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Design and Development of a Data Acquisition and Communication System for Point Absorber Tracking

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Abstract

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The recent trend in generating energy from the waves has led to several advancements in the methods and the various research is conducted across the world, to study the behaviour of point absorbers on the waves. The point absorbers such as wave buoys are designed to move according to the waves and the generator that is mechanically coupled with the buoys, generate electricity. But these buoys can also be used for measuring important parameters like the force acting on it due to the incident waves and their movement can be tracked to study the effects on the buoy due to the incident waves.

This project, as an extension of a previous work titled 'Design and Development of a Measurement System to Track the Motion of a Point Absorber' by Juliana Lüer, focuses on modifying and replacing the controller data acquisition and the communication system. The main aim is to increase the stability of the system and increasing the size of data storage and range of the data transmission. This is done in 3 steps that are as follows:

- The Arduino based controller is replaced with an advanced Raspberry Pi based computer called RevPi Compact.
- The Secure Digital (SD) card storage is replaced with a solid-state (Universal Serial Bus) USB memory stick with a large capacity.
- The Radio Frequency (RF) based data transmission is replaced with a 4G (fourth generation) internet modem.

The 60 W solar panels are retained from the previous project. But the Lead-Acid battery is replaced with two Lithium Polymer (Li-Po) batteries of 768 Wh capacity each. This increases the stability of the power source and enables the buoy to stay active for a longer time even when there is no useful solar irradiance for many days.

There are two force transducers (strain gauge) to measure the line force and the angular force acting on the buoy. The Ellipse2-D Inertial Measurement Unit (IMU) from SBG systems is retained from the previous experiment. This sensor can track the Altitude and Heading Reference (AHRS) data along with the Global Positioning System (GPS) data with high levels of accuracy.

All the data collected are can be tracked instantaneously due to the 4G internet communication protocol and this is enabled by Telenor™ connection and Huawei™ 4G modem. A copy of these data is also stored in a SanDisk USB memory of 500 GB capacity.

The tests are carried out under the laboratory conditions and the outputs are as expected. The whole setup is to be installed in a metallic buoy and to be tested in the Lysekil test site in the future.

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Abbreviations

AC	*Alternating Current*
2G	*Second Generation*
3G	*Third Generation*
4G	*Fourth Generation*
5G	*Fifth Generation*
ADC	*Analog to Digital Converter*
Ah	*Ampere-hour*
AHRS	*Attitude and Heading Reference System*
BPS	*Bytes Per Second*
CLK	*Clock*
CMOS	*Complementary Metal Oxide Semiconductor*
COM port	*Communication port*
CPU	*Central Processing Unit*
DAQ	*Data Acquisition System*
DC	*Direct Current*
DIN	*Deutsches Institut für Normung*
DOF	*Degrees Of Freedom*
ECI	*Earth-Centred Inertial*
EMEC	*European Marine Energy Centre*
EMF	*Electro-Motive Force*
EMI	*Electro-Magnetic Interference*
FM	*Frequency Modulation*
GNSS	*Global Navigation Satellite System*
GPS	*Global Positioning System*

GSM	*Global System for Mobile communication*
GUI	*Graphical User Interface*
Gyro	*Gyroscope*
HDMI	*High-Definition Multimedia Interface*
HF	*High Frequency*
I/O	*Input/Output*
IC	*Integrated Circuit*
IMU	*Inertial Measurement Unit*
INS	*Inertial Navigation System*
LAN	*Local Area Network*
Li-Po	*Lithium Polymer*
LTE	*Long Term Evolution*
MEMS	*Micro Electro Mechanical Systems*
MPPT	*Maximum Power Point Tracking*
NMEA	*National Marine Electronics Association*
OS	*Operating System*
PCB	*Printed Circuit Board*
PWM	*Pulse Width Modulation*
RAM	*Random Access Memory*
RF	*Radio Frequency*
RTK	*Real Time Kinematic*
SD-card	*Secure Digital Memory Card*
SPI	*Serial Peripheral Interface*
USB	*Universal Serial Bus*
UTC	*Coordinated Universal Time*
WCWI	*West Coast Wave Initiative*

