

Wireless Ion-Sensitive Field Effect Transistor PH Sensor Network for Offshore Microalgae Cultivation

Pramod Kumar Singh^{*1} and Manoj Kumar Singh²

ABSTRACT

One of the preeminent challenges facing scientists and engineers in the 21st century has been and will likely continue to be the development of economically and technically feasible renewable energy technologies. While many of these efforts, such as wind, solar, and geothermal, address electricity generation, there are relatively few options to consider for transportation fuels which account for over 1/3 of the US energy needs. Biofuels, from corn or other plant products, have tremendous promise as they can serve as a drop-in replacement for use in our existing infrastructure. However, there is real concern over whether “conventional” bio-feedstock can be viable replacements for fossil fuels due to their need for arable land, high water usage, and relatively long growth cycle. Microalgae, on the other hand, does not suffer from these same limitations and many researchers world-wide have started to explore the cultivation of microalgae for biofuel production.

These efforts vary from open ponds to closed photo bioreactors. For example, one technology under development is the NASA OMEGA project. With roots in developing life support systems for long spaceflights, NASA has developed the OMEGA system. This system uses the nutrient content in treated wastewater and waste carbon dioxide from flue gas sources to cultivate microalgae in floating photo bioreactors. The resulting biomass can then be harvested for biofuels and other algae products. Regardless of the specific cultivation process, it is critical to monitor several operating parameters to ensure the health and maximum yield of the algae culture. Measurement of pH is especially important as it can be used a proxy for measuring the amount of carbon dioxide available to growing algae culture.

As carbon dioxide is added to the system, carbonic acid is formed, and the pH decreases. Since the algae can only photosynthesize in daylight, during night the algae respire, using O₂ and creating CO₂. In light of these rapidly changing growth editions, it is critical that the pH in the system is monitored accurately and continuously for correct operation of the control systems responsible for maintaining the health of the algae culture. The sensor systems must be robust enough to maintain reliable operation in a harsh marine environment, and be well tolerant of biofueling both inside and outside the system. The accessibility challenges inherent in any large scale cultivation system also require that the system be easily and infrequently maintained. A wireless system provides additional advantages, such as reducing the cost and maintenance work associated with numerous sensor cables running throughout a large-scale cultivation system.

The fragile and costly sensor cables are replaced with radio links. For example, damaged sensor cables needed frequent maintenance and/or replacement at the OMEGA system. A wireless system also allows greater flexibility in choosing the point of attachment to the system, without a need to consider the cable length or it's physical accommodation. This work proposes the development of a wireless ISFETbased (Ion-Sensitive Field Effect Transistor) pH sensor network for use in an offshore microalgae cultivation system.

Keywords : ISFET, pH sensor, sensor cable, Microalgae, Cultivation System etc.

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- 1.* Pramod Kumar Singh, Associate Professor, Department of Applied Sciences, School of Management Sciences, Technical Campus, Lucknow, India, E-mail : pksingh.lu@gmail.com
 2. Manoj Kumar Singh, Reader, Department of Mechanical Engineering, School of Management Sciences, Technical Campus, Lucknow, India. E-mail : manoj_iit2004@yahoo.co.in

1. INTRODUCTION

Microalgae technology continues to show tremendous promise for becoming a major source of renewable transportation fuel in the coming decades. However, for microalgae to provide a significant fraction of the current US demand for fuel, their cultivation will be required on an enormous scale. One of the many formidable challenges that must be met to achieve this scale is the development of appropriate sensor networks to provide information about the growth conditions and the algae themselves by Y. Chisti et al.[1]. These sensors would monitor the heterogeneity of (a) environmental parameters, such as pH, oxygen, and nutrient levels and (b) algal characteristics such as size, oil content, and viability. project (Offshore Membrane Enclosures for Growing Algae). The pH is measured using Ion Sensitive Field Effect Transistor (ISFET) technology,. A hossain et al.[2] which is more robust and has a faster response than traditional glass pH electrodes. A custom circuit drives the ISFET sensor and interfaces with an ANT wireless network system. G.C. Dismukes et al.[3] The wireless network consists of a network hub which can service up to 8 sensor nodes and a series of relays to transmit the data to a PC. The data is logged with a custom LabVIEW program. J.R. Sandifier and J.J. Voycheck et al[4]. In this work, we demonstrate operation of this network using a single ISFET pH sensor, one hub, and two Here we present a wireless sensor network to measure the local pH in NASA OMEGA by J. Trent et al. [5].

2. WIRELESS ION- SENSITIVE EXPERIMENTAL SET-UP

The foremost design consideration of the enclosure is to create a waterproof barrier between the process fluid (algae culture) and the sensor electronics.

Additionally, the enclosure electronics must be protected from the elements, yet still accessible for basic maintenance and battery replacement. These objectives for the enclosure have been accomplished with a combination of PVC pipe components and silicone caulk. The barrier is accomplished with two PVC plug fittings glued back-to-back. Through this barrier, a hole is drilled for the ISFET probe. The ISFET probe is then embedded in this hole, and sealed with silicone caulk. This barrier between the electronics and the process fluid has been shown to be watertight under pressures up to 15 psi. This structure is depicted in Figure 1. Since each PVC plug fitting is threaded, the probe side can be attached to any compatible location in the process plumbing of the OMEGA system. The electronics side is also standard PVC threaded, and a pipe and cap fitting provide a weatherproof and easily accessible enclosure for the electronics.



Fig.1. Photograph of waterproof package for the ISFET pH probe depicting the PVC and silicone barrier between the sensor probe and electronic connections.

