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Smart Farm Using Smart Dust Cubic- Millimeter Computer

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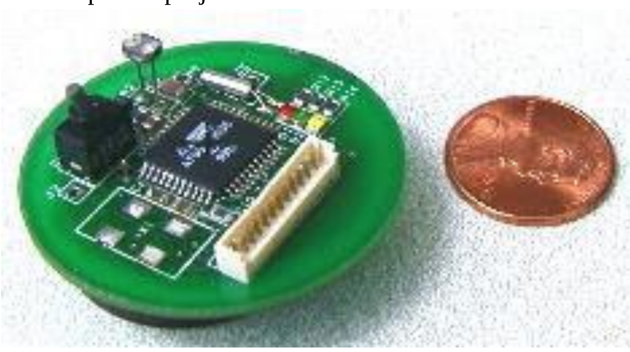
***Abstract*: -** One of the Major problems which we face today is agriculture. If the agriculture is done in a large scale the monitoring of large farms becomes a tedious process, so a computational method which monitors the nutrient content of the different parts of the farm land is required to enhance the crop yield of the farm land. so my aim is to instantaneously monitor the farm land continuously using a new technology called smart dust and send the information for processing and if there is a lack of a particular nutrient then automatically the required amount of the nutrient is mixed with the water and then irrigated , and if the farm lacks in water then it is sensed by the smart dust and information is transmitted , then the pump is automatically switched on. By using this technology the farm can be monitored 360 degrees which will then result in increased crop yield.

INDEX*: - Introduction- smart dust requirements sensors and motors- computing at the millimeter scale-low energy consumption-remote programmability-communicating from a grain of sand- optical communications-passive reflectivesystems- active steered laser systems- listening to a dust field- advantages of imaging recievers-references*

I. INTRODUCTION

The Smart Dust project is probing microfabrication technology's limitations to determine whether an autonomous sensing, computing, and communication system can be packed into a cubic-millimeter mote to form the basis of integrated, massively distributed sensor networks. Decreasing computing device size, increased connectivity, and enhanced interaction with the physical world have characterized computing's history. Recently, the popularity of small computing devices, such as handheld computers and cell phones, burgeoning Internet growth, and the diminishing size and cost of sensors— especially transistors—have accelerated these trends. The emergence of small computing elements, with sporadic connectivity and increased interaction with the environment, provides enriched opportunities to reshape interactions between people and computers and spur ubiquitous computing research.1 The Smart Dust project2 is exploring whether an autonomous sensing, computing, and communication system can be packed into a cubic-millimeter mote (a small particle or speck) to form the basis of integrated, massively distributed sensor networks. Although we've chosen a somewhat arbitrary size for our sensor systems, exploring microfabrication technology's limitations is our fundamental goal. Because of its discrete size, substantial functionality, connectivity, and anticipated low cost, Smart Dust will facilitate innovative methods of interacting with the environment, providing more information from more places less intrusively. We use Smart Dust to pursue projects such as



- deploying defense networks rapidly by unmanned aerial vehicles or artillery;
- monitoring rotating-compression-blade highcycle fatigue;
- tracking the movements of birds, small animals, and insects;
- monitoring environmental conditions that affect crops and livestock;
- building virtual keyboards;
- managing inventory control;
- monitoring product quality;
- constructing smart-office spaces; and
- providing interfaces for the disabled.

