Wireless Networked Vehicles for High Resolution Temporal and Spatial Sampling of the Near-Surface Ocean

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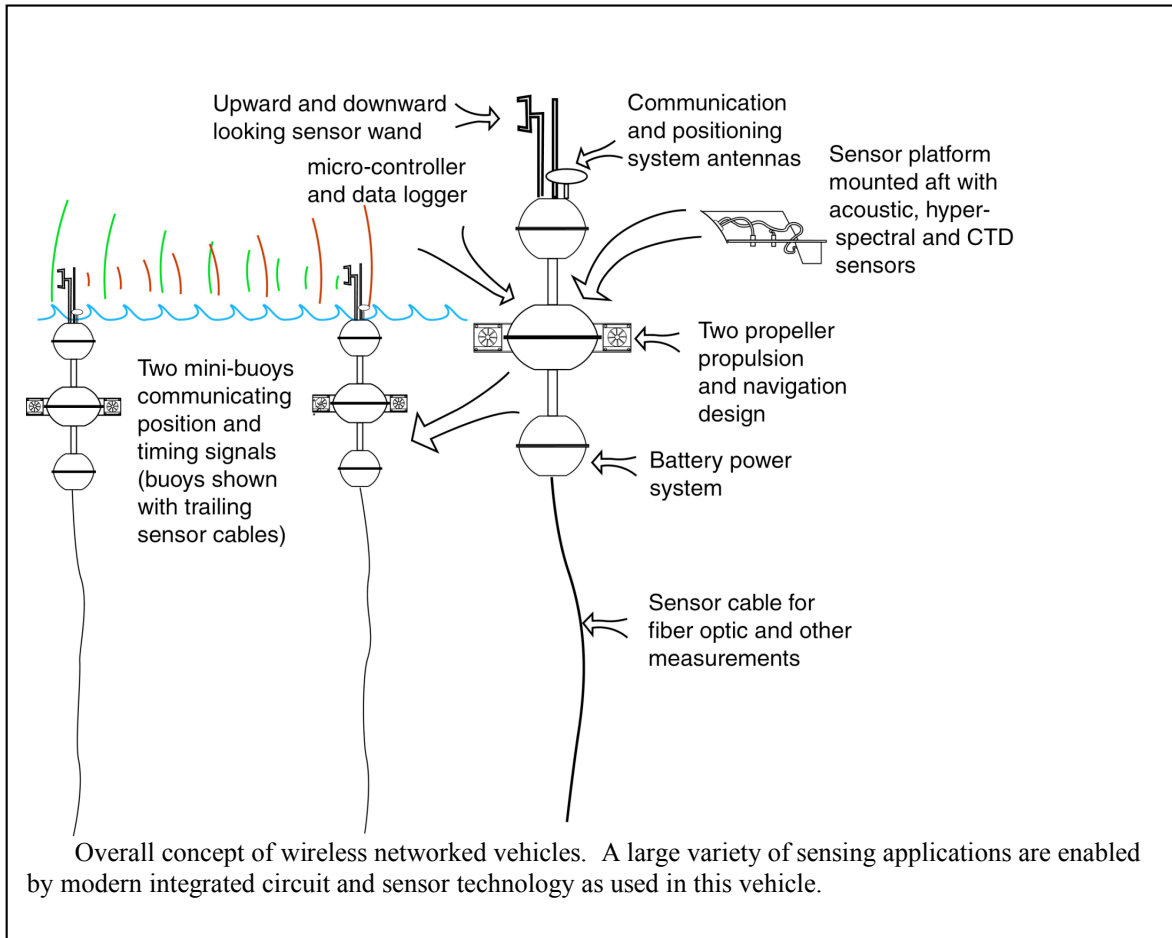**Electrical Engineering Dept., UC Santa Cruz**

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   Introduction: Our overall approach, illustrated above, is centered on a coordinated group of wireless-networked, self-propelled vehicles, about 10 inches in maximum diameter and about 2 ½ ft tall or smaller. This constellation or swarm differs from traditional drifting buoys in that it functions as a group, capable of communication with nearby vehicles and of station keeping or drifting in formation. The objective of deploying a constellation of propelled vehicles is to acquire measurements that optimally characterize a region, in terms of resolution and volume or area of coverage. For short deployments, the system we propose will have many of the advantages of an array of moorings at a fraction of the cost of deployment. The initial deployment proposed here will be for a small number of vehicless, two or three, but will serve as a proof of concept for larger deployments of many vehicles, capable of characterizing much larger regions. A completed vehicle prototype is shown at right.

