Analysis of Controllers and Data Acquisition Systems for Tracking a Point Absorber System

Balakrishnan Kannan

Supervisor: **Irina Temiz**

Abstract

Oceans are a great source for generating renewable energy. The waves carry an enormous kinetic energy that can be converted into electrical energy using the devices called Wave Energy Converters (WECs). Point absorbers are smaller WECs and named because of their negligible size. Many point absorbers are installed offshore in order to efficiently harness the wave energy. Before installation, it is necessary to study the waves in the particular location. Wave buoys are fitted with sensors and deployed to collect crucial data about waves such as the force acting, displacement and the corresponding orientation of the buoys.

Inertial Measurement Unit (IMU) is used for buoy's positional and orientation data and a strain gauge transducer is used to measure the force acting on it. The data should be safely logged onto a memory device. The use of Arduino in the previous projects has stability issues and it is required to manually restart every time. This in turn creates a loss of recorded data and sometimes damages the existing data on the memory card as it overwrites. A stable tracking and measurement system should remain unaffected by the harsh and rough sea conditions. So, it becomes necessary to look for a stable solution for this measurement system.

This paper is mainly focusing on a few controllers and Data Acquisition Systems (DAQs) that were considered for the application and their advantages and limitations. A detailed analysis of controllers from various developers is discussed based on various parameters, performance, speed, cost, mechanical strength etc., and checked for its suitability in the project.

Table of Contents

1 INTRODUCTION …………………………………………………………… 4

2 SYSTEM DESCRIPTION ……………………………………………………..4

2.1 Electronics..……………………………………………………………..4

2.2 SBG-Inertial Measurement System.……….…………………………..6

2.3 Force Sensor ……………………………………………………………6

2.4 Power Supply……….…………………………………………………...6

2.4.1 Solar Panels ……………………………..…………………6

2.4.2 Batteries …….………………………………………………7

3 ANALYSIS OF VARIOUS CONTROLLERS AND DAQs …………………7

3.1 Arduino microcontroller ..…………………………………………………8

3.2 Data Acquisition Systems ………………………………………….…9

3.2.1 Krypton CPU from Dewesoft……………………………….…9

3.2.2 Krypton ONE from Dewesoft………………………………10

3.3 Software Configuration……………...……………………………..11

3.3.1 SBG-Center………………...…………………………………11

3.3.2 DewesoftX Software………..….……………………………...12

3.4 Output…………………….……..……………………………………12

3.5 Drawbacks……………………………….……..…………………..15

3.6 DAQ/Controllers from National Instruments……………..….……………….15

3.6.1 Comparison of NI Controllers and DAQ………….….…………….16

3.6.2 CompactRIO………………………………...………………16

3.6.3 Strain Gauge Transducer Interface…………………..….…………..17

3.6.4 Drawbacks.……………………………..….…..….………...17

3.6.5 MyRIO…………………………………...…………………17

3.6.6 Drawbacks..…….…...….………………………………………...18

3.6.7 Software Requirements…………...………..….………………...18

4 CONCLUSION………………………………...…..……………………...18

5 FUTURE WORK……………………………..…..…………………………19

6 REFERENCES..……………………………………..…..………………………20

1. Introduction

The recent climate crisis has brought in a massive impact on the power production sector. This has turned the interest towards renewable energy sources for generating electrical power. Solar and wind energy are very popular and well-established in terms of research and commercialisation. On the other hand, wave energy still remains a less preferred option in renewable energy as it is not yet completely developed commercially. This is mainly due to the harsh marine environment which is harmful for the devices installed. It is estimated that 120-190TWh/ year can be generated in the European Union alone [1].

Ocean waves are produced by the combined effect of wind and the gravitational effect of the Earth. This enormous potential of the waves can be effectively harnessed to produce electricity. The energy of waves in the ocean is actually in the form of a huge mass of water that moves according to the wave direction. This motion of water waves can be converted into electricity by devices called Wave Energy Converters (WECs). These devices convert the kinetic energy of the waves into electrical energy. Point Absorbers are one of the WECs that is small in size and usually their size is negligible in comparison with the wavelength of the wave itself.

A point absorber WEC system is generally placed offshore (for example the Uppsala University Point Absorber [2]) or on the sea beds (for example, Archemedes Wave Swing [3]). A number of such point absorbers are connected in an array for a larger power generation network. Before deploying a point absorber (buoy) for power generation it becomes necessary to have data in hand regarding the forces acting on the buoy, its position and movement in a three-dimensional axis in the waves during various times. Previously a research team from the Uppsala University has designed a similar kind of system for measuring the effects of the wave on the buoys to be installed in the Lysekil Test site [4] which is located on the West coast of Sweden. This system is to be designed to measure the accelerometer pitch/roll and force acting [4]. But the measured data on analysis was found to have matching errors and also a drift in the data was observable [4]. So, it is recommended to integrate a Real Time Clock (RTC) for having a check on the time frame in which the data was measured.

