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Motion Activated Smarty Robots in Cryogenic Conditions for Military Data Transmission using Encryption Algorithm

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Abstract

Secured robots are becoming more common place in the framework of military service, as well as other forces Military robots are already performing repetitive tasks like moving supplies and loading cargo, as well as particularly dangerous missions like evacuating casualties under explosive devices and collecting information in hostile environments. All experts agree that their utility will continue to expand at an increased pace.

In today's geopolitical climate, ensuring the protection of secure facilities or key locations against resourceful and determined intruders is of paramount importance to the defense of a national border as well as industries of national importance. The greatest threat to national security is "Terrorism" and it cannot be defeated by conventional military force alone.

Autonomous robot to avoid obstacles and two sensors are connected to identify dangerous situations those are fire and metal detector to identify explosives. RF communication is used to intimate others nearby. Wireless sensor nodes will become inexpensive and common over the next decade. Some of the physical limits to the underlying technology are discussed.

Introduction

We are surrounded by sensor networks. We drive in cars (which have seat occupation and belt sensors) on roads (that have car presence sensors), to work in buildings (that have temperature and motion sensors), which are all part of the tremendous infrastructure that we take for granted, in part because of the sensor networks that help to make it maintainable. We are increasingly surrounded by wireless communication networks. The cell phone and pager networks are the most obvious and recent examples. Microwave towers and satellite links have become so common that they are no longer noticed.

We are surrounded by computation. Most of us carry at least one (admittedly simple) computer on our person all day long - wristwatch, cell phone, hearing aid, etc. In the latter two cases, the signal processing capabilities of the silicon we wear exceeds the capabilities of the most powerful computers just a few decades ago, yet we complain that the batteries run low too quickly!

No one seriously questions the exponential improvement in computing technology. This work explores a few of the military implications of exponential improvement in all three of the above capabilities: sensing, computation, and communic ation. Where are the limits and what are some of the applications?

Technology Roadmap

Existing technology

There are many groups currently working under DARPA funding on wireless sensor networks using MEMS technology. Initially the DARPA effort focused on developing the sensor technology itself. As sensor capabilities improved, the emphasis shifted to

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developing sensor systems. (One of?) the first of these was an effort led by Ken Wise at the University of Michigan[i], in which the goal was to produce a wrist-watch sized, battery powered sensor system (*Error! Reference source not found.*). Shortly thereafter, Bill Kaiser and the humble author at UCLA launched the LWIM project (Low Power Wireless Microsensors)[ii] with the goal of putting a completely autonomous sensor node with power, processing, and communication into a cubic centimeter volume. LWIM has been quite successful, with many technology demonstrations in military exercises. The success of the project has spawned many follow-on contracts at UCLA including WINS and AWAIRS. In 1998 the humble author, now at UC Berkeley, was funded to build autonomous sensors in a cubic millimeter volume, and the term Smart Dust[iii] was launched. Early motivation and concept develop ment for Smart Dust was a result of a RAND workshop[iv] and two DARPA ISAT meetings[v].With several wireless sensor network projects making progress, it became clear that one of the major roadblocks in sensor networks was power. This was one of the reasons why the most recent round of DARPA MEMS program funding was in the area of MEMS power generation, focusing mostly on the conversion of hydrocarbon fuels to electric power.

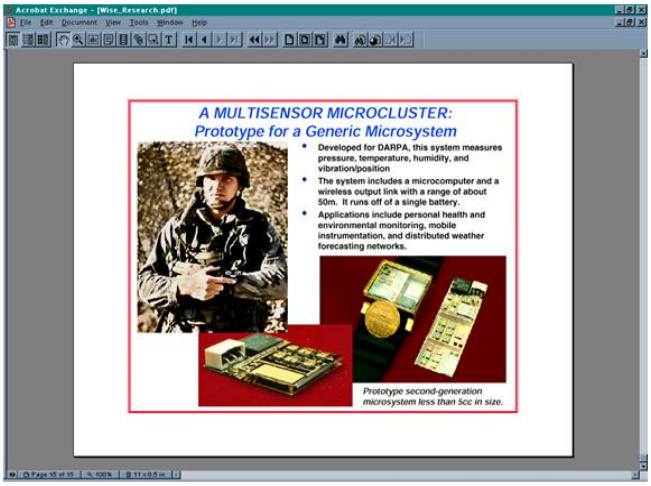

Figure 1:The Michigan multi-sensor micro-cluster project.