Prototype of the mobile sensor platform in preparation for pool-based deployment demonstration.

   The great advantage of networking

Upward and downward looking sensor wand

micro-controller and data logger

Communication and positioning system antennas

Sensor platform mounted aft with acoustic, hyper-spectral and CTD sensors

Two mini-buoys communicating position and timing signals (buoys shown with trailing sensor cables)

Two propeller propulsion and navigation design

Battery power system

Sensor cable for fiber optic and other measurements

Overall concept of wireless networked vehicles. A large variety of sensing applications are enabled by modern integrated circuit and sensor technology as used in this vehicle.
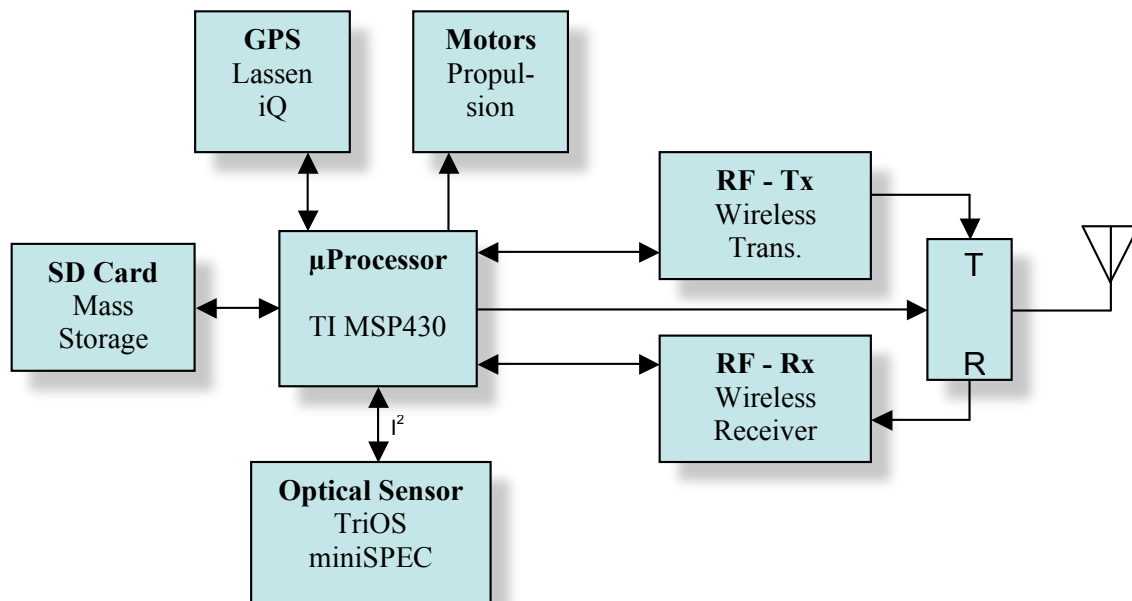
these vehicles lies in the ease of communication between the many closely spaced nodes, the ability to share resources and to overcome sensor and vehicle failures. We take advantage of our experience using the wireless networked sensors or 'smart dust' pioneered by Prof. Kris Pister and colleagues at Berkeley.

