研究・活動成果報告書

衛星を利用した世界的水位観測ネットワーク

1.0

大学宇宙工学コンソーシアム (UNISEC)

2016/09/20

作成：東北大学　桒原 聡文

添付文書：

[1] 水位計測用 HY-3 受信実施結果.pdf
[2] S&F Ground Station System Description.pdf
[3] S&F Field Test Report.pdf

改訂年月日	版数	改訂履歴	作成
2016/09/20	1.0	初版	東北大学 栗原　聡文

1. 概要

本文書はWNI気象文化創造センターからの第四回気象文化大賞受賞を受け、「衛星を利用した世界的水位観測ネットワーク」に関して実施した研究開発活動の成果報告を行うものである。本研究開発においては以下の項目を目標とした。

イ) 小型軽量な水位観測装置の研究開発

ロ) 超小型人工衛星を用いたデータ中継技術の実証

ハ) 留学生を対象とした水位観測装置政策のハンズ・オン・トレーニング

ニ) イリジウム衛星を用いたデータ中継・運用の模擬実験

本研究開発活動を実施するにあたり、初版の事情によりUNISEC内で実施者の交代があった。それに伴い、実施期間が1年3ヶ月延長された。2015年度にイ)及びロ)を、2016/2017年度にハ)及び二)を実施した。以降これらについて成果をまとめる。

2. 2015年度成果報告

地上無線機から、水位データおよび送信機番号を送信し、軌道上にある超小型人工衛星HY-3号機で受信ができることを確認した。また、受信したデータを解析、データの復調を行うことで、通信が正常に行われたことを確認した。この詳細な報告は以下の文書に譲る。

[1] 水位計測用HY-3受信実施結果.pdf

尚、本実験で用いられた電波中継技術は、以下の出願特許に依る。

出願2013.4.1,「衛星を利用したデータ中継システムおよびデータ中継方法」桒原聡文・小島要, 日本, 特願2013-76520

3. 2016/2017年度成果報告

東北大学では上述の中継システムを現在開発中の超小型人工衛星にも搭載していく方針である。これにより超小型人工衛星によるS&Fデータ中継コンステレーションを構築し、世界規模での現地観測網の構築を目指している。このような背景から、東北大学の留学生を対象に、上記ハ)、及び二)の活動を実施した。対象となったのは、ベトナム人留学生4名、フランス人留学生1名、アイルランド人研究員1名、日本人学生複数名であった。特にニ)に関しては、現在東北大学で研究開発している、水質及び水位測定システムを題材として用いた。これは地球上の水域に分散的に配置された測定局からのデータを衛星を用いて収集し、衛星からの光学観測データとの比較評価によりより詳細かつ角度の高い観測データを取得することを目指すものである。この技術は水位計測と合わせ、世界各国の協力の下実施していくことに意義がある。

対象となったのが留学生であったことから、本活動の内容、及び成果報告は主に英語で記述してある。本活動報告の詳細は以下の文書に譲る。尚、2016/2017年度に関しては小型測定局を構成するのに必要な電気部品、太陽電池及び二次電池、国内3G回線通信費、並びにイリジウム衛星中継に必要となる装置及び通信費に予算を使用させていただいた。本活動の結果、将来的な世界的水位観測ネットワークの構築のための基盤を構築することができた。今後UNISECの活動として更に活動の幅を広げていけるよう努めたい。

[2] S&F Ground Station System Description.pdf

[3] S&F Field Test Report.pdf

(ここまで)

水位計測用 HY-3 受信

実施結果

初版

2015 年 5 月 21 日

東京大学　中須賀研

承認	査閲	作成
		松本

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1. 試験目的と実施項目

地上無線機から、水位データおよび送信機番号を送信し、軌道上にある HY-3 号機で受信ができることを確認する。また、受信したデータを解析、データの復調を行うことで、通信が正常に行われたことを確認する。構成を図1-1 に示す。

1.1 実験概要

(1) 送信機からの電波を千葉県犬吠崎で発射し、それを衛星の受信機で受信し、メモリに溜める。

(2) パッチアンテナを衛星に手動で向けることで、確実に衛星に電波を届ける。

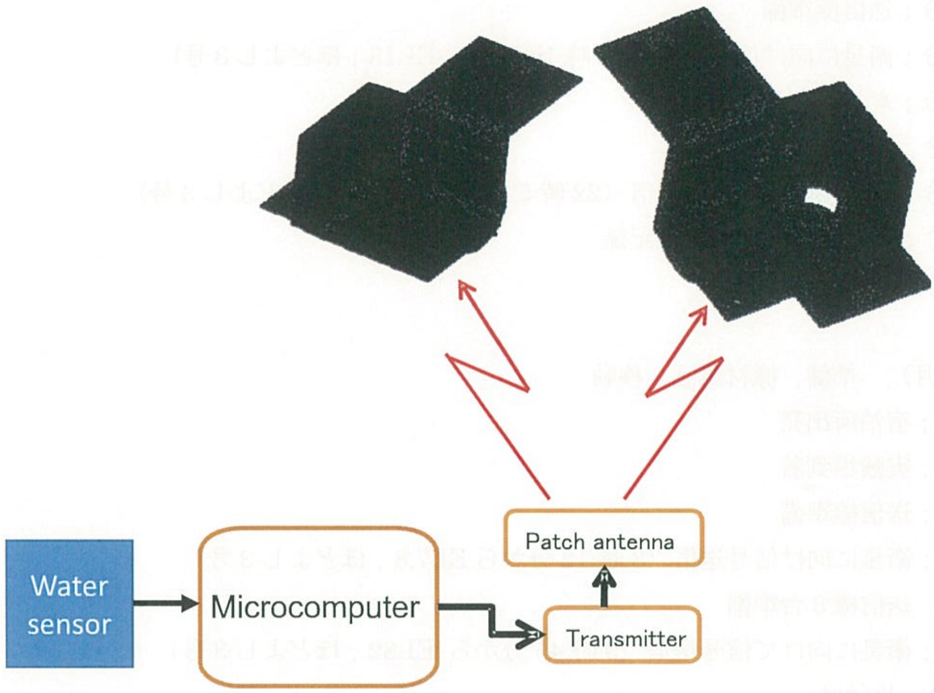

図 1−1 実験システムの概要

2. 実験概要

2.1. 実施場所

2015 年 5 月 17・18 日

〒288-0003 千葉県銚子市黒生町　鹿島灘

緯度 35.733826, 経度 140.870406

添付図 1 に実験場所の地図を示す。

2.2. 参加者（敬称略、順不同）

＋中澤　賢人

＋松本　健

2.3. 現地実施期間、作業スケジュール

実施期間： 2015年5月17日（日）

作業スケジュール：

5月17日（日） 準備、機材組込、移動

16時30分；東大出発
19時00分；実験場所到着（下見）
19時30分；実験場所出発
20時30分；宿泊所到着
20時50分；宿泊所出発
21時00分；送信機準備
21時15分；衛星に向け信号送信（21時16分からEL13；ほどよし3号）
21時35分；水位計計測
22時30分；送信機準備
22時50分；衛星に向けて信号送信（22時52分から EL41；ほどよし3号）
23時20分；実験場所調査および記録
23時50分；撤収

5月18日（月） 準備、機材組込、移動

7時30分；宿泊所出発
8時00分；実験場到着
8時10分；送信機準備
8時12分；衛星に向け信号送信（8時12分からEL7.8；ほどよし3号）
9時40分；送信機8台準備
9時42分；衛星に向けて信号送信（9時45分から EL82；ほどよし3号）
10時15分；片付け
10時30分；水位計設置および記録
11時30分；撤収

3. 搬入器材

3.1. 東大から持ち出し 試験終了後戻し

① RFケーブル(5m, SMA-M) 3本
② バッテリー(5V) 4個
③ 水位計 1式
④ arduino、送信機、アンテナ 8台
⑤ USBケーブル 5本

3.2. ほどよしEM品、予備品

① マルチメータ(テスター) 1個
② 変換コネクタ 5個

③　可変 ATT(10dB Step, 110dB)　　1 個

④　可変 ATT(1dB Step, 11dB)　　1 個

⑤　固定 ATT(20dB)　　1 個

⑥　副資材

＊ガムテープ

＊両面接着テープ

＊カッターナイフ

＊USBメモリ

＊ビニール袋 45L　10枚以上

＊巻尺(5m)

