Design and Implementation of a 3D Printed Sensory Ball for Wireless Water Flow Monitoring

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***Abstract*- Sensor networks can detect and communicate information regarding the ambient environment using wireless and real-time methods. Consequently, sensor node design is of critical importance for monitoring water quality. This paper describes the design, fabrication and implementation process of a 3D-printed sensory ball that can remotely collect water flow parameters in real-time. A sensory ball that is 10-cm in diameter was used to measure water flow parameters. Data was then captured in real time and sent to a personal computer via wireless communications. Discussions regarding alternative applications of this device are provided in this manuscript.**

Keywords—Environmental Sensory Device; 3D Printed Ball; Water Flow Monitoring.

I. INTRODUCTION

Water flow parameters were previously monitored using ineffective and untimely manual methods. During recent years, there has been an increased interest in exploiting real-time and remote monitoring, so that unusual phenomena can be recognised from parameter changes in front of a computer [1].

Over the past decade, Sensor Network technologies have been proposed as an intelligent method for monitoring environmental problems. Tiny electronic devices and advanced communications technologies now enable people to remotely monitor dangerous and difficult to reach places.

For water investigations, Environmental Sensor Networks (ESN) provide a new way for scientists to monitor large-scale watersheds and gives more intuitive visual information. The USGS program is an example that investigates the physical and chemical information of the surface and underground waters all around the US and disseminates the data to the government and public to manage water resources [2].

The sensor node is the most basic unit in an ESN (Represented as 'balls' in Fig.1), which is also our focus in this paper. They are deployed in harsh environments like a high-mountain watershed, ocean and glaciers, where attended monitoring and frequent maintenance are hardly possible [3].

Since these sensor nodes suffer a high risk of being destroyed by tremendous forces and destructive nature conditions, they need to be robust and durable enough to keep

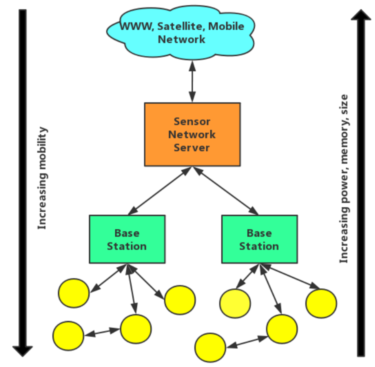

Fig. 1. Schematic diagram showing the constitution of an Environmental Sensor Network.

they long-term operation. Moreover, since they are to fully discern the environmental parameters (acceleration, angular velocity), its physical properties should fit the condition. On the other hand, designs should also allow calibration and fixation quickly [4].

Water acceleration and angular velocity are treated as critical evaluations of how torrential the stream flow is. More turbulent stream increases bank and channel scouring and erosion, which eventually affects the water temperature, concentrations of each substance in the water and even all the habitats of nearby creatures [5]. Magnetic field intensity is also an essential parameter in determining the contamination and pollutant chemicals in the water [1]. Also, it is measured to detect the impact of electromagnetic interference on the use of the flowmeter [6] whose principle is based on the Faraday law of electromagnetic induction [7]:

$$E = K \cdot B \cdot d \cdot V \quad (1)$$

Where V (m/s) is the average velocity of the fluid to be measured. B (Tesla) is the magnetic field intensity produced by the device.

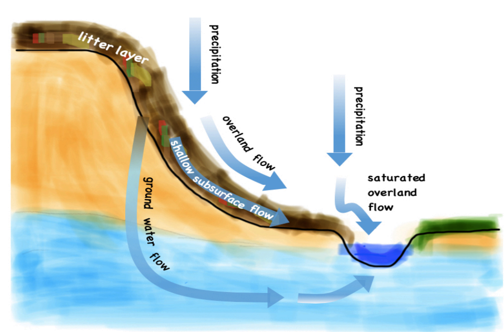

Fig. 2. Flow paths of water over a surface.

II. DATA TRANSMISSION

The 'water ball' should send back water acceleration, angular velocity and magnetic field intensity data of the watershed it is moving through wireless communication. Moreover, the visualization of data is needed to vividly demonstrate the parameters' changing with time, which entail the user interface design.

Inside the 'water ball', the LP1768 microcontroller is the core to make connections between JY901 posture module and HC-12 wireless transceiver chip. Both modules could use the serial port to communicate with the microcontroller. Once the HC-12 inside the ball get the JY901 data, the HC-12 connected to the laptop also get. It then sends the data to the laptop via a USB-TTL cable. The full communication path is shown in the diagram below.