The enclosures for the hub and relay units are similarly constructed from a short section of pipe capped at both ends. The specialized electronics for the ISFET sensor are placed on a customized printed circuit board (ExpressPCB, Santa Barbara, CA), which measures approximately 9 cm by 3.6 cm. It is photographed with its main regions labeled in Figure 2. Once the sensor output is processed by the analog-to-digital converter, the ANT wireless system handles the data communication until it is eventually logged

by a PC with a custom LabVIEW interface. The main component of the ANT communication network in the configuration used for this work is the sensor hub. This is the next wireless link in the chain after the sensor node itself. The sensor hub sends out a message sequentially requesting data from each sensor on its programmed list, and then awaits a response from that sensor with a new data message.

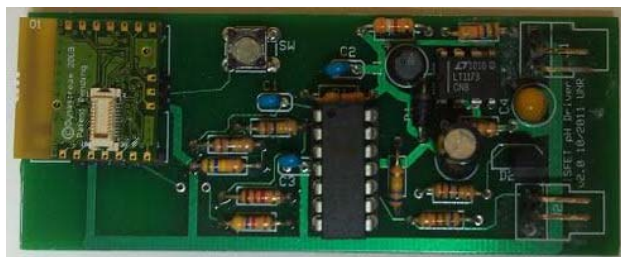


Fig.2. ISFET sensor node custom circuit board with regions labeled by primary function.

This experiment was conducted with the use of one sensor hub and two relay units between the sensor and the USB interface. For the experiment presented in this work, one wireless pH sensor was constructed to be compatible with standard 3/4" PVC fittings, located on a sensor manifold in the OMEGA system that sampled the flow at the exit of the photobioreactors. To facilitate more in-depth troubleshooting of the circuit board, the circuitry was not enclosed in a PVC pipe section for this experiment. Instead, the board was left open in a small plastic box with a plastic sheet to prevent rain entering the compartment. The PVC barrier was left in place.

3. SIMULATION RESULT AND DISCUSSION

The evaluation of calibration stability was accomplished by measuring the voltage output of the sensor circuit in standard pH buffer solutions of pH 7 and 10, at a time before and after the main data collection run of this experiment. This demonstrates a very stable calibration for the ISFET sensor, moving less than 2 percent in 17 days.

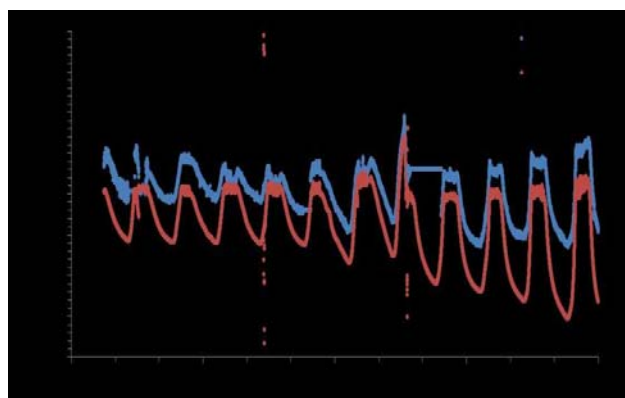


Fig.3. Wireless and wired pH data from 22 April 2012 - 3 April 2012. The flat region in the wireless data represents network downtime. Vertical groups of outlying data points from the wired data represent points in time where the OMEGA sensor manifold was taken offline.

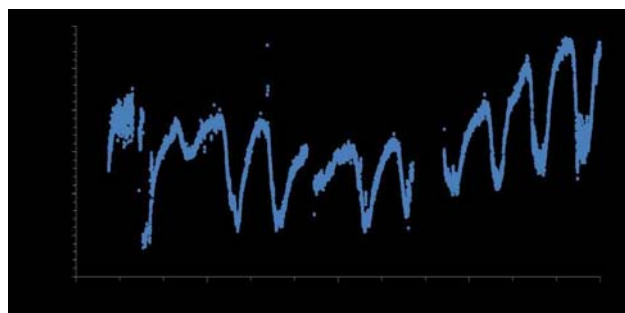


Fig.4. Offset pH vs. time. This gives the difference between the wireless and wired data as a function of time.

Figure 3 is the plot over time of the wireless pH data alongside the existing wired system at OMEGA. From this figure it can be seen that the general trend of the wireless pH data matches the daily cycling of the wired pH data, but has a significant positive offset from it. This offset, the difference between the wireless and wired pH data, is plotted in Figure 4. This also exhibits a daily cyclical variation, and a close inspection of the data shows that the pH offset is greater at lower measured values of pH, giving a suggestion of a nonlinear response in one or both of the sensor systems. Subsequent work is planned to characterize this condition in more detail.

4. CONCLUSION

In this work, a wireless ISFET pH sensor has been demonstrated in operation in the context of the OMEGA microalgae cultivation system designed for offshore use and prototyped in conditions replicating a near-shore protected waterway. The calibration stability has been characterized, and the difference in measurement between the wireless device and a parallel wired system has been examined. The performance characteristics of the sensor and the reliability of the data communication show promise for this technology to be featured in monitoring systems for large scale algae cultivation operations, including those located in marine environments. Additional experiments are planned along several lines of inquiry. Additional data on the ISFET performance can be collected by running additional data collections in parallel with other monitoring systems and by comparison with a frequently calibrated pH measurement standard. The analog/digital conversion capability of the ANT modules suggests that the wireless communication method can be extended to other types of sensors of interest to algae cultivation operations, including temperature and dissolved oxygen probes.

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