⑦　カメラ

4. 通信概念図

地上模擬実験の通信概念図を図 4-1 に示す。

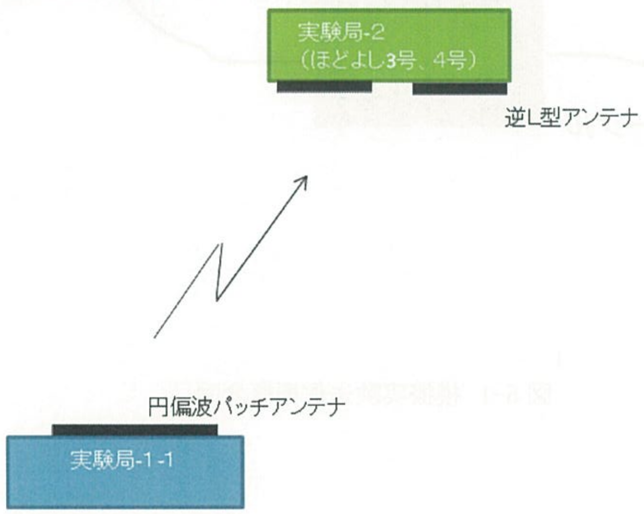

図 4-1　空間移動模擬実験概念図

5. 送信機概念図

地上模擬実験の送信機概念図を図 5-1 に示す。

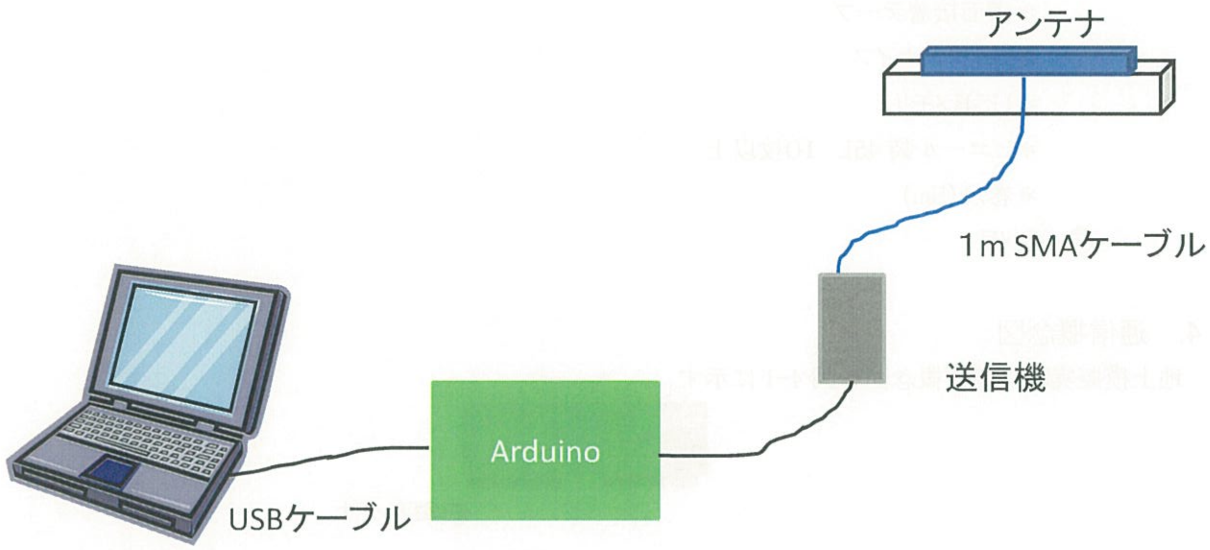

図 5-1 模擬実験送信機概念図

6. 通信フォーマット

- 本実験では Arduino マイコンを用いて送信機型番を 10 秒間おきに衛星に向かって送信する。
- 変調は ASK 信号(DPD認識コード 40ksps,10 秒)＋BPSK 320bps(データ部)とする。
- 通信フォーマットおよびデータ量を表 6.1 に示す。

表 6.1 データ量およびデータフォーマット

	データ量[byte]	例
EB90	2	
data	26	11111111・・・
EB90	2	

- 送信されるデータ例(Hex)

EB9011111111111・・・EB80EB911111111・・・EB81

7. 実施手順

7.1 事前準備

(1) 受信側組み付け受信確認

作業者	作業	確認
	・電気＋ＲＦ配線	□
	送信機準備	
	・Arduino と送信機を接続する。	□
	・Arduino とパソコンを接続する。	□
	＊Arduino の電源を、PC の USB から取ること。	
	・Arduino ソフトウェアよりプログラム名「_20150518_chiba」or「_20150517_water_sensor」を転送する。	□
	・アンテナを上空が見えるところに設置する。(シールド線はつながない)	□
	・送信アンテナは車の屋根に固定する場合と手動で衛星方向に向けて実験をおこなう。	□

8. 実験

実施期間：　2015年5月17日（日）

時間	作業	確認
19時00	①　実験場所到着（下見）	□
21時00分	②　送信機にＲＦケーブルを接続。電源コードは２本を接続。	□
21時15分	③　[実験1]衛星に向け信号送信（21時16分からEL13；ほどよし3号） 図8-1に実験中の写真を示す。	□ □
21時35分	④　水位計計測 図8-2に水位計測中の写真を示す。	
22時30分	⑤　送信機準備	□
22時50分	⑥　[実験2]衛星に向けて信号送信（22時52分から EL41；ほどよし3号）	□
23時20分	⑦　実験場所調査および記録	□
23時50分	⑧　撤収	

実施期間：　2015年5月18日（月）

作業者	作業	確認
8時00分	⑨　送信機にＲＦケーブルを接続。電源コードを接続。	□
8時10分	⑩　送信機および回路を接続	□
8時12分	⑪　[実験3]衛星に向け信号送信。送信機1台を1分として、8台を順番に試験。（8時12分からEL7.8；ほどよし3号）実験中の写真を図8-3に示す。	□
9時40分	⑫　送信機および回路を接続	□
9時42分	⑬　[実験4]衛星に向け信号送信。送信機1台を1分として、8台を順番に試験。（9時45分から EL82；ほどよし3号）	□

10 時 15 分	⑭　片付け	□
		□
10 時 30 分	⑮　水位計設置および計測 図 8-2 に水位計測中の写真を示す.	
11 時 30 分	⑯　撤収	□

図 8-1　実験中写真

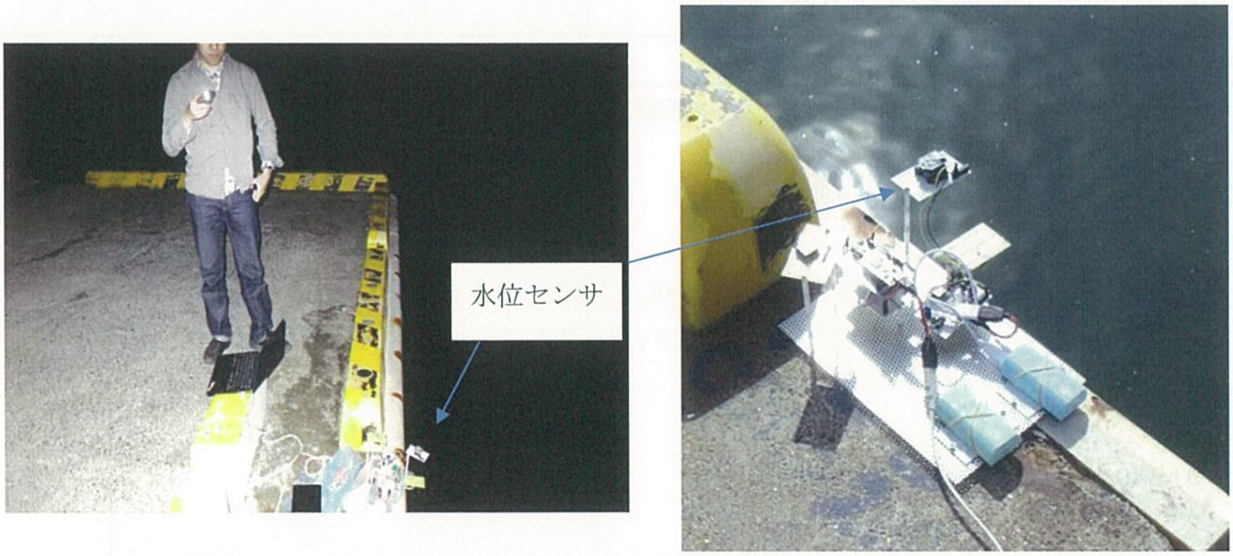

図 8-2 実験中写真


送信アンテナ

図 8-3 実験中写真

9. 実験結果

[実験 1 の結果]

信号を受信し、デコード出来た。

[実験 2 の結果]

信号を受信し、デコード出来た。

[実験 3 の結果]

信号を受信し、デコード出来た回数は 0 回であった。

[実験 4 の結果]

信号を受信し、デコード出来た回数は 0 回であった。

10. 考察

本実験を行った際、衛星の姿勢が不安定となっていたことが後日わかった。そのため夜では受信できたものの、朝になって衛星受信面が地上方向を向いていなかったと考えられる。

11. まとめ

今回水位計測システムを用いたほどよし S&F とのかみ合わせでは、衛星と正常に通信が出来ることが確認できた。

添付図１

川口町
銚子ポートタワー
ウオッセ21
ヤックスドラッグ
銚子明神町店
ケーヨーデイツー
銚子明神店
港町
仲町
銚子本町郵便局
通町
植松町
田原缶詰
竹町
幸町
銚子市立第一中
浜めし
新地町
橋本町
銚子植松郵便局
中央町
銚子本通郵便局
和田町
清水町
黒生町
千葉銀行銚子支店
新生町
島田総合病院
後飯町
東町
馬場町
陣屋町
銚子電気鉄道線
本銚子
銚子市立双葉小
円福寺
南町
観音
仲ノ町
妙見宮妙福寺
前宿町公園
愛宕町
笠上黒生
一山いけす
銚子市立第三中
銚子愛宕郵便局
銚子市野球場
銚子市立病院
西海鹿島
妙見町
西小川町
榊町
海鹿島町
南小川町
千葉県立銚子高
稲生神社
国木田
独歩詩碑
海鹿島
(株)カスミ 南小川店
小畑新町
海鹿島保育所
大徳ホテル
高神原町
君ヶ浜
ファミリーセンター
タカヨシ小畑店
ヤックスドラッグ
銚子南小川町店
粟島町
ポーツ
センター
渡波岐神社
君ケ浜
君ケ浜しおさい公園
Earth
君ヶ浜
Google

STORE AND FORWARD GROUD STATION SYSTEM DESCRIPTION

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List of abbreviates

DPD	Data Packet Decoder
DPT	Data Packet Transmitter
MDG	MicroDragon
SBD	Short Burst Data
S&F	Store and Forward
SFGS	Store and Forward Ground Station

1. Introduction

Store and Forward ground station (SFGS) is a part of Store and Forward mission of MicroDragon (MDG) satellite. Vietnam has a long coastal. Fishery and seafood aquaculture have an important role in Vietnamese economic. Effectively monitoring coastal line and coastal water quality is a key of developing fisheries of Vietnam.