The aim of this work is to compare different Micro controllers and Data Acquisition Systems (DAQs) and select the best suitable device that satisfies the specific requirements of the project. Designing a stable measurement system primarily involves having a trailblazing controller or DAQ that is able to communicate with the sensor peripherals and secure the data collected with minimal power consumption. The choice of the controllers and DAQs depend on several parameters that are described in the upcoming chapters. But it is important to plan and design the circuitry of the system.

2. System Description

Firstly, it is necessary to design the whole system based on the sensors and required output. This section explains in detail about various parts of the system and its necessity.

2.1 Electronics

Data collection being the primary objective, it is essential to have a reliable and secure data storage system. The use of an Arduino microcontroller in the previous project [5], uses a simple memory card for this purpose. Considering the stability issues in the Arduino controller, the data storage system needs to be more sophisticated. The use of a Data Acquisition System (DAQ) as the core will be a stable solution. The modern DAQ systems are available with ample storage memory and processors inbuilt. The high-performance processors are also easily programmable and communicate easily with the sensors through Control Area Network (CAN) or RS-232 protocols. So, it is considered to use such a system so that it satisfies input handling, storage and data transmission requirements. With this consideration, a suitable schematic of the electronics circuit is developed.

The mail block diagram of the proposed circuit is as shown in figure 1.

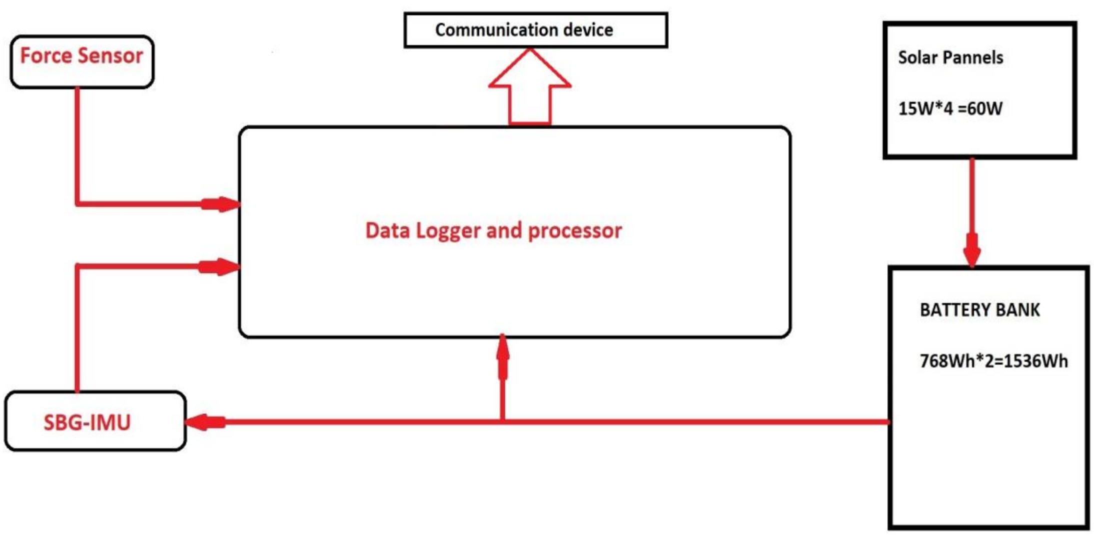

Figure 1: A basic block diagram of the proposed schematic.

Various DAQ systems were referred to and analysed for the advantages and disadvantages. The primary concern is regarding the sensors available. The selection of DAQ should be in such a way that it can communicate with all the sensors and transmitters without any barriers.

2.2 SBG-Inertial Measurement System

An Inertial Measurement Unit (IMU) is capable of perfectly sensing the Global Positioning System (GPS) data and its orientation on a three-dimensional axis (accelerometer data). The IMU used in this project, as suggested in the previous project [5] is a high-sensitive device from SBG systems (shown in figure 2). It is a digital sensor that provides a highly accurate GPS data and communicates in RS-232 protocol.

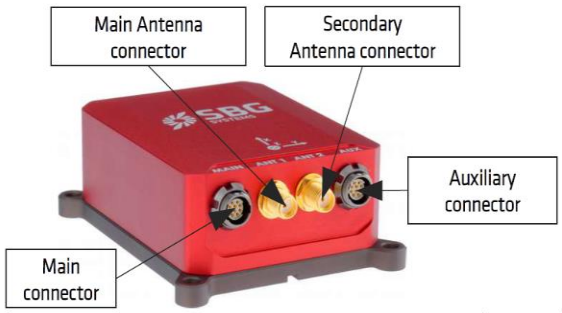

Figure 2: Model of the IMU sensor used [6].

2.3 Force Sensor

A strain gauge is used in order to measure the force of the waves acting on the buoy. The force transducer used in the project is Force Transducer DDENA2H from Applied Measurements Limited [7]. It has an inbuilt operational amplifier that gives an output as analog voltage from 0.1 to 5 V and a current from 4 to 20mA.

2.4 Power Supply

The power supply becomes the most important consideration as the system is going to be isolated offshore. So, it is necessary to have a stable power supply and storage so that the data collection process remains uninterrupted. The required power is planned to be harvested from solar energy. As solar energy is inconsistent and cannot be relied on completely, it becomes necessary to have good storage such as batteries.