WEC	*Wave Energy Converters*
WERC	*Wave Energy Research Centre*
Wh	*Watt-hour*
WiFi	*Wireless Fidelity*

1. Introduction

1.1 Background

The present-day interest shifting towards wave energy research is a very important change in the fight against the climate crisis. Almost 80% of the total world energy demand is satisfied by fossil fuels such as coal petroleum and natural gas [1]. These are also called non-renewable energy sources which means that their reserves will soon run out of resources. This brings the necessity of using the existing available renewable energy resources more efficiently. These renewable sources of energy are mostly non-polluting in nature and inexhaustible as well [2]. Wave energy is one such important inexhaustible source of renewable energy. Wave energy study and survey are necessarily done before setting up a power generation site and it is conducted in various test sites around the world. Several wave and tidal energy research are done in the UK [3] in the wave hub located in the West of Cornwall and the Orkney Island where the facilities are established by the European Marine Energy Centre (EMEC)[1]. Similarly, the Canadian wave energy has an estimated extractable potential of 10,100 to 16,100 MW along the Pacific and Atlantic coastlines [4]. The Wave Energy Research Centre (WERC)[2], Canada, operates a research centre with six mooring sites for wave data collection and aquaculture farms [5]. The wave height recorded by the researchers is as high as 11 metres and has a depth of 25 metres. The West Coast Wave Initiative (WCWI) has completed high-resolution wave resource assessment and has also simulated wave energy converter technology in detail along with short term and long-term integration study of the electrical system [4].

The European Union, on the other hand, has an immense wave energy potential estimated to be around 120-190 TWh/year [6]. The Swedish wave energy research is carried out offshore near Lysekil (west coast of Sweden) by the Centre for Renewable Electric Energy Conversion at the Uppsala University. The project was initiated in 2004 and the site is used for the development and testing of several wave measurement and energy conversion devices [7]. The research site is known for having Wave Energy Converters (WECs) that are connected to a measuring station onshore, Wave Rider™ buoy for wave measurements, 25 buoys for environmental impact measurements and a surveillance tower [7].

One other important feature of the experiments carried out in Lysekil, apart from WECs, is the wave data measurement. Several attempts have been done in tracking and collecting various useful data from wave buoys that are made to float offshore. The collected data is useful in analysing and predicting the wave patterns in the particular region. Also, it is important to track the movement of the buoys over the waves. This movement should be tracked as accurately as possible. The corresponding force acting on the buoy is correlated with this motion data to get a picture of how much power can be extracted from the buoy of the given dimensions.

This project, as an extension of the previous experiment explained in [8], concentrates on designing and building a stable measurement system for a wave buoy and transmit the data through the internet instead of the radiofrequency that was used for transmission in the previous experiment [8]. The measurement system is to track the force acting on the buoy and the inertial

[1] *http://www.emec.org.uk/projects/*

[2] *https://www.collegesinstitutes.ca/applied-research/wave-energy-research/*

data. Further, the data collected is corelated with the force acting on the buoy at that particular instant (time) to picturise the motion of the buoy along the wave profile and understand the effect of the force on the buoy due to the waves encountered by it.

1.2 Wave Energy Converters

Wave Energy Converters (WECs) are devices that are capable of converting mechanical energy (produced by wave motion) into electrical energy. There are different methods to accomplish this. The Uppsala University WEC is based on the linear synchronous generator and hence it is robust and simple in design. The WEC is placed on the seabed and has a magnetised piston coupled with the motion of the buoy. Since the movement of the buoy is linear, this setup does not involve a complex gearbox or hydraulic couplings. The magnetised piston is surrounded by a coil of conducting wires (stator) and can freely move up and down. This essentially brings a change in magnetic flux with respect to the coil and hence an Electro-Motive Force (EMF) is generated in the stator coils. A model of this idea is shown in Figure 1: Pictorial representation of the Uppsala University (UU) Wave Energy Converter (WEC).. This idea, developed by the research group in the Uppsala University (UU), was further refined and commercialised by the Seabased Group [8].