The development involved an intensive effort by an excellent team including the Co-PI's, graduate student Cyrus Bazeghi, analog and communications expert, Stephen Petersen and part-time graduate student Rich Harris. We have developed a propulsion scheme using 2 propellers driven by electric motors and a short-range communications concept (900 MHz). We conducted an in-water demonstration in Sept. 2005. Details are discussed below.
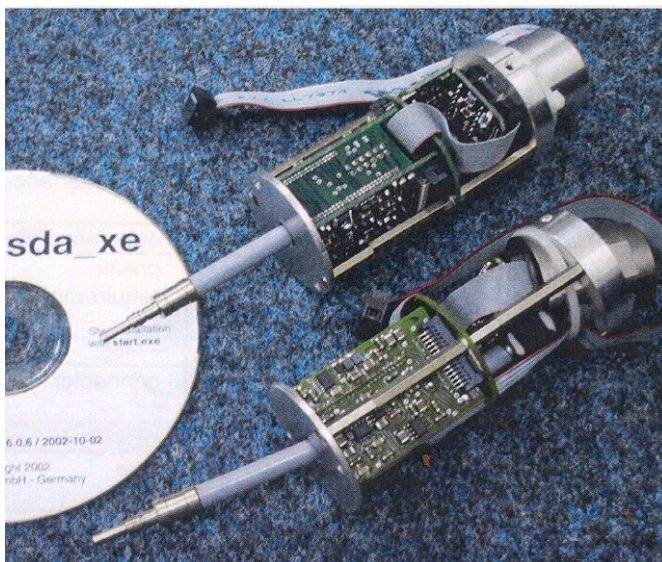
Vehicle System Overview

Our overall approach is centered on a coordinated group of wireless-networked, self-propelled vehicles, about 10 inches in maximum diameter and about 2 ½ ft tall or smaller. The engineering design of overall system is illustrated in the schematic block diagram below.

GPS
Lassen
iQ

Motors
Propul-
sion

µProcessor

TI MSP430

SD Card
Mass
Storage

RF - Tx
Wireless
Trans.

RF - Rx
Wireless
Receiver

T

R

I^2

Optical Sensor
TriOS
miniSPEC

Schematic block of vehicle subsystems, including propulsion, control, sensors, communications. Not all sensors are shown.

Sensors

One of our key requirements is to support airborne sensor development with surface truth measurements. To do this we have identified a very nice sensor for measuring spectral radiance, shown below. It is the TriOS miniSPEC, 256-channel sensor for the 320-950 nm band. One of the PI's talked extensively with TriOS representatives at a conference exhibit and got a quote from the sales representative present. This sensor is very small and light as shown in the figure at left. The sensor is available in several wavelength ranges and we have chosen the 320-950 nm band. The input is through and optical fiber that can be attached to an optical switch or connected directly to a lens for gathering input light. For this initial prototype we plan to have the sensor input through a flat optical surface looking vertically downward into the water from the submerged portion of the vehicle.

Integration time can be varied from 4 ms to 8 s so averaging can be conducted in a variety of ways. The data rate from the sensor depends on the averaging time and runs from 1.2 to 38.4 kbits/s. The interface is a serial RS-232 connection that makes for easy integration into the data system shown in Fig. 2.

Sea surface temperature and conductivity can be measured by a number of readily available sensors; such as the miniature conductivity and temperature probe at right from Precision Measurement Engineering. Salinity will be derived from the conductivity measurements. We will monitor the internal temperature of the vehicle at several points with an Analog Devices diode sensor that is accurate to about 0.1 °C.

The GPS sensor we have chosen is the Trimble Lassen iQ. This sensor has an external antenna that we plan to mount in a waterproof enclosure as far above water level as practical. We will also investigate GPS antennas specifically designed for near the water operation. The Lassen iQ yields location, speed and heading every second along with a time stamp. We anticipate an accuracy of ≈ 2 m.

Digital Electronic Systems
Vehicle microcontroller: Since one of the goals of this project is to determine the best types of data to acquire and also to serve as a test bed for communications and propulsion, we require a very flexible and feature rich microcontroller. We have chosen to use in this version of the vehicle a Texas Instrument MSP430 family of microcontrollers; specifically the MSP430F1611. Since deployment time and power consumption are critical to this project the MSP430 is an ideal choice. It is an ultra-low power processor (250 µA/MIPS activity) and has 5 power-savings modes (down to 0.2µA with RAM retention), and supports supply voltages from 1.8 V to 3.6 V. Clock frequency ranges are also flexible from 100 KHz up to 8 MHz, providing ample processing capabilities for our current needs. The MSP430 family is very large and contains many configuration options including program flash, SRAM, I/O lines, DMA controllers, hardware timers, USARTs, I^2C ports, ADC, and DAC. The MSP430F1611 contain 48 KB of program space, 10 KB of SRAM, 2 USARTs, I2C support, a 12-bit ADC, a 12-bit DAC, and temperature sensor. This microcontroller has been used in a variety of student projects at UCSC and we are very familiar with its abilities and limitations. Some of the projects it was used in successfully at UCSC were an atmospheric monitoring weather balloon, a tracking device for coyotes, a tracking device for elephant seals, and a coral reef environment monitor.

