Automated Scour Detection Arrays using Bio-Inspired Magnetostrictive Flow Sensors

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Executive Summary

This report details the embedded hardware developed for autonomous remote sensing of bridge scour using magnetostrictive scour sensing posts. Data aggradation from multiple posts on site as well as transmission of data to the remote bridge owner are the two major tasks that this hardware must be capable of completing. On-board data computation reduces power consumption in the field as the results from engineering algorithms are transmitted in lieu of raw data. Hardware needed for sensor posts as well as for cellular-enabled base stations is detailed.

Outputs:

- Autonomous, wireless scour sensing posts.
- Solar powers, cellular-enabled base station units.

Contents

Introduction

In this study, a low-power wireless sensor network constructed from the *Narada* wireless sensing unit is used to create a wireless monitoring system with enhanced longevity in the field. The power source for the system is provided via solar energy. The system under study deploys and tests an embedded array of sensors located near bridge foundations, at varying heights and determines the sediment depth and profile around the waterway in real time. The hardware of the system consists of bio-inspired magnetostrictive flow sensors that detect water flow by bending. A wireless sensing unit, Narada WSU that converts analog voltage output signals from sensor into digital signal, collects and analyzes data, communicates with the remote base station and relays the analyzed data. A base station system which includes a Narada Base Station, single board computer, cellular data link and power source, that aggregates the data collected from multiple units, creates a decision file and sends scour alerts to relevant authorities using a cellular link.

Sensors

The magnetostrictive flow sensors utilized in this study are developed at University of Maryland. Different ruggedness tests and various methods of sensor protection have been carried out at University of Maryland. During the course of this study three different sensors have been used: 1) whisker-inspired sensors; 2) airfoil sensors; and 3) seaweed sensors.

Whisker inspired magnetostrictive Galfenol sensors

The whisker shaped sensors are inspired by the whiskers of marine animals. Whiskers provide the marine animals with important sensory information about the world around them. The configuration of the whisker sensor is very simple and easy to assemble. It consists of five main components: 1) Galfenol whisker 2) GMR sensor 3) clamping fixture 4) Small permanent magnet and 5) Low power operational amplifier. Figure 2 shows a typical flow sensing components.

Figure 1. Marine animals with whiskers (Source www.flickr.com)

The whisker-inspired flow sensors are constructed using a magnetostrictive Galfenol wire. Magnetostrictive materials have the ability to transducer or convert magnetic energy to mechanical energy and vice versa. Galfenol is an alloy of iron and gallium which has corrosion properties that are similar to those of steel, and four times less that iron.

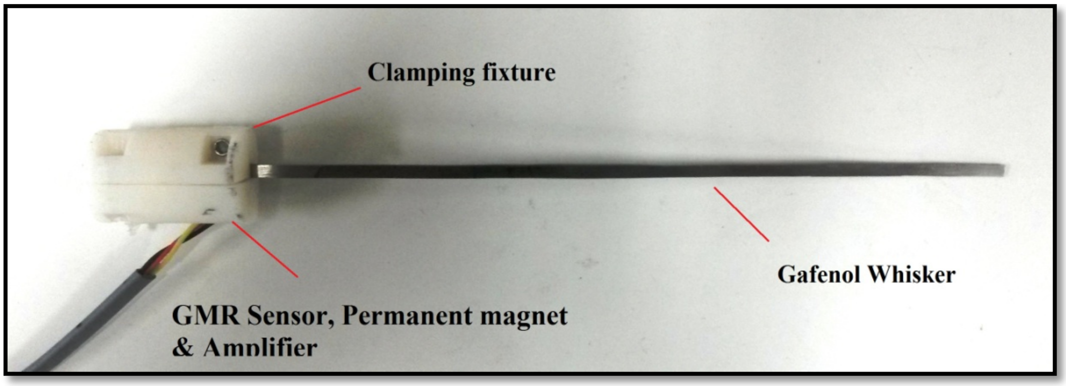

Figure 2. Bio-inspired magnetostrictive whisker sensor

One end of a Galfenol whisker is fixed and the other end is free to deflect under fluid flow-induced drag forces (Figure 3). The bending causes stress near the fixed end of the whisker which produces local change in the orientation of magnetic domain, which is followed by a global change in the magnetic flux density in the whisker. A giant magnetoresistance (GMR) sensor at the fixed end of whisker senses this change of magnetic field and converts it into electrical signal which is amplified, and transmitted. The GMR sensor is soldered to a printed circuit board and includes a Burr Brown INA118 instrumentation amplifier. A permanent magnet is in contact with the whisker to align magnetic domains along the whisker when it is not deformed. Different strength magnets can be used as long as a proper magnetic field strength is achieved at the root of the whisker to ensure internal magnetic dipole rotation in response to movement of the whisker without saturating the GMR sensor.