Figure 1: Pictorial representation of the Uppsala University (UU) Wave Energy Converter (WEC) [9].

1.3 Previous Designs and Challenges

This section gives a detailed insight into controllers and communication methods used in the previous designs, their limitations and present-day trends.

1.3.1 History

A number of experiments were carried out at the Lysekil test site since 2004. Time series of wave elevations were measured by a Datawell Waverider buoy. The data collected were much useful in predicting the power capture capability of a cylindrical buoy and to study the wave climate at the particular site [7].

The first experimental setup was launched in March 2005, which measured the maximum line force acting on the buoy. The buoy was 3 m in diameter with a height of 0.8 m. It was in operation without any damping system [7] [10].

The design of a measurement system in [10] used a 16-bit data logging system operating at a frequency of 16 Hz. The data collected from the sensors are transmitted to the ground using a Global System for Mobile communication (GSM) also known as the second generation (2G) network [11]. Three different types of data are measured from the buoy: force, acceleration and pitch/roll velocity. The sensor types are discussed in detail in [10]. Apart from the onboard sensors, there is also an optical measurement system to monitor the movement of the buoy. The images were transmitted to the ground through the 3G network (third Generation) at a temporal resolution of one image per second. The buoy acceleration is measured by an accelerometer (Analog Devices ADXL202) sensor and the pitch roll velocity is measured by a yaw rate gyro (Analog Devices ADXRS614). All the data recorded by this system are first transmitted to a ground station situated at 3 to 5 km from the buoy for post-processing [10].

Challenges

The disadvantage of this system explained in [10] is the size and capability of the datalogger and the transmission system. Both 2G and 3G networks are not suitable for transmitting data at higher volume and speeds [12]. The present-day cellular networks are operating in 4G, 4G+ and heading towards 5G technology. So, the 2G and 3G services are slowly shutting down. Using the 4G communication enables large volumes of data to be transmitted at high speeds. Also, the buoy position on the latitude-longitude coordinate system is not measured i.e., no Global Positioning System (GPS) sensors are used. It will be hard to locate the buoy in the future without this real-time GPS data.

1.3.2 Recent Design based on Arduino

The design of a data measurement and communication system explained in [8], uses an Arduino based core as the controller. Arduino Mega 2560 is used as a controller. Data measured from the sensors are designed to store in a memory card. This is then transmitted to a ground station through a Radio Frequency (RF) transmitter. The battery used in the system is 60 Ah and 12 V.

Challenges

Arduino microcontrollers are efficient when it comes to power consumption[3]. But the main drawback of using Arduino based microcontrollers is the reliability of the controllers when operated at a higher frequency for data measurement applications. Programming the Arduino devices to handle the coordination of sensors and measuring devices sometimes run into endless loops. The controller needs to be manually restarted before further measurements are recorded. The design also has a very low onboard storage and with the RF communication which is not very reliable, large onboard storage becomes essential to avoid data loss.

The RF communication system becomes unrealistic in the buoy location due to the presence of small rocks, cliffs and islands which acts as obstacles to wave propagation. The maximum

[3] *https://docs.arduino.cc/hardware/mega-2560*

range achieved by the RF transmitter-receiver setup was 3 km [8]. The orientation of the buoy, on the other hand, is not fixed and tends to change based on the waves that strike. The buoy might also be partially or fully submerged for a considerable period of time depending on the wave nature. All these factors might interrupt the RF communication system.

The Lead-Acid batteries, proposed in the system, are prone to leaks, that are hazardous and requires higher levels of maintenance which is challenging for a standalone off-shore system. The whole system is designed to operate on a standard 12 V DC supply. This might not be suitable for the current application as most devices require a 24 V DC supply. Also, the power consumption of the new design is above 215 Wh/day for which requires larger battery storage.