2.4.1 Solar Panels

Four solar panels of 15W each are used to convert the sunlight into DC electricity. This is then connected to a charge controller which regulates the charging of the Lithium Polymer (Li-Po) batteries.

2.4.2 Batteries

Two Li-Po batteries of 768Wh capacity each are used to store this energy and act as a stable power supply to the system especially when the whole system relies on solar energy as the main source.

3. Analysis of various Controllers and DAQs

This section gives a detailed comparison of various controllers and DAQs from different manufacturers. DAQs and controllers are compared and classified according to various important parameters such as processor type, power consumption, communication protocol, mechanical stability etc. The detailed comparison is tabulated in table 1.

Table 1: A detailed comparison of various controllers and DAQ according to different parameters and performance

	Arduino [5]	SBOXfe-Dewesoft Systems [8]	KRYPTON CPU-Dewesoft systems [9]	cRIO-9040 [10]	myRIO [11]
Type	Microcontroller	DAQ Intel Processor	DAQ Intel Processor	DAQ Processor 1.30 GHz Dual-Core CPU Intel Atom E3930	Embedded Processor Xilinx Z-7010 Dual core
Power (W)	4W	30W	10W	60W	14W
Sampling Rate	115kHz (Baud Rate)	20000Hz	20000Hz	115kHz (Baud Rate)	500 kHz
Input Type	RS-232	USB-3.0 and USB-2.0	USB-2.0	RS-232 RS-485 USB 2.0 USB 3.1 x2	USB 2.0 x2 Serial I/O pins
Storage	32GB External SD card	500 GB removable SSD Hard Disk Storage	256 GB Internal SSD Hard Disk Storage	2GB RAM and 4GB Storage	256MB RAM and 512MB Storage
Dimensions	102mm x 54mm	265 x 150 x 80mm	231 x 77 x 51mm	219.5 mm x 88.1 mm x	136mm x 88mm x

				121.2 mm	24.7mm
Weight	37g [12]	2.4kg	1kg	1.8kg	0.193kg
Protection	No hard casing provided.	Metallic chassis with electrically isolative and thermally conductive rubber coating.	Aluminium Casing with electrically isolative and thermally conductive rubber coating completely waterproof.	Metallic casing with cable connectors well isolated. Screws provided for better contact.	Plastic Casing and no screws securing the cables.
Performance	Higher Baud rates required for collecting Raw Data from SBG	Direct configuration on High-performance processor with 8GB RAM	Rugged Device suitable for marine applications		

3.1 Arduino Microcontroller

In the previous project Arduino Mega 2560 was used as the main controller. All the sensors are calibrated and connected to the board. The radio frequency (RF) transmitter was also connected to the same board and used for transmitting the data from the offshore system to the ground station.

Though this system was energy efficient and able to handle the data, it had stability issues. Arduino controllers (and programs) sometimes run into indefinite loops which might need a manual restart. In such cases, there is a potential hazard of losing old data and an interruption in collecting real-time data. Apart from this, frequent manual restarts are practically impossible as the system operates offshore for long periods. So, it is now necessary to look for a better alternative solution which is energy efficient as well as reliable in terms of data safety.

Power and Energy Calculations (Arduino Mega 2560) [5]
The energy required to drive the system is calculated from power consumption of individual devices and their hours of operation (table 2).

Table 2: A detailed analysis of daily energy consumption by various devices

Sno	Component	Max. Power [mW]	Expected Working Hours [h]	Max. Energy Usage [Wh/day]
1	Ellipse 2-D	1500	24	36
2	Arduino Mega 2560	4000	24	96
3	Adeunis RF ARF7940BA	500	24	12
4	Force Transducer DDENA2H	264	24	6.34
Total Energy Consumed in Wh/day				**150.34**

3.2 Data Acquisition systems

Data acquisition systems are widely used storage devices capable of communicating and collecting information from various input devices and logging the data in specified formats in the software. These data can be later viewed and analysed for further processing. Some advanced data loggers have trailblazing softwares that gives a detailed processing result such as interactive graphs and animations. These advancements enable the user to perform the analysis quicker and also view the system status from a remote location. From Table 1 it is evident that the Krypton CPU is very much suitable for the requirements due to its high memory capacity, rugged design, and low power consumption.

3.2.1 Krypton CPU from Dewesoft

The Krypton CPU from Dewesoft systems is a sophisticated computer that runs on an Intel Atom Quad-core processor and handles sampling rate of up to 20000 samples/second. The Krypton CPU has an inbuilt Solid State (SSD) memory of 256GB and can be expanded using external memory devices. The use of SSD memory is advantageous for the marine environments that involve a lot of vibrations due to waves. Rotary disk-based memory devices may develop scratches overtime due to constant vibration, resulting in loss of data. The Krypton CPU uses CAN bus protocol and also supports USB 2.0.