The objectives of SFGS are:

- Monitoring water quality and water level for science purpose
- Transmitting sensor data to a satellite which has a compatible receiver.
- Working as a standalone system when the system lost connection to network.

A SFGS is equipped:

- A set of water quality sensors
- A water level sensor HC-SR04.
- A solar power supply solution which makes SFGS become a standalone system.
- A 3G network module with an antenna
- A Data Packet Transmitter (DPT) with an antenna which can communicate with a satellite has a compatible receiver.

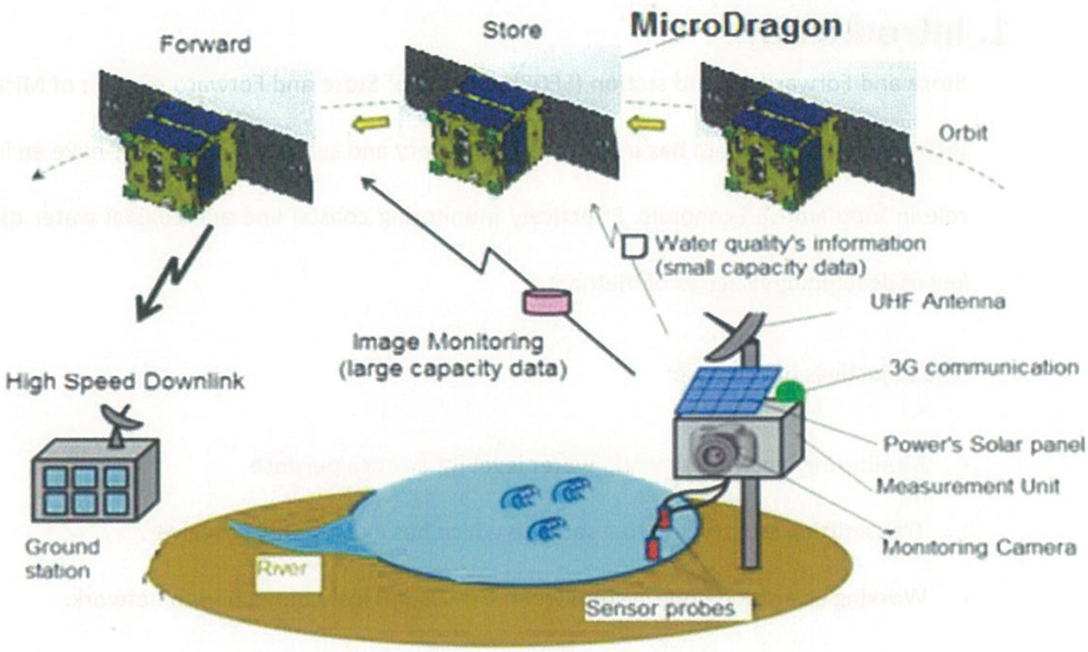


Fig 1. Store and Forward Mission

In a working scenario, SFGS measures water quality and water level. After finishing the measurement and encoding data, if SFGS is tracking a satellite, it will transmit sensor data to satellite. The satellite *stores* the data and *forwards* data when it has connection to satellite ground station.

2. System block diagram

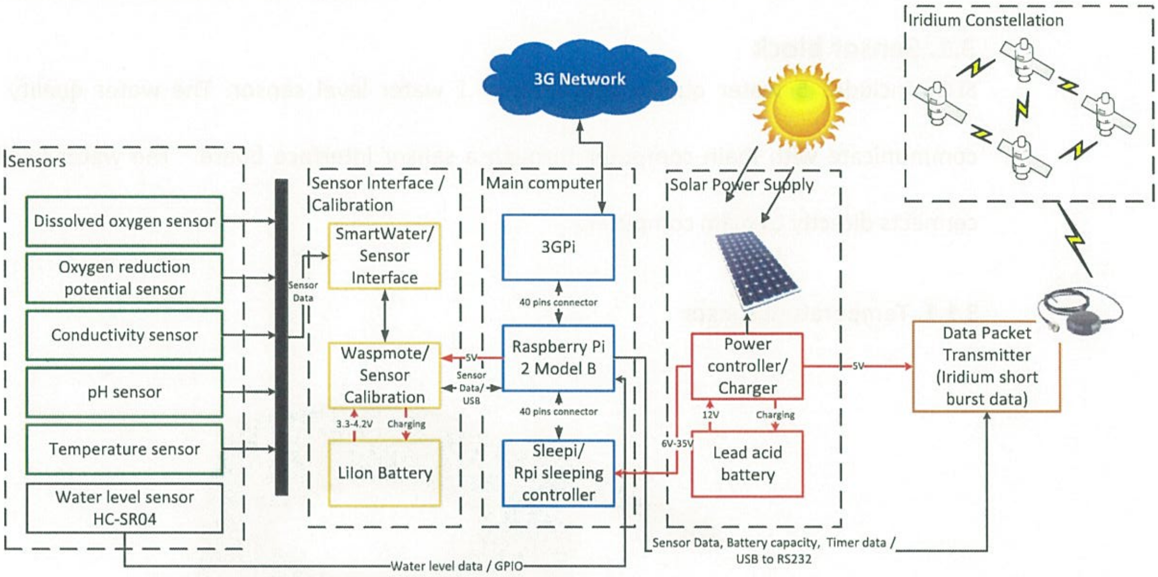


Fig 2. Store and Forward Ground Station Block Diagram

In a normal working scenario, main computer block and sensor interface/calibration block stay in sleep mode thanks to Sleepi module. These block only wake up at predefined time in one day. After waking up, sensor interface/calibration block reads water quality data, encodes it and send to main computer block. After receive water quality data, Raspberry Pi will measure water level, format it with water quality data together and save it into MicroSD card. Raspberry Pi use a flag to know which packet is not sent.

When saving data process have already finished, Raspberry Pi check Iridium network is available or not. If it is available, Raspberry Pi will request Iridium short burst data send sensor data packets one by one.

In the final of a successful scenario, you will receive an email include sensor data packet from Iridium.

3. Hardware Equipment

3.1. Sensor block

SFGS includes 5 water quality sensors and 1 water level sensor. The water quality sensors communicate with main computer through a sensor interface board. The water level sensor connects directly to main computer.

3.1.1. Temperature sensor

Fig 3. Temperature sensor

Measurement range: 0 ~ 100ºC

Accuracy: DIN EN 60751

Resistance (0ºC): 1000Ω

Diameter: 6mm

Length: 40mm

Cable: 2mm

Cable length: < 150mm

3.1.2. Conductivity sensor

Fig 4. Conductivity sensor

Sensor type: Two electrodes sensor

Electrode material: Platinum

Conductivity cell constant: 1 ± 0.2 cm^{-1}

Cable length: < 500 cm

3.1.3. Dissolved Oxygen sensor

Fig 5. Dissolved Oxygen sensor

Sensor type: Galvanic cell

Range: 0~20mg/L

Accuracy: ±2%

Maximum operation temperature: 50ºC

Saturation output: 33mV ±9mV

Pressure: 0~100psig (7.5Bar)

Calibration: Single point in air

Response Time: After equilibration, 2 minutes for 2mV

Cable length: < 102 cm

3.1.4. pH sensor

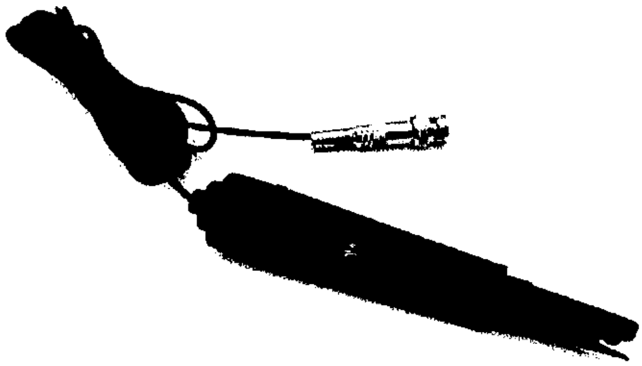


Fig 6. pH sensor

Sensor type: Combination electrode

Measurement range: 0~14pH

Temperature of operation: 0~80ºC

Zero electric potential: 7±0.25p

Response time: <1min

Internal resistance: ≤250MΩ

Repeatability: 0.017

PTS (percentage of slope): >98.5

Noise: <0.5mV

Alkali error: 15mV

Reader accuracy: up to 0.01 (in function of calibration)

Cable length: < 300 cm

3.1.5. Oxidation-reduction potential sensor

Fig 7. Oxidation-reduction potential sensor

Sensor type: Combination electrode

Electric Potential: 245~270mV

Measurement range: 0 ~ ±1999mV

Reference impedance: 10kΩ

Stability: ±8mV/24h

Cable length: < 300 cm

3.1.6. Water level – ultrasonic sensor

Fig 8. Water level sensor

Sensor part: HC-SR04

Working Voltage: DC 5 V

Working Current: 15mA

Working Frequency: 40Hz

Max Range: 4m

Min Range: 2cm

Measuring Angle: 15 degree

Dimension: 45*20*15mm

3.2. Sensor interface block

Sensor interface/calibration block is designed for calibrating, formatting the sensor data and communicating with the main controller. A Sensor interface block includes two modules:

- Waspmote – A calibration sensor and communicate board.
- SmartWater – A sensor interface board

The roles of SmartWater are

- Communicate with sensor
- Convert the sensor data to digital format
- Send the sensor data to Waspmote.