1.4 Research Question

To overcome the above-mentioned challenges from the previous experiences, and to increase the reliability of the measurement system, the following methods are adopted to design a new stable measurement system that can provide a reliable data measurement solution.

(a) *Controller/Data Acquisition System:*
This part of the whole system acts as a brain that controls the entire system and coordinating the working of all the electronics on-board. So, the right choice of controller plays a vital role in increasing the stability and reliability of the project. The factors that affect the choice of controllers are mainly its compatibility with the digital and the analogue sensors, low power consumption, high storage facility, speed and feasible price.

(b) *Communication System:*
To test if the 4G (4^{th} Generation) internet communication is a better alternative to RF communication. This is more like a comparative study. The comparison is done based on the following factors.

- Speed of the data transmission.
- Range of the transmission.
- Antenna Requirements.
- Power consumption.
- Orientational limits (directional or omnidirectional)

2. Theory and System Planning

This chapter describes the concepts, working and design of different electronic components used in the design. Both the sensors are used from the previous designs [7], [8] and [10].

2.1 Spatial Axes and Degrees of Freedom

The buoy is free to move in 3 spatial axes and 6 Degrees Of Freedom (DOF). This is represented in Figure 2. The forward and backward motion is considered to be X-axis, left and right as Y-axis and up and down as Z-axis. The terminologies used in marine studies are heave, sway and surge for motion along X, Y and Z axes respectively [13]. This is clearly shown in Figure 2. Practically, the movement of the buoy will be in one or the combination more than one degree of freedom. This is purely because of the unpredictable wave forces acting on the buoy. But since the buoy is anchored to the bed of the sea, the motion is slightly restricted within a confined floating area. This motion of the buoy as it encounters the force of the waves is the interest of this project. The inertial and the GPS data are combined to picturise the movement of the buoy.

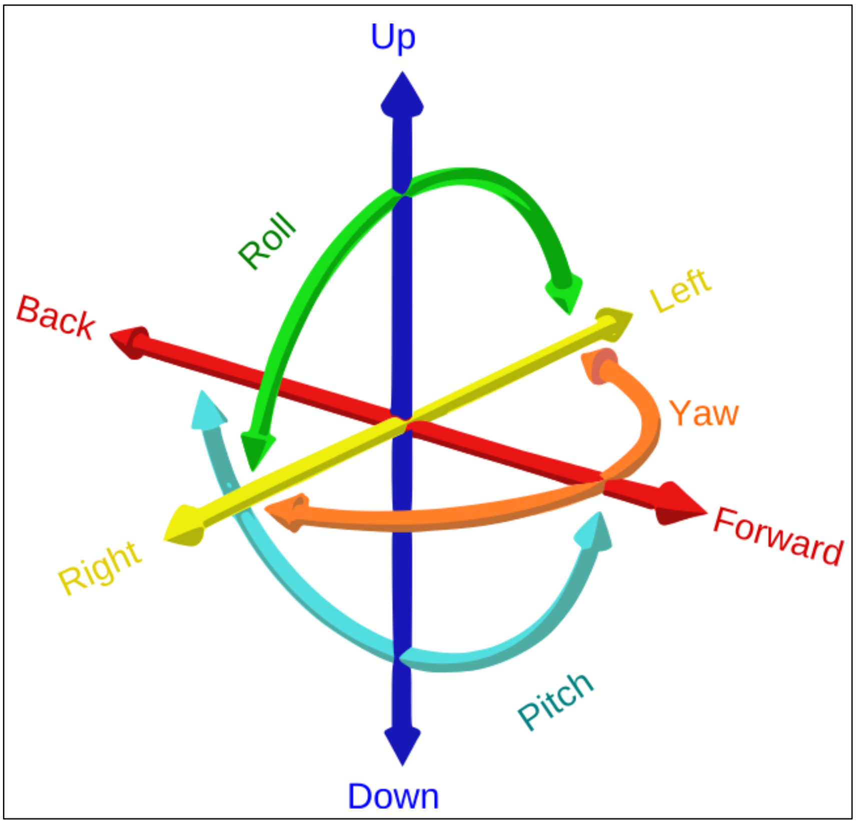

Figure 2: The six degrees of freedom [14]

