



Expanded Development of Consumer-level Unmanned Aerial Vehicles for Oceanographic Research

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Abstract:

Unmanned Aerial Vehicles (UAV) are rapidly proving their worth in many fields of science, yet their adoption in ocean sciences is lacking. UAVs are cost effective vehicles capable of being rapidly deployed and used in places dangerous and hard-to-reach for typical vessels. They are especially useful in the quick acquisition of data for rare events such as storm sewage outflow events that only occur for short periods of time after large storms in cities. Performed at the Ocean Tech Center at the University of Washington, this project works to prove the ability of UAVs to greatly improve efficiency, accuracy, and repeatability of nearshore research. A Splashdrone 3+ UAV was purchased and modifications and sensor design and implementation were conducted to adapt the UAV to perform nearshore science observation. The culmination of the project in a field test to retrieve water using a niskin-type sampling bottle and the gathering of temperature and total dissolved solids data proves that the UAV is a valuable tool for oceanographers over the traditional manned water-vessels and aircraft that are typical to the field of science.

Introduction:

Unmanned Aerial Vehicles (UAVs) are a range of remote controlled helicopters, quadcopters, powered-fixed wing aircraft and gliders that are typically extremely small, light, and cheap compared to their manned counterparts. UAVs are slowly making their way from the consumer hobbyist market to the world of science because they are allowing researchers to access more regions of interest with one device rather than the conventional collection of vessels and aircraft previously required (McGonigle et. al 2008). This also allows for data acquisition in volatile areas unsafe for humans (McGonigle et. al 2008). Rather than operating manned

aircraft, exposing both flight and ground crew to high levels of risk, UAVs are an extremely safe platform to operate. UAVs are also extremely capable of modular adaptability, allowing for a simple and quick change of sensor package to vary the mission set. These missions range from in situ data collection to remote sensing from the air— the options are extensive (Lomax et al. 2005). As the scientific research community using UAVs expand, there is incredible opportunity to leverage this new technology through the use of relatively cheap and easy to use consumer-available UAVs. This project will examine the application of consumer-available UAVs to nearshore ocean science and the feasibility of their use in today's market.

UAV's today are already being used in many fields of science, particularly in mapping and forestry. A recent study was conducted to look at the efficacy of UAV usage for rapid remapping terrestrial areas after major landslides destroyed much of the area (Puniach, 2018). Other researchers have used UAVs to monitor vegetation health by looking for signs of water-related stress and disease, hoping to improve farming efficiency and to ensure only wholesome food gets to the world's tables (Everaerts, 2008). UAVs have consistently proven themselves to be effective tools to retrieve data from hard-to-reach areas and doing so with time, cost, and infrastructure efficiency.

The goal of this project is to prove the efficacy of UAV systems as low cost, easy to use, and time efficient tools for the nearshore oceanographer operating in harsh environments. This project will prove that payload limits and functionality of consumer level UAVs fall within the operational requirements of nearshore ocean science. Also addressed will be the potential legal road-blocks to UAV use by citizen and student scientists. To achieve this, multiple modifications

and sensor systems were built and tested to be compatible with The University of Washington Ocean Tech Center's Splashdrone 3+ UAV. These include: A system similar to a traditional niskin bottle to capture water at the surface and then return it to shore for testing, taking in situ measurements both as point samples and as transects with a temperature sensor, total dissolved solids sensor, and a turbidity sensor, as well as using the onboard camera to aid in the use of tools such as a secchi disk.

Testing was performed throughout the build process and ended in a field trial case study. The case study focused on the water quality of the nearshore environment surrounding a simulated Carkeek Sewage Treatment plant in Seattle, WA. The Carkeek plant suffered critical mechanical casualties over the winter of 2017 which resulted in the flow of over 250 million gallons of untreated sewage into the Puget Sound (Mapes). The treatment plant, when exposed to far-greater-than-normal inflow, has to bypass the sewage directly into the Puget Sound. Sewage overflow poses a major threat to public health, and understanding of the potential exposure near the treatment plant should be widely publicized (Singh et al. 2004). This specific case study highlights all of the capabilities of UAVs in maximizing efficiency for nearshore environmental managers and researchers alike. The culmination of the Carkeek case study as well as the results from the other test series allow for a strong understanding of the capabilities of the UAV platform.