The roles of Waspmote are:

- Calibrate the measurement data
- Encode a data packet which includes sensor data, timer data, and battery level.
- Send the data packet to main computer – Raspberry Pi 2 model B.

Notice: Sensor interface block need its own battery which does not relate to Lead – Acid battery.

3.2.1. Waspmote Features

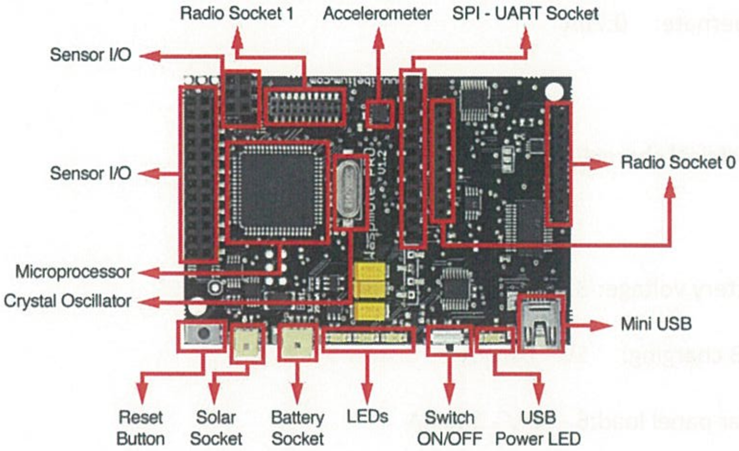


Fig 9. Waspmote – sensor calibration board (above)

Microcontroller:	ATmega1281
Frequency:	14MHz
SRAM:	8KB
EEPROM:	4KB
FLASH:	128KB
SD Card:	2GB
Weight:	20gr
Dimensions:	73.5 x 51 x 13 mm
Temperature range:	[-10ºC, +65ºC]

Consumption

ON:	15mA
Sleep:	55uA

Deep Sleep: 55uA

Hibernate: 0.7uA

Electrical characteristics

Battery voltage: 3.3V - 4.2V

USB charging: 5V - 100mA

Solar panel load:6 - 12 V - 280mA

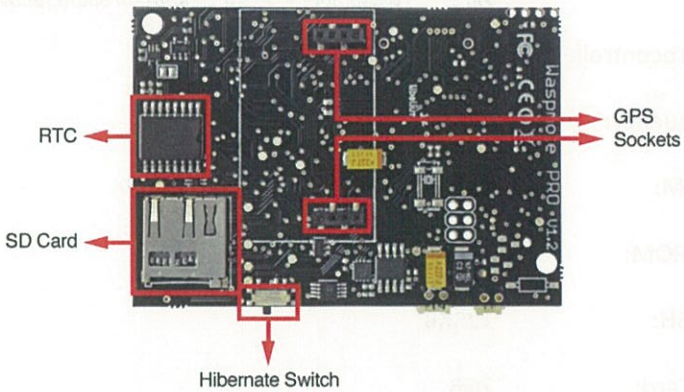


Fig 10. Wapsmote – sensor calibration board (under)

3.2.2. SmartWater Features

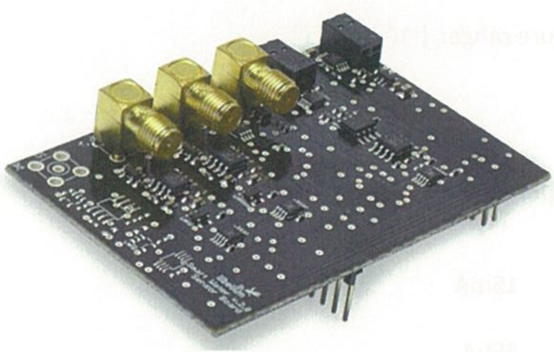


Fig 11. SmartWater – sensor interface board

Weight: 20gr

Dimensions: 73.5 x 51 x 1.3 mm

Temperature Range: [-20ºC, 65ºC]

Board Power Voltages: 3.3V and 5V

Sensor Power Voltages: 3.3V and 5V

Maximum admitted current (continuous): 200mA

Maximum admitted current (peak): 400mA

Sensor Interface Packet:

- Temperature sensor PT1000
- Conductivity sensor
- Dissolved oxygen sensor
- pH sensor
- Oxidation-reduction potential sensor

3.3. Data Packet Transmitter – Iridium

Data Packet Transmitter (DPT) is a Store and Forward ground equipment which is used as a data encoder and a satellite communication solution. Basing on DPT, a S&F ground station can work with many micro satellite have a compatible receiver. In the case of MDG satellite, DPT works in UHF range.

However, we are using a Iridium 9602 Short Burst Data Only Transceiver for DPT purposes at the moment. The Iridium 9602 Short Burst Data Only Transceiver (9602) is designed to be integrated into a wireless data application with other host system hardware and software to produce a full solution designed for a specific application or vertical market. Examples of these solutions include tracking a maritime vessel or automatic vehicle location.

Fig 12. Iridium 9602 short bus data

The 9602 only supports Iridium's Short Burst Data (SBD) capability. It does not support voice, circuit switched data, or short message service (SMS). The SBD is controllable by using `AT command` method. **In the case of our system, SBD can transfer maximum 120 bytes data in one time without frame check sequence.**

In order to make the 9602 be compatible with our main controller, we also use the 9602 developer kit. The 9602 developer kit is designed to be a peripheral supporter for the 9602. The developer kit supports a RS232 port which can be used to control the 9602 by `AT command.`

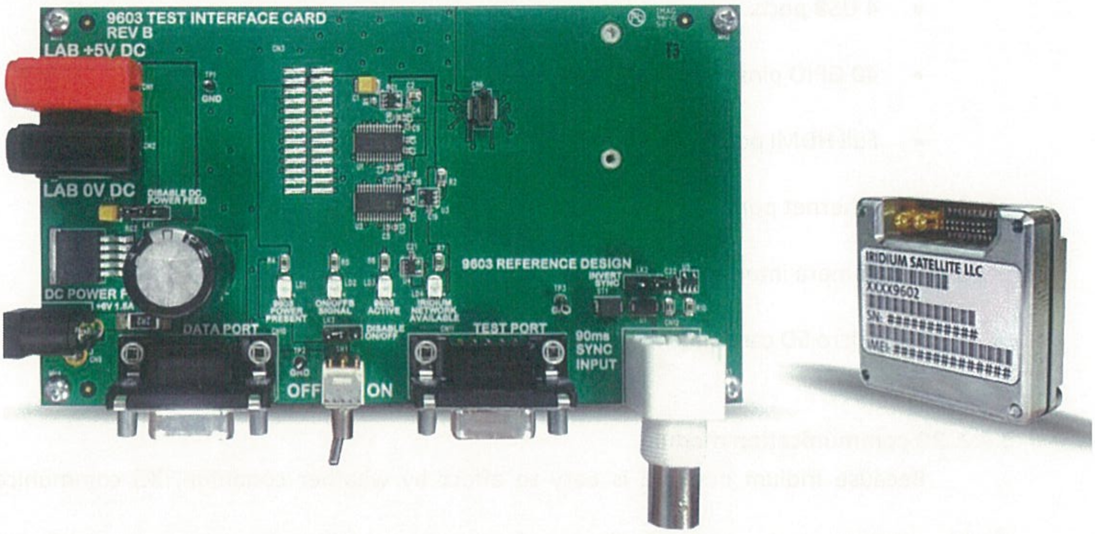


Fig 13. ***Iridium 9602 developer kit***

3.4. Main controller – computer

3.4.1. Raspberry Pi 2 Model B

Raspberry Pi 2 model B is used as the main controller of SFGS. Raspberry Pi controls sensor interface block, encodes data and transfer it through Iridium SBD or 3G network. Raspberry Pi also is sensor interface block power supply.

