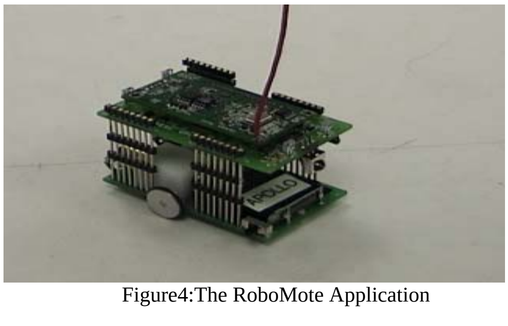


Figure4:The RoboMote Application

VI.III The Extreme Scale Mote (Xsm)

This new mote is an integrated application-specific sensor network node for investigating reliable, large-scale, and long-lived surveillance applications. The improved reliability stems from hardware and firmware support for recovering from Byzantine programs. Large-scale operation is better supported through an improved hardware user interface and remote tasking. Long-lived operation is realized through the use of adaptive low-power sensors and a hierarchical and event-driven signal processing architecture. The motivating surveillance application is the detection, classification, and tracking of civilians, soldiers, and vehicles. Performed under the aegis of the DARPA NEST Extreme Scale 2004 Minitask, a fundamental goal of this work is to demonstrate operation of a wireless sensor network at the heretofore unprecedented and extreme scale of 10,000 nodes occupying a 10km2 area and for a duration approaching 1000 hours. Operations at such scales make it impossible to manually adjust parameters, repeatedly replace batteries, or individually program sensor nodes. These severe constraints were selected to “kick the crutches out” and had the intended effect of elevating to first-class status several factors, such as reliability, usability, and lifetime, which might otherwise have become afterthoughts. Another very real constraint was cost since every decision was amplified by a multiple of 10,000. Some of the more innovative ideas did not survive budgetary scrutiny and were not included in either the XSM design or in this work.

Figure 5: Top view of XSM (version 2).

The XSM, shown in Figure 5, integrates a platform with a suite of sensors. In the TinyOS community, “platform” has come to mean the microcontroller, memory, and radio subsystems, as well as supporting hardware like power management or timekeeping but not the sensing and signal conditioning hardware or packaging. In keeping with this tradition, this section discusses the processor, radio, and supporting subsystems.

Sensor nodes for intrusion detection may experience diverse and hostile environments with wind, rain, snow, flood, heat, cold, terrain, and canopy. The sensor packaging is responsible for protecting the delicate electronics from these elements. In addition, the packaging can affect the sensing and communications processes either positively or negatively. Figure 5.1 shows the XSM enclosure and how the electronics and batteries are mounted. The XSM enclosure is a commercial-off-the shelf plastic product that has been modified to suit our needs. Since the enclosure plastic is constructed from a material that is opaque to infrared, each side has a cutout for mounting a PIR-transparent window. Similarly, a number of holes on each side allow acoustic signals to pass through. A water-resistant windscreen mounted inside the enclosure sensor reduces wind noise and protects the electronics from light rain. A telescoping antenna is mounted to the circuit board and protrudes through the top of the enclosure. A rubber plunger makes the RESET and USER buttons easily accessible yet unexposed.

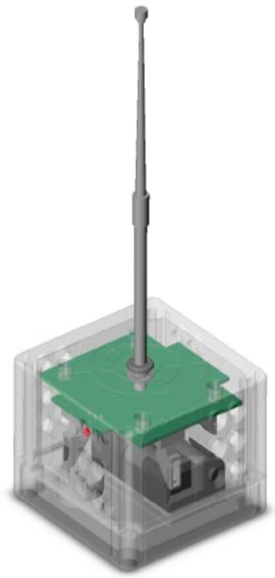
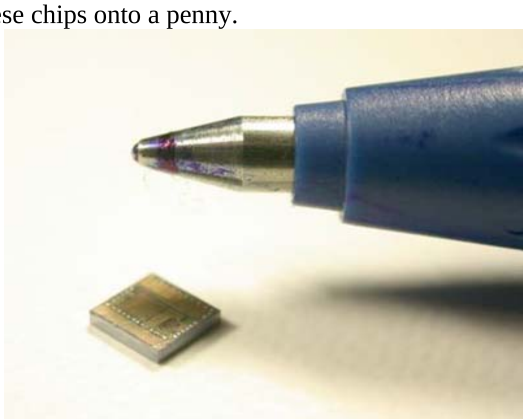


Figure 5.1: This model shows how the XSM electronics and batteries are mounted in the enclosure.

VII THE FUTURE

In March, 2003, researchers managed to cram all of the parts needed for a mote onto a single chip less than 3 millimeters on each side. The total size is about 5 square millimeters, meaning that you could fit more than a dozen of these chips onto a penny.



The chip contains all of the components found in a mote: a CPU, memory, an A/D converter for reading sensor data and a radio transmitter. To complete the package you attach the sensor(s), a battery and an antenna. The cost of the chip will be less than a dollar when it is mass produced.

CONCLUSION

This paper has presented a review of currently available mote technologies. For these different motes, a series of 5 categories have been considered, namely processor and memory, protocols, cost, power consumption, applications and their pros and cons. In terms of individual observations, we have found that the Sun SPOT motes are the best option if processing power and a high computational overhead are envisaged in the application requirements. SHIMMER motes, with their small form factor and integrated 3-dimensional accelerometer sensors, are best suited for wearable applications such as health monitoring, MicaZ and TelosB are the cheapest amongst all and can be used where low cost is a concern. IRIS motes have an increased range so can be used where long distance communication is required. In-Motes EYE application which is an agent based real time In-Motes application developed for sensing acceleration variations in an environment. The application was tested in a prototype area, road alike, for a period of four months. We presented the robomote, a mobile robotic test bed for mobile sensor network experiments. We also presented two case studies where the robomote was used to experimentally validate algorithms designed for next generation mobile sensor networks.

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