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Sensor-Network based Intelligent Water Quality Monitoring and Control

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***Abstract*—Recent advances in communication technology, especially wireless sensor networks have inspired numerous remote sensing and control applications. Here, we focus on the monitoring and control of water quality in natural water bodies such as rivers and lakes. An intelligent system that combines monitoring and actuation capabilities is designed. Major technical challenges such as sensor selection and control over wireless networks are discussed and appropriate algorithms are adopted based on system design requirement.**

***Index Terms*—sensor network, water quality monitoring, distributed control.**

I. Introduction

Water quality monitoring has become a crucial question around the whole world. Traditionally, remote water sensing based on satellites is widely used to monitor the water quality for rivers, lakes, seas and oceans. However, satellites only offer a macro view of the water quality. When it comes to a particular region of interest, the accuracy of the satellite surveillance may not meet our requirements.

With the development of communication technology and sensor technology, especially the concept of wireless sensor network and Cyber-Physical System (CPS), many efforts have been made toward building new water quality surveillance technologies based on wireless sensors deployed underwater.

Sensors have been developed for underwater environment that are able to collect accurately several water quality parameters such as; temperature, chemical substances, water density etc. These sensors can be equipped with improved communication capability, for instance, transmitting data through acoustic waves. Using wireless communication network, it is now possible to organize sensors as an autonomous sensor network that provides continuous, accurate water quality measures in relatively large water body such as lakes. Underwater sensors network can serve as a promising and a complementary approach with satellite surveillance for an accurate remote sensing of water quality.

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On the other hand, when a source of pollution is located through monitoring system, actions should be taken to effectively remove it. While most common practice nowadays is to send technical stuff to the pollution spot to handle it, new technologies in robotics and Networked Control Systems (NCS) do support the possibilities of autonomous pollution source removal.

In this work we describe the concept of an intelligent water quality and control system based on wireless sensor networks. This system exploits new technologies in wireless sensors, distributed estimation, networked control system, and provides the capability of remote water quality monitoring and control. The system is composed of the following parts:

1) Wireless low cost sensors that obtain multi-modular water quality and send them through communication link.
2) Central Monitoring Station (CMS) that receive measurements from selected subset of sensors then execute data fusion and filtering algorithms to monitor water quality. In the presence of pollution sources, it will also track its location in real-time.
3) Network controlled Unmanned Autonomous Vehicles (UAVs) that are controlled by CMS through communication network. On the discovery of pollution sources, these UAVs will be sent out to retrieve it.

The rest part of this paper is organized as follows: the structure of the system is described in Section 2. Section 3 addresses two major technical challenges in the intelligent water quality monitoring and control system: sensor selection and control under unreliable communication. Section 4 discusses other possible implementations of the system based on several new estimation and control technologies. Conclusion and future works are in Section 5 and 6, respectively.

II. Related Works

Several studies on applying sensor networks for water quality monitoring have been reported in [1, 2, 3]. In these works design and implementation issues are discussed but usually the sensor selection issue is not detailed. Sensor selection is challenging topic and can usually be formulated as NP-hard problem, algorithms that either use heuristic or approximately solve some variation of the problem can be found in [5, 7, 14, 16], some of them are based on information theoretic criterions. Our approach is also related to the topic of networked control systems (NCS). Stability and performance issues in networked control systems has

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attracted great interest in the past decade [4, 6, 8, 9, 10, 12, 13], these works do not directly address design issues but provided guidelines for system implementation.

III. Proposed System Structure and Technical Challenges

In this section, we are proposing the structure of the wireless sensor network in which a large amount of sensor nodes are placed in a lake. A much smaller number of UAVs also patrol the lake and they are directly controlled by the central monitoring station (CMS). These three components of the proposed system are depicted in Figure.1. The sensor nodes and UAVs are both mobile whereas the CMS is stationary. The CMS collects the data from the sensors and process them. Suppose the number of sensor nodes are very large so that within the transmission range of each sensor node there are always at least one other sensor node. This is to exclude the possibility of isolated node that cannot transmit its data to the CMS. The UAVs are fewer in number and larger in size, so we can equip them with more expensive devices such as long range transceivers, therefore it's assumed that the UAVs are capable of communicating with the CMS directly (as indicated by the blue arrows in Figure.1). The wireless sensors can transmit data either directly to the CMS or through another wireless sensor, as indicated in Figure.1 by the red arrows. When collecting data from wireless sensors, the CMS is a sink and when guiding UAVs to pollution sources, it serves as both as a source and a sink because two-way communication is needed for the control of UAVs: it needs to send commands to UAVs and also receive feedback information from each of them to form a closed loop.

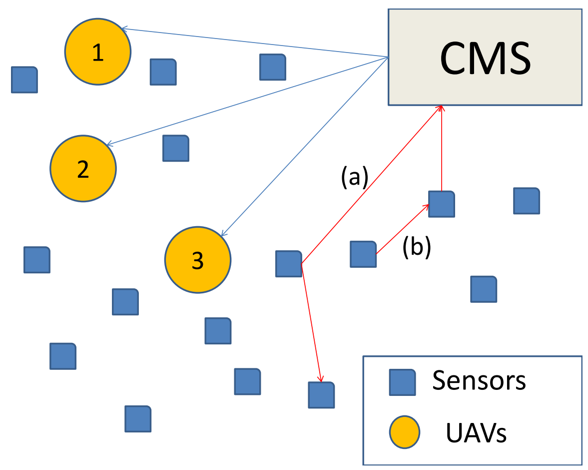

Fig. 1The architectural of the proposed water quality monitoring and control system.