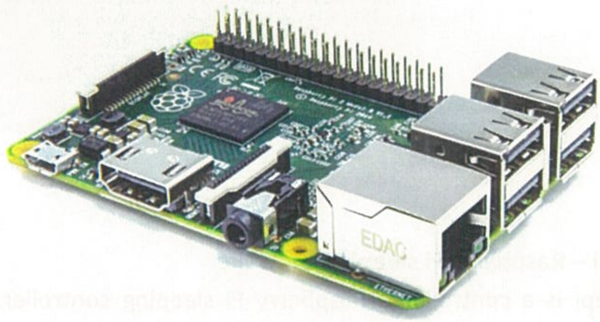


Fig 14. ***Raspberry Pi 2 Model B***

- A 900MHz quad-core ARM Cortex-A7 CPU
- 1GB RAM

Like the (Pi 1) Model B+, it also has:

- 4 USB ports
- 40 GPIO pins
- Full HDMI port
- Ethernet port
- Camera interface (CSI)
- Micro SD card slot

3.4.2. 3G communication module

Because Iridium network is easy to affect by weather condition, 3G communication module – 3GPi is used an alternative telecommunication solution. After power on, if 3G network is available, main controller will log in to network automatically. Raspberry Pi also can control 3GPi by `AT Command`

Fig 15. 3GPi

3.4.3. Sleepi – Raspberry Pi sleeping controller

Sleepi is a controllable Raspberry Pi sleeping controller. It can force Raspberry Pi to sleep or wake Raspberry Pi up in a desired time interval or in a desired date.

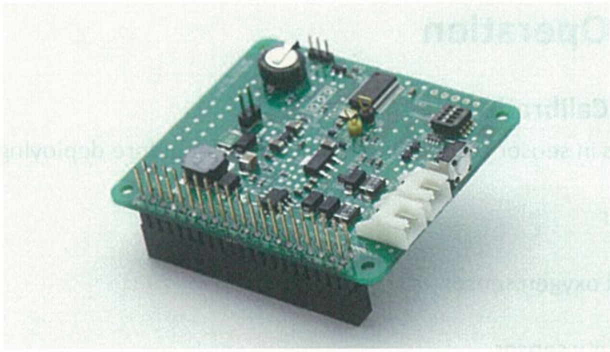


Fig 16. Sleepi

3.5. Solar power supply

A solar power supply is used to make SFGS can become a standalone system. It includes a solar panel, a 12V-6A battery and a power control board which provide a battery charger and a stable 5V output.

The solar power supply will power Main controller block and Iridium short burst data.

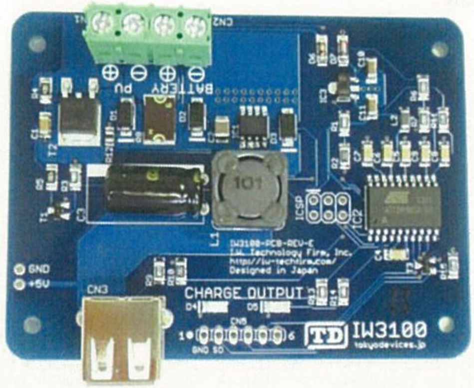


Fig 17. IW3100-BP Battery Charger PWM

4. Hardware Integration

TBD

5. System Operation

5.1 Sensor Calibration

Some sensors in sensor block need to be calibrated before deploying:

- pH sensor
- Dissolved oxygen sensor
- Conductivity sensor
- Oxidation-reduction potential sensor.

Please check the ***SFGS_TestProcedure*** document for more detail calibration information.

5.2. System Operation

After power on, the software on main controller block will start automatically. If it is integrated a HDMI monitor and Iridium network is available, the following string will appear on the command window:

```
Initialization

Initialization Complete

IRIDIUM NETWORK AVAILABLE

%Sensor Data Packet%

SA0.6340089321#67.8703079223#0.1307506561#10.2835588455#23.230468750
0#40#3.7354838848#16061302183542EE3.17EEE

BINARY TRANSFER

PERFORM SBD SESSION

%Successful transfer data packet to Iridium satellite%
```

OK

Fig 18. System Box Integration

6. Data Format

A data packet of SFGS is formatted in a predefined template. The template structure is described below:

SA***C*****#DO#ORP#pH#T#BL#BV#Timer**EE**WL**EEE

where:

- SA: the beginning characters
- #: the separate characters
- ***C*:** conductivity sensor data
- ***DO:*** dissolved oxygen sensor data
- ***ORP:*** oxidation reduction potential data
- ***pH:*** pH sensor data
- ***T*:** temperature sensor data
- ***BL:*** battery level data

SFGS Description

- ***BV:*** battery voltage data
- ***Timer:*** timer data (generate in the same time with timer data)
- EE: end of water quality sensor data
- ***WL:*** water level sensor data
- EEE: the ending characters

Store&Forward Field Test Report

1. Purpose:

This documents summarizes the hardware configuration of the S&F ground station, field test procedures, as well as the test results. The established ground station worked well, and the data transfer through satellite communication network could be successfully demonstrated, using Iridium satellite network in this time. Based on this achievements, global water level measurement network will be able to be implemented via S&F communication network through micro-satellite constellation. Through the activity, it is also shown that the international collaboration between young engineers worked very well.

2. Required Equipments:

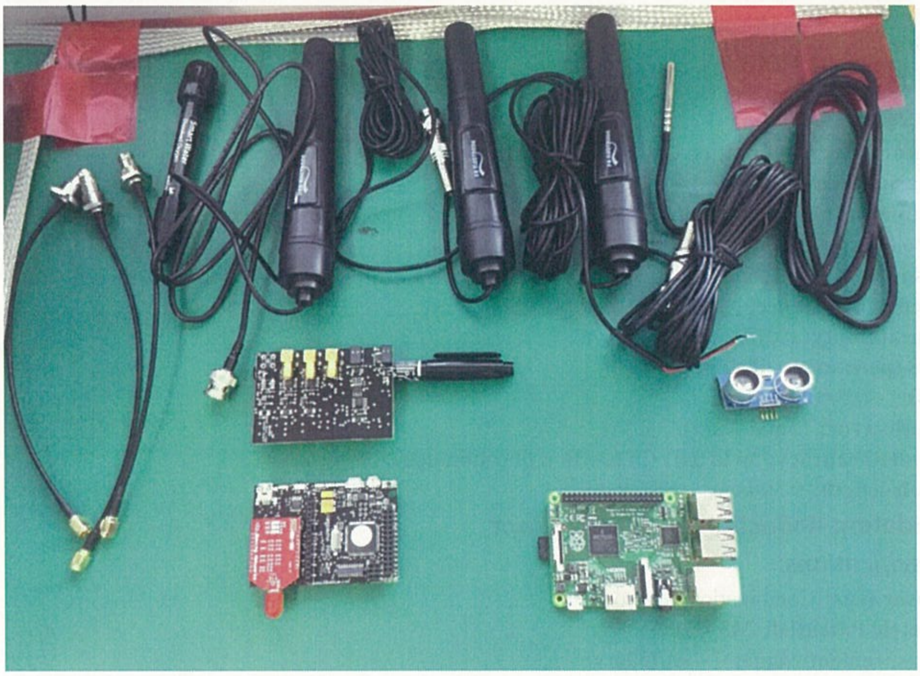


Figure 1. *Sensors, sensor boards and micro controller*

2.1. Sensors

- **Temperature Sensor (PT1000)**

  Specifications:

  Measurement range: 0 ~ 100°C
  Accuracy: DIN EN 60751
  Resistance (0°C): 1000Ω
  Diameter: 6mm
  Length: 40mm

Cable: 2mm
Cable length: < 150mm

- **Conductivity Sensor**

  Specifications:
  Sensor type: Two electrodes sensor
  Electrode material: Platinum
  Conductivity cell constant: 1 ± 0.2 cm^{-1}
  Cable length: < 500 cm

- **Dissolved Oxygen Sensor**

  Specifications:
  Sensor type: Galvanic cell
  Range: 0~20mg/L
  Accuracy: ±2%
  Maximum operation temperature: 50°C
  Saturation output: 33mV ±9mV
  Pressure: 0~100psig (7.5Bar)
  Calibration: Single point in air
  Response Time: After equilibration, 2 minutes for 2mV
  Cable length: < 102 cm

- **pH Sensor**

  Specifications:
  Sensor type: Combination electrode
  Measurement range: 0~14pH
  Temperature of operation: 0~80°C
  Zero electric potential: 7±0.25p
  Response time: <1min
  Internal resistance: ≤250MΩ
  Repeatability: 0.017
  PTS (percentage of slope): >98.5
  Noise: <0.5mV
  Alkali error: 15mV
  Reader accuracy: up to 0.01 (in function of calibration)
  Cable length: < 300 cm

- **Oxidation-Reduction Potential Sensor**

  Specifications:
  Sensor type: Combination electrode
  Electric Potential: 245~270mV
  Measurement range: 0 ~ ±1999mV
  Reference impedance: 10kΩ
  Stability: ±8mV/24h
  Cable length: < 300 cm

- **Ultrasonic Sensor (HC-SR04)**

  Operating voltage: 5V
  Static current: 2mA Max
  Induction angle: 15°
  Detection range: 2-200cm
  High precision up to 3 mm