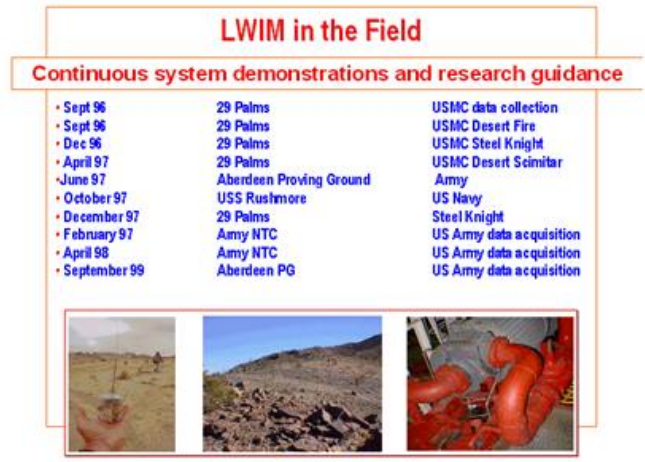

Figure2: The UCLA LWIM project demonstrate ions.

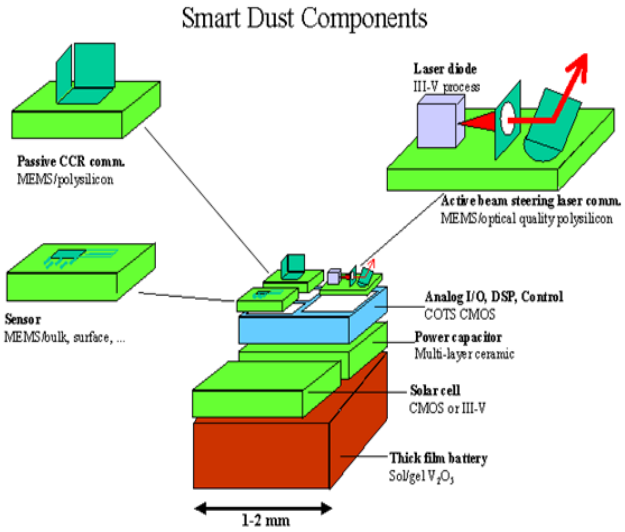

Figure 2 The UCB Smart Dust project goal.

The parameters of greatest interest in most wireless sensor networks are sensor performance, power, and cost. The issue of size is typically *not* a constraint for most applications once the move to MEMS sensors is accomplished. For most applications, the difference between a cubic inch sensor node and a cubic millimeter sensor node is relatively unimportant. However, size is indirectly important because of it's relationship to cost. If we assume an integrated solution to the autonomous sensor problem, then size and cost are mostly likely strongly correlated.

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Sensor Performance

Sensor performance is often *inversely* related to size, despite what most MEMS researchers would like you to believe. Certainly the raw sensitivity of pressure sensors, accelerometers, gyroscopes, and microphones all degrade substantially as the size of the sensor decreases. On the plus side, frequency response of most sensors does improve with decreasing size.