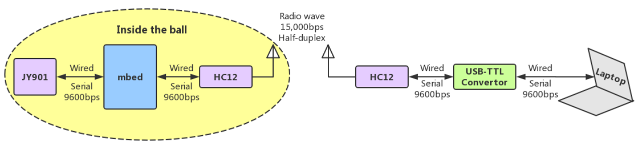

Fig. 3. Diagram showing the complete communication path.

JY901 posture module uses hexadecimal numbers to communicate with end users. By knowing the range of the value being represented and the number of bytes it takes, we can know how each real value is represented. For example, JY901 uses two bites to represent its angular velocity ranging from −2000°/s to +2000°/s. Since a two-byte hex number can represent a decimal number in between −32768 to +32768, then we can obtain the sensitivity of this parameter through this equation [8]:

$$\text{Sensitivity for angular velocity} = \frac{2000}{32768} = 0.06\ °/\text{s} \quad (2)$$

JY901 has its protocol to communicate with a computer. Table.1 shows how each number is transmitted [9].

Every part is a 4-bit hexadecimal number. Leading with different data headers, value of each dimension is divided into a high part and a low part in transmission. For example, the presence of '55 52' marks the angular velocity data is coming. The equations below show how to calculate the real values of x-axis angular velocities:

$$\text{Wx} = (\text{wxH} \ll 8)|\text{wxL}, \ \ \omega\text{x} = \frac{\text{Wx}}{32768} \times 2000\ °/s \quad (3)$$

Acceleration values and magnetic field intensities are also coded like that except beginning with other data headers. Once the software gets serial data, it first detects each data headers, then extracts and calculate current parameters. Finally, these new parameters are used to update the real-time plotting on the interface. The self-designed user interface allows users to select which parameter to display.

Table 1. Data transmission protocol of JY901

Data Name	Data header	Lower part of the x-axis data	Higher part of the x-axis data	Lower part of the y-axis data	Higher part of the y-axis data	Lower part of the z-axis data	Higher part of the z-axis data
Acceleration (A)	55 51	AxL	AxH	AyL	AyH	AzL	AzH
Angular velocity (w)	55 52	wxL	wxH	wyL	wyH	wzL	wzH
Magnetic field intensity (M)	55 54	MxL	MxH	MyL	MyH	MzL	MzH

III. DESIGN AND IMPLEMENTATION

In this project, a spherical outer case is preferred to sense fluid mobility. The crux of the matter lies here: the outer case needs to be assembled as rigid as possible to keep the water out but at the same time, be able to reopen easily to make maintenance possible [10-14]. Here we seek to create another way of locking that is low-cost, standard, repeatable and tight.

Inspired by the structure of bottle caps, we come up with a strategy of adding screw threads surround the joints. The professional 3D CAD system SolidWorks is the tool used to design the sphere enclosure. It is such a powerful software that once properties are set, it can automatically add screw threads to surround a chosen cylinder. Internal threads are added to a cylinder gouged inside the upper hemisphere, while external threads in the same profile are added to the outside of a cylinder that stands above the lower hemisphere. After elaborate adjustment of their pith, profile and deviation, the two threads can engage with each other [15]. To allow users to screw them up easily, the complete threads are set to have multiple starts. To increase the waterproofness of this joint, a protective layer is attached to the upper hemisphere, which forms another shell. The features of two threads and the auxiliary shell can be seen clearly in Fig.4.

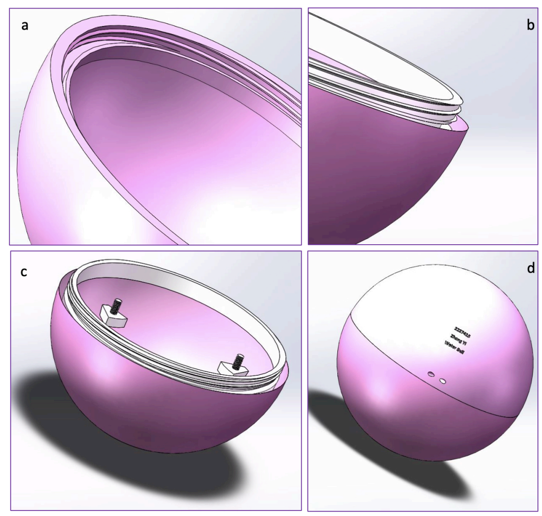

Fig. 4. Features of joint design: (a) the screw threads and groove of the upper hemisphere; (b) the screw threads of the lower hemisphere; (c) capture of the lower hemisphere; (d) capture of the complete assembled ball.