Figure 3: Krypton CPU from Dewesoft Systems [9]

The Krypton CPU has a high mechanical stability. The outer casing is made out of aluminium and filled with rubber that conducts heat and is electrically insulative, making it extremely rugged, waterproof and able to withstand shocks up to 100g [9]. It runs on DC power supply that can be variable from 9V to 48V with an average power consumption of 13W.

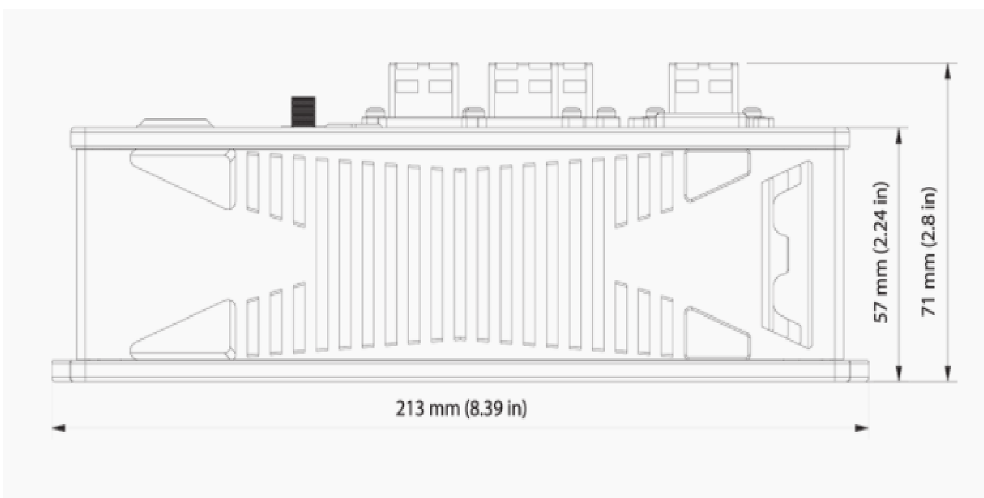

Figure 4: Dimensions of Krypton CPU (Top View) [9]

3.2.2 Krypton One from Dewesoft

Krypton One is an interfacing device between any analog sensor and the Krypton CPU. Analog sensor does not necessarily have a signal conditioning system inbuilt and it becomes highly necessary to get the output of the sensor in a readable format so that it can be fed into the Krypton CPU. To interconnect the strain gauge sensor and the Krypton CPU the Krypton One acts as a signal Conditioning device in between. The Krypton One Consumes a maximum of 2W power and needs a DC voltage from 9V to 48V [13].

Power and Energy Calculations

The detailed power and energy consumptions of the system using Krypton devices is shown in table 3.

Table 3: Detailed list of devices and their respective power and energy consumptions.

Sno.	**Component**	**Max. Power (W)**	**Working (Hours)**	**Energy (Wh/day)**
1	Ellipse-2D	1.5	24	36
2	Force Transducer	.264	24	6
3	KRYPTON-CPU	10	24	240
4	KRYPTON One	2	24	48
Total energy consumed in Wh/day				**330**

3.3 Software configuration

3.3.1 SBG-Center

The SBG centre software is basically required to configure the SBG-IMU sensor and calibrate it according to the need so that specific data is collected at required sampling rates.

3.3.2 DewesoftX software

The first step is to install the DewesoftX software on a computer and also install the plugin called SerialCom. This plugin basically enables the software to communicate with the SBG module even without a CAN bus and just using the available RS-232 protocol. Once the software and plugin are installed, the required inputs can be enabled from the settings (shown in figure 5). Since the SBG module does not support a CAN bus protocol, it is necessary to manually map every data with its respective code by referring to the Firmware Reference Manual [14] provided by the SBG systems. The SerialCom plugin can be found under the extension tab and is required to establish a serial communication with the SBG sensor.

