Demo Abstract: Wind Measurements for Water Quality Studies in Urban Reservoirs

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I. Introduction

Water quality monitoring and prediction are critical for ensuring the sustainability of water resources which are essential for social security, especially for countries with limited land like Singapore. For example, the Singapore government identified water as a new growth sector and committed in 2006 to invest S$ 330 million over the following five years for water research and development [1]. To investigate the water quality evolution numerically, some key water quality parameters at several discrete locations in the reservoir (e.g., dissolved oxygen, chlorophyll, and temperature) and some environmental parameters (e.g., the wind distribution above water surface, air temperature and precipitation) are used as inputs to a three-dimensional hydrodynamics-ecological model, Estuary Lake and Coastal Ocean Model - Computational Aquatic Ecosystem Dynamics Model (ELCOM-CAEDYM) [2]. Based on the calculation in the model, we can obtain the distribution of water quality in the whole reservoir. We can also study the effect of different environmental parameters on the water quality evolution, and finally predict the water quality of the reservoir with a time step of 30 seconds. In this demo, we introduce our data collection system which enables water quality studies with real-time sensor data.

By recent limnological studies [3], environmental scientists find that the distribution of wind stress on the surface of a lake can significantly impact water hydrodynamics and affects water quality. In a previous study on sensitivity analysis [4], based on uniform wind distributions, we also find that in Marina Reservoir, wind forcing variability has significant impact on vertical and spatial variability of phytoplankton distribution which can cause substantial change to the water quality. We conduct our studies in Marina reservoir which is located in downtown of Singapore with a water surface of $2.2km^2$. Due to seasonal effects and the urban landform created by a variety of high-rise buildings surrounding two basins of the reservoir, the wind field is of high temporal and spatial variations. If we divide Marina Reservoir into small grids of 20m*20m and assume that each grid is a location with uniform wind field, we need to cover the Marina Reservoir with more than 5k locations. We cannot deploy such large number of wind sensor above the water surface; thus, we need to find the most important locations to deploy the limited number of wind sensor and develop an efficient approach to generate the wind distribution above the whole reservoir with the real time sensor data at some discrete locations. In order to maximize the accuracy of field measurements, the optimal sensor placement together with the spatial prediction is therefore a key problem this project needs to address.

In this demo, we present the whole procedure of deploying wind sensors around and on the water surface of Marina Reservoir, including the definition of the sensor placement problem according to the unique features of wind measurement in this project, the in-field deployment of wind sensors, and the processing of real-time sensor readings. During the demo on the conference site, we will play a video which introduces the background of our project, the sensor placement approach in steps with some intermediate results, the installation of our wind measurement stations and our data collection system. At the same time, viewers can access the online wind sensor readings through internet at real time. We also prepare a poster which will give an overall introduction of our work. Therefore, we need the following 3 facilities, i.e., a projector to post the video, a panel to hang the poster and internet access.

II. Sensor placement and spatial prediction

Common approaches for sensor placement assume that the target observations at each location follow a Gaussian distribution and the joint distribution of the variables over all locations can be modeled as a Gaussian process [5, 6]. The GP assumption, however, does not hold for wind directions over a large time period in our application. The inaccurate Gaussian fitting leads to large errors in understanding wind correlations within the field and jeopardizes the results of sensor placement and spatial prediction. In addition, to use the GP model, existing approaches require full prior-knowledge of

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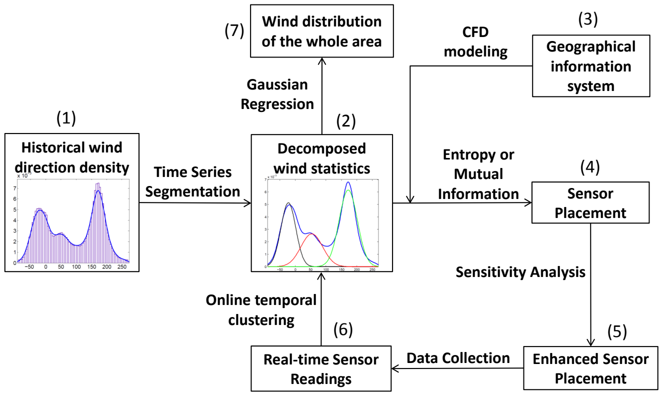


Fig. 1: Overview of the proposed approach for sensor placement and spatial prediction [7].

