HydroSense: An Open Platform for Hydroclimatic Monitoring

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Abstract—In the world of water resource management, commercially available hydroclimatic monitoring systems are often large, expensive, and disconnected. As the desire to collect more data grows, the current technology is inaccessible to smaller community groups, citizen scientists, teachers, and even scientists needing to collect real time or high density data. The HydroSense project aims to build an open-source hardware and software framework to enable hydro-climatic monitoring in a cost effective manner. At present, several prototype system components have been designed, fabricated, and tested. Our design demonstrates that a complete hydroclimatic monitoring system can be deployed at 1/8th the cost of modern commercially available systems. Furthermore, we demonstrate the ability to interface with existing water quality sensors, allowing stakeholders the ability to use instruments they may already own.

Keywords—remote sensing, monitoring, watershed, hydrology, discharge, dissolved solids, innovative technology, environmental chemistry, Chesapeake Bay

I. INTRODUCTION

The United Nations states that water is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself [1]. It is vital for reducing the global burden of disease and improving the health, welfare and productivity of human populations. It is central to the production and preservation of a host of benefits and services for people. Water is also at the heart of adaptation to climate change, serving as the crucial link between the climate system, human society and the environment.

Sustainable management of water, both in the United States and around the world, requires the ability for communities to be able to measure key water quality parameters in their local streams, lakes, wetlands, and groundwater aquifers. A crucial element is access to affordable and reliable instruments that can be used to continuously measure basic water quality parameters at sufficient temporal and spatial resolution. Government agencies and universities incorporate these instruments in limited quantities as part of their assessment programs, but most local community groups, citizen scientists, and teachers cannot afford them. With increased monitoring density, pollution can be detected and prevented early or even eliminated entirely. Low-cost monitoring also enables precision conservation and prevention, a hot topic in the Chesapeake Bay Watershed.

Open-source technologies have been identified as the most promising solution to this challenge [2]. As a result, some watershed groups have begun developing their own low-cost monitoring solutions on an as-needed basis [3]. Bucknell University piloted this idea in 2014 [4] and 2015 [5], [6]. In 2014 researchers from Johns Hopkins University and Cornell University published an affordable open-source turbidimeter [7].

By developing a low-cost monitoring sonde that is compatible with modern computing systems and open-source development methodologies, we will enable local interest groups, communities, and individuals to readily deploy their own water quality monitoring stations. Data from these stations can be combined to provide quantitative measures of watershed health and help support sustainability efforts. Research centers like the Stroud Water Resource Center [3] and advocacy organizations like the Chesapeake Conservancy [2] are upfront about their needs for precision conservation technologies.

Despite the existence of professional water monitoring technologies, there exist two main hurdles that inhibit the widespread deployment of hydroclimatic monitoring systems. The first hurdle is the reliance on legacy industrial data loggers as the primary sensor interface. These systems are very flexible but as a result are also large, complex, expensive, and power hungry. The second hurdle is the lack of an affordable data collection network. Many systems log data to SD cards or USB sticks which are manually collected. Other approaches rely on costly cellular or satellite connections to deliver relatively small amounts of data to proprietary data collection software. Neither of these solutions is ideal for widespread hydroclimatic research.

Hydroclimatic parameters such as temperature, flow rate, pH, turbidity, etc. change very slowly relative to the data transmission speed of modern computers and computer networks. The sample rate of these parameters for long-term, continuous monitoring stations is in the scale of a few minutes to hours. The geographic separation between monitoring stations in a watershed depends on the study needs. Detailed investigations may place several sensors in a small area (less than 1 km²) while other projects may aim to cover a complete watershed with 2-100+ kilometers between sensors. For example, Figure 1 shows the 27,510 mi² Susquehanna River Basin. The Susquehanna River Basin Commission maintains a network of 58 monitoring stations in the basin. Each $20,000 station sam-
amples water temperature, pH, conductivity, dissolved oxygen, and turbidity every 5 minutes. Data is communicated using a combination of cellular and satellite communications [8]. Although a good starting point, this network only covers a small portion of the Susquehanna River Basin with detailed monitoring as it would be extremely costly to cover the entire basin. The goal of the HydroSense project is to develop a more practical solution to hydroclimatic motioning.

![A map of the 27,510 mi² Susquehanna River Basin](image)

### II. WATER QUALITY PARAMETERS

To provide maximum utility, six fundamental monitoring parameters were selected for initial support. Each of the supported parameters, along with a brief statement of their significance and measurement approach is detailed below.