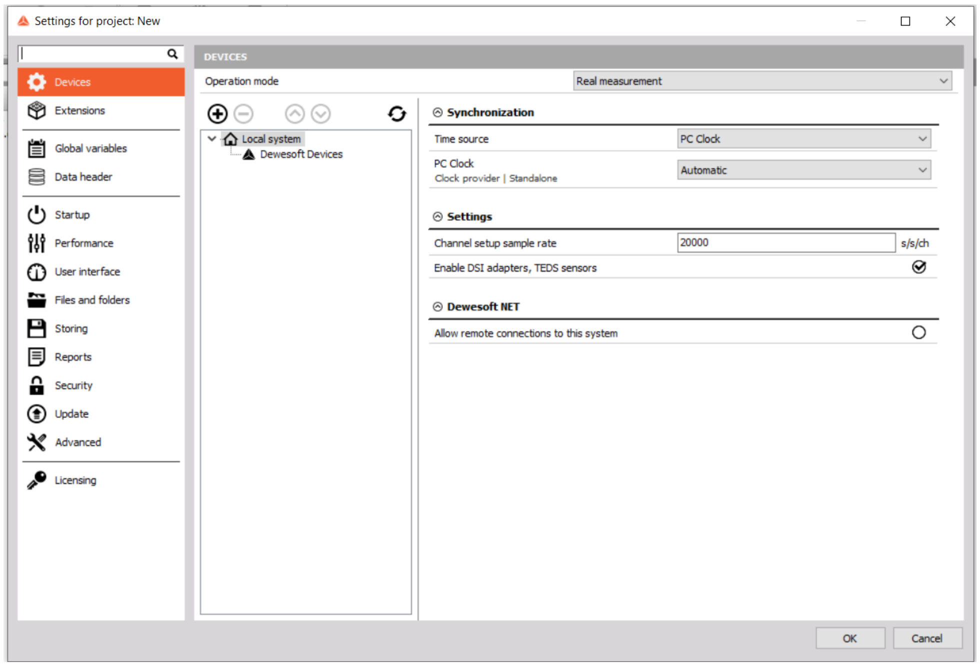

Figure 5: The settings window used for serial communication enabling

3.4 Output

The raw data sample output available from the SBG sensor appears in a '.txt' file as shown below:

Time	Longitude	NMEALog
s	'	
0.95000		$PASHR,,,T,+000.06,+000.01,+000.00,0.182,0.182,,0,0*12
0.94500		$GPVTG,286.33,T,287.31,M,0.732,N,1.355,K,N*2B
0.94100	$GPGST,000323.00,0.000,999.000,999.999,0.00,999.99,999.00,999.00*55	
0.93500		$GPHDT,,T*1B

0.93300 $GPZDA,,,,,,*48
0.92500 $

The Dewesoft software was able to read the data from the SBG-IMU device and provides a very interactive output. This sample output that is shown in the figure gives the exact values of Time, Roll, Pitch, Heave latitude and longitudes.

The latitude and longitude displayed (48˚51’N, 20˚07’E) correspond to Uppsala, Sweden, where the IMU device was tested and the output is shown in figure 8. The real-time graph that is shown (figure 9), plots the obtained values and it tracks the motion of the IMU and moves accordingly. The frequency of data obtained can be varied in the software and can also be manually varied during the set-up of IMU on the SBG systems application. All the communication channels and the type of input through each channel can be monitored as shown in figure 6 and the events tab shows the sequential events taking place during the operation (shown in figure7).

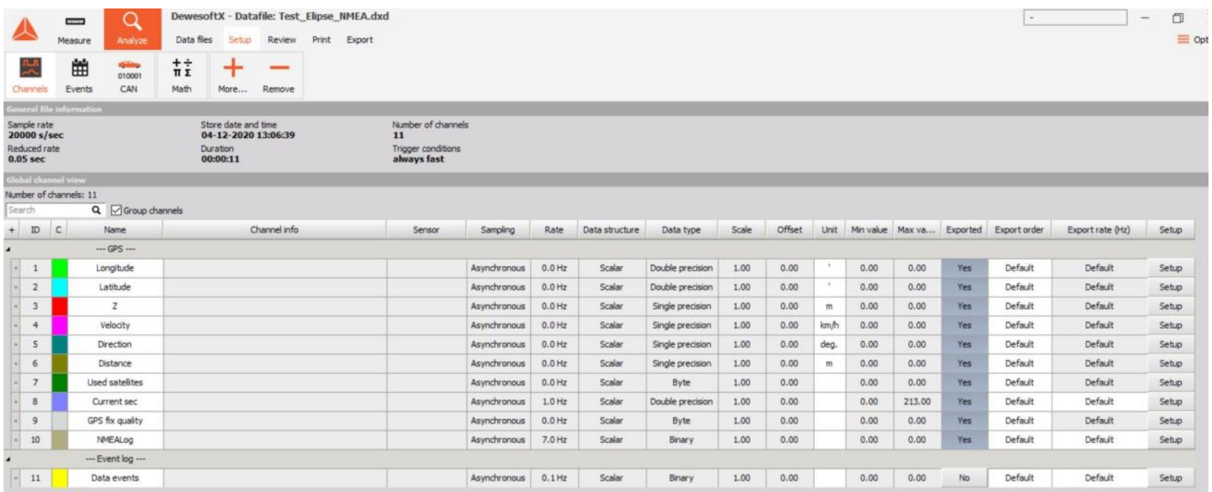

Figure 6: Enabling the required inputs from the IMU to feed the data into the software.

