Iowa State University

Senior Design

Remote-Controlled Dissolved Oxygen Monitoring System

Final Document

Students:
Terry Fett-EE
Josh Dunham-EE
Brian Peck-CprE
Grant VerMeer-CprE

Advisors:
Dr. Joseph Shinar
Dr. Ruth Shinar
Robert Mayer
Brian Lewis
Alex Smith

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1 Introduction

1.1 Purpose

The goal of this project is to assist Integrated Sensor Technologies, Inc. (ISTI) in developing a remote-controlled DO monitor. Our advisors, Dr. Joseph Shinar and Dr. Ruth Shinar, are also our clients; ISTI is their company. According to our clients, the project is funded by the National Science Foundation (NSF) and the United States Department of Agriculture (USDA), and they want to deliver additions to the existing system. As such, we are set to do as much as we can to help them meet their deadlines. We have our primary objectives, but we will also help in whatever decision making is necessary for any part of the project.

1.2 Problem Statement

Our primary goal for this project is designing an RF transmitter to communicate between multiple monitor units and a master controller.

Currently, the DO monitor is comprised of two parts:

- The monitor unit controller board
- The sensor probe

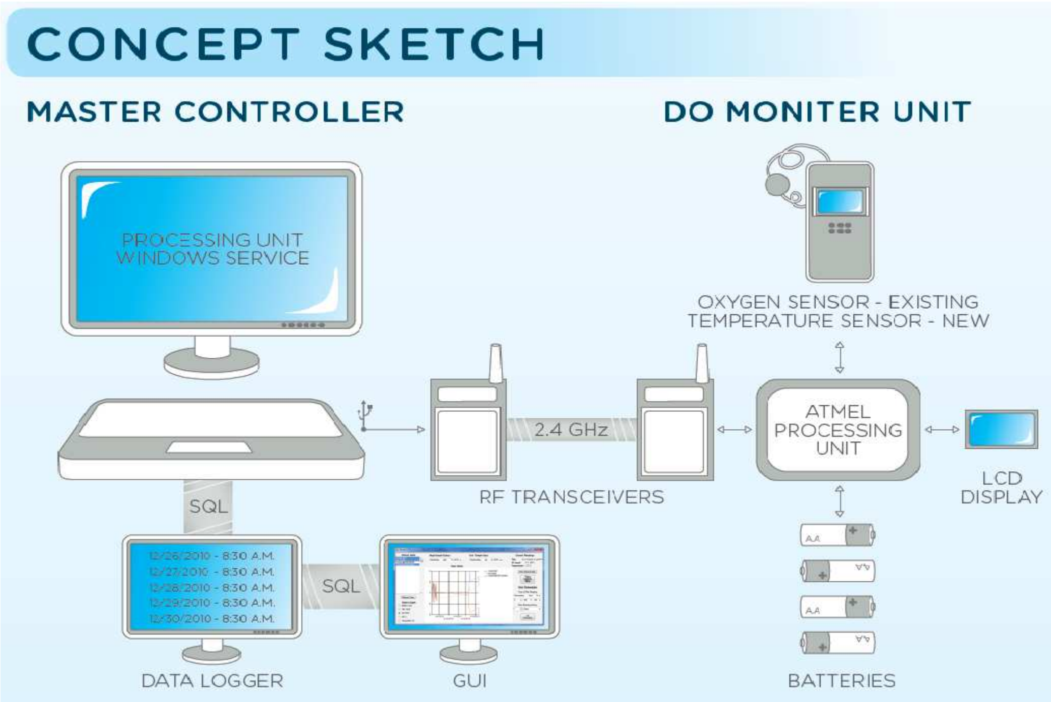
We propose a third part, an RF transceiver utilizing the IEEE 802.15.4-2003 wireless standard in each monitor unit. This transceiver needs a protocol for delivering data and talking to several units. Our master controller will be able to communicate with each monitor unit and retrieve data collected, or tell the unit to sample, and then collect the data. The configuration will form a star network where each DO unit communicates directly with the master controller. If a client has many monitor units, manually checking each unit on a regular basis would be time consuming.