Fig. 2: Locations of wind sensors and underwater sensors.

data distribution over the entire field such that the pairwise correlations of all locations in the field can be captured. Intrusively gaining such knowledge through pre-deployment is also not possible due to the large number of required sensors.

We propose a novel approach to address the problem. More details about the sensor placement and spatial prediction problem can be found in [7]. In this abstract, we mainly introduce the key techniques used in our solution of sensor deployment. Fig. 1 illustrates the main framework in steps. We obtain the historical wind data from the two meteorological stations at Marina Bay (2007-2008) and Marina Channel (2007-2008 and 2011-2013). We find clear difference of the dominating wind directions between different time periods, which conforms to the monsoon climate in Singapore [1]. We develop a maximum likelihood based time series segmentation method and divide the sensor data of a whole year into two monsoon seasons and two intermonsoon seasons. In each segment, the wind can thus be modeled or transformed to a Gaussian distribution. The wind speed of each season can be perfectly modeled as a mixture of multiple Gaussian distributions according the division scheme derived from the wind direction, since the wind speed of the whole year is Gaussian distributed. To learn the correlation between any two locations, we conduct a variety of offline Computational Fluid Dynamics (CFD) simulations which can capture the detailed impact of surrounding high-rise buildings to the wind distribution through calculating classic formulas of fluid mechanics. Based on the learnt Gaussian process model, in each monsoon season, the optimal sensor locations are selected according to certain information criteria, e.g., entropy or mutual information. Due to high computational complexity of calculating mutual information, entropy is used in this work. The results of all seasons are combined to calculate the final sensor placement scheme.

[1]Singapore has two monsoon seasons every year, Northeast (NE, roughly Dec.-Mar.) and Southwest (SW, roughly Jun.-Sep.). The name indicates their dominating wind direction. The monsoon seasons are separated by two intermonsoon periods, PreSW and PreNE, in which the wind is more evenly distributed.

The potential deployment area of Marina reservoir covers a water surface space of $2.2km^2$ plus the terrain area within 100m from the water's edge since some locations on land may provide more information about the wind observations on other locations than those on water surface. Finally, we deploy 10 wind sensors at the selected locations. Based on the sensor readings of discrete locations and the learned Gaussian model, we generate the wind distribution over the target area.

III. DEPLOYMENT AND DATA COLLECTION

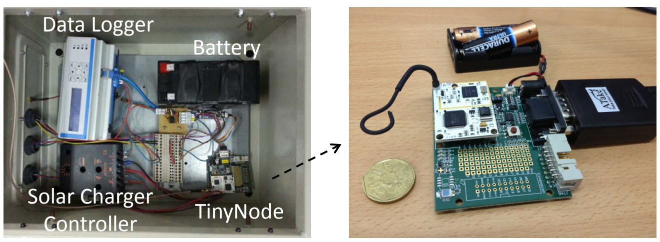
10 wind measurement stations are deployed, as shown in Fig.2, including 5 land sensors around the water and 5 floating sensors on the water surface of the reservoir. We also deployed several sets of underwater sensors to measure some key parameters of water quality, such as dissolved oxygen, conductivity, chlorophyll, pH value and temperature, at 3 locations, as depicted in Fig.2.

Three types of wind sensor are constructed, including land based, floating and mobile sensors, as shown in Fig. 3. Land sensors are installed on the ground with a stable reference direction. Floating sensors are fixed on a platform floating on the water surface. We equip an OS5000 3-axis digital compass from OceanServer for each floating sensor to determine the instant reference direction (which will be used to offset the relative wind direction measurement so as to obtain the absolute one). We also build a mobile wind sensor used to collect data for performance evaluation.

For each sensor, the wind monitor model 05305L of R.M. YOUNG is used, which provides an accuracy of 0.2m/s for speed and 3° for direction. In an early version of the data collection system, all wind sensors are equipped with a RTCU DX4 data logger, as depicted in Fig. 4. Accurate clock is provided in the data logger and all the sensor readings are instantly synchronized in-field. A solar panel is equipped to provide continuous power to the wind anemometer and data logger. For the mobile wind sensor, a portable battery is used to offer energy instead of solar panel and all the other components are same as the land and floating wind sensors.