Methods:

This project developed through three distinct major stages. The first step was selecting a suitable retail-available UAV and appropriate sensors for nearshore ocean science. The second stage was the development of a complete sensor package and water-sampling device as well as modification of the UAV itself to accept the sampling equipment. The third stage was a case study performed in the field to test the final sensor package and sampling equipment in conjunction with the UAV.

Researching different consumer-level UAVs was the critical base to the success of this project to develop a UAV system for nearshore oceanographic research. Research began by comparing payload capacity, loiter time, cost, ease-of-use, features, and available customer support. Next, we needed to determine which sensors would be required to integrate within our test system to prove the feasibility of using UAVs in nearshore ocean science. An assortment of sensors were reviewed and it was determined that developing a simple Arduino powered temperature sensor, total dissolved solids, and turbidity sensor would be suitable. In addition to taking in situ sensor measurements, returning water samples to ship or shore is paramount to ocean science and we determined that producing a device to capture water samples was necessary to the project.

	Phantom 4 Advanced	Splashdrone 3+	S900
Cost (USD)	1500	2000	3500
Max payload (kg)	0.5	1.0	8.1
Flight Time (minutes)	~30	~25	~30
Native Camera	Yes	Yes	No

	Phantom 4 Advanced	Splashdrone 3+	S900
Native Controller	Yes	Yes	No
Modularity	No	Yes	Yes
Waterproof	No	Yes	No

Table 1: Comparison of consumer-level characteristics critical to UAV selection.

Design and Build:

Design began with the water sampling device that would be used by the Splashdrone 3+. Water sampling is regularly performed by oceanographers and many use the classic “Niskin” bottle (Gardner et. al). We first began with reverse engineering an example Niskin bottle that has previously been used within the

University of Washington School of Oceanography. The

design relies on a tube with both ends open and two end caps that are connected by some form of elastic chord. The two ends are pulled from from sealing the two ends and restricted in their movement until water-capture is intended. When the command to capture water is executed, the end caps are freed to move and the elastic band traps water within the tube. The basic concept of the Niskin bottle resulted in our first prototype show in Figure 1.

Needed improvements were identified and resulted in the design and build of our final iteration of the Niskin-type bottle after one more prototype. The changes needed were an improved end



Figure 1: Basic pieces of the prototype Niskin bottle, featuring an open tube, two end caps and an elastic connection chord.

cap shape, stronger elastic chord, and an effective way of connecting the end caps to the release mechanism on the Splashdrone 3+.

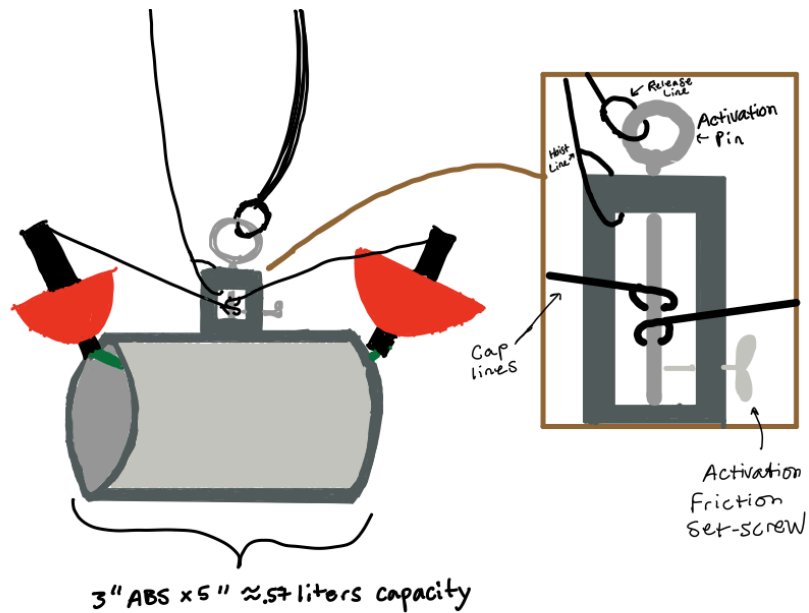


Figure 2: Design concept of Niskin-type bottle and associated actuation mechanism