The sensor units are implemented based on Zigbee wireless technology, the block diagram is shown in Figure 2 (note that the sensors are omitted). The sensor measurements in the form of electrical signal and send to signal processing circuit for local processing (quantization, scaling if necessary). The digital signal is then sent to the microprocessor and sent to CMS through transceiver circuit TI-CC2430. A Li-ion battery pack is mounted to the mobile senor node to power all these components.

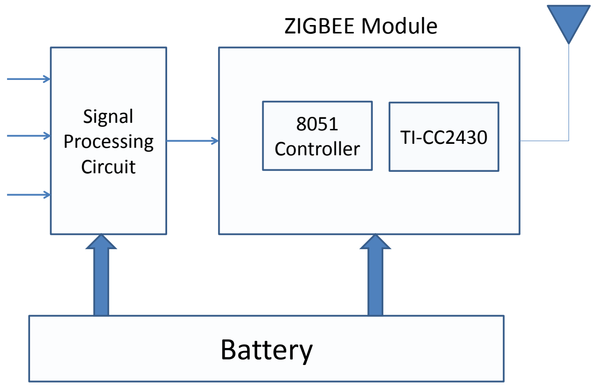

Fig.2 Block diagram of Zigbee based wireless sensor node (transceiver part)

The structure of the UAVs is plotted in Figure 3. The MCU is the on-board decision-maker that coordinates all its components. UAVs are equipped with its own sensors such as acoustic sensor, camera, etc. Actuators includes propeller, step motor for rudders and possibly robot arms, they are directly control by MCU or remotely controlled from CMS. Battery management unit monitors the battery state of health (SoH) and state of charge (SoC), and decides the power supply strategy for all components. For example when the battery is low, some in-essential functions of the UAV are temporarily turned off to save energy. The wireless transceivers on the UAVs are omitted from Figure.3.

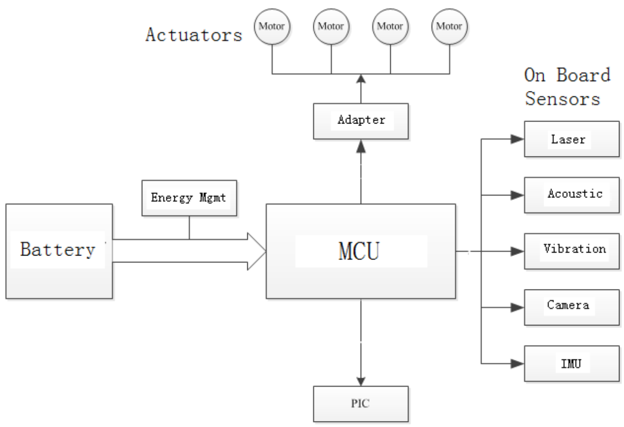

Fig. 3Typical structure for the UAVs

On the algorithm side, the most important components running on the CMS are: sensor selection algorithm, data fusion algorithm and networked control algorithm. The data fusion algorithm is responsible of estimating the water quality based on the collected data, and locating the pollution source when there is any. This problem has been discussed thoroughly in the literature. The other two problems are relatively more challenging: the task of sensor selection is to choose a subset of sensors to activate at a given time. This is important because for wireless sensors the battery has limited capacity and transmitting-receiving message is the most energy-consuming action [1, 2]. Therefore to maximize the lifetime of these sensors most of them are in hibernate mode and only wake up when it is necessary (e.g. the CMS believe its measurement is important). The control of UAVs over potentially unreliable wireless link is another challenging task, because the link can suffer from packet loss, delay and multi-path effects which degrade the control performance in a significant way [4, 8, 11]. In the next section, we propose a fast algorithm for sensor selection based on the work [14]. For the control of UAV a lie-group based control scheme from [22] is adopted.

IV. Sensor Selection and Networked UAV Control

In this section, we describe our strategies for sensor selection and UAV control. Our strategy for sensor selection is adapted from the simplified greedy sensor selection algorithm reported in [14], with modification to make it feasible for mobile sensor nodes. The algorithm solves an optimization problem in the form

$$\max_S\{f(S)| \quad |S| \leq m\} \qquad (1)$$

Here S is a subset of sensors with number less than m, $f(S)$ is a monotone sub-modular function derived from Max A Posteriori (MAP) criterion or Maximum Likelihood (ML) criterion. It can be shown [14] that for such optimization problems a greedy algorithm results in a solution which is not guaranteed to be optimal but is within $1-\frac{1}{e}$ of the optimal objective value. Starting from an empty set, at each step the greedy algorithm picks the wireless sensor node that maximizes the objective when included with previously chosen sensor node set. The procedure repeats until no constraints are violated.

To make the algorithm work for mobile sensors, we add two additional actions: a). when a sensor moves away from its original location, it reports its destination to CMS so that a new sub-modular cost function can be computed (this is possible since a moving sensor cannot be in hibernate mode). b). when the sensor distribution changes are significant enough the CMS execute the sensor selection algorithm again using the new locations of moved sensors and its stored position information of all other sensors. This generates a new set of m sensors to be activated.

For the control of UAVs over unreliable wireless channel, we chose the algorithm developed in [22] since its planar formation control property fits our application needs very well. Although the algorithm was for flying vehicles it can be applied to surface vehicles with no modification since only 2-D case is discussed. The stability of the system under mild packet drop was tested and the preliminary results are promising. However a theoretical guarantee of stability and performance is the subject of future research.

V. Conclusion

In this work we introduced an intelligent water quality and control system based on wireless sensor networks. This system use mobile wireless sensors to monitor water quality in a remote fashion and can detect pollutant location effectively. Wireless controlled UAVs are integrated for the marking, separation and removal of pollutant. The technical challenges such as sensor selection and wireless control are addressed with customized novel algorithms.

In the future the research effort will focus on improving the UAV control algorithm. New advances in networked control system such as event-triggered control [15, 17, 19, 2, 23] will be tested on our system.

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