**Water Temperature** is widely considered to be the most fundamental parameter. In addition to being needed for temperature corrections of pH, conductivity, and other sensors, temperature has significant biological and industrial importance. Temperature affects metabolic rates in organisms, oxygen concentration in water, and even compound toxicity. Furthermore, thermal pollution from power plants and industrial sites can seriously affect watersheds, increasing the need for monitoring of areas near their discharge. Water temperature can accurately be measured with a simple thermistor.

**Water Depth** or stage is a critical parameter in relation to flood conditions, effects of precipitation, and as a marker of water body volume [9]. Water depth can be accurately measured using widely available pressure sensors. The pressure sensor is submerged and the hydrostatic pressure generated by the water above is directly related to the water depth. Using this method it is important to account for the variable barometric pressure above the water surface. This can be done with a gauge referenced sensor and vented cable or by using a separate barometric pressure sensor [10] on the HydroSense datalogger. This allows simpler absolute pressure sensors to be used for depth measurement.

**Dissolved Oxygen** or DO is the amount of oxygen present in the water. It is particularly relevant to biologists as it is how aquatic organisms subsist. Oxygen is diffused into a body of water from the atmosphere, but also comes from photosynthesis of aquatic plants [9]. Dissolved oxygen can fluctuate during the day as a function of surface wind and solar radiation, making extended temporal monitoring of DO especially relevant for fish and wildlife agencies or other stakeholders monitoring aquatic life. Dissolved Oxygen can be measured with a polarographic or galvanic sensor probe. Both contain polarized electrodes isolated by a semi-permeable membrane [14]. Galvanic probes do not require an external voltage while polarographic probes do. Both types produce an output current (< 2µA) proportional to the amount of DO present. The low-level current signal can be converted by a transimpedance amplifier to a usable voltage level for a standard analog-to-digital converter.

**Specific Conductance** describes the ability of the water to conduct electricity. Minerals and other dissolved compounds increase the conductivity, especially in high flow conditions when sediments are washed into a body of water from the surface runoff. Conductance is correlated to total dissolved solids and turbidity [9]. Specific conductance sensor probes are widely available. When performing a measurement it is important to avoid DC signals which can cause chemical changes through electrolysis. Some approaches use alternating current signals but a simpler approach uses an easier to generate short-duration square-wave signal [15].

These six parameters cover the fundamental water-quality parameters and are suitable for studies on water level, quality, and biological conditions. However, there are important parameters we have left for future work. Below are three of the most important that are next on our list of parameters to support.

**Turbidity** is a measure of the cloudiness (or inversely, clearness) of water. We have intentionally left out support

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for turbidity as commercial water quality turbidity sensors are significantly more costly than the parameters above. However, there is ongoing work to develop a low-cost turbidity sensor [7]. Another possible approach is to adapt appliance-grade turbidity sensors (commonly used in dishwashers) to water quality measurement. We will explore both of these approaches in the future.

Two other important parameters are nitrates and phosphates. Nitrates are a form of nitrogen needed for plant growth. Nitrates can be washed into streams via surface runoff, which collect in rivers and bays where high concentrations are harmful. In an extreme condition, high levels of nitrates will rob the water of dissolved oxygen and block light from penetrating the water surface which is harmful to aquatic life [16]. Phosphates are important for the growth of aquatic plants and animals. However, high levels can speed up eutrophication (a reduction of dissolved oxygen caused by an increase in organic nutrients) of a body of water, causing similar problems to high nitrate concentrations [17]. Support for these parameters will be added in the future.

III. SYSTEM OVERVIEW

A diagram of the HydroSense components is shown in Figure 2. There are four key components: 1) a datalogger to store measurement data, 2) a water sonde (monitor) to interface to the various water quality sensors, 3) a weather sensor interface to interface to common weather sensors, 4) a 900 MHz long-range radio for communication, and optionally, commercial off-the-shelf SDI-12 digital sensors.

In addition to the hardware, open-source software libraries for Arduino and Raspberry Pi computers are being developed. It is important to provide open-access to the system to allow researchers and hobbyists alike to easily use and expand the system. HydroSense provides a complete foundation for deploying low-cost hydroclimatic monitoring stations.