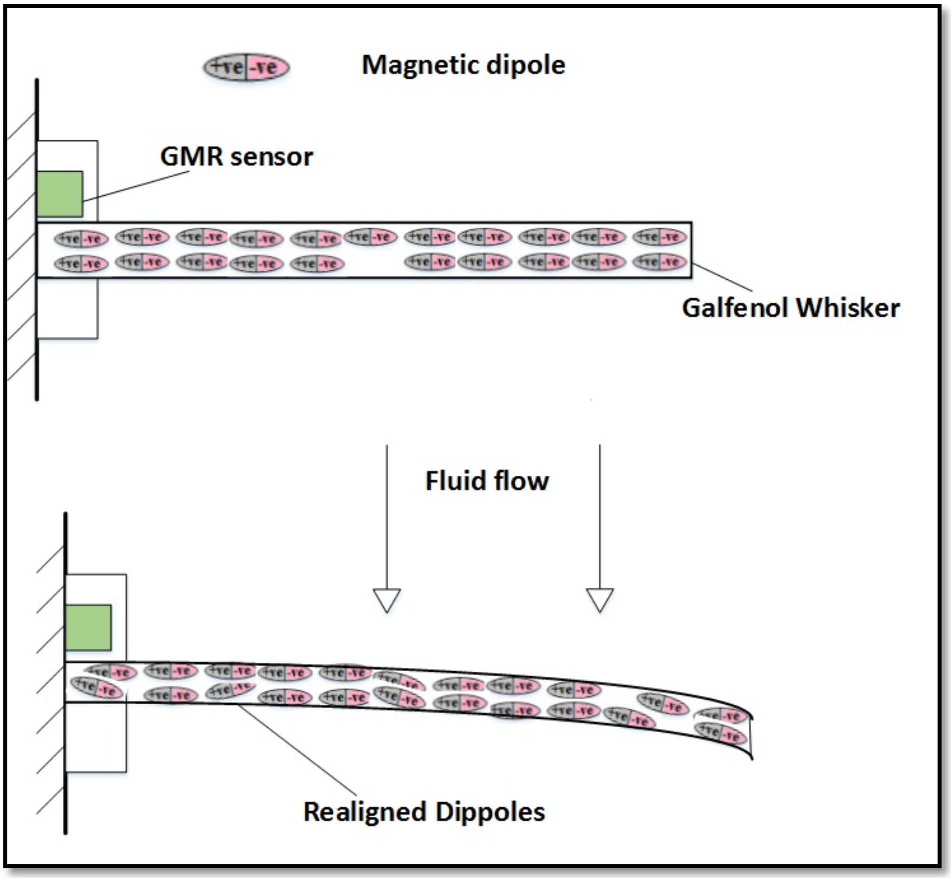

Figure 3. Working principle of magnetostrictive sensor

Airfoil magnetostrictive Galfenol Sensors

The Airfoil sensors are an improved version of whisker inspired magnetostrictive Galfenol sensors. Airfoil sensors work on the exact same concept as the bio-inspired whisker flow sensors. However, the airfoil sensors are much more robust compared to the whisker inspired sensors. A wax layer in a shape of airfoil was added in the sensors to improve its sensitivity (Figure 4).