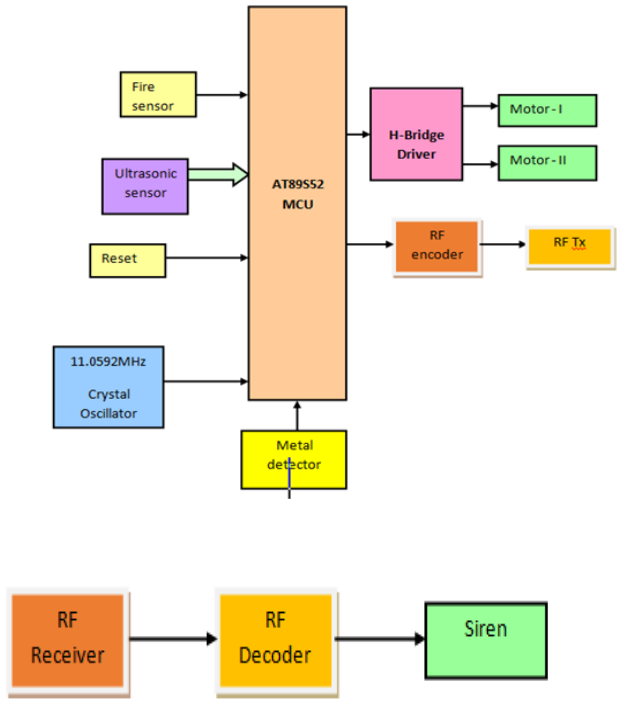
The fundamental limit in most MEMS sensor systems is thermal noise. In a nutshell, the vibration of molecu les (which is the very definition of temperature), causes all mechanical and electrical devices to jitter around as well, with an average kinetic energy of kT/2 (a few thousandths of a billionth of a billionth of a Joule). While your desk and the power coming out of the wall are relatively unaffected by this amount of energy, MEMS components (and the electronics that interface to them) are small enough that this amount of energy is important. In particular, the proof mass of a MEMS accelerometer is not much bigger than the pollen grains that Robert Brown saw through his microscope in 1827. What use is an accelerometer if random collisions with air molecules cause it to bounce around with Brownian motion? Not much.

This then provides a lower limit on the size to which we can miniaturize our sensors - they must be either massive enough or stiff enough to not be unduly influenced by the air itself[1].For example, a device like the ADXL202, a two-axis, +/-2g full-scale accelerometer is within spitting distance of the thermal limit to sensitivity. More performance can only be achieved in this device by either increasing the size of the proof mass, decreasing the bandwidth, or increasing the power dissipated in the excitation and sensing electronics. Similarly, for hearing aid microphones (both MEMS based and non-MEMS), the noise in the microphone signal is not very much larger than the fundamental thermal limit, the amount of noise caused by the thermal vibration of the microphone membrane itself.

Power consumption in sensors

Sensor excitation and sensor electronics power requirements are intimately related to the thermal noise in the sensor itself. This is one area where most MEMS products have not made much progress, because sensor power constraints from the system level are generally mild. One exception is the latest few accelerometer products from Analog Devices which burn dramatically less power than the original ones did, even though their performance is better. Typically, there are several orders of magnitude available between the hundreds of milli Watts currently used by most of these sensor systems and the theoretical limits of the sensor and electronics, which are typically in the micro Watt to milli Watt range.

Block diagram



Power consumption in computation

Currently, power consumption in a power-optimized microprocessor[vi] is roughly 1nJ/instruction[2]. This

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corresponds to a general-purpose 32 bit microproc essor. For specific tasks, application specific integrated circuits (ASICs) typically outperform general purpose processors by a factor of 100 to 1000 in the area of power consumption, so we can look forward to power consumption in the 1-10 pJ/instruction with dedicated silicon.

Power consumption in RF communication

It is difficult to make generalizations about power consumption in communication systems, because there are so many variables that come into play in evaluating performance of these systems. However, the fundam ental limits are again related to thermal noise. For a receiver with a noise bandwidth B (roughly the bit rate), the thermal noise power from the antenna is kTB. The quality of the electronics in the receiver determines how close the actual noise performance is to this theoretical limit, and is represented by the noise figure of the receiver, N_f. N_f is the ratio of the actual noise to the thermal limit. The strength of the radio signal received needs to be greater than the noise by an amount determined by the down-stream signal processing of the signal, and is given by SNR_{min}. This means that overall, the signal power received by the antenna must be greater than kTB N_f SNR_{min}