The primary communication between the components is by a SDI-12 network. This protocol is unique because it requires a total of only 3 wires to communicate: power, ground, and a bi-directional serial data line. It is widespread in use, with the U.S. Geological Survey employing over 4,000 SDI-12 sensors in its data collection networks. The SDI-12 bus can connect up to 62 sensors over a distance up to 2,000 ft [18]. The protocol was designed for low power applications of low system cost with multiple sensors on one cable. Coupled with the many off-the-shelf SDI-12 compatible sensors available for weather and hydroclimatic monitoring, this protocol was the obvious choice around which to base our system.

Basic operation is driven by the datalogger which periodically polls the OpenSonde, weather interface, and other SDI-12 sensors. As data is received on the SDI-12 bus, it is stored on the SD card and simultaneously transmitted to the wireless base station. The base station can store the data locally, to a remote, or cloud-based database such as MySQL or MongoDB.

A. HydroSense Datalogger (1.)

The datalogger, shown in Figure 3, is at the center of the HydroSense system. It is responsible for powering, sampling, storing, and reporting data from the connected sensors. It is deployed on the river bank near the HydroSense OpenSonde or other sensors. To enable users to easily install new sensors, communications, or implement custom logic, the datalogger is based on the familiar Arduino Leonardo platform. In addition to the standard Atmel ATmega32U4, we add the following:

- Solar charge controller (LT3652H) with maximum peak power tracking and up to 2 A charge output for 12 V batteries [19].
- Wide input range (4.75-32 V) switched-mode power supply (R-78B3.3-1.0) providing up to 3.3 Watts of power at > 80% efficiency [20].
- SD card interface for storing data.
- Two SDI-12 [18] interfaces for connecting digital sensors.
- Barometric pressure sensor (BMP180) for compensating underwater pressure sensors. [10].
- Arduino shield headers.
- XBee radio headers.

Fig. 2. The four key components of the HydroSense system.

Fig. 3. The HydroSense Datalogger and sealed lead acid battery installed in a waterproof enclosure.
There are also several general purpose IO ports available for connecting additional instruments. It is fully compatible with the Arduino Integrated Development Environment (IDE) and complies with the Arduino standard shield interface. The HydroSense Wireless Link is designed specifically to connect to the Datalogger. However, many other Arduino compatible shields could also be used, such as specialized sensor interfaces, cellular data modems, or radios. The assembled board cost is $83.70 in low-volume. With a waterproof enclosure (≈$25.00), 12 V sealed lead acid battery (≈$30.00), and 15 Watt solar panel (≈$50.00), the datalogger is ready to deploy for less than $200.00 (excluding radio).

B. HydroSense OpenSonde (2.)

An underwater instrument is needed to measure water-quality parameters. In the field of water quality monitoring this instrument is referred to as a Sonde, the French word for probe. A robust enclosure is required to survive the underwater conditions. Figure 4 shows the prototype underwater enclosure for shallow water applications (e.g., rivers and streams). The enclosure is constructed from low-cost readily-available parts. The body is a clear 4 inch PVC tube. The top and bottom plates are laser cut from PVC and acrylic sheets. A suction pump strainer is used to protect the probes (not shown). Liquid-tight cord grips are used to seal measurement probes to the bottom plate. O-rings, bolts, and PVC cement are used to complete the assembly. Eye bolts provide secure connection points to anchor the Sonde. A single water-tight connector provides the 3-wire SDI-12 interface (+12 V, data, GND).

The HydroSense OpenSonde board is installed into the OpenSonde enclosure and interfaces to the underwater sensor probes. The sensors are monitored by the OpenSonde and the current values are stored in memory. The datalogger can poll the OpenSonde to retrieve the latest measurements. Like the datalogger, the OpenSonde PCB is based on the familiar Arduino Leonardo platform. This allows users to use the standard Arduino IDE and libraries to customize operation of the OpenSonde. In addition to the standard Atmel ATmega32U4, we add the following:

- One SDI-12 [18] interface to provide power (+12 V) and communication to the datalogger.
- Wide input range (7-28 V) switched-mode power supply (R-78E5.0-1.0) providing up to 5 Watts of power at > 80% efficiency [21].
- Two 16-bit delta-sigma analog to digital converters with programmable gain amplifier and input multiplexer (ADS1118) for monitoring two differential or four single-ended inputs (each) [22].
- Two dedicated analog front-ends for pH and ORP measurement (LMP91200) [12].
- Moisture protection circuit and sensors to disable power if water enters the enclosure.

Fig. 5. The HydroSense OpenSonde PCB, top and bottom view.