Bench-testing this actuation mechanism proved this design effective and work then began on designing and building a frame to allow for the Splashdrone 3+ to carry and utilize the Niskin bottle. Extra clearance was needed under the factory landing gear to allow for the end caps to be cleared from the tube openings so water can flow through the tube unimpeded. This required a secondary landing gear to be built. Aluminum was chosen as the build material for its lightweight and high ductility, allowing for weld-free construction and easy hand-formed bends. The resulting secondary landing gear allowed for full clearance for the Niskin bottle to be mounted and for improved landing stability due to a wider based.



Figure 3: First prototype of landing gear with Niskin bottle mounted.

Next was the design and construction of the sensor package to be carried by the Splashdrone 3+. First, the required materials were determined as shown in table 2.

Part Name	Purpose	Brand	SKU #/Part #
Bluno	Arduino clone microcontroller to power and control sensors	DF Robot	DFR0416
Gravity Expansion Shield for Arduino	Offers I/O improvements for regular Arduino micro controllers	DF Robot	DFR0625
SD Card Expansion Shield	Allows for easy integration of SD card with Bluno board	DF Robot	DF0071
Analog Turbidity Sensor	Measures turbidity and outputs analog signal to Arduino board	DF Robot	SEN0189

Part Name	Purpose	Brand	SKU #/Part #
Total Dissolved Solids Sensor	Measures total dissolved solids in water and outputs analog signal to Arduino board	DF Robot	SEN0244
Temperature Sensor	Measures temperature and outputs analog signal to Arduino board	Gikfun	DS18B20
Micro SD Card	Stores sensor data	Sandisk	SDC4/8GBET
Energy Shield 2 Pro	Battery power source for Arduino board and provides realtime clock	Nighthawk	NSR-1002-1

Table 2: Part list of sensor package

The micro controller and associated parts were then connected and each sensor was programmed and tested individually until full functionality was reached (turbidity sensor was never fully operational). After data was successfully saving to the SD card, the electronics were moved to a watertight housing and cables were routed through watertight fittings. The electronics were then bench tested for water resistance and then were used in the field test.