II. SMART DUST REQUIREMENTS

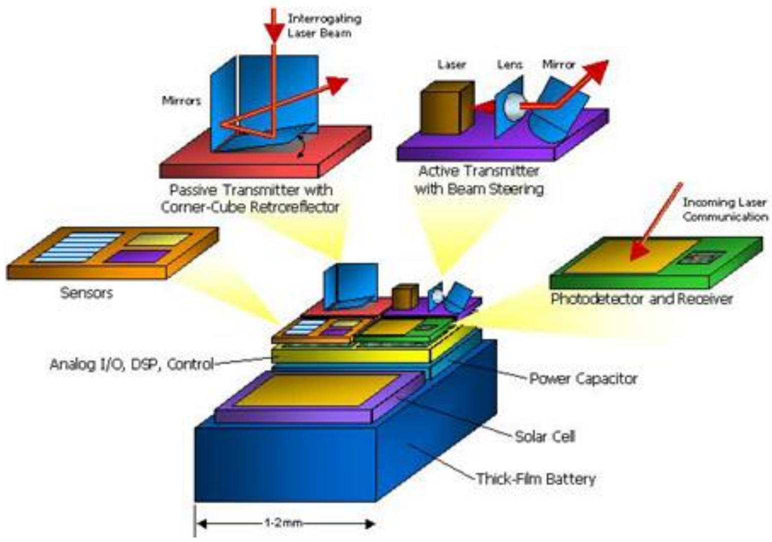
Smart Dust requires both evolutionary and revolutionaryadvances in miniaturization, integration, and energy management. Designers can use microelectromechanical systems (MEMS) to build small sensors, optical communication components, and power supplies, whereas microelectronics provides increasing functionality in smaller areas, with lower energy consumption. Figure 1 shows the conceptual diagram of a Smart Dust mote. The power system consists of a thick-film battery, a solar cell with a charge-integrating capacitor for periods of darkness, or both. Depending on its objective, the design integrates various sensors, including light, temperature, vibration, magnetic field, acoustic, and wind shear, onto the mote. An integrated circuit provides sensor-signal processing, communication, control, data storage, and energy management.

A photodiode allows optical data reception. We are presently exploring two transmission schemes: passive transmission using a corner-cube retroreflector, and active transmission using a laser diode and steerable mirrors. The mote's minuscule size makes energy management a key component. Current battery and capacitor technology stores approximately 1 joule per cubic mmand 10 millijoules per cubic mm, respectively, whereas solar cells provide 1 joule per day per square mm in sunlight and 1 to 10 millijoules per day per square mm indoors. Our optical receiver consumes approximately 0.1 nanojoule per bit, and the transmitter uses 1 nanojoule per bit. We expect our analog-to-digital converter to require 1 nanojoule per sample and computations to consume less than 1 picojoule per instruction, in contrast to present processors such as the CoolRisc 813 core, which uses 22 picojoules per instruction, and the StrongARM SA1100, which consumes approximately 1 nanojoule per instruction. These estimates demonstrate that for every sensor sample or transmission, we can perform about 1,000 8-bit operations, so it is advantageous to exchange extra calculations for fewer samples or transmitted bits. Further, given our 1 millijoule per day of energy from indoor lighting, each second we can sample a sensor, think about the result, and transmit some data.

To determine our research baseline and quickly develop hardware for testing networking algorithms, we used commercial off-the-shelf hardware to build a series of wireless sensor nodes. We used either optical or radio-frequency communication models to produce one-cubic-inch devices. Furthermore, other research groups have used these motes to develop a tiny oper-ating system and deploy a 100-node network.

III. SENSORS AND MOTORS

The multibillion-dollar MEMS industry has been growing for several decades, with major markets in automotive pressure sensors and accelerometers, med-ical sensors, and process control sensors. Recent advances in technology have put many of these sensor processes on exponentially decreasing size/power/cost curves. In addition, variations of MEMS sensor tech-nology are used to build micromotors; millions of these micromotors are used in commercially available projection display systems, such as the Texas Instruments Digital Micromirror Device. Micro-motors, combined with Smart Dust, raise the inter-esting possibility of making synthetic insects (see the "Microrobotics" sidebar).