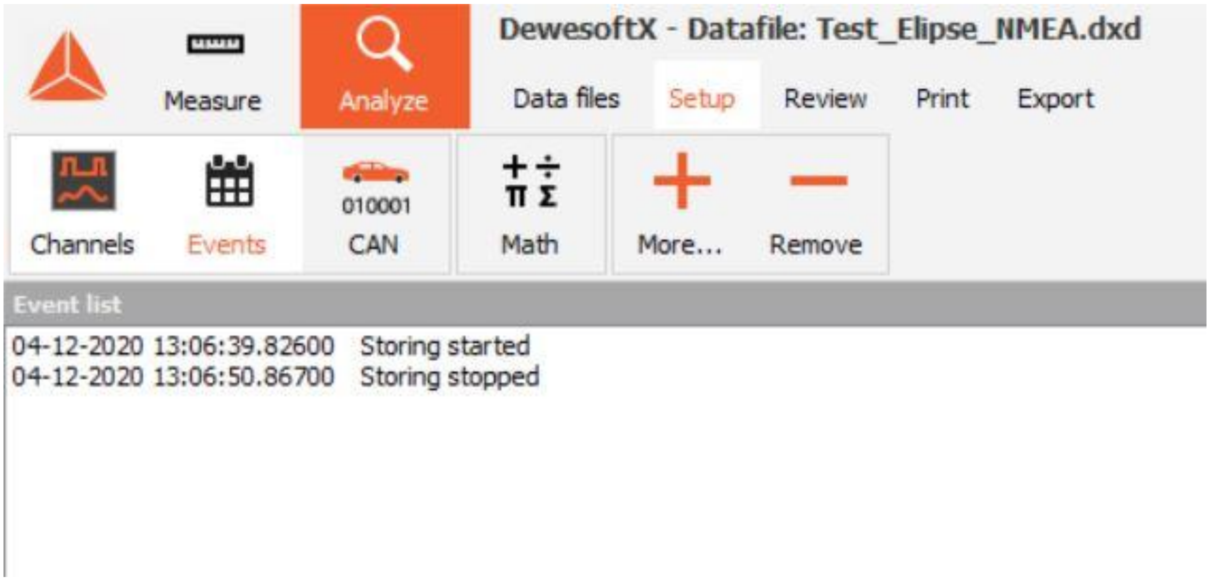

Figure 7: Event logging window showcasing all the event updates.