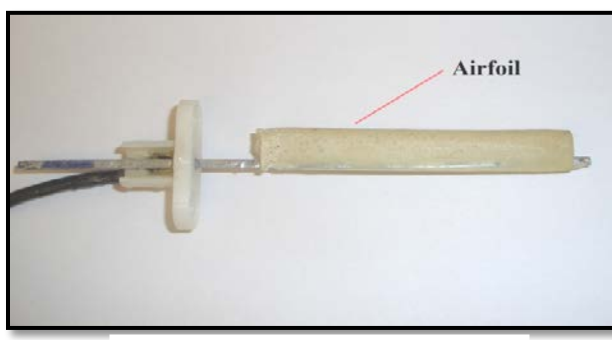

Figure 4. Airfoil-type sensor

Magnetic Seaweed Sensor

Seaweed type sensors are the latest sensor that has been developed after the aifoil type sensors. The seaweed sensors have undergone quite a few changes compared to its predecessor. The airfoil and gafenol whisker have been replaced by a strip of thin fabric material. The strip has a small magnet attached to it. The strip deflects under fluid flow, causing change in the magnetic field. The GMR sensor at the fixed end of the strip, inside the clamping fixture detects this change of magnetic field and converts it into electrical signal. A seaweed-type sensor is depicted in Figure 5.

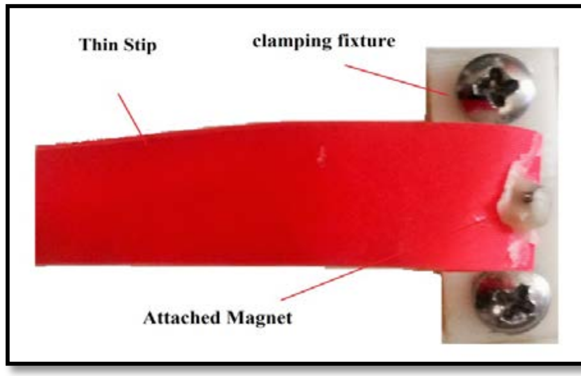

Figure 5. Seaweed-type sensor

Wireless sensing unit for scour sensing posts

For a wireless network design to excel, specific hardware requirements must be satisfied to tackle the inbuilt challenges of wireless network operations. In order for a wireless sensing unit to perform to its full capacity it must have low power consumption, low latency, and the ability to quickly process data and execute control algorithms. For wireless sensor nodes to communicate with one another a digital wireless radio is required and as the output from most sensors is analog, the signal at some point must be converted into digital signal domain in order to be transmitted. Furthermore, the tasks performed by the sensing node such as sampling computations, communications require time-specific coordination. To full fill these requirements wireless sensing unit must contain the following modules: 1) sensing interface; 2) communication interface; 3) computational core; and 4) actuation interface. The wireless sensing interface used in this research is Narada wireless

Figure 6. Narada WSU

sensing unit (Figure 6) and are produced by Civionics Inc.

The Narada is a low-power wireless sensor node designed explicitly for the monitoring of civil infrastructure systems and has been successfully used in many types of structures in the past including buildings, bridges, wind turbine towers, and naval vessels. It has been designed for applications requiring high resolution data collection, and/or real-time control.

The Narada features ADS8341 16-bit digitalization of analog sensor data with four analog input channels that can read analog signals ranging from 0 to 5Volts. The core of the wireless sensor is an 8-bit ATmega128 microcontroller that is responsible for the overall node operation including the storage of sensor data. The ATmega128 is an 8 bit, low power microcontroller that has 128 kB of flash memory to store data and embedded algorithms, and 4 kB of electrically erasable programmable read only memory (EEPROM). The computational core of the Narada consists of the AT mega128 augmented with 128 kB of external static random access memory (SRAM) for temporary data storage. The maximum number of sampling points that can be saved in the core is limited by the node's 128kB static random access memory (SRAM) bank. The Narada features an IEEE 802.15.4 compliant wireless modem, the Chipcon CC2420 that adopts the 2.4 GHz IEEE 802.15.4 radio standard (Zigbee). The transceiver is designed with a power amplifier (Figure 7) to boost the communication power of the node of long-range communication (i.e., 700 m line-of-sight). The Narada utilizes low-power wireless signal network the Zigbee to communicate with local base stations. However, every sensor board has to be able to reach the base station in order to transfer data, limiting the distance between the base station and the sensor that is farthest away.

In the Narada WSU any type of sensor can be attached and external sensors on the Narada system allows easy removal in case of the sensors are damaged or faulty by any reason. However, the drawback of Narada is that it has inflexible power management schemes and relatively slow floating-point calculations emulated its fixed point microcontroller.