IV. COMPUTING AT THE MILLIMETER SCALE

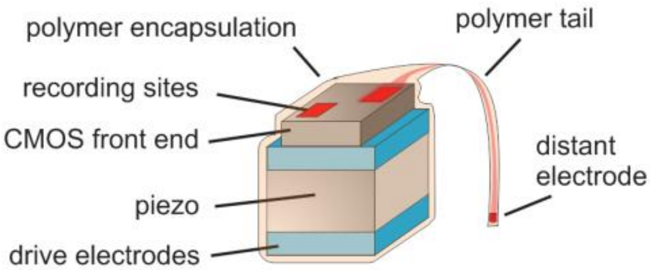
Traditional computer architecture design has focused on decreasing a given task's execution time. To accom-plish this goal, engineers have improved semiconduc-tor processing exponentially, increasing the transistors' speed while decreasing their size, thus allowing more complex architectures that use increased parallelism on a single die. In contrast, computing in an autonomous cubic-millimeter package must focus on minimizing a given task's energy consumption. Smaller, faster tran-sistors have reduced parasitic capacitance, thereby resulting in diminished dynamic power consumption. Constant electric-field scaling has reduced supply volt-ages, producing dramatic power reductions for both high-performance and low-energy computing because dynamic power has a quadratic dependence on supply voltage. However, constant electric-field scaling also calls for a reduction in the threshold voltage. This will result in larger leakage currents, which are already a concern in the high-performance processors to be released in 2001 that will leak amps of current. Therefore, process engineers need to keep leakage cur-rents low, which will also benefit low-energy designers. In millimeter-scale computing, the shrinking transis-tor's size lets designers compact significant computing power into this small area. For example, the Intel 8088 core, originally fabricated in a 3-micron process, would only require 0.12-square millimeter after shrinking lith-ographically into a current 0.18-micron process, with a corresponding 100□ decrease in energy/instruction.

V. LOW-ENERGY COMPUTATION

Besides advanced microfabrication technology processes, using other techniques at every level achieves low-energy computation. First, because we use a high-performance process but operate at low speeds, we can drop the supply voltage to the mini-mum level at which the devices still function; theoret-ically this is 0.1 volt,6 but for 0.5- to 0.2-micron processes it is more realistically 0.2 to 0.3 volt. To min-imize current leakage, which can cause significant power consumption at the low clock rates and duty cycles that these low-energy architectures use, we can increase the channel-to-source junction's reverse bias, thus increasing the threshold voltage. Initially, adding two extra supply voltages in this package may seem onerous; however, if the mote scavenges solar power, placing two small photodiodes on the integrated cir-cuit provides the few atto-amps per device necessary to bias these junctions. Various low-power layout, cir-cuit, and logic level techniques have been published.7 Figure 2 shows a consequence of using these tech-niques—the worst-case energy consumption of an 8-bit adder in a 0.25-micron process.

The Smart Dust mote's tasks closely relate to the physical realm, where the fastest sampling is 10 to 20 kHz for vibration and acoustic sensors so the amount of data is small enough that we can use low data trans-mission rates. Therefore, we can use clock rates in the 1- to 100-kHz range to decrease dynamic power con-sumption. Despite these low clock rates, the circuits perform all their transitions during a small portion of the cycle; then they remain idle. Thus, powering down blocks for even a few clock cycles saves energy.

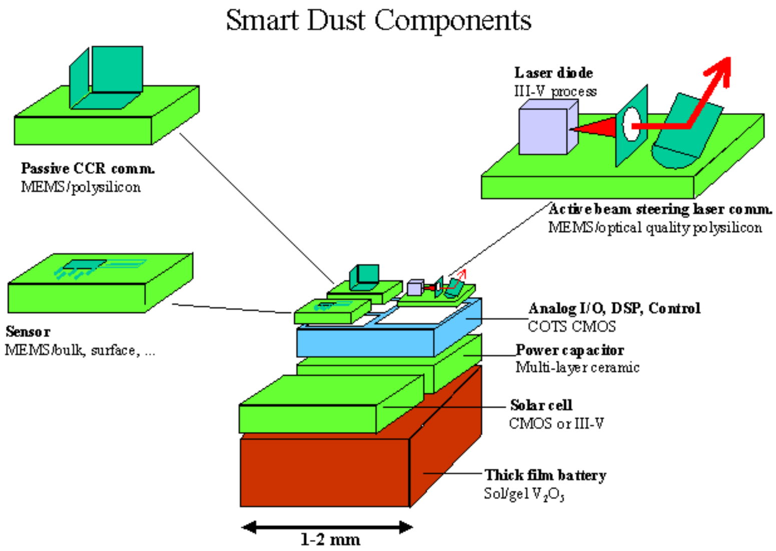
VI. REMOTE PROGRAMMABILITY



An autonomous cubic-millimeter platform's com-puting requirements depend on the target application because dedicated hardware solutions usually con-sume less energy than a software solution. To prevent extraneous power consumption, we need to determine the minimum amount of programmability necessary for a useful platform.