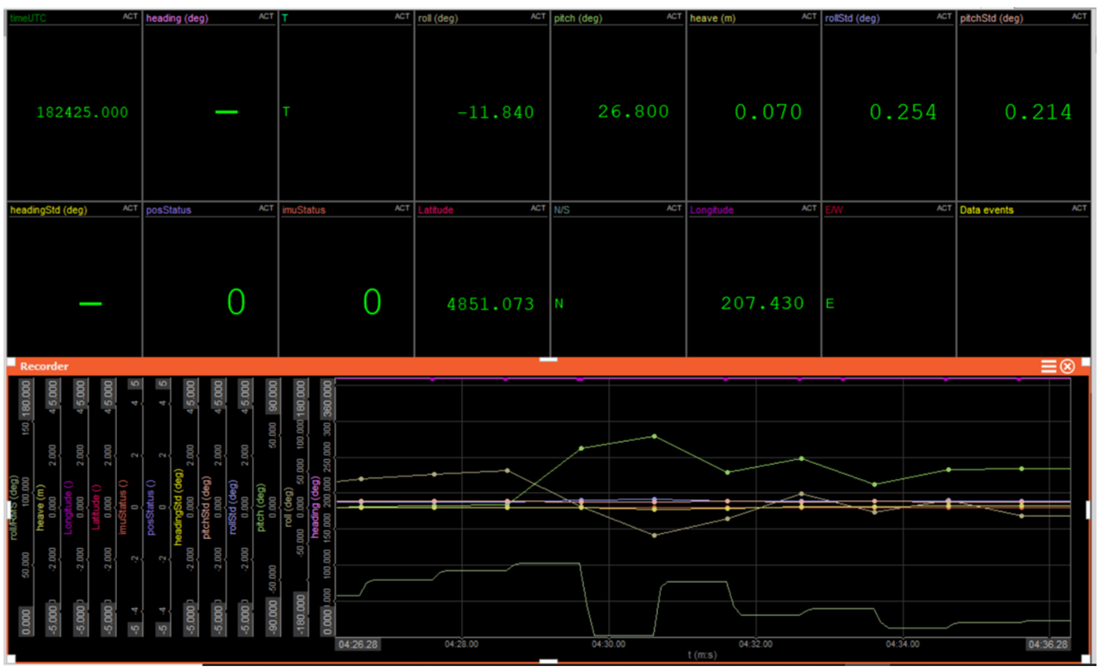

Figure 8: A user-friendly graphical output obtained from the DewesoftX Software

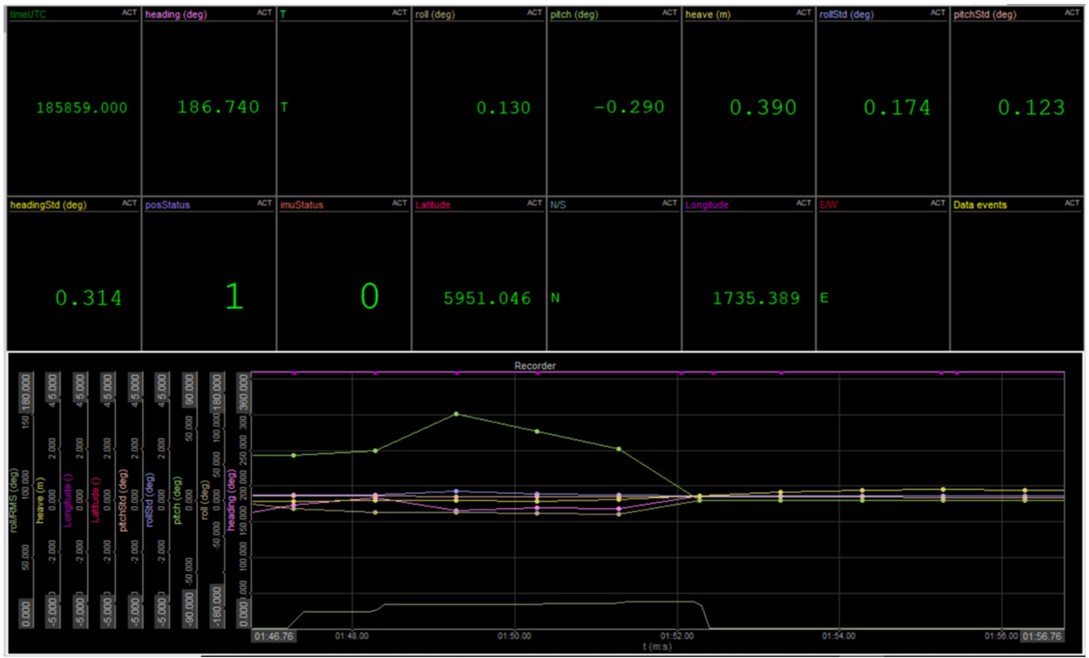

Figure 9: Change in the graph and values for various orientations of the IMU.

3.5 Drawbacks

The main reason for considering this system was due to the plug and play concept. All parts are ruggedised and perfectly intact. This greatly reduces the probability of loose connections or sudden interruptions in connections. Though this system perfectly fits all the requirements of the project, the primary downside of the system is its extreme initial cost (around 9000€). The device is an actual computer ruggedised for extreme conditions and this explains the high price of the system.

So, this system is economically not feasible for such non-profiting applications.

3.6 DAQ/Controllers from National Instruments

National Instruments provides a wide range of DAQs and controllers which are quite rugged and suitable for low power applications.

3.6.1 Comparison of NI Controllers and DAQ [10] [11] [15]

Table 4: Comparison of various parameters of cRIO-9040 and myRIO controller DAQs

Comparison Parameters	**cRIO-9040**	**myRIO**
Core Processor	1.30 GHz Dual-Core CPU Intel Atom E3930	Xilinx Z-7010
Memory	2GB RAM and 4GB Storage	256MB RAM and 512MB Storage
Speed	1.3GHz	667 MHz
Voltage and Max Power Consumption	24V (Recommended) 60W	14W
Dimensions	219.5 mm × 88.1 mm × 121.2 mm	136mm x 88mm x 24.7mm
Weight	1.8kg	0.193kg
Software	LABView Professional and LABView Real time	LABView Professional and LABView Real time

3.6.2 cRIO-9040

The cRIO-9040 (shown in figure 10) is a highly sophisticated Controller DAQ from National Instruments. Its module casing is highly rugged and there are some slots for expansion. These slots are fitted with other peripheral devices such as sensor interface, memory, communication devices etc. It can communicate with the external device through RS-232 and USB channels available.

Figure 10: A view of cRIO 9040 [15]

This system needs an interfacing device for the strain-gauge transducer and additional storage devices for uninterrupted data-logging for a longer time.

3.6.3 Strain Gauge Transducer Interface

The use of a strain gauge transducer as a force sensor needs an interface to communicate with the DAQ. The device NI-9219 (shown in figure 11) from National Instruments consisting of four channels with an inbuilt Analog to Digital converter (ADC) and can be used as an interfacing device can be a plug-in addition in the cRIO-9040 in one of the slots provided. The device consumes a maximum of 0.75W [16].

Figure 11: A view of NI-9219 universal analog input module with its four channels [16].

3.6.4 Drawbacks

The main drawback of this model is its bulk appearance. Though very rugged, the chassis and its safety locks make the whole system heavier. Another major drawback is the connection of cables. The interconnection of sensor cables to the device is done through the exposed wires tightened by screws This may not be a secure option especially for data transmission as it might lead to loose connections. So additional safety has to be done to secure the connections intact.

3.6.5 MyRIO

My RIO is a slightly smaller controller developed by National Instruments especially for academic projects. It has an inbuilt three-axis accelerometer that can sense the orientation of the device. This is secondary accelerometer data and can be used for comparison reference with the primary data from the SBG module. The two main advantages of this device are its low power consumption and the onboard Wi-Fi. The device consumes a maximum of 14W [11] which is highly necessary for this project with minimal source power available.

Figure 12: MyRIO An Embedded system with and without casing [17]

3.6.6 Drawbacks

The fundamental limitation of this device is that it does not have a hard metallic or ruggedised chassis. The connectors are not secured with any screws which might give rise to a lot of data errors due to loose connections. Additional care should be taken in securing the whole device in a hard case with right ventilation so that it is not affected by any environmental factors after deploying in the sea, offshore.

3.6.7 Software requirements

Both the devices mentioned in sections 4.2 and 4.3 need to be programmed in LabVIEW Professional and LabVIEW Real Time softwares.