To put some numbers to this, consider the GSM cellular phone standard. The noise bandwdith is roughly 200kHz for a 115kbps link. The receiver has about 8 times more noise than the thermal limit, and the downstream electronics needs a signal to noise ratio of about 10 to achieve an adequately low bit error rate. In decibels relative to 1 milliWatt (dBm), that gives a sensitivity of:Cordless phones operate with similar data rates at less than one tenth the power, but with a range reduced to 10-100 meters. On the order of 1 uJ/bit is common.The Bluetooth radio [vii] is designed for short range, 1Mbps communication in a household or office environment. Transmit power is 1mW, but the total radio power is still roughly one hundred mW regardless of transmit power, because of all of the radio circuit overhead. Even so, the Bluetooth standard is still the most promising for civilian sensor networks with short-range communication cost of roughly100 nJ/bit in the 2.4GHz band.

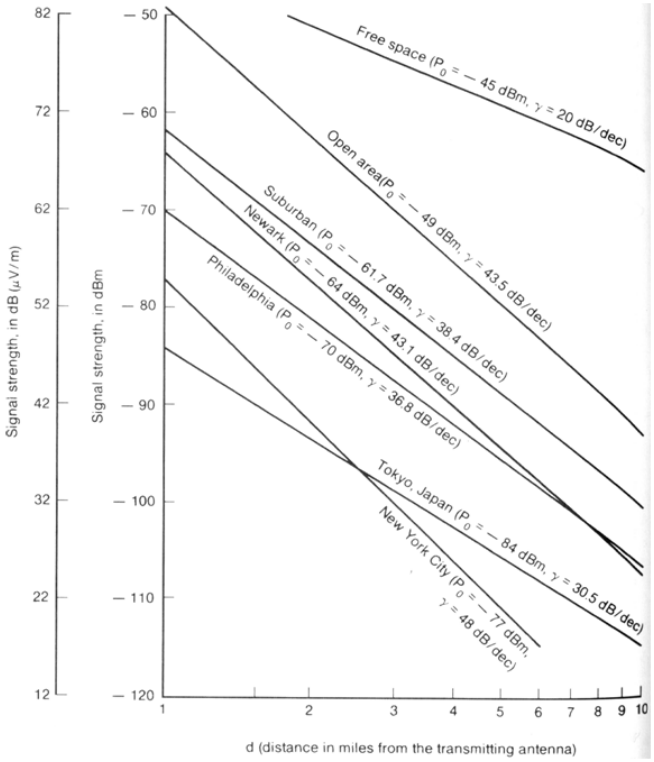

Figure 3 Signal strength vs. distance for cellular telephone. Po is the signal strength (power received, in dB relative to 1mW) at 1mile, and gamma is the attenuation exponent, giving power loss in dB per decade of increased frequency. Note that in all environments, attenuation goes as roughly the fourth power of distance (gamma=40). (From Lee [viii])

Power Generation and Storage

The most likely and simplest type of power storage for wireless sensor nodes is lithium batteries. The latest generation of lithium batteries is rechargeable, and roughly 300Watt-Hr/kg, or 2,000 J/cc. This means that you can run your 4W laptop PentiumX for about 8 minutes off a 1 cc of battery. A power optimized sensor node with duty-cycled communication might consume an average of 100uW of power, which gives a lifetime of nearly a year per cc of battery.

The latest revolution in capacitive energy storage is the Ultracapacitor[ix] which provides an energy density of nearly 10 J/cc. While this is only 1% of the energy density of a good battery, the energy from these new

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capacitors can be delivered in a matter of seconds, whereas most batteries can not be discharged at such high rates.

For scavenging energy from the environment it is hard to beat solar radiation as a host source. Full sunlight gives around 1mW/mm^2 and bright indoor illumination is roughly one thousandth of that. Conversion efficiency is around 30% for the best cells. For applications where duty-cycling is acceptable, solar cells or other power scavenging sources can be used to trickle-charge a capacitor (or battery), and then the stored energy can be used at much higher power rates than the charging power.