(a) Land (W10) (b) Floating (W2) (c) Mobile (6)

Fig. 3: Three types of wind sensors.



(a) (b)

Fig. 4: All the electronic devices are enclosed in a weather-proof box (a). TinyNode is equipped with an omnidirectional antenna extended outside the box (b).

The minutely measured data are first logged and then transmitted back to our backend server directly through cellular network. To further reduce the cost of each wind sensor and enhance the universality of our system, we are replacing the data collection network of GSM communication module by a low power wireless sensor network composed of a long distance mote, i.e., TinyNode [8], which retrieves the sensor readings from the anemometer via a RS232 interface. The sensor network can work automatically for a long lifetime without request of any external infrastructures or base stations. Although solar panels are available, we implement the duty-cycle mode in the wireless sensor network to save energy for the proper operation of anemometer. Moreover, the design with duty-cycled sensor nodes can be easily extended to other applications without the energy harvesting capacity.

The real time data are hosted in the server and can be accessed online through our data collection user interface, as shown in Fig. 5. With this user interface, we can also monitor the status of each wind sensor. For example, Fig. 6 presents the wind speed collected on 6th January 2014.

IV. Conclusions

In this demo, we introduce our data collection system deployed for the water quality studies in an urban reservoir, including the calculation of optimal sensor locations and spatial prediction, the structure of wind measurement station and the deployment of wireless data collection system.

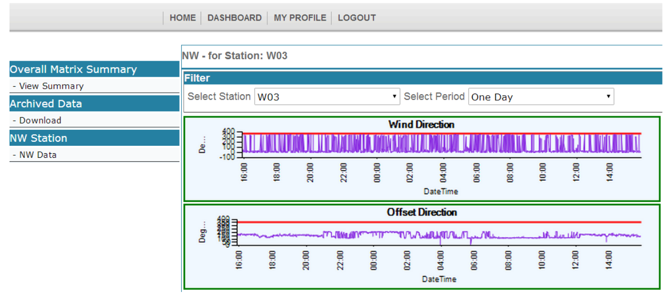


Fig. 5: The online user interface for data collection.

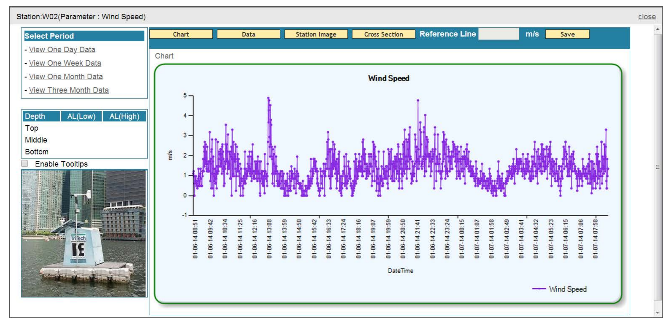


Fig. 6: The collected wind speed data.

Acknowledgments

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References

[1] I. O. B. Luan, "Singapore water management policies and practices," *Water Resources Development*, 2010.

[2] B. Laval, J. Imberger, B. R. Hodges, and R. Stocker, "Modeling circulation in lakes: Spatial and temporal variations," *Limnology and Oceanography*, 2003.

[3] R. Alexander and J. Imberger, "Spatial distribution of motile phytoplankton in a stratified reservoir: the physical controls on patch formation," *Journal of plankton research*, 2009.

[4] Z. Xing, C. Liu, L. H. C. Chua, B. He, and J. Imberger, "Impacts of variable wind forcing in urban reservoirs," in *the7th International Symposium on Environmental Hydraulics*, 2014.

[5] N. Cressie, *Statistics for spatial data*. John Wiley and Sons, Inc, 1993.

[6] C. Guestrin, A. Krause, and A. P. Singh, "Near-optimal sensor placements in gaussian processes," in *ICML*, 2005.

[7] W. Du, Z. Xing, M. Li, B. He, L. H. C. Chua, and H. Miao, "Optimal sensor placement and measurement of wind for urban ecological studies," in *ACM/IEEE IPSN*, 2014.

[8] H. Dubois-Ferrire, R. Meier, L. Fabre, and P. Metrailler, "Tinynode: A comprehensive platform for wsn applications," in *ACM/IEEE IPSN*, 2006.