It is this random motion that forms the basis of inertial data. The motion of the buoy in the above-mentioned degrees of freedom is measured in degrees in positive or negative values calculated with reference lines (X, Y and Z). Section 2.2 in [8] gives a detailed overview of different concepts involved in sensing and measurement of the changes in buoy motion such as using ultrasonic sensors and cameras. Then the inertial measurement unit is found to be suitable for this application considering the demerits of other devices.

2.2 Inertial Measurement Unit

An Inertial Measurement Unit (IMU) is a commonly used sensing device that is capable of tracking even the minute movements of a body in all three spatial axes with 6 DOF. These sensors are a combination of gyroscope and accelerometer. Gyroscopes are used to measure the angular motion (rotational) and accelerometers are used to detect and measure the linear motion. With the present day's Micro Electro Mechanical Systems (MEMS) technology, these devices have become extremely compact. They are fabricated on semiconductor chips and these chips are small enough to fit into a mobile phone [15]. These tiny chips are connected to signal conditioning devices that convert analog signals from the chip to digital signals. The linear and angular motions are calculated according to a standard reference frame. This frame is called Earth-Centred Inertial (ECI) reference frame [16].

The Table 1 in [8] gives a detailed comparative study of various IMU devices available in the market. Out of all these devices, the Ellipse2-D [17] is found suitable for the application due to its high accuracy in heading, roll, pitch and heave values. So, the same sensor is also incorporated in this project.

2.3 Force Transducer

The strain gauge transducer works on the resistive property of a conductor. Any conductor has a slight change in their resistance when they undergo physical deformation. This is because of the relationship of resistance with the material's physical properties. This is expressed as,

$$\text{Resistance, } R = \rho \frac{L}{A} \qquad [1]$$

where,
ρ is the resistivity of the conductor (constant for a given material)
L is the length of the conductor; and
A is the area of cross-section of the conductor.

For example, Figure 3 shows a conductor of length L and cross-sectional area A (case a) is applied with a uniform force F across its length. Due to this stress applied, the conductor experiences a deformation. The length of the conductor increases from L to L' and the area of cross-section decreases from A to A' (case b).