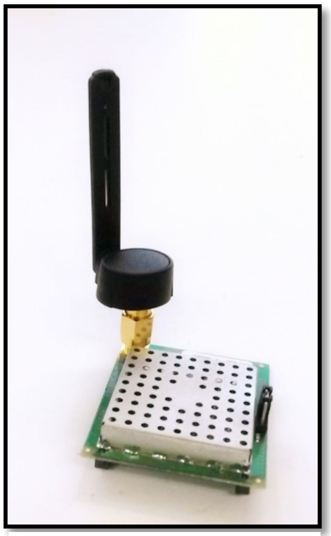

Figure 7. Antenna and radio daughter board

The Narada wireless sensing unit contains an inbuilt actuation interface. The actuation interface allows the network to engage in active sensing and to be applied to a wireless feedback control application. The actuation interface consists of a Texas Instruments DAC7612 2 channel 12-bit DAC capable of outputting analog signals from 0 to 4.1 V with a resolution of 1mV.

Table 1. Technical Specification of Narada WSU

Dimensions	69 mm x 72mm x 12mm	CPU	
Base station to PC interface	RS-232,USB	Processor	Atmel ATmega 128
Voltage Actuation		FLASH	128 kB
Output Channels	2	EEPROM	4 KB
DIGITAL TO Analog Conversion	12-bit resolution	SRAM	4 KB
Maximum output Current	15 mA	External SRAM	128 kB
RADIO		Power Consumption	
Transceiver	TI CC2420	Current draw in sleep mode	10 mA
Frequency Band	2.4000 - 2.4835 GHz	Current draw in active mode	30 mA
Data Rate	250 kb/s	Current draw in Rx/Tx mode	52 mA
Range (line of sight)	500-600m	Input Voltage	6.0-9.0 V
Data Acquisition			
Input Channels	4 single ended/2 differential	DC Sensor Excitation	+5 V DC
Analog to Digital Conversion	16 bit resolution	Real time data throughput	1500 sample/sec
Data Storage Capacity	128 kB	Maximum Sampling Rate	10000 samples/sec

Assembled smart scour sensing posts

The smart scour-sensing posts developed are made of 13 feet long PVC pipe (steel is also an option). The bottom 1 foot of the posts was filled with concrete so that the posts could be easily driven into the ground near abutments or placed using an auger. Four transducer elements with 3 feet spacing to each other were mounted on the posts. Polycase waterproof enclosures made of polycarbonate and (YH-080604 YH Series Hinged Waterproof NEMA Electrical Enclosures) of dimensions 8.59 x 6.59 x 5.11 in. containing an embedded data collection and interrogation electronics, power manager and a long-lived battery pack packaged were mounted on top of the post using mounting flange assembly. The tops of these posts are designed to be located in air to facilitate wireless operation. Low-power components and use of sleep mode was employed to extend the battery life. Figure 8 depicts the electronics in the protective enclosure and Figure 9 shows a packaged smart scour-sensing post prepared for field installation.