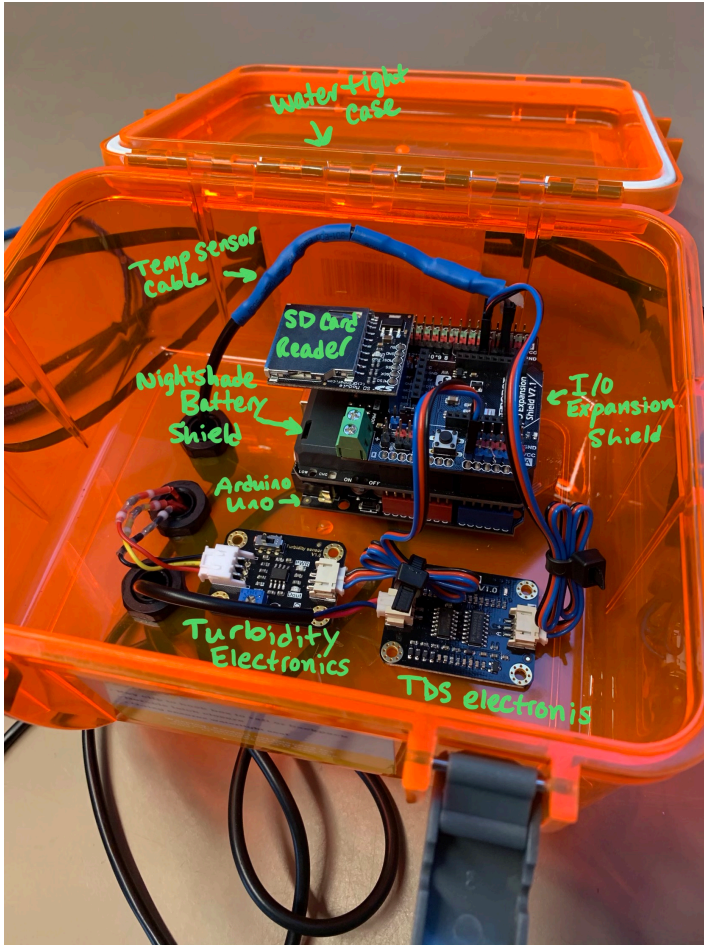
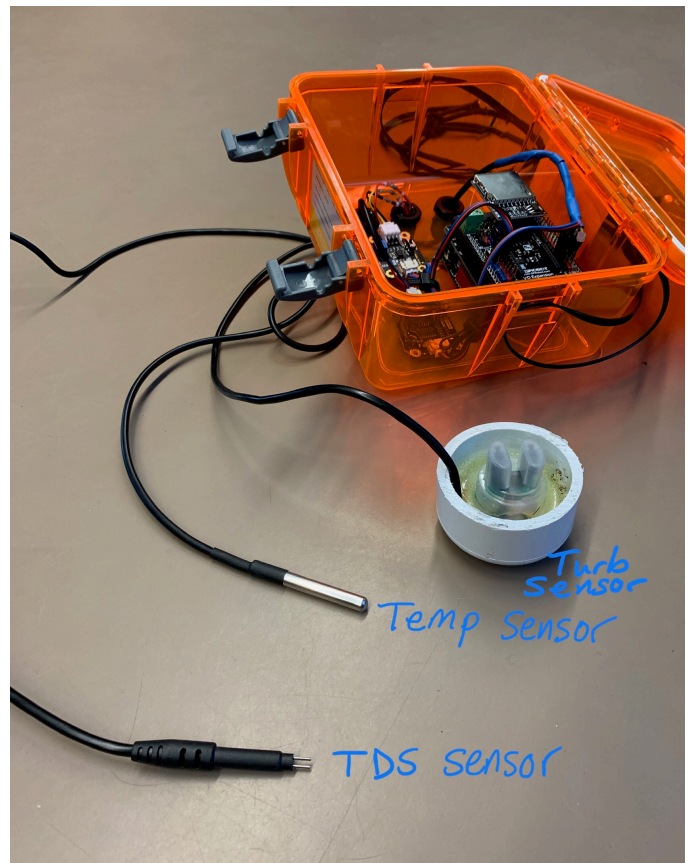


Figure 4: Diagram of sensor package and electronics within the watertight case.

Figure 5: Diagram of the sensor package outside of the watertight case.



All code for the sensor package was written within the Arduino IDE to enable all sensors to work in conjunction with the Arduino board (See Appendix A). Within the Arduino IDE, all appropriate libraries were imported and declared, in addition to Serial Peripheral Interface (SPI) and Standard Digital (SD) write protocols. All General Pin Input Output (GPIO) assignments were then made for physical connections between the Arduino board and sensors. The Nightshade Energy Shield, associated Real Time Clock (RTC), and SD card module were then initialized within the setup method. Within the standard loop method, sensor input is received and basic calculations are conducted to return temperature, turbidity, and total dissolved solids measurements. A string containing all data and time information is then assembled and saved to a file on the removable SD card for storage. The Arduino is then instructed to wait for 1 second before repeating the process.