As for the inner structure, the primary design purpose is to fix the inner devices. To make the measurements accurately represent the fluid moving characteristics and keep their electricity integrity, the inner devices should not move nor slide. A printed circuit board (PCB) is designed to integrate all devices inside to reduce relative motions, which lies the matter in fixing the circuit board to the sphere. As we know the board need to be placed inside the lower hemisphere, there are many considerations of the footprints' arrangement:

i) devices should be arranged uniformly to keep the weight balance;

ii) the height of each device should not exceed that of the higher hemisphere, which entails a compact placement;
iii) to make the board capacious, we use two layers to route;
iv)to fix the PCB with the sphere enclosure, four via holes are reserved on each corner to let screw bold come through.

To fix the printed circuit board with the lower hemisphere, we add four built-in bolts to the top of a datum plane. The bolts are designed to penetrate the hole reserved on the PCB and the tapping hole in the cap nut from the bottom to top. This design allows the operator to screw the nuts down from outside manually. Screw threads are set to suit standard M3 nuts. The features of all inner structures are shown in Fig.6.

The industrial SLA (Stereolithography Apparatus) printer is preferred to produce fine and smooth models so that the completed threads can be realised. The printed version of the 10cm-diameter 3D enclosure models is shown in Fig. 5(c).

IV. FIELD TESTING

To test the functionality of the 'water ball' in a natural environment, we put the ball in a slow stream and a torrential stream respectively in the university as shown in Fig. 6. Note that the ball has to be rushed down by a small waterfall in the latter condition.

Transmitting data back to the user interface, the ball functions well both in these two conditions, even after the strike of the waterfall. The data of accelerations, angular velocities and magnetic field intensities of these two conditions are compared in Fig. 7.

Through careful observation, we find that the average acceleration and angular velocities for the torrential stream teat are much larger than that those for the gentle stream test. The magnetic field intensity values also oscillate more frequent in the torrential stream.

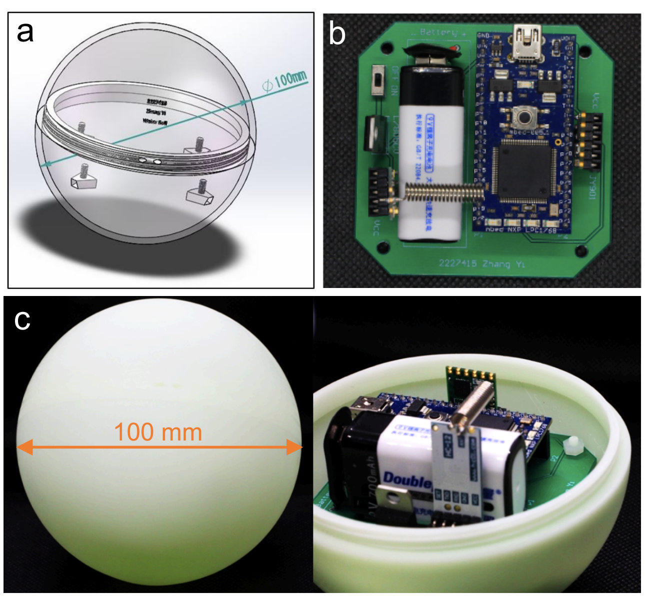

Fig. 5. (a) view of the complete assembled ball, (b) The internal PCB comprises sensors, microcontroller and battery. (c) the assembled enclosures and the assemblage of PCB.

Fig. 6. Photos of the water ball in field tests: (top) in a gentle stream; (middle) in a waterfall; and (bottom) in a torrential stream.

V. APPLICATION MODEL

In this paper, in a foaming watershed, our 'water ball' could be applied for a limited duration, within a limited geographic, and be collected back by supervisory personnel. However, a more forward-looking way is to build a public and acknowledged supervise mechanism. Multiple base stations can be built along the observed watershed to sustain wireless communication with each ball. To distinguish different signals from each ball, we allocate each ball a unique radio channel (i.e. HC-12 module can communicate 100 radio channels, which allows 100 water balls to be deployed.). Through knowing which ball is connecting to which base station, we can also get information about where the ball is. The diagram demonstrating this model is shown in Fig. 8. These base stations could also function as observation stations. It means that many water balls may be observed in any fragment along a whole river and be collected and renovated by a nearby observation station. The information collected by each ball as well as the electrical and physical status of each ball will be uploaded to the internet, which contributes to the morphology analysis of the whole watershed and facilitates the management of these balls.