For our positioning we have chosen to use a Trimble Lassen iQ GPS receiver. We have used this receiver before and chose it because of its low power consumption, small size, configurability, and speed. The receiver uses approximately 26 mA when active and supports 12 simultaneous channels. It has dual sensitivity modes with automatic switching which speeds acquisition and aids in accuracy. The dimensions are very small,

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26 mm W x 26 mm L x 6 mm H, which is also important for our system. The receiver supports a variety of protocols, NMEA 0183, TSIP, TAIP, and DGPS, which will allow us to easily configure the device to give us only the data we desire at the rate we need. The operating voltage range of the Lassen iQ is flexible, ranging from 3V to 3.6V, which will make it interface directly to the MSP430.

Data Collection and Storage: Two primary goals of this project are deployment time and sensor data. The MSP430 will interface with the sensors and the control the communication channels. Data will be buffered by the MSP430 internally or externally in a mass storage device until transmitted wirelessly to another vehicle or base station. To facilitate the vast amounts of data we will be acquiring for post processing we selected an easy to use mass storage system. We have chosen SD Card memory devices as they are easy to interface with the MSP430 microcontroller, very dense in size, low cost, fast, and energy efficient. Currently SD Cards are available in sizes up to 1GB for around $70 with future versions up to many GBs.   A SanDisc SD card used in a recent experiment in the School of Engineering remained functional after three days submerged in ocean water – so they are pretty robust devices. The access speed of SD Cards is also amble for our requirements, reading and writing at 10MB/s. Power usage for the SD Card is also low: <250 μA when asleep. <65 mA when reading and <75 mA when writing. Operating voltages are flexible, ranging from 2.7V to 3.6V, allowing direct interfacing to the MSP430 via an SPI interface.

To save even more on power consumption we plan on turning the SD Card interface off completely, reducing the current draw to zero, when we are not actively storing to the device. The SRAM size of the MSP430 will allow us to buffer sensor data internally until we "dump" it to the SD Card. Along with the small size, 24 mm W x 32 mm L x 2.1 mm H, low power, high density, and ease of interface, the SD Card is ideally suited for our requirements.

Communications and Analog Electronics Systems
     The primary objective of the RF wireless design is to realize inter-platform communications capable of eventually supporting an ad-hoc network of many vehicles. This will provide an effective means to spatial deployment and research coordination among a group of such platforms.

     Choice of what RF frequency to employ depends on available and physically realizable wireless hardware along with domestic and international regulatory considerations. Accordingly, we have considered the following in choosing what frequencies to use for this first prototype:

     The two bands considered were 902-928 MHz and 2.435-2465 MHz[1]. Narrowband radiators are allowed in these ranges if the far-field electric field intensity is limited to $500 \, mV/m$ at 3 meters. Spread spectrum (SS) techniques allow for 1 Watt ERP for antennas under 6dBi, with a linear decrease in power for antenna gains exceeding this

value[2]. It follows that SS is preferred because comparatively the far-field power density is higher.

Antennas considered for this first prototype were restricted to simple omnidirectional vertically polarized "whip" antennas. These are simple to construct, rugged and have radiation/reception characteristics independent of azimuth. Most likely, 5/8 wave vertical antennas will be used since they yield additional horizontal gain over ¼ wave verticals. If spread spectrum is used this antenna will be modified to increase its effective bandwidth to maintain radiation efficiency over the entire spread of frequencies used. This will be done using NECWIN Pro, a popular and suitable EM modeling program for this purpose.

References

Ganguli, A., S. Susca, S. Martinez, F. Bullo & J. Cortes, On collective motion in sensor networks: sample problems and distributed algorithms, American Control Conference, June 8-10, 2005, Portland, Oregon

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