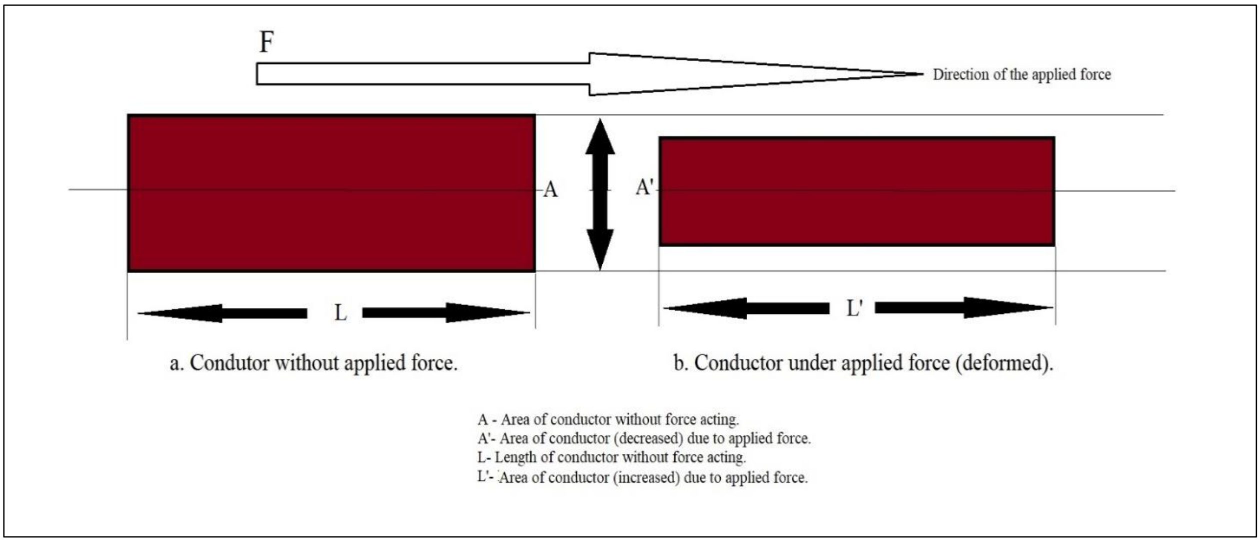

Figure 3: An example of physical deformation of a conductor under the uniform force applied in a direction.

An increase in the length and decrease in the cross-sectional area increases the resistance according to Equation 1. This small change in resistance has an effect on the voltage drop measured across it. This small change in voltage is proportional to the force applied and hence can be used to detect the force across the conductor. Practically, this is done using a Wheatstone bridge. The Wheatstone bridge with four strain-gauges is called a full bridge (shown in Figure 4) and with one and two gauges are called a quarter-bridge and half-bridge respectively [18].

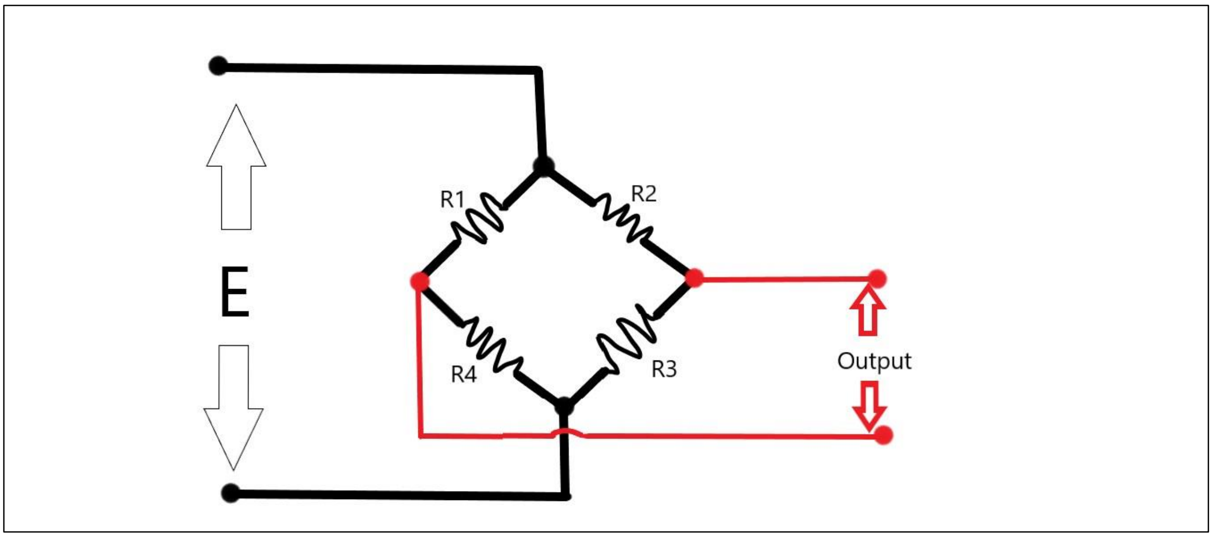

Figure 4: A typical Wheatstone Bridge configuration diagram with 4 (strain-gauge) resistors - Full bridge.

Under a perfect bridge balance condition, the net output voltage from the circuit is 0 V. If any one of the resistor values changes, a small amount of voltage can be measures at the output terminals. The amount of voltage measured at