VI. CONCLUSION

This paper presents a low-cost, repeatable and convenient method for environmental sensor node prototyping. The designed multi-sensory water ball could allow users to gain access to hydrological information of any water environment remotely. The enclosure obtains good waterproofness and robustness in both gentle and torrential conditions.

The deployment model put forward at the end provides a potential methodology for further applications. The information recognised from the sensor data provides insight into water quality, water morphology and ecology analysis, which would be useful in academic or engineering projects.

More works can be done to improve the overall functionality and practicability of this project. Here listed some suggestions:

- Further data processing tasks can be done to transfer these first-hand data to direct useful information like surface water velocity and flooding possibility.
- The significant obstacle that prevents this project from practical applications is the unawareness of the Water Ball's location. If its whereabouts can be traced, we can not only know where to collect it back but also gain the hydrological information of its new place. A GPS module can be assembled to help with this [16].
- To make the wireless communication distance much longer, we can connect 4G or 5G chips to this sensor node. This method allows every ball to communicate directly with the public mobile communication base stations.
- Develop more significant to the public and upload the data collected by Water Ball to the internet to help the construction of observation networks of the local water environment.

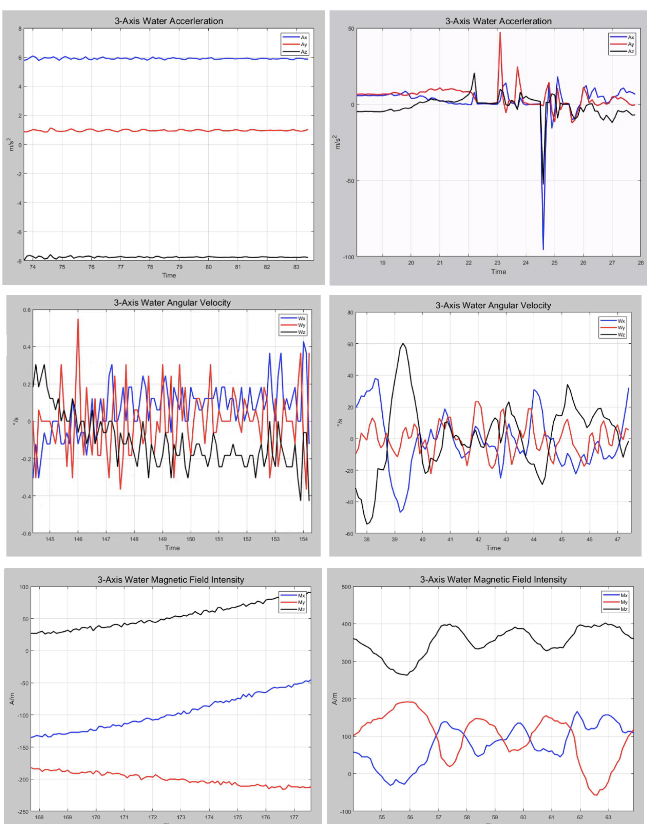

Fig. 7. Real time data in field tests: Comparison between accelerations in the gentle stream (top left) and in the waterfall (top right); Comparison between angular velocities (middle) and magnetic field intensities (bottom)in the gentle stream (left) and in the torrential stream (right).

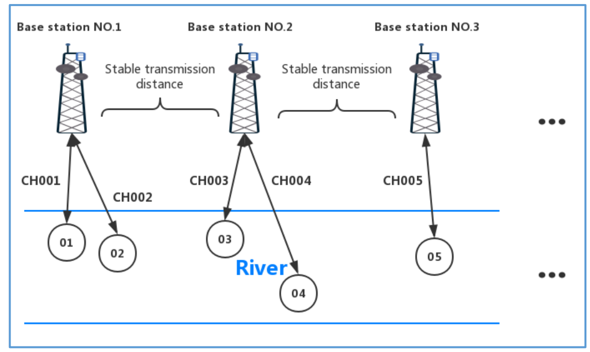

Fig. 8. Picture showing the communication concept of one application model of the project, circles representing the water balls; towers representing base stations along the river.

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