Additional problems in the current setup include poor battery life and little measurement management. The first problem will be improved with sleep modes. These will allow the monitor unit to rest when not being asked for a sample. The battery will only be needed to listen for signals from the master controller during these sleep periods. This will be achieved through software methods implemented in the RF transceiver and the monitor unit's processor.

The last problem concerning measurement management will be solved in the master controller. We envision some data being saved for use in trending. This past information could be accessed by the user to see how measurements have changed and if certain trends exist. Our solution will be a Structured Query Language (SQL) database accessible to the user through a Graphical User Interface (GUI).

2 Project Plan

2.1 Concept Sketch



2.2 System Requirements

2.1.1 Functional Requirements

1. The monitor units should be able to wirelessly transmit their readings to the master controller.
2. The master controller should be able to request readings from each monitor unit.
3. The master controller should have a graphical user interface to display information from each monitor unit to the user and allow an operator to obtain data from a specific unit.
4. The master controller should be able to log all data processed through the unit.

2.2.2 Non-Functional Requirements

1. The system should have an optimal operating range of 1000 meters.
2. The system should be able to configure in a star-like topology.
3. The battery life of the monitor units should be maximized.
4. A temperature probe should be attached to the existing sensor probe to increase calculated accuracy.

2.3 Market Literature

Currently there are no remote controlled optical DO monitors. Our RF circuit will enable the development of a remote controlled network of such DO monitors. The wirelessly transmitted data will allow our clients to easily check data and maintain a constant state of control over any sample they are monitoring. This development will save time and allow for more efficient data collection.

The following excerpt is the market information provided by Dr. Ruth Shinar.

Motivation & Significance

Integrated Sensor Technologies, Inc. is developing novel structurally integrated DO monitors.

The market for DO monitors is > $100 M.[i] The leading customers include wastewater treatment plants, plants using industrial feedwater (e.g., power, lumber, paper), food/brewing/beverage processing, pharmaceutical, and chemical plants, fish farms, and monitors of rivers, lakes, and seawater (both coastal and deep sea). In industries that use boiler feedwater, maintenance of a minimal DO level helps to limit corrosion. In aerobic wastewater treatment plants, of which there are > 16,000 in the US alone, the minimum objectionable odor potential, maximum treatment efficiency, and stabilization of wastewater are dependent on maintenance of adequate DO.[i] **At the same time, power consumption is one of the largest expenses in operating wastewater treatment facilities, and aeration in activated sludge plants accounts for ~40% of all power-related costs. Often aeration blowers operate constantly at full power, providing excessive oxygen to the treatment process. Continuous DO monitoring to prevent costly over-aeration is therefore a cost-effective energy efficiency strategy. Over-aeration can also cause undesirable biological changes in the wastewater, leading to further expenses and reducing operational efficiency. The monitor system developed by** ISTI will be suitable, with small modifications, for all of these applications.

3 Design Plan

3.1 System Analysis

3.1.1 Monitor Unit (MU)

The monitor unit will consist of the sensing unit and processor, which currently exists, with the addition of a transceiver and temperature probe.

3.1.2 DO Monitor Unit Processor

The unit will take measurements of dissolved oxygen from an environment when instructed to do so by the transceiver. It will then communicate the dissolved oxygen to the transceiver via the SPI bus.

3.1.3 Monitor Unit Transceiver

The monitor unit transceiver will enable communication between the DO monitor unit processor and a master controller transceiver. It acts as an interface between SPI (for the DO monitor unit) and ZigBee wireless (for the master controller transceiver).