Field testing was then conducted to test the functionality of the sensor package and Niskin bottle. Figure 6 depicts the series of events for the field testing which included surface water samples, in situ point samples with the sensor package, and a horizontal transect with the sensor package. Water samples



Figure 6: Field testing event locations

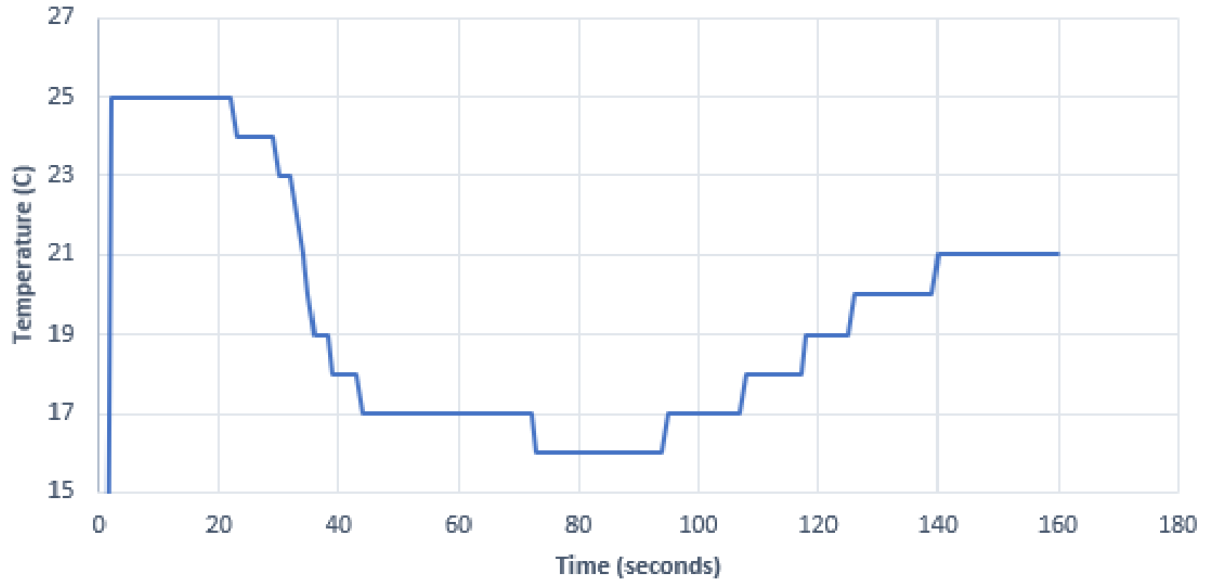
were taken and carried back to shore ready to go to a lab for further analysis. Horizontal transects began just off the shore of Ocean Science campus at the University of Washington. The sensor package was left to sit near the surface of the water (~1m) and was dragged away from shore for 80 seconds and then towed back in a slightly offset angle (~20 degrees to towards Ocean Teaching Building) to get results variability across the length of the lakefront of the Ocean Teaching Building. Each direction of the testing run lasted about 80 seconds and was 100m in length.

Results:

Operation of the Splashdrone 3+ was extremely easy throughout the entire work period. Ease-of-assembly and charging the batteries for the vehicle itself and the controller are both simple. Modification steps to use the niskin bottle and sensor package were also rather simple. The niskin bottle functioned well, however, future study should work to use lightweight materials to maximize water capturing capacity. Flight characteristics with the niskin bottle were also skewed from the regular design, and therefore research and development will have to go into refinements to improve center of gravity dynamics when the bottle is empty and the full, as well as testing more materials for the landing gear to ensure they do not catch on rough ground surfaces and induce a ground-flip.