The basic mote periodically samples one or more sensors, stores the values in memory, listens to an incoming packet, and transmits current or stored data. Because transmitting the data and sampling the sen-sors consume more energy than performing a com-putation, we can add more computation—such as thresholding, filtering, spectral analysis,8 classifica-tion,9 Doppler shift determination, and encryption to improve memory use and determine the significance of readings—thus providing smarter sampling rates and reducing the data transmission volume.

Remote programmability plays an important role in millimeter-scale computing. Given their small size and large numbers, we prefer to program these devices en masse, without direct connections. Remote pro-grammability also avoids the costs of recollecting and reprogramming devices after we deploy them.

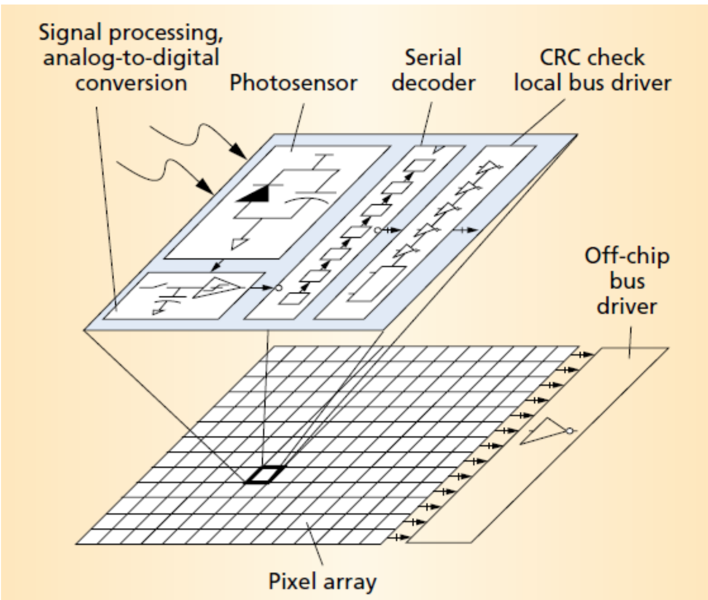


VII. COMMUNICATING FROM A GRAIN OF SAND

Smart Dust's full potential can only be attained when the sensor nodes communicate with one another or with a central base station. Wireless communica-tion facilitates simultaneous data collection from thousands of sensors. There are several options for communicating to and from a cubic-millimeter com-puter. Radio-frequency and optical communications each have their strengths and weaknesses.

Radio-frequency communication is well under-stood, but currently requires minimum power levels in the multiple milliwatt range due to analog mixers, filters, and oscillators. If whisker-thin antennas of centimeter length can be accepted as a part of a dust mote, then reasonably efficient antennas can be made for radio-frequency communication. While the smallest complete radios are still on the order of a few hun-dred cubic millimeters, there is active work in acade-mia and industry to produce cubic-millimeter radios.

Semiconductor lasers and diode receivers are intrinsically small, and the corresponding transmission and detection circuitry for on/off keyed optical communication is more amenable to low-power operation than most radio schema. Perhaps most important, optical power can be collimated in tight beams even from small apertures. Diffraction enforces a fundamental limit on the divergence of a beam, whether it comes from an antenna or a lens. Laser pointers are cheap examples of milliradian collimation from a millimeter aperture. To get similar collimation for a 1-GHz radio-frequency signal would require an antenna 100 meters across, due to the difference in wavelength of the two transmissions. As a result, optical transmitters of mil-limeter size can get antenna gains of one million or more, while similarly sized radio-frequency antennas are doomed by physics to be mostly isotropic.



Collimated optical communication has two major drawbacks. Line of sight is required for all but the shortest distances, and narrow beams imply the need for accurate pointing. Of these, the pointing accuracy can be solved by MEMS technology and clever algo-rithms, but an optical transmitter under a leaf or in a shirt pocket is of little use to anyone. We have chosen to explore optical communication in some depth due to the potential for extreme low-power communication.

VIII. OPTICAL COMMUNICATIONS

We have explored two approaches to optical com-munications: passive reflective systems and active-steered laser systems. In a passive communication system, the dust mote does not require an onboard light source. Instead, a special configuration of mir-rors can either reflect or not reflect light to a remote source; this procedure resembles how a heliograph operator bounces sunlight off a mirror to flash a Morse code message to ships—an idea traced to the fifth century BC, when the Greeks used reflected sun-light as a beacon signal. Figure 3 shows the corner-cube retroreflector (CCR)10 used to adapt this idea to Smart Dust. Designers have used this device, but on a macroscale, for years in laser range-finding applica-tions. A similar device helped scientists determine the moon's distance from Earth.