The mechanical sonde enclosure materials cost $86.66. The assembled PCB cost $110.00 in low-volume. The six sensor probes (temperature, pressure, pH, ORP, DO, and conductivity) totaled $865.00. This yields a total cost of $1,061.66 per sonde, excluding site-specific hardware such as steel cable, anchors, and the SDI-12 cable.

C. HydroSense Weather Interface (3.)

Weather can also have a strong impact aquatic conditions. Therefore, it is important to capture these parameters in the vicinity of the hydroclimatic monitoring stations. To accomplish this with HydroSense we have developed an interface to standard low-cost weather sensors similar to the sonde interface (except above the water). The sensors typically use simple analog interfaces on RJ11 connectors. A typical sensor set is shown in Figure 6. The analog sensors are sampled and stored in memory on the weather interface. The datalogger can poll the weather interface to retrieve the stored readings.

Like the datalogger and sonde, the weather interface is based on the Arduino Leonardo platform. This allows users to use the standard Arduino IDE and libraries to customize operation of the Weather Interface. In addition to the standard Atmel ATmega32U4, we add the following:
Fig. 6. Typical low-cost off-the-shelf weather sensors.

- One SDI-12 port to communicate weather readings to the datalogger.
- Two RJ11 ports with low-pass filters for connecting analog pressure and solar radiation sensors.
- One RJ11 port with low-pass filter for connecting an integrated anemometer and wind vane.
- One RJ11 port with low-pass filter for connecting a contact closure tipping bucket rain gauge.
- One RJ11 port to connect an external NTC thermistor.
- One RJ11 port with I2C for connecting external digital sensors.
- One 16-bit delta-sigma analog to digital converters with programmable gain amplifier and input multiplexer (ADS1118) for monitoring two differential or four single-ended inputs [22].

Fig. 7. The HydroSense Weather Interface PCB.

The weather interface PCB is shown in Figure 7. The assembled PCB cost is $76.82 in low-volume. The sensors (solar radiation, anemometer/weather vane, temperature, humidity, and rain gauge) total $465.00. With a waterproof enclosure ($≈25.00), the complete weather station cost is $≈566.82, excluding SDI-12 cable to the datalogger.

D. HydroSense Wireless Link (4.)

Often the goal of hydroclimatic monitoring is to assess the health of an entire watershed covering many thousands or tens of thousands of square miles with relatively few monitoring stations. As a result, we need a wireless link that can communicate over great distances. The HydroSense Wireless Link achieves long-range at the cost of low-data rate. The radio uses the CC1120 narrowband radio with CC1190 front-end providing 27 dBm output in the 900 MHz ISM band [23], [24]. Due to the low-data rate, a cellular model is used to avoid congestion caused by ad-hoc packet forwarding. Each radio network cell is managed by a base station node running on a Raspberry Pi computer with Internet access via DSL, cable modem, or cellular network. The expected communication range is 2 km - 25+ km depending on antenna height and terrain. A time and spatially synchronized network protocol (TDMA/SDMA) is being developed to allow efficient use of the limited network bandwidth and reduce the power consumption on each node by allowing very low duty cycles of the radio (e.g., ≪1%).

Fig. 8. Prototype HydroSense Wireless Link atop an Arduino Uno (without antenna). RF components are on the left side of the board, while peripherals are towards the right.

The HydroSense Wireless Link board includes a global positioning system (GPS) receiver for time synchronization and position awareness and a real-time clock to maintain precise timing without GPS. The board has a novel dual interface to provide compatibility as an Arduino Shield or a peripheral for a Raspberry Pi (models A/B and generations 1/2). This dual interface allows sensor nodes and gateway nodes to share the same wireless link board, reducing cost and development time. The base station nodes uses a Raspberry Pi to provide connectivity between the 900 MHz network and a WiFi or wired Ethernet Internet connection. Low-level hydroclimatic sensing applications are more suited to the Arduino platform due to its flexible hardware interface, improved timing, and lower power consumption. The assembled PCB cost is $102.03 in low-volume.

IV. System Testing

The HydroSense system is still under active development for field deployment in the Summer of 2016. Most of the subsystems have been tested in isolation. In this section we will briefly describe some of these preliminary tests and what is yet to be done.
A. Datalogger

To test the solar charger, a 15 watt PV panel was attached to the datalogger along with an 18 AH sealed lead acid battery. An Agilent 34401A multimeter was connected inline with the battery to measure the charge or discharge current of the battery. The setup, pictured in Figure 9a, allowed the testing of the solar charging system, designed around the LT3652HV. The LT3652HV handles all charging metrics and efficiently regulates the PV input, simplifying the circuitry required to add solar charging. With more components and additional cost, other battery chemistries could be supported, however the higher cost of lithium-ion or nickel-cadmium batteries limits their usefulness in a low-cost system.