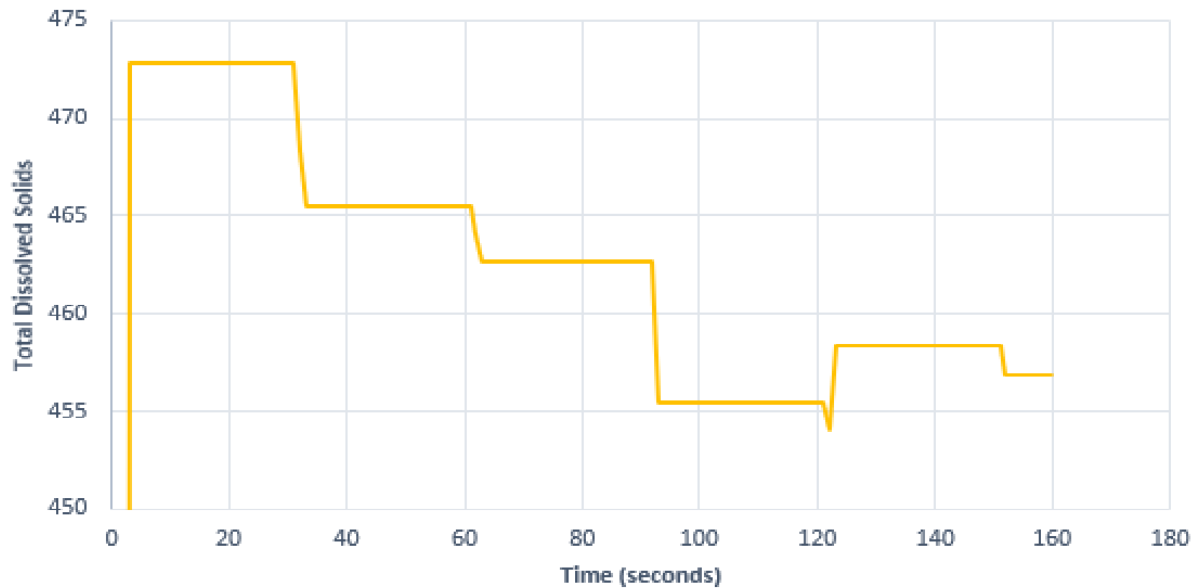
Data was captured effectively with the sensor package and data processing was very easy due to its simple formatting on the SD card aboard the Arduino Uno. The following two plots show the temperature and total dissolved solids data from one test run (the turbidity data all proved to be irrelevant due to sensor malfunction).

Temperature vs. Time



Plot 1: Plot of temperature at ~1 meter depth in Portage bay starting at shore. High first sample temperature is due to sensor equilibration

Total Dissolved Solids vs. Time



Plot 2: Plot of total dissolved solids at ~1 meter depth in Portage bay starting at the shoreline.

Discussion:

The field test readily illustrates the relative ease of which UAVs can be integrated into nearshore oceanography study. With simple UAV modification, many different sensor units can be attached and deployed and even water samples can be retrieved. Cost, additional capability, expandability, and even future technological advancements all show great promise in the UAV for research and prove them highly effective compared to or in compliment with their traditional ship/boat competition.

Legal restriction of UAVs has elevated in recent few years since the Federal Aviation Administration (FAA) has levied new restrictions on UAV operators (Unmanned). Operators are now required to obtain a Part 107 certification when flying a UAV for commercial or research purposes (Unmanned). These restrictions are entirely focused on safety of the operator and the general public, but it does add to the barriers of flying UAVs for citizen science in many cases. UAVs also face many local restrictions, often regulating where they can takeoff from and land. Seattle City Parks for example has banned the use of UAV usage anywhere on their property without a special use permit (Seattle). These restrictions can make access to the research subject waters legally inaccessible. Without immediate access to water via parks, many citizen scientists will likely have to be granted special permission to fly over individual property owner's land.

The primary benefit of the UAV is extremely low relative cost compared to ship acquisition, operation, and maintenance costs. A high level consumer drone only costs around 2000 dollars and can be flown for tens to hundreds of hours with electricity to charge the batteries as its only

cost. A simple 11 foot Boston Whaler costs around \$15,000 and regular maintenance and constant gasoline refills are needed to keep it running. The boat also requires a trailer and vehicle to tow it, whereas the UAV can be easily transported by hand or in the back of nearly any vehicle, lowering costs even further. High payload drones are also available and price is directly relatable, but these vehicles are more suitable for missions that would otherwise be carried out by manned aircraft. Average hourly operating costs of the extremely common Bell UH-1 Huey is \$13,000/hr, where that price is just for maintenance and fuel recuperation, not cost of ownership. Operating costs of the extremely capable MQ-9A Reaper drone comes in around \$4,000/hr. Manned and unmanned aircraft are not directly comparable as different capabilities come with both, yet the hourly operating costs and initial purchase costs are compared, it becomes abundantly clear that the frugal decision is to use a UAV over a manned aircraft when possible.