Vibration has been proposed as a scavengable energy source. Indeed, vibration spectra of office windows, copy machines, and industrial motors reveal that there is useable energy here - typically on the order of ten micro Watts per gram of mass of the converter.

Existing Products

The closest existing commercial products to wireless sensor networks are home security systems and RF ID tags. During the 1990s, the home security market underwent a revolution in which all of the wired sensor nodes (window vibration, door opening, IR motion sensors, fire sensors) were converted to wireless communication. While the technology to do this was available for decades, the cost and power requirements dropped dramatically in the 1990 time frame, and so it became economically attractive to spend more money on the hardware in order to avoid the installation cost of running wires in houses.

The RF ID tag and keyless-entry system markets have existed for at two least two decades, with the Texas Instruments TIRIS system as one of the long-time leaders. Both RF ID tags and keyless-entry systems are unpowered wireless devices which absorb energy from a local RF broadcast source. In the case of the keyless-entry systems, the reflected signal from the node gives the source sufficient information to determine it's ID. specialized systems with limited performance will be manufactured for under ten cents.

Applications

Here I present only three of many ideas that were generated in discussions with military personnel and DSSG mentors. Bunker mapping was chosen because it seems to address one of the "open questions" that we were given during our tours. Intrusion detection was chosen because it seems like the most immediately easy and useful demonstration of this kind of network. Stockpile Stewardship was chosen because this is an application that most people will not have thought of before.

Bunker mapping

Scenario: An underground facility is being construc ted or has been constructed. The geometry of the facility is unknown, in terms of size, depth, and shape. Vehicles enter and exit the facility on a fairly regular basis.

Goal: determine the geometry of the underground facility.

Approach: Attach a small inertial measurement device to a vehicle before it enters the facility. After the vehicle leaves the facility, download the sensor data, and use it to reconstruct part of the internal structure of the facility. With multiple data sets, a comprehensive map of the internals of the facility will be constructed.

The sensor data would be downloaded by either RF or line of sight optical communication to some local re transmitter.

The move would be placed on the vehicle by one of several methods:

- hand emplaced. This provides the best chance for hiding the mote, and guaranteeing any alignment that may be necessary. Most risky.
- ballistically delivered. The mote could be fired from a gun of some kind.
- perched MAV drop. Fly in an MAV and perch on a tree, bridge, building, or other structure that overlooks a road into the facility. This approach has the advantage

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that the MAV can be used as the relay station for communication after the mote has returned out of the facility.

- flying MAV drop. The MAV swoops down on the truck and delivers the mote ballistically. This method requires some level of skill in piloting, and risks discovery.

Feasibility: Assume that we have a three axis accelerometer, three axis gyro, and three axis magnetometer on the mote. Currently this combination of sensors, together with a microprocessor, bi-directional RF communication (50m), and power supply can be built in a volume of less than one cubic inch. This is already probably small enough to be used under some circumstances. Power requirements even with existing off-the-shelf components give a lifetime of days to months depending on duty cycle.

In addition to the mapping activity, the sensor nodes could be augmented with a variety of other sensors. The most useful of these might be an image sensor. Reasonable quality digital image sensor with wide angle lenses is commercially available in a few cubic centimeter volumes. These could be reduced in size somewhat, but the limits imposed by optics are on the order of a few millimeters. Reasonable quality images require roughly 10kB of storage, so hundreds of images could be stored in a few MB of flash memory. Images could be programmed to be acquired on a regular timed basis, or under the control of the inertial measurement unit (e.g. every time the vehicle stops, or turns, or travels a given distance), or some combination of both. Most likely a CMOS imager would be needed, rather than a CCD image sensor, for reasons of power consumption. In addition, integration of the image compression circuitry with the imager would make for a small, lower power system. Finally, whether a custom CMOS imager or a COTS imager is used, it would be possible to use image data to augment or potentially even replace the inertial navigation data.

Dynamically Placed Intrusion Sensor Networks

Scenario: Military units clearing urban terrain must clear a building, but cannot afford to leave people behind to ensure that it stays cleared.

Goal: Notify the force if anyone enters the cleared portion of the building after they have left.