IX. PASSIVE REFLECTIVE SYSTEMS

In its simplest passive configuration, the passive-reflective device consists of three mutually orthogonal mirrors. Light enters the CCR, bounces off each of the three mirrors, and is reflected back parallel to the direc-tion it entered. In the MEMS version, the device has one mirror mounted on a spring at an angle slightly askew from perpendicularity to the other mirrors.

In this position, because the light entering the CCR does not return along the same entry path, little light returns to the source—a digital 0. Applying voltage between this mirror and an electrode beneath it causes the mirror to shift to a position perpendicular to other mirrors, thus causing the light entering the CCR to return to its source—a digital 1. The mirror's low mass allows the CCR to switch between these two states up to a thou-sand times per second, using less than a nanojoule per $0 \rightarrow 1$ transition. A $1 \rightarrow 0$ transition, on the other hand, is practically free because dumping the charge stored on the electrode to the ground requires almost no energy.

Our latest Smart Dust device is a 63-mm3 autonomous bidirectional communication mote that receives an optical signal, generates a pseudorandom sequence based on this signal to emulate sensor data, and then optically transmits the result. The system contains a micromachined corner-cube reflector, a 0.078-mm3 complementary metal oxide semiconduc-tor (CMOS) chip that draws 50 microwatts, and a hearing aid battery. In addition to a battery-based operation, we have also powered the device using a2-mm2 solar cell. This mote demonstrates Smart Dust's essential concepts, such as optical data trans-mission, data processing, energy management, minia-turization, and system integration.

A passive communication system suffers several lim-itations. Unable to communicate with one another, motes rely on a central station equipped with a light source to send and receive data from other motes. If a given mote does not have a clear line of sight to the central station, that mote will be isolated from the net-work. Also, because the CCR reflects only a small frac-tion of the light emitted from the base station, this system's range cannot easily extend beyond 1 kilome-ter. To circumvent these limitations, dust motes must be active and have their own onboard light source.

X. ACTIVE-STEERED LASER SYSTEMS

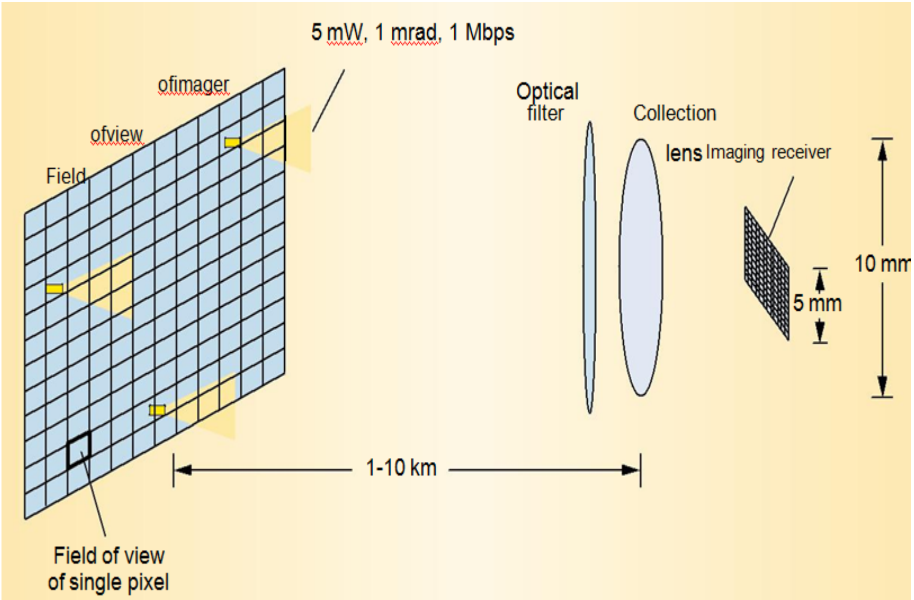
For mote-to-mote communication, an active-steered laser communication system uses an onboard light source to send a tightly collimated light beam toward an intended receiver. Steered laser communication has the advantage of high power density; for example, a 1-milliwatt laser radiating into 1 milliradian (3.4 arc-seconds) has a density of approximately 318 kilowatts per steradian (there are 4 π steradians in a sphere), as opposed to a 100-watt lightbulb that radiates 8 watts per steradian isotropically. A Smart Dust mote's emit-ted beam would have a divergence of approximately 1 milliradian, permitting communication over enor-mous distances using milliwatts of power.