In Figure 9b we see the measured battery current. The datalogger draws about 10 mA of current from the battery when there is no sun. As the day goes on, there are several spikes of up to 200 mA of charge current. The design limit of 1.5 A is not observed because 1) the day of the test was cloudy and 2) the battery was nearly full charged at the beginning of the test. This simple test verifies the charge circuit was able to charge the battery without interrupting power to the datalogger. In the future we will verify the maximum power point tracking and compute the efficiency of the charger.

The SD card was tested by periodically writing to a CSV file over a period of time. The written data was verified by simply plugging the SD card into an appropriate adapter into a computer; the FAT filesystem used allows all modern operating systems to easily read, write, and modify the contents of the SD card written by the Arduino. The Arduino SD Library was utilized to interface with a microSD card for easy, nonvolatile data storage due to its open source nature and abundant documentation. The library worked as expected, however it did require a large portion of the ATmega32U4’s flash memory. In the future we will investigate if the memory overhead can be reduced or if a microcontroller with more memory is necessary.

Another important functionality of the HydroSense system is the ability to accept third-party sensors. A research group may already own SDI-12 sensors or require specialized sensors outside the scope of the HydroSense system. Furthermore, these third party sensors are application-specific and come with certificates of calibration. For testing the functionality of third-party sensors with the HydroSense Datalogger we selected the Decagon Devices CTD-10 sensor. The CTD-10 measures water temperature, depth, and conductivity, useful for studies with groundwater wells [25]. Moreover, at less than $600 this sensor is reasonably priced for a professional sensor.

To implement the SDI-12 protocol on the Arduino-based datalogger we utilized the software SDI-12 library from the Stroud Water Resource Center [26]. This library uses a software serial library to implement the protocol, which uses only a single data line for serial transmissions. When polled (a process involving requesting the sensor to take a new reading then fetch the reading) a serial string is returned containing all three parameters as shown here:

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1+119+25.3+302
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The string is comprised of the sensor address (1), depth (119 mm), temperature (25.3 C), and conductivity (302 µS/cm). All values except the sensor address are preceded by the appropriate sign (either + or −); the sign characters serve as delimiters to separate each parameter. This string was easily parsed on the Arduino to obtain the three separate data points. To display this data it was then passed to a Python program which graphed the data in real time using the Matplotlib plotting library. This visualization (Figure 10) would be replaced with SD card datalogging in a field application, but serves as an excellent demonstration for interested users.

In order to reliably and accurately parse the serial data provided by the CTD sensor, a regular expression to search for and return the individual sensor values was used. Because the serial string may not contain all correct values (for example, if the parsing program is started when the serial buffer is not full).
Fig. 10. Output of the Decagon CTD-10 as collected by the HydroSense Data-logger. Changes in temperature, depth, and conductivity that were simulated in a tank in the lab and are displayed on the graph in real-time.

completely full), the data is validated before plotting to ensure no anomalies of record.

B. OpenSonde

The OpenSonde enclosure was constructed and fitted with six sensor probes (without PCB). After initial tests, the enclosure was submerged in a water tank for one week without any water infiltration. More testing is needed to verify performance at greater depths. For added protection in the field, we have been recommend to install the OpenSonde in another larger PVC tube (e.g. 6 inch diameter) to offer more protection from rocks and other debris.

The Texas Instruments analog-to-digital converters (ADC) on the OpenSonde board (and Weather Interface) provide 16-bit samples, which offers 64 times more precision than the ATmega32U4’s integrated 10-bit ADC. This allows analog sensors to be more finely and accurately read. We verified the operation of the high-precision ADC by testing a known voltage provided by a lab-grade power supply and measuring on both the ADC and a lab multimeter. Our readings agreed to the thousandths of volts which demonstrates that our software library interacting with the ADC is functioning properly. The pH, ORP, DO, and pressure sensors produce analog voltages that can be read directly by the high-precision ADC. While we did not specifically test these probes, sampling these output voltages is a simple task.

The square-wave conductivity test algorithm was implemented and produced accurate results when the probe was placed in various calibration solutions.