4. Conclusion

The choice of a good DAQ controller in this project is influenced by two major constraints. One is the limited source power available and secondly, the budget. Going for a very sophisticated DAQ system is also not necessary considering the low sampling rate required and the minimal number of sensors and other peripherals used.

Though Dewesoft DAQs proves to log data very effectively, its high cost makes it unemployable in this particular project. Alternate DAQs such as the National Instruments might be a cost-effective solution. But this still requires a proof of concept before moving into further steps. A detailed analysis of various controller DAQs, merits, drawbacks in terms of cost, stability, performance etc., is performed which can be used for reference in similar projects in the future. Once the controller DAQ satisfies all the prerequisites, it can be deployed for real time measurement.

5. <u>Future Work</u>

The Raspberry Pi processor is powerful enough to coordinate all these sensors used. This microprocessor is programmed in Python and has a minimal power consumption (<4W) [18] [19]. The microprocessor is known to easily connect with many different sensor types and is very popular in the field of automation and robotics. The minimal programming required is one more advantage as it reduces the possibility of getting into endless loops which is the problem with Arduino, requiring manual restarts. Down side of the system is its fragile design. No hard casing [18] is provided and comes with all exposed connecting slots. So, designing printed circuit boards (PCBs) are necessary for the external circuits. The whole setup should be secured inside a plastic container before placing into the buoy to protect it from salty wind and waters. Ventilation should also be given importance to prevent integrated chips frying.

6. References

[1] H. Bernhoff, Wave power compendium: Technology, environment and system [Compendium], Uppsala, Sweden.

[2] M. Leijon, R. Waters, M. Rahm and O. Svensson, "Catch the wave to electricity: The Conversion of Wave Motions to Electricity Using a Grid-Oriented Approach," IEEE Power and Energy Magazine, vol. 7, no. 1, pp. 50-54, 2009.

[3] "ARCHIMEDES WAVESWING SUBMERGED WAVE POWER BUOY," AWS Ocean Energy Ltd, 2021. [Online]. Available: http://www.awsocean.com/archimedes-waveswing.html#. [Accessed February 2021].

[4] Tyrberg S, Svensson O, Kurupath V, Engstrom J, Stromstedt E, Leijon M., "Wave Buoy and Translator Motions On-Site Measurements and Simulations," in 9th European Wave and Tidal Energy Conference, Southampton, UK, 2011, 2011, 2011.

[5] J. Luer, "Design and Development of a Measurement System to Track the Motion of a Point Absorber," p. 84, 2020.

[6] "SBG Ellipse Hardware Manual," SBG Systems, 2018, p. 50.

[7] "Load Cell Data Sheet," 2020. [Online]. Available: https://appmeas.co.uk/shop/load-cells/dde-miniature-in-line-load-cell/. [Accessed November 2020].

[8] "https://dewesoft.com/products/daq-systems/sbox," Dewesoft Systems, 2020. [Online]. Available: https://dewesoft.com/products/daq-systems/sbox. [Accessed December 2020].

[9] "KRYPTON CPU from DEWESOFT," Dewesoft Systems, 2020. [Online]. Available: https://dewesoft.com/products/rugged-daq-systems/krypton-cpu/tech-specs. [Accessed December 2020].

[10] "cRIO-9040 Datasheet from National Instruments," 2021. [Online]. Available: https://www.ni.com/pdf/manuals/377158f_02.pdf. [Accessed February 2021].

[11] "MyRIO Datasheet," May 2016. [Online]. Available: https://www.ni.com/pdf/manuals/376047c.pdf. [Accessed January 2021].

[12] "Arduino Mega 2560," Arduino, 2020. [Online]. Available: https://store.arduino.cc/arduino-mega-2560-rev3. [Accessed December 2020].

[13] "KRYPTON Technical Specifications," 2020. [Online]. Available: https://dewesoft.com/products/rugged-daq-systems/krypton/tech-specs. [Accessed December 2020].

[14] "Firmware Reference Manual- SBG systems," 2020. [Online]. Available: https://www.sbg-systems.com/ellipse-ellipse-micro-support/. [Accessed December 2020].

[15] "cRIO," National Instruments, 2021. [Online]. Available: https://www.ni.com/sv-se/support/model.crio-9040.html. [Accessed February 2021].

[16] "NI-9219 Datasheet," 2021. [Online]. Available: https://www.cnrood.com/en/amfile/file/download/file/4023/product/7111/. [Accessed January 2021].

[17] "MyRIO Model," National Instruments, 2021. [Online]. Available: https://www.ni.com/sv-se/shop/hardware/products/myrio-student-embedded-device.html. [Accessed 2021 January].

[18] "Raspberry Pi Hardware Documentation," 2021. [Online]. Available: https://www.raspberrypi.org/documentation/hardware/raspberrypi/mechanical/rpi_MECH_3bplus.pdf. [Accessed January 2021].

[19] RaspberryPi, "RaspberryPi," 2021. [Online]. Available: https://www.raspberrypi.org/documentation/hardware/raspberrypi/power/README.md. [Accessed January 2021].