Forming ad hoc multihop networks is the most excit-ing application of mote-to-mote communication. Multihop networks present significant challenges to current network algorithms—routing software must not only optimize each packet's latency but also con-sider both the transmitter's and receiver's energy reserves. Each mote must carefully weigh the needs to sense, compute, communicate, and evaluate its energy reserve status before allocating precious nanojoules of energy to turn on its transmitter or receiver. Because these motes spend most of their time sleeping, with their receivers turned off, scheduling a common awake time across the network is difficult. If motes don't wake up in a synchronized manner, a highly dynamic network topology and large packet latency result. Using burst-mode communication, in which the laser operates at up to several tens of megabits per second for a few mil-liseconds, provides the most energy-efficient way to schedule this network. This procedure minimizes the mote's duty cycle and better utilizes its energy reserves.

The steered agile laser transmitter consists of a semi-conductor diode laser coupled with a collimating lens and MEMS beam-steering optics based on a two-degree-of-freedom silicon micromirror, as Figures 4 and 5 show. This system integrates all optical com-ponents into an active 8-mm3 volume.

XI. LISTENING TO A DUST FIELD

Many Smart Dust applications rely on direct opti-cal communication from an entire field of dust motes to one or more base stations. These base stations must therefore be able to receive a large volume of simul-taneous optical transmissions. Further, communica-tion must be possible outdoors in bright sunlight which has an intensity of approximately 1 kilowatt per square meter, although the dust motes each trans-mit information with a few milliwatts of power. Using a narrow-band optical filter to eliminate all sunlight except the portion near the light frequency used for communication can partially solve this second prob-lem, but the ambient optical power often remains much stronger than the received signal power.



XII. ADVANTAGES OF IMAGING RECEIVERS

As with the transmitter, the short wavelength of opti-cal transmissions compared with radio frequencies overcomes both challenges. Light from a large field of view can be focused into an image, as in our eyes or in a camera. Imaging receivers utilize this to analyze dif-ferent portions of the image separately to process simul-taneous transmissions from different angles. This method of distinguishing transmissions based on their originating location is referred to as space division mul-tiple access (SDMA). In contrast, most radio-frequency antennas receive all incident radio power in a single signal, which requires using additional tactics, such as frequency tuning or code division multiple access (CDMA), to separate simultaneous transmissions.

Imaging receivers also offer the advantage of dra-matically decreasing the ratio of ambient optical power to received signal power.11 Ideally, the imaging receiver will focus all of the received power from a single transmission onto a single photodetector. If the receiver has an n □ n array of pixels, then the ambient light that each pixel receives is reduced by a factor n2 compared with a nonimaging receiver. Typically, using a value for n between 8 and 32 makes the ambient light power negligible compared with the electronic noise in the analog electronics.

XIII. VIDEO CAMERA

A video camera is a straightforward implementation of an imaging receiver. If each mem-ber in a colony of Smart Dust motes flashes its own signal at a rate of a few bits per second, then each transmitter will appear in the video stream at a dif-ferent location in the image. We have implemented such a system using a laptop with a frame grabber that processes a real-time video signal in software.

We tested this system to transmit weather infor-mation from Twin Peaks in San Francisco to a video camera in Berkeley, 21.4 kilometers across San Francisco Bay. The transmitter consists of a one-cubic-inch Smart Dust mote mock-up that modulates an ordinary red laser pointer at a few bits per second, using only 3.5 milliwatts of peak optical transmis-sion power in a 2-milliradian cone.12 Smart Dust's improved system will allow similar link distances, with the added advantage of automated transmitter-receiver alignment.

Using a high-speed camera and a dedicated digital signal processor to process the video signal achieves higher data rates. With modern cameras and DSPs, pro-cessing video at about 1,000 frames per second should be feasible. This would allow communication at a few

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