To complete the OpenSonde software, we will implement a variation of the SDI-12 protocol so the datalogger can communicate with the OpenSonde as a SDI-12 device.

C. Weather Interface

The weather interface PCB was connected to a set of SparkFun Weather Meters. The anemometer, wind vane, and the rain gauge all functioned as expected. An external Honeywell Digital Humidity/Temperature (HIH6030) sensor was connected via the I2C bus and reported accurate temperature and humidity values.

Similar to the OpenSonde, the weather interface requires a sensor-side implementation of the SDI-12 protocol. Once complete, this can be directly reused enabling the datalogger to query weather parameters using the SDI-12 protocol.

D. Wireless Link

The wireless link board is designed around the CC1120 radio. The radio communicates using the SPI interface. We are able to configure the radio and successfully transmit and receive packets. Further tuning is required to improve the RF performance. The onboard GPS and real-time clock also function as expected. We have developed a GPS time-based frequency-hopping spread spectrum (FHSS) algorithm to synchronize channel selection without incurring communication. To optimize the remaining TDMA timing parameters, we have been studying the performance of the radio and microcontroller (MCU) in the system. We have concluded to improve timing performance, separate the critical RF functions from routine data sampling, reduce memory usage on the datalogger, and enable FCC certification, our next revision will include an onboard MCU to handle critical radio tasks.

V. System Cost

The total cost for a HydroSense monitoring station is shown in Table I using the cost information from the initial prototypes. The prototype system is able to monitor six fundamental water-quality parameters, very similar to the $20,000.00 stations currently deployed for water-quality monitoring. Not included in this cost are materials required for deployment (mounting, anchors) and cabling. Including a generous budget for these items, it is clear that a HydroSense monitoring station can be deployed for less than $2,500.00.

TABLE I. Cost Breakdown of a Complete HydroSense Monitoring Station.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Datalogger</td>
<td>$83.70</td>
</tr>
<tr>
<td>Radio Link</td>
<td>$102.03</td>
</tr>
<tr>
<td>Weather Interface</td>
<td>$76.82</td>
</tr>
<tr>
<td>Weather Sensors (solar radiation, anemometer, wind vane, humidity/temperature, and rain gauge)</td>
<td>$465.00</td>
</tr>
<tr>
<td>Enclosure, 12 V battery, 15 Watt solar panel</td>
<td>$105.00</td>
</tr>
<tr>
<td>OpenSonde</td>
<td>$110.00</td>
</tr>
<tr>
<td>OpenSonde Enclosure</td>
<td>$86.66</td>
</tr>
<tr>
<td>OpenSonde Sensors (PH, ORP, DO, temperature, pressure, and conductivity)</td>
<td>$865.00</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$1,894.21</td>
</tr>
</tbody>
</table>

3https://www.sparkfun.com/products/8942
VI. CONCLUSIONS AND FUTURE WORK

Commercially available hydroclimatic monitoring equipment is supplied by well-established manufacturers at significant cost. Further, most of these systems rely on proprietary hardware and software interfaces. These factors make it impractical for small community groups, citizen scientists, and teachers to monitor local hydroclimatic parameters of interest. In this paper we present HydroSense, a complete open-source Arduino-compatible platform for practical hydroclimatic monitoring. Through our initial prototype, we have validated the primary functions of the system and demonstrate the total system cost is less than 1/8 th of commercial systems. All of the developed hardware and software components are freely available on our website, [http://hydrosense.net/](http://hydrosense.net/). We believe that by providing an open foundation to support low-cost hydroclimatic monitoring, we can fuel the next generation of hydroclimatic monitoring.

With the demonstration of the key components of the HydroSense system complete, we are preparing to deploy several monitoring stations this summer. These stations will be deployed alongside already deployed commercial stations to enable validation of the reported data. This deployment is certain to provide significant real-world feedback about the system. We will use these experiences to improve the future generations of the HydroSense system.

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REFERENCES


[19] Linear Technology Corporation, LT3652HV Power Tracking 2A Battery Charger, 2013, rev A.

[20] RECOM Power GmbH, R-78Bxx-1.0 DC/DC-Converter 1.0 AMP SIP3, 2015, rev 0.

[21] ——, R-78Exx-1.0 DC/DC-Converter 1.0 AMP SIP3 Single Output, 2015, rev 0.


[23] ——, CC1120 High-Performance RF Transceiver for Narrowband Systems, 2015, rev H.