UAVs offer incredible flexibility in their deployment methods over the typical boat/ship due to the nature of the compact size, ability to fly over bad sea states, and quick deployability. Boats are easily constrained by their draft in shoal waters that may be the focus of study, whereas drones with their non-existent draft can easily operate in shoal waters with no risk of running aground. They also are capable of easily operating around islands and structures in the water without worry of collision compared to the unwieldy nature of water vessels. Boats are easily influenced by waves making research harder or sometimes evenly impossible. UAVs, however, are not particularly susceptible to rough seas and are able to keep operating, allowing for the research to continue.

Conclusion:

The question of feasibility of using commercially available UAV's for nearshore oceanography research is abundantly clear— they are an extremely useful resource to add to any oceanographers tool belt. Quality, capability, and expandability is greatly variable from UAV to UAV primarily based on cost, yet total cost remains to be non-prohibitively low compared to many other technologies such as conventional ship time. UAV usage in the private sector is still extremely young, and it is even younger in ocean science. The future of UAV usage is extremely bright as new systems are being developed frequently and scientists will learn how to leverage them more effectively to benefit their studies and improve research turnaround times most likely at a lower cost. The future of technology is autonomy and that very well is where science is leading as well, and the UAV will be at the forefront of this movement.

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Appendix A:

```

//libraries to include and variable declarations
#include <NS_energyShield2.h>
#include <NS_eS2_Uutilities.h>
NS_energyShield2 es2;

#include <OneWire.h>
#include <DallasTemperature.h>
/*****/
// Data wire is plugged into pin 2 on the Arduino
#define ONE_WIRE_BUS 2
/*****/
// Setup a oneWire instance to communicate with any OneWire devices
// (not just Maxim/Dallas temperature ICs)
OneWire oneWire(ONE_WIRE_BUS);
/*****/
// Pass our oneWire reference to Dallas Temperature.
DallasTemperature sensors(&oneWire);
/****/
#include <SPI.h>
#include <SD.h>
const int chipSelect = 10;

#define TdsSensorPin A1
#define VREF 5.0 // analog reference voltage(Volt) of the ADC
#define SCOUNT 30 // sum of sample point
int analogBuffer[SCOUNT]; // store the analog value in the array, read from ADC
int analogBufferTemp[SCOUNT];
int analogBufferIndex = 0, copyIndex = 0;
float averageVoltage = 0, tdsValue = 0, temperature = 25;

void setup()
{
  Serial.begin(115200);

```

```

es2.begin(); // Initializes the energyShield 2
delay(10);
es2.setTimeDate(00, 00, 00, 0, 00, 00, 00); //set the time for the RTC
pinMode(TdsSensorPin, INPUT);
int turb_in = 13; // Connect turbidity sensor to Digital Pin 2
pinMode(turb_in, INPUT); //Set the turbidity sensor pin to input mode
Serial.println("Dallas Temperature IC Control Library Demo");
sensors.begin(); // Start up the library
Serial.print("Initializing SD card...");

// see if the card is present and can be initialized:
if (!SD.begin(chipSelect)) {
  Serial.println("Card failed, or not present");
  // don't do anything more:
  while (1);
}
Serial.println("card initialized.");

//prints string with data formatting stored on file
File dataFile = SD.open("datalog.txt", FILE_WRITE);

// if the file is available, write to it:
if (dataFile) {
  String formatIndex = ("H , Min, Sec, M, D, Y, Temp, Turb, TDS");
  dataFile.println(formatIndex);
  dataFile.close();
}
// if the file isn't open, pop up an error:
else {
  Serial.println("error opening datalog.txt");
}

}

void loop()
{

  int turb = digitalRead(4); // read turb
  int sensorValue = analogRead(A0); // read the input on analog pin 0:
  float voltage = sensorValue * (5.0 / 1024.0); // Convert the analog reading (which goes from 0 -
1023) to a voltage (0 - 5V):
  // call sensors.requestTemperatures() to issue a global temperature
  // request to all devices on the bus
  /*****/