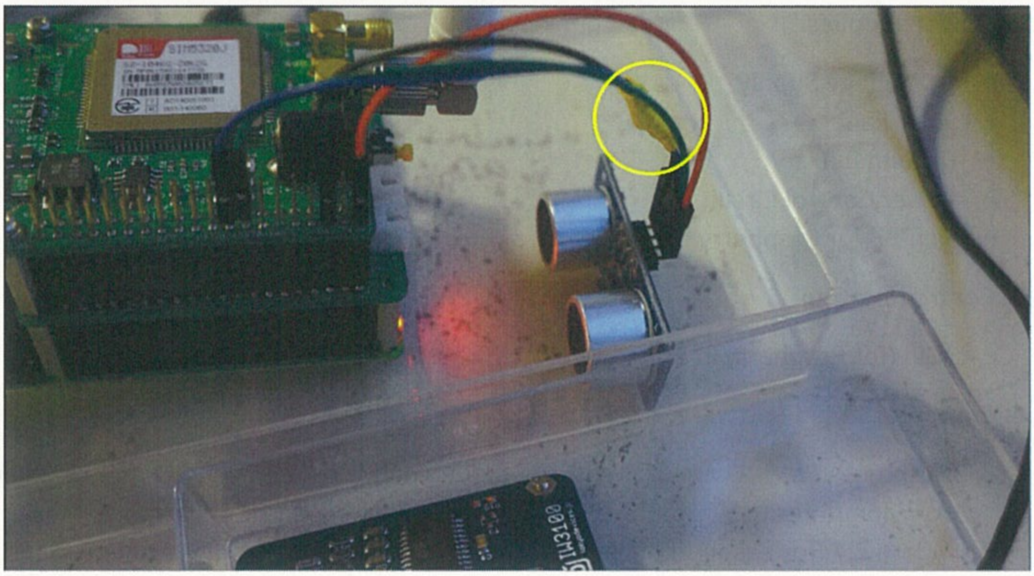


Figure 2. HC-SR04 Ultrasonic Sensor Assembly

- A quick look of HC-SR04 Ultrasonic sensor model: The HC-SR04 ultrasonic sensor uses sonar to determine distance to an object like bats or dolphins do. It offers excellent non-contact range detection with high accuracy and stable readings in an easy-to-use package. From 2cm to 400 cm or 1" to 13 feet. It operation is not affected by sunlight or black material like Sharp rangefinders are (although acoustically soft materials like cloth can be difficult to detect). It comes complete with ultrasonic transmitter and receiver module [4].
- Because of the difference between voltage supply of HC-SR04 and Raspberry Pi 2B (**5** Volts vs. **3.3** Volts), a resistor has been added series to the connection lines of the two modules in order to match the supply voltages (marked as yellow circle in **Fig.2**).

2.2. Circuit boards

- **SmartWater Board**

  Electrical Characteristics:
  - **Board Power Voltages: 3.3V** and **5V**
  - **Sensor Power Voltages: 3.3V** and **5V**
  - **Maximum admitted current (continuous): 200mA**
  - **Maximum admitted current (peak): 400mA**
- **Waspmote Sensor Board**

  - See the detailed specifications of Waspmote in **[2]**
  - See the setup for Waspmote in **[3]**

2.3. Microcontroller

- **Raspberry Pi 2B**

2.4. Power supplies

- DC Voltage Supply
- Solar Panel
- Lithium Battery
- Power Control Circuit
- Slee-Pi (for Raspberry Pi 2B)

2.5. Communication

- 3GPi (for Raspberry Pi 2B)

2.6. Computer Aided Software

- Waspmote Pro IDE v.04 (for compile and upload sensor measuring and controlling code from computer to Waspmote Sensor Board)
- Python 2.7 (for Raspberry Pi to connect and read the data from Waspmote Sensor Board)

3. DPT Schematic Diagram

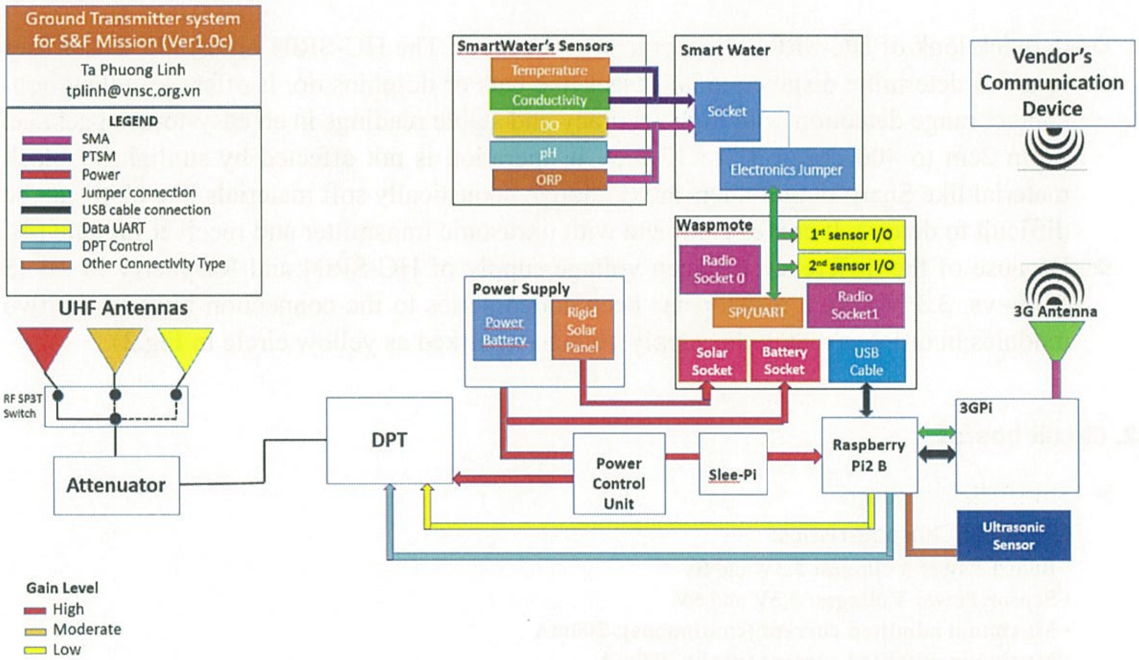


Figure 3. DPT schematic diagram

4. Test Procedure

4.1. Indoor sensors testing

Step 1: Connect SmartWater to Waspmote, then connect them to Raspberry Pi 2B.

Figure 4. *Sensor boards and MicroController connectivity*

Important Note: When measuring the water component with more than two sensors simultaneously, it is need to connect Waspmote with its battery to maintain the sufficient power level.

Step 2: Test with Temperature Sensor

#1: Connect to SmartWater

- Type of connector: **PTSM**

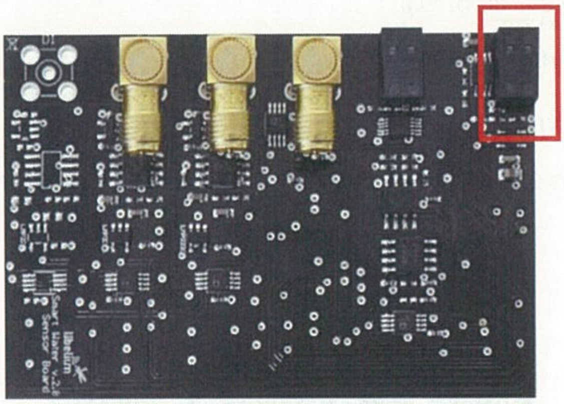


Figure 5. *Temperature Sensor's socket*

#2: Carry out the measurement

Note: The temperature sensor is directly powered from the 5V supply, so is no necessary to switch the sensor ON

Step 3: Test with Conductivity Sensor

#1: Connect to SmartWater

- Type of connector: **PTSM**

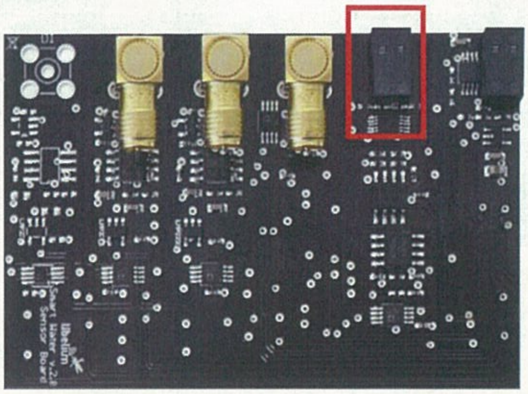


Figure 6. *Conductivity Sensor's socket*

#2: Carry out the measurement

In order to get an accurate measurement it is recommended to calibrate the conductivity sensor to obtain a precise value of the cell constant. Although a single point calibration should be theoretically enough, a two point calibration is advisable to compensate for side effects of the circuitry, such as the resistance of the sensor wire or the connector. For a proper calibration two solutions of a conductivity as close as possible to that of the target environment should be used **[1]**. Once the required Calibration Kit has been delivered, the calibration process will be done based on the **4.2.4** section of **[1]**.