3.1.4 ZigBee Communication

When a message is sent over a communication network, the message is sent as a packet. The packets are pieces of data which are sent over communication networks. These packets are sent with information concerning the sender's and receiver's unique address, information which tells the network how many packets are being sent and the number of the particular packet. These packets travel via the wireless protocol used by the network. For our purposes, the packets will be sent directly between the monitor units and the master controller. The protocol is able to incorporate more complicated routing procedures which could be available in future projects. When the packets are sent wirelessly, the wireless network must adhere to a set of standards, or protocol, which governs data representation, signaling, authentication and error detection. ZigBee is a type of protocol which allows for communication networks to transmit in an unlicensed frequency band and serves mostly for monitoring and controlling communication networks.

3.1.4.1 Unique Addressing System

The Zigbee protocol is an IEEE approved protocol for use without licensing. This provides a free frequency band, but most situations use standard Media Access Control (MAC) addresses. For this unique application, we created a system of unique addresses for more reliable transfer of information. The EEPROM in the transceiver allocates 8 bytes of memory that will not be erased during power resets. When started, the transceiver will check to see if it has been assigned a unique value, if not, then it will request an address from the master controller. The first two bytes will be specific to the master controller so that no cross communication will happen if multiple master controller networks are present. The last six bytes will be randomly generated by the master controller and compared to a list to ensure no duplicates are used. The master controller will then send an 8 byte address to the transceiver to be used in all packets for identification.

3.1.5 Master Controller

The Master Controller will be run on a standard PC. The system software will be broken up into two main modules, the Processing Unit (PU) and the Graphical User Interface (GUI).

3.1.6 Processing Unit (PU)

The PU will be responsible for the entirety of the data collection and analysis. The PU will run as a Windows Service such that it is always running and available. The PU will communicate with the RF device to collect samples from the individual monitor units, as well as log the data it collects.

3.1.6.1 Processing Unit Core

The main processing unit subsystem will be responsible for coordinating the entire efforts of the service portion of the system. It will collect requests from the GUI via SQL and retrieve data from either the RF Transceiver or the Data Logger. It will also coordinate the data collection based on user entered schedules.

3.1.6.2 RF Transceiver

The RF Transceiver is responsible for all communication between the master controller and the individual DO monitor units. The RF Transceiver will receive instructions from the PU and alert the specified monitor unit. This module will use a buffer in the event that multiple DO monitor units are being sampled at a single moment.

3.1.6.3 Data Logger

The Data Logger subsystem is responsible for logging all data collected by the system, as well as retrieving any past data on demand. This module will use an embedded installation of Microsoft SQL Server Express 2008.

3.1.7 Graphical User Interface (GUI)

The GUI will be responsible for interfacing between the user and the PU. It will provide a variety of options to the user and display collected data in an understandable fashion. The GUI will run as a Windows Application and connect to the PU via SQL connection when it is running.

The GUI will be the primary interaction point between the user and the DO monitoring system. From the GUI Application, the user will be able to select and receive instantaneous data from individual DO monitor units, view past data, and create a sampling schedule.

3.2 Detailed Design

3.2.1 Input/Output Specification

Hardware communications need to be established in two locations: between an RF transceiver and the master controller and between an RF transceiver and the DO monitor unit. The communications between the RF transceivers will be executed using the ZigBee wireless protocol at 2.4 GHz.

The connection between the RF transceiver and the master controller will be accomplished with a mini USB to USB cable. We have purchased a Meshnetics Development board to enable more rapid development. A mini USB port is provided on the board and enables quick and easy communication to the USB port on a computer. These ports also provide power to the development board. Designs following this prototype will incorporate a transceiver that plugs directly into a USB port.

SPI ports will be used for data transfer between an RF transceiver and the processor in the DO monitor unit. The Meshnetics transceiver we are using has devoted SPI pins and USART pins that can act like SPI. We have used the USART/SPI pins in testing and will continue to use them for consistency. These pins were chosen because the dedicated SPI pins on the Meshnetics development board were not accessible. The pins needed for data transfer are the clock, master-in slave-out (MISO), master-out slave-in (MOSI), and the slave select. MISO, MOSI, and the clock are specified pins labeled on the transceiver, while the

slave select can be chosen from any output pin. Power and ground have designated pins assigned on the board. Lastly, an interrupt is needed which can be connected using any spare output pins.
The transceiver connected to the DO monitor unit will be using the new Atmel Atxmega128A1 processor which replaces the original Atmega32 processor. The RF transceiver is the master and the ATX processor is the slave in the relationship between the two. The ATX pins are configurable for SPI transmission.