Approach: Soldiers would carry something like a Pez dispenser[x], possibly attached to their weapons, filled with sensor nodes that could be shot or emplaced quickly by hand on a wall, stairwell, or doorway. The sensors, using some combination of acoustic, IR, visual, or vibrational cues would pass information about intruders to the appropriate person/people.

This scenario was suggested by Col. Henry Kinnison with some input by Chris Kearns[xi]. In particular, Col. Kinnison suggested that the soldier could speak a message as he emplaced the sensor node, and that that would be the verbal message that would be relayed to the soldiers when that sensor detected an intruder. The message would typically be descriptive of where the sensor was put, e.g. "third level broken window", and would use descriptions that were relevant during the actual maneuver, rather than what might have been discussed during planning.

Feasibility: This could be done today with off the shelf components in the cubic inch size range. To be militarily useful it would certainly require substantial modification (for size, ruggedness, security of communication, etc), but Kearns and his group at the Dismounted Battle space Battle Lab at Ft. Benning are ready to try out the off-the-shelf version as soon as someone makes it.

Stockpile Stewardship

During the DSSG visit to Los Alamos it became clear that there were many interesting applications of wireless sensor networks in Stockpile Stewardship. Many classified discussions were had with people[xii] involved in different parts of weapons design, storage, re-manufacturing, etc. Unfortunately, virtually any interesting information about this topic is classified. The following has been cleared:

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Characterize pressure, temperature, and materials inside complicated engineered devices with as little collateral interaction as possible. This would involve insertion of sensors via hypodermic needles and catheters. Applications for Stockpile Surveillance.

Characterize pressure, temperature, resistivity, and velocity differences between dissimilar materials and components subject to high accelerations and velocities. Since these ultra small sensors would be non-intrusive, they would prove useful in quantifying weapon environments.

Chronic sensors for stockpile weapons. This would involve the development of ultra small feedback controllers, temperature monitors, and other devices useful for characterizing aging effects in the stockpile. General areas such as delaminating, elasticity changes, and chemical releases could be quantified using these types of devices.

This is a very promising area for the application of MEMS techniques in general, and wireless sensor networks in particular. Contacts[xiii] at Sandia National Laboratory indicated that there is a large effort ongoing in this area already at SNL. While it is certainly true that SNL is doing great things in MEMS, it is also certainly true that no one at LANL had any collaboration with them in the areas discussed above. It is also certainly true that the academic community is completely unaware of the potentially great benefit of MEMS in these stockpile-related applications. While there are obviously issues of secrecy to be dealt with, this message needs to get to the university community.

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1) Michigan microsensor microcluster: http://www.engr.umich.edu/~wise

2) LWIM/WINS/AWAIRS projects: http://www.ee.ucla.edu/~kaiser

3) http://www.eecs.berkeley.edu/~pister/SmartDust

4) "Future Technology Driven Revolutions in Military Conflict", RAND 1992, and a follow-on study by Steeb and Brendley, "Military Applications of MEMS", RAND, 1993?

5) DARPA/ISAT web page: http://atlas.ida.org:8500/

6) http://www.strongarm.com Power optimized microprocessor family with Pentium-quality speed and less than 10% the power dissipation.

7) http://www.bluetooth.com Local area radio.

8) William C.Y. Lee, Mobile Cellular Communications, 2nd. Ed., McGraw-Hill, 1995.

9) http://www.powercache.com A 4 Farad, 2.3 V, 2A capacitor the size of three stacked nickels.

10) http://www.pez.com

11) Christopher Kearns, kearnsc@benning.army.mil, US Army Dismounted Battlespace Battle Lab, Chief, Dismounted Forces Div. Col. Henry Kinnison, KinnisonH@benning.army.mil .

12) A good place to start for future discussions would be with George Hrbek, hrbek@lanl.gov . Also very interested is mbaron@lanl.gov .

13) Two good people to talk to are Mark Rosen, marosen@sandia.gov, and Kent Meeks, kdmeeks@sandia.gov .