Step 4: Test with Dissolved Oxygen Sensor

#1: Connect to SmartWater

- Type of connector: **SMA-RP**

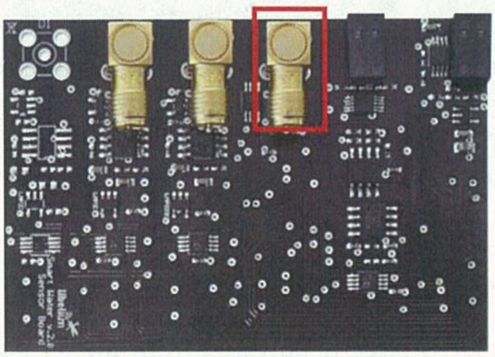


Figure 7. *Dissolved Oxygen Sensor's socket*

#2: Carry out the measurement

The calibration process for the dissolved oxygen sensor can be divided into two parts. The first one corresponds to a single point calibration, which should be enough for most applications. In the second one, the calibration is extended to a second point, which leads to a more accurate value, although it implies a high leap in complexity. This second point is specially advisable if the sensor is going to operate in an environment with a low oxygen concentration.

Once the required Calibration Kit has been delivered, the calibration process will be done based on the **4.3.4** section of **[1]**.

Step 5: Test with pH Sensor

#1: Connect to SmartWater

- Type of connector: **SMA-RP**

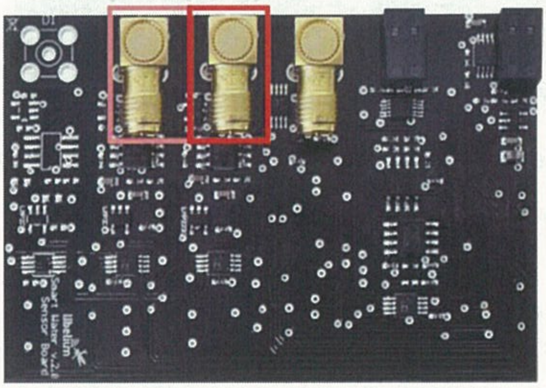


Figure 8. *pH Sensor's socket*

#2: Carry out the measurement

A periodic calibration is highly recommended for the pH sensors if an accurate measurement is desired. If the sensor is going to be deployed in an environmental with a changing temperature or the calibration is going to be carried out under a different temperature from the operation conditions, it will also be required a temperature compensation to update the sensitivity of the sensor to the actual conditions.

The required material for the pH sensor calibration consists of a Waspmote and Smart Water sensor board, the pH sensor to be calibrated (plus a PT1000 sensor if temperature compensation is going to be applied) and three pH buffer solutions, one of 7.0pH and two of higher and lower values (4.0pH and 10.0pH). Note that for a proper calibration all the buffers must be at the same temperature, being a temperature the closest possible to that of operation or, if this one is not known, of approximately 25ºC.

Once the required Calibration Kit has been delivered, the calibration process will be done based on the **4.4.4** section of **[1]**.

Step 6: Test with Oxidation-Reduction Potential Sensor

#1: Connect to SmartWater

- Type of connector: **SMA-RP**

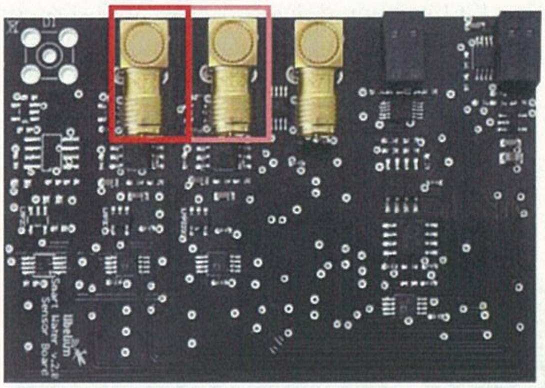


Figure 9. *Oxidation-Reduction Potential Sensor's socket*

#2: Carry out the measurement

Since the sensor output is a straightforward voltage directly measured by the Waspmote's analog-to-digital converter there is not a conversion function. Thus, the calibration process will consist in a verification of the proper operation of the sensor with an ORP calibration standard solution, which will lead to the application of a correction offset in the code or in the data processing in the receiver.

Once the required Calibration Kit has been delivered, the calibration process will be done based on the **4.5.4** section of **[1]**.

Step 7: Test with Ultrasonic Sensor

Step 8: Collect the data

4.2. Outdoor test with Iridium

The outdoor testing is carried out as illustrated in this figure below, with the Iridium 9602 SBD model plays as mobile's ground station L-band transceiver. This transceiver corresponds to the Iridium Subscriber Unit (ISU) at this figure.

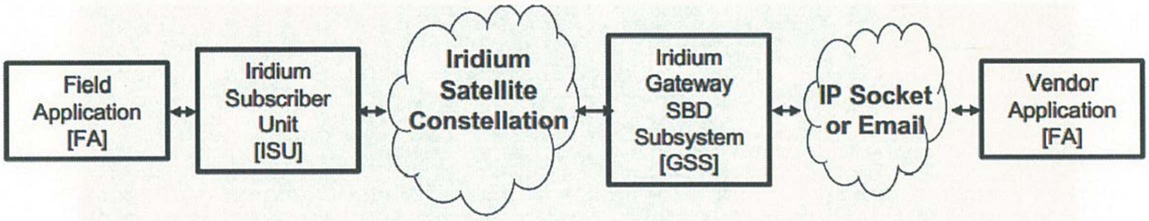


Figure 10. *Iridium's short burst data architecture*

Data collected from sensor (Field Application) will be processed by Raspberry Pi 2B microcomputer, then has been up-converted and attached with carriers at the transceiver unit. The radiofrequency uplink data will be sent to Iridium Satellite Constellation, which included of 64 LEO satellites, before queuing and pending at the SBD Subsystem (SBD). After that, data will be sent to the vendor's communication devices via either IP socket or Email methods. In the former way, the data is formalized in binary.

Because of the limitation of maximum 132 symbols for each sending session, we are able to send only sensors data, and current status of microcomputer (operation mode, battery level and its corresponding voltage).