The flow of information will start with a signal being sent through the transceivers to the DO monitor unit to take a sample. The DO processor receives the signal, performs the necessary reading, and forwards the data to the RF transceiver. The transceiver then creates a small packet with the result of the DO calculation plus necessary packet information. After the packet arrives at the master controller, the background service will compile all the information. When a user is ready to access the material, he may use the GUI to retrieve the data from the service.

3.2.2 User Interface Specification

The primary user interface will be a Graphical User Interface (GUI) on the Master Controller. The GUI will contain a variety of ways for the user to interact with the system.

3.2.2.1 Data Display Area

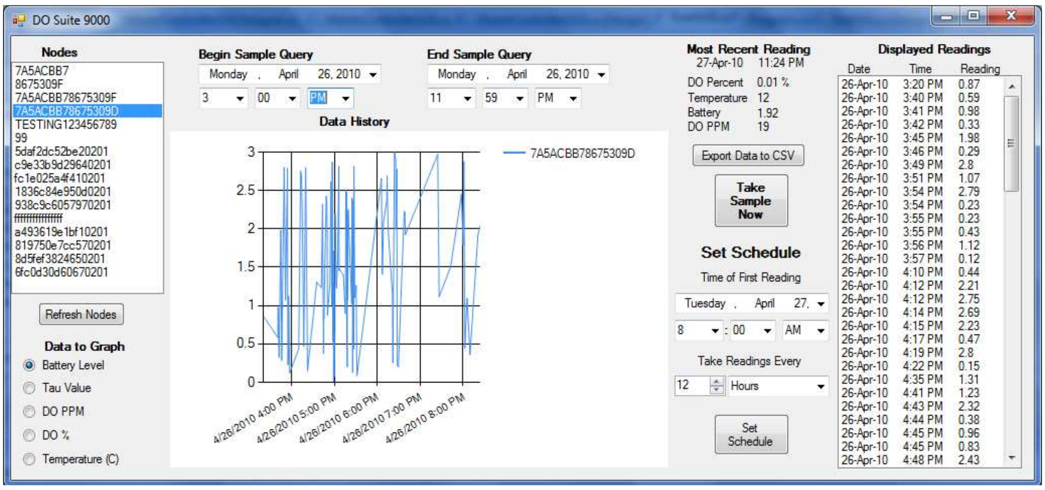
The Data Display Area will show the data that is requested by users through various actions. This data can be displayed in graphical or spreadsheet form.

3.2.2.2 Data Logger Query Area

The Data Logger Query Area will allow the user to enter a query to pass to the Data Logger. The results will be shown in the Data Display Area. Information that could be queried is past readings or sampling schedule information.

3.2.2.3 DO Monitor List

The DO Monitor List will show a list of the DO Monitor Units within range of the Master Controller RF transceiver, allowing the user to select one or multiple for data sampling.