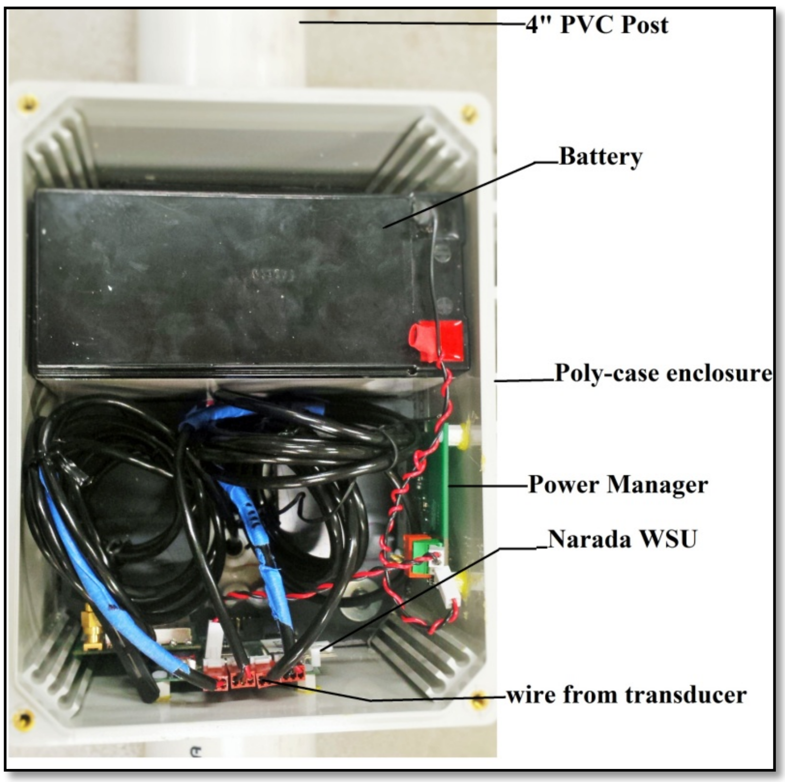

Figure 1 Post electronics packaged in Polycase enclosure

Figure 9. Packaged smart scour-sensing post

Base Station

The base station aggregates the data from multiple on-site posts and it creates a decision file in accordance to the data received from the wireless sensing units. The base station then relays the file to relevant authorities using a cellular data link to aid them to take suitable required action.

The base station is composed of Narada Base Station, Single Board computer (SBC), cellular data link and a power supply for the setup.

Single Board Computer

The Single board computer used for this research is an industrial platform that can safely operate in harsh field. The PPM-LX800-G manufactured by WinSystems (Figure 10). The PPM-LX800-G is a highly integrated, PC/104-Plus single board computer (SBC) designed for embedded, space limited, low power applications. The

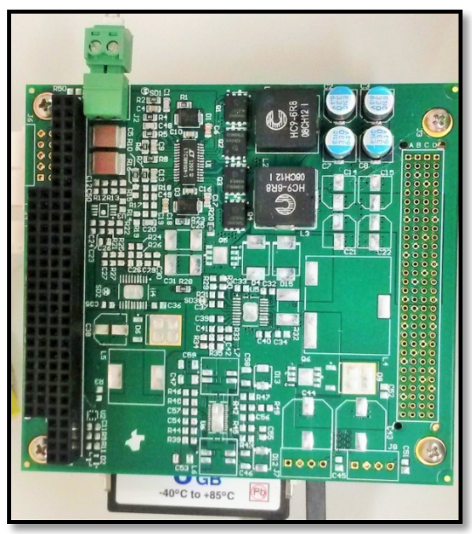

Figure 10. Single board computer for base station (PPM-LX800-G)

PPM-LX800-G is well suited for rugged applications requiring excellent processor performance in an embedded PC design. Its low power dissipation permits fan less operation from -40° to +85°C [WinSystems].

The server consists of a low-power single board computer (SBC) that operates Linux (Ubuntu 11.10).

Table 2. Technical Specifications of SBC (WinSystems)

Processor	LX800 @ 0.9W with 500MHz system clock
Memory	256KB of L2 cache Up to 1GB with a 200-pin SDRAM in a SODIMM connector
Network Interface	One 10/100 Mbps using the Intel 82551ER LAN
Storage	One Compact Flash socket supports Type I or II devices
Power	+5V required, 1.2A typical

Cellular Data Link

A 3G cellular modem is included in the server for the communication of data to and from the server. The cellular data link used is Pantech 4G LTE USB Modem UML290 is utilized as the cellular data link (Figure 11). The UML290 is designed with manufacturer designed power management and system overhead reduction functions to take advantage of the USB interface to reduce power consumption. It contains an internal antenna which is designed to optimize data transfer rate and sensitivity to network signals”. The UML290 has typical download speeds of up to 5 to 12 Mbps in mobile broadband coverage

Figure 11. UML 290

area. The UML290 comes equipped with a fold–away, 180 degree rotating USB connector. The UML290 is also well-suited for use with Linux with minimal driver installation effort required by the user.