```

```

Serial.print(" Requesting temperatures...");
sensors.requestTemperatures(); // Send the command to get temperature readings
Serial.println("DONE");
/*****/
Serial.print("Temperature is: ");
int loggedTemp = sensors.getTempCByIndex(0);
Serial.println(sensors.getTempCByIndex(0)); // Why "byIndex"?
/*****/
Serial.print("turbidity");
Serial.println(turb); // print out the value you read:

/*****/
static unsigned long analogSampleTimepoint = millis();
if (millis() - analogSampleTimepoint > 40U) //every 40 milliseconds,read the analog value from
the ADC
{
    analogSampleTimepoint = millis();
    analogBuffer[analogBufferIndex] = analogRead(TdsSensorPin); //read the analog value and
store into the buffer
    analogBufferIndex++;
    if (analogBufferIndex == SCOUNT)
        analogBufferIndex = 0;
}
static unsigned long printTimepoint = millis();
if (millis() - printTimepoint > 800U)
{
    printTimepoint = millis();
    for (copyIndex = 0; copyIndex < SCOUNT; copyIndex++)
        analogBufferTemp[copyIndex] = analogBuffer[copyIndex];
    averageVoltage = getMedianNum(analogBufferTemp, SCOUNT) * (float)VREF / 1024.0; // read
the analog value more stable by the median filtering algorithm, and convert to voltage value
    float compensationCoefficient = 1.0 + 0.02 * (temperature - 25.0); //temperature
compensation formula: fFinalResult(25^C) = fFinalResult(current)/(1.0+0.02*(fTP-25.0));
    float compensationVolatge = averageVoltage / compensationCoefficient; //temperature
compensation
    tdsValue = (133.42 * compensationVolatge * compensationVolatge * compensationVolatge -
255.86 * compensationVolatge * compensationVolatge + 857.39 * compensationVolatge) *
0.5; //convert voltage value to tds value
    Serial.print("TDS Value:");
    Serial.print(tdsValue, 0);
    Serial.println("ppm");
}
// make a string for assembling the data to log:
es2.readClock();
String dataString = String(es2.hour());
dataString += ",";

```

```

dataString += String(es2.minute());
dataString += ",";
dataString += String(es2.second());
dataString += ",";
dataString += String(es2.month());
dataString += ",";
dataString += String(es2.dayOfMonth());
dataString += ",";
dataString += String(es2.year());
dataString += ",";
dataString += String(loggedTemp);
dataString += ",";
dataString += String(turb);
dataString += ",";
dataString += String(tdsValue);

// open the file. note that only one file can be open at a time,
// so you have to close this one before opening another.
File dataFile = SD.open("datalog.txt", FILE_WRITE);

// if the file is available, write to it:
if (dataFile) {

    dataFile.println(dataString);
    dataFile.close();
    // print to the serial port too:
    Serial.println(dataString);
}
// if the file isn't open, pop up an error:
else {
    Serial.println("error opening datalog.txt");
}
delay(1000);
}
int getMedianNum(int bArray[], int iFilterLen)
{
    int bTab[iFilterLen];
    for (byte i = 0; i < iFilterLen; i++)
        bTab[i] = bArray[i];
    int i, j, bTemp;
    for (j = 0; j < iFilterLen - 1; j++)
    {
        for (i = 0; i < iFilterLen - j - 1; i++)
        {
            if (bTab[i] > bTab[i++])
            {

```

```
    bTemp = bTab[i];
    bTab[i] = bTab[i++];
    bTab[i + 1] = bTemp;
  }
}
}
if ((iFilterLen & 1) > 0)
  bTemp = bTab[(iFilterLen - 1) / 2];
else
  bTemp = (bTab[iFilterLen / 2] + bTab[iFilterLen / 2 - 1]) / 2;
return bTemp;
}
```

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