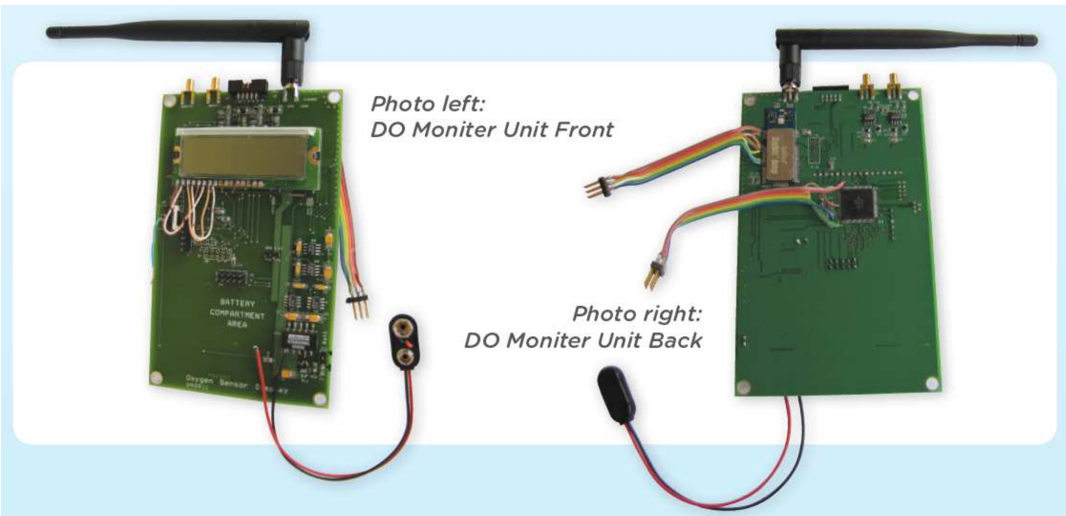
Graphical User Interface

3.2.3 Hardware Specification

3.2.3.1 Communication Hardware

The hardware necessary for the design project includes: MeshBean amp board, USB 2.0 A/mini-B cable, 2.4 GHz 3.2 dBi Pulse W1037 Omnidirectional antenna, U.FL to RP-SMA bulkhead pigtail, and a software and documentation distribution disk. The MeshBean amp board is a development board that will be utilized for testing purposes. The actual part of the MeshBean amp board that will be needed for the final product is the ZigBit amp module. It is capable of wireless connectivity, thereby making the MeshBean amp board a node in a ZigBee network. The following is a more detailed specification of the hardware.[1]

- The MeshBean amp board contains a ZigBit amp module equipped with a built in U.FL antenna connector and includes the ATmega 1231V microcontroller and the AT86RF230 RF Transceiver. The amp board operates in the 2.40-2.4835 GHz range and is in compliance with IEEE 802.15.4-2003. It has 8K bytes of RAM, 128K bytes of flash memory, and performs up to 4 MIPS throughput at 4 MHz clock.
- The Omni-directional antenna is connected to the board via the IPEX U-FL to RP-SMA bulkhead pigtail connector. The antenna is approximately 6.65 inches in length.
- The software disk contains a full-featured, next generation embedded software stack called BitCloud. The software development platform provided is reliable, scalable and secure for any wireless application running on the ZigBit module. BitCloud is also fully compliant with ZigBee standards for wireless sensing and receiving. The following applications are included in the software: SerialNet allows for AT-commands to be interpreted locally or forwarded on for execution on remote nodes, Hardware Test is used to test MeshBean2 board components for correct operation, Range Measurement Tool is used to measure radio performance of ZigBit-based devices, WSNDemo, and Serial Bootloader is used to program an application code into WSN nodes via USB or serial port, without the use of a JTAG connector.



3.2.4 Software Specifications

3.2.4.1 DO Monitor Unit

Currently the software is capable of taking a dissolved oxygen reading using an attached sensor probe. The software will be modified so that after taking a reading, it will send the reading to the transceiver and then enter sleep mode. The software will also be modified to begin taking a reading as soon as it is woken from sleep mode.

3.2.4.2 Monitor Unit Transceiver

The transceiver will be in sleep mode and will wake according to a defined schedule. Upon waking, the transceiver will check in with the master controller. If a reading is requested, the transceiver will wake the monitor unit. If a reading is not requested, the transceiver will enter sleep mode again.

3.2.4.3 Master Controller Transceiver

The software will be connected to a computer via USB. It will wait for an instruction from the computer to request a reading from a monitor unit. It will then form and send a ZigBee packet to instruct the monitor unit to take a reading. The software will wait for a response from the monitor unit and either send the data or a timeout notification to the computer via USB.

3.2.4.4 Application Level Software Specification

The software will be able to support a variety of functions, including the collecting of data, the viewing of data, and the scheduling of data collection.