Table 3. Technical Specifications UML 290

Broadband	4G LTE Mobile Broadband and Mobile Broadband (Rev. A) capable
Memory	Qualcomm MDM9600
Network bands	CDMA 1xEV–DO Rev. A/Rev. 0: 800/1900 MHz, LTE CDMA (700MHz)
Antenna	External Antenna Connector

Narada Base Station

The Narada base station (Figure 12) is a IEEE802.15.4 data transmission device that connects to a PC via USB and serves as the base station's low-power link to the on-site posts. The Narada Base Station is produced by Civionics Inc. The Narada Base station is a wireless data acquisition hub built around the Atmel ATmega128 microcontroller. The ATmega128 is an 8 bit, low power microcontroller. The Narada Base station connects to the PC through an available USB port and can facilitate data collection, real-time control, and network maintenance tasks (Civionics).

Figure 12. Narada Base Station

Table 4. Narada Base Station Technical Specifications: (Civionics)

Dimensions	3.0” x 2.0” x 1.5”
Base station to PC interface	RS-232,USB
CPU	
Processor	Atmel ATmega128
	FLASH 128 kB
	EEPROM 4 kB
	SRAM 4 kB
	External SRAM 128 kB
	External Clock Speed 8 MHz
RADIO	Transceiver TI CC2420
Frequency Band	2.4000 - 2.4835 GHz
Data Rate	250 kb/s
Range (line of sight)	600m

Assembled Base Station

Polycase waterproof enclosures (YH-161407 YH Series Hinged Waterproof NEMA Electrical Enclosures) of dimensions 16.59 x 14.59 x 8.24 in. was used for the base station which included a Narada base station, Single board computer, a wireless communication interface, Power manager and a battery pack. The base-station units were fitted with solar panels for battery recharging. Figure 13 shows the base station assembly and Figure 14 shows the solar panel that was used to recharge the base station battery.

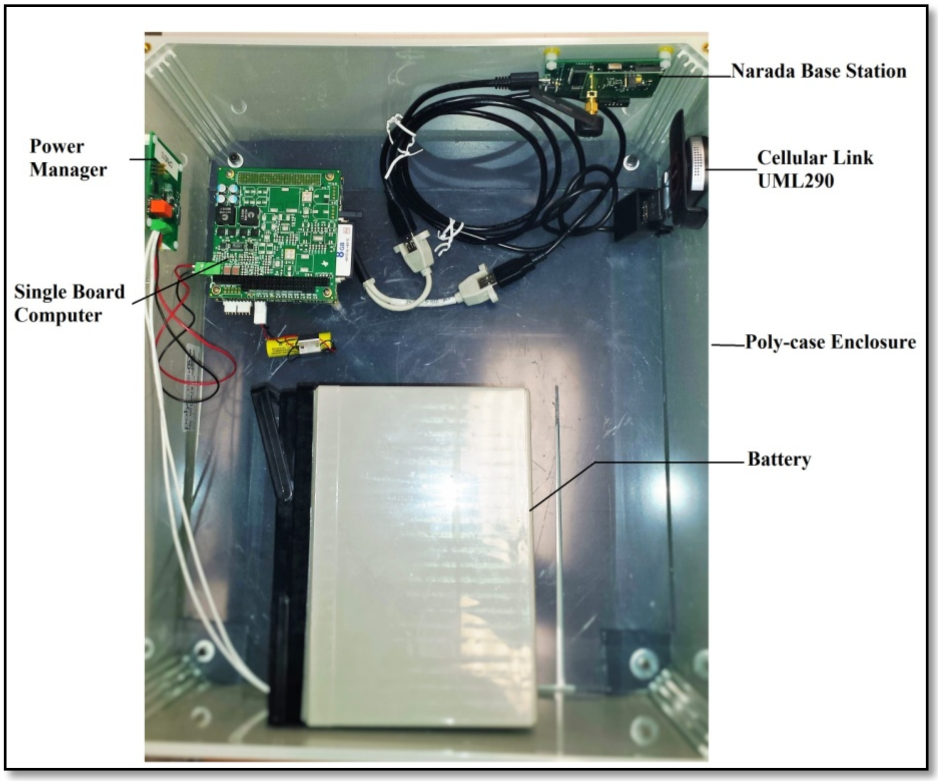

Figure 13. Base station electronics in protective enclosure

Figure 14. Assembled based station with solar panel installed in the field

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