Figure 11. *DPT indoor test*

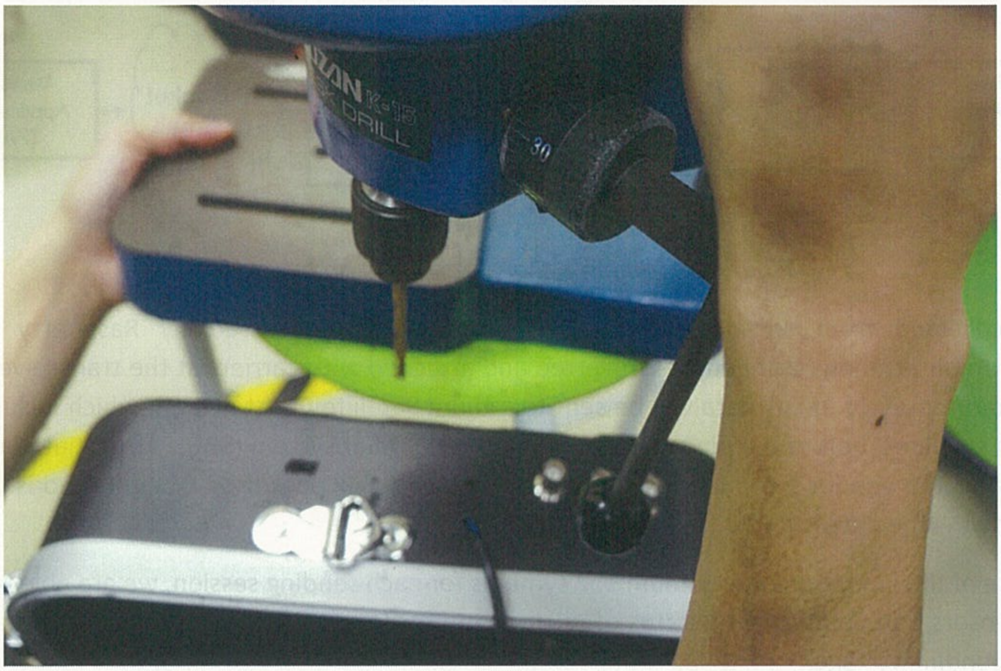


Figure 12. *Packaging the DPT module*

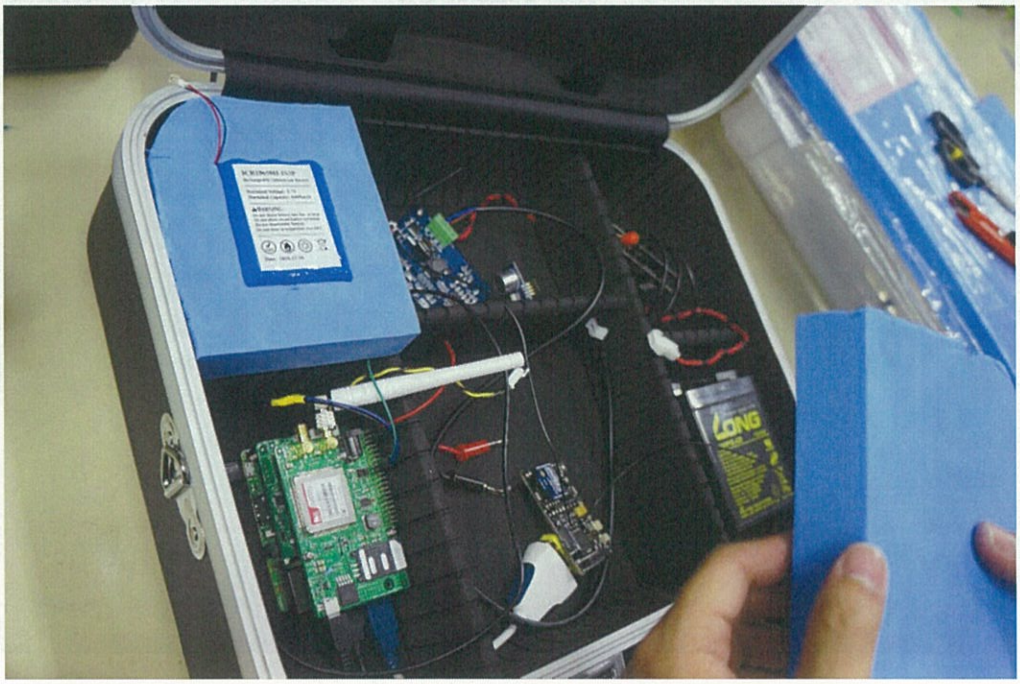


Figure 13. *Packaging the DPT module*

Figure 14. *DPT with waterproof case*

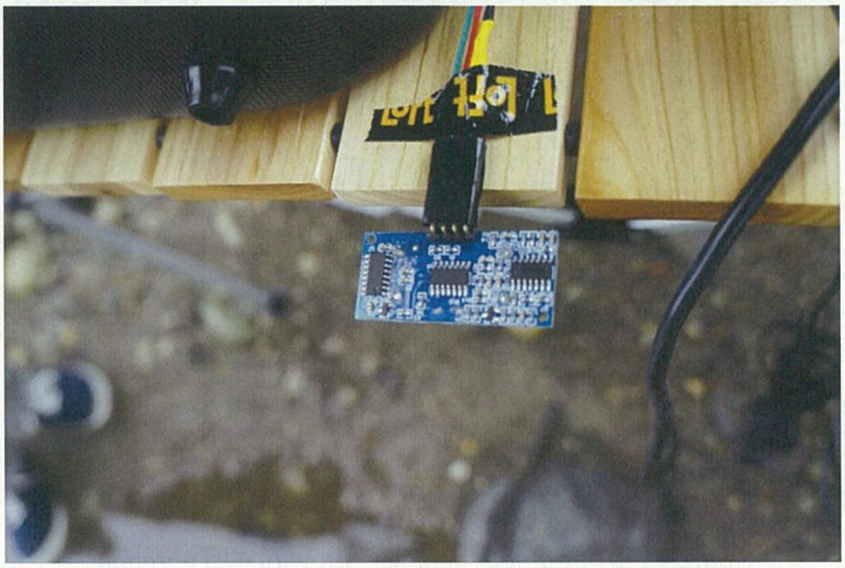
Figure 15. *DPT with waterproof case*

Figure 16. *DPT field test preparation*

Figure 17. *DPT field test preparation*

Figure 18. *DPT outdoor deployment, with GPS antenna*

(a)



(b)

Figure 19. *Sensors deployment.*

(a) *Waspmote's Smart Water sensors* ***(b)*** *HCR04 ultrasonic sensor*

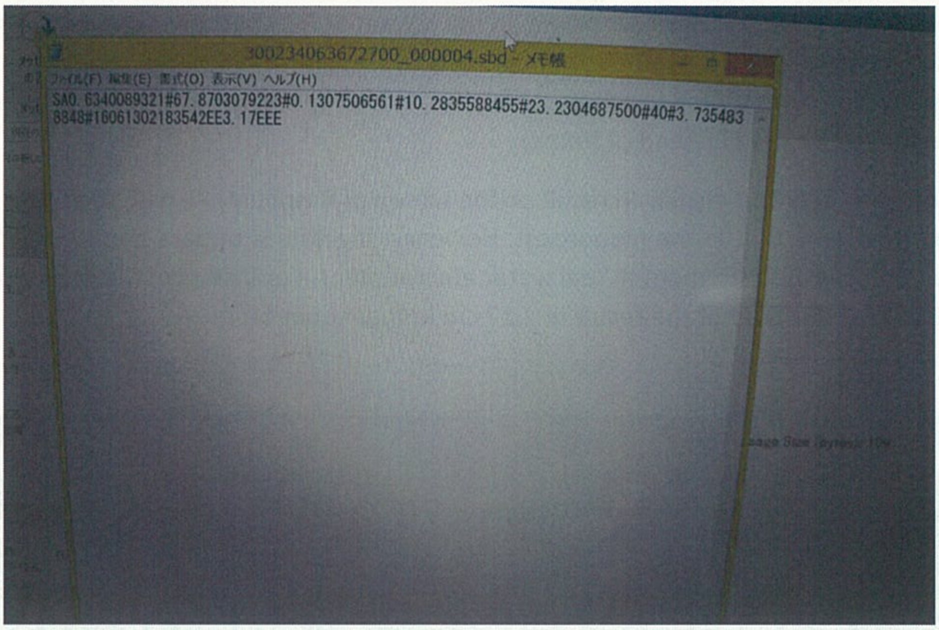


Figure 20. *The result displayed on Raspberry Pi 2B screen monitor.*

Figure 21. *Data collected by sensors.*

Fig.20 shows the indoor test's result frame on the screen of Raspberry Pi, from left to right: SAO (start frame), data sensor (alphabetical displayed, separated by hash key): Conductivity, Dissolved Oxygen, Oxidation-Reduction potential, pH and Temperature. Ultrasonic sensor was the last, right before the EEE (end of frame).

Fig.21 shows the field test displayed result on the screen of Raspberry Pi, with the order of sensor data is just the same as it in the indoor test. However, the values of data are different because we carried out this measurement in real water environment. For instance, the ultrasonic sensor result is 68.58 cm (instead of the result of 3.17 cm in the indoor test).

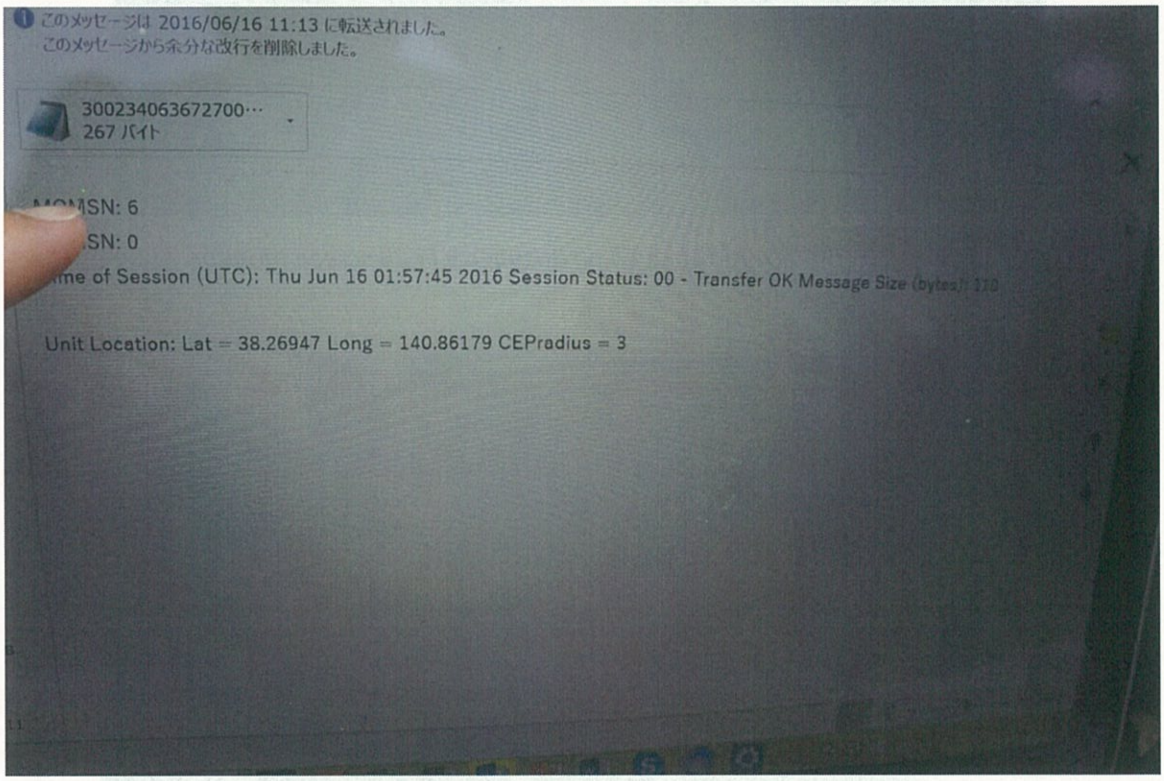


Figure 22. *The data was successfully received by computer's email*

Fig.22 shows the format of receiver email, with the time of Session in UTC standard and the position (which is included longitude, latitude of the vendor's application with tolerable radius of 3km); the received data has the length of 110 bits.

Referenced Documents:

[1] Smart Water Technical Guide

[2] Waspmote Technical Guide

[3] Waspmote Quickstart Guide

[4] Product User's Manual – HC-SR04 Ultrasonic Sensor