3.2.4.5 Collect Data

The user has the ability to use the Master Controller to collect data from an individual DO monitor. To do this, the user opens up the GUI portion of the Master Controller, which connects to the already running Processing Unit. The user selects the specific monitor unit from which they want data. The processing unit collects the data and then returns it to the GUI, where it is displayed to the user.

3.2.4.6 Analyze Data

The user has the ability to use the Master Controller to analyze past data collected from various DO monitors. To do this, the user opens up the GUI portion of the Master Controller, which connects to the already running Processing Unit. The user enters the data they wish to view and the processing unit returns data from the data logger to the GUI, where it is displayed to the user.

3.2.4.7 Schedule Data Collection

The user has the ability to use the Master Controller to schedule recurring data collections on individual or multiple DO monitors. To do this, the user opens up the GUI portion of the Master Controller, which connects to the already running Processing Unit. The user enters the specific monitor units they wish to set up schedules for and the frequency of the sampling. This information is sent to the processing unit which stores the schedule for future sampling.

4 Evaluation

Our evaluation of the project was based upon how well we achieved our functional and non functional requirements stated at the beginning of the project. Unfortunately our advancements outpaced the progress of the 2^{nd} generation circuit board and program design being implemented by Integrated Sensor Technologies, Inc. This required us to feed the DO monitor unit dummy information in place of sampled information for use in testing our range of communications. Despite that setback, all of our improvements are functional and will be ready for implementation when ISTI completes their necessary upgrades.

Functional Requirement 1:
Data will be transmitted between master and control unit wirelessly.

Result :
Communication has been tested and verified between all points in the system. These points include: between master controller and transceiver, transceiver to transceiver, and transceiver to DO monitor unit.

Functional Requirement 2:
Data collection can be controlled by user via GUI.

Result :
Our graphical user interface has proven functional in communication with the data logger, Windows service application, and the DO monitor unit. Functions of the GUI include data viewing, sample schedule creation, and unit inventory.

Functional Requirement 3:
Master controller requested data.

Result :
The master controller is able to request data be taken immediately and also on a specific schedule as designated by the user via a GUI. The requests generated by the master controller are sent to the DO monitor unit transceiver which wakes up the DO monitor itself. The DO monitor unit will sample, and send the results back to the master controller where they are displayed to the user.

Functional Requirement 4:
Data logged on master controller.

Result :
Our master controller GUI is capable of storing all information sent from the transceivers. Current information we are ready to receive is DO levels in ppm and percentage, battery levels, tau number, and temperature. These values can be displayed on a graph to view trends or can be exported to a CSV file for matrix style viewing. All of these values can be sorted by the type of value and the time period in which it was taken.

Non-Functional Requirement 1:
Optimal transmission range of 1000m.

Result:
Testing showed optimal line of site transmission to reach approximately 2200m. Other testing was performed in an urban environment without line of sight and with much interference caused by buildings, cars, trees, and rain. These tests averaged around 400m.

Non-Functional Requirement 2:
System able to configure in star-like topology.

Result:
The system has successfully tested with two units and is concept-ready to accept more nodes. The restriction to two units was based on only having two DO oxygen monitor boards to work with at testing time.

Non-Functional Requirement 3:
Maximized battery life.

Result:
The original lifetime of the DO monitor unit was approximately eight hours before any improvements were made. We implemented a sleep mode which would cut down power consumption considerably by not using the processors when not testing. Exact measurements have not been taken due to constant circuit board redesigns, but sleep mode cuts current consumption down to a few milliamps when in sleep mode. Battery life will be more of a concern in future generations of the product when other options such as different batteries and solar panels can be considered.

Non-Functional Requirement 4:
Attach temperature probe to increase output accuracy.

Result:
A temperature probe has been designed and built to work with the unit. Unfortunately the 2^{nd} generation board being designed by the company is not yet complete and the proper inputs have not been placed on the boards we currently possess. The components will be service-ready by completion time of the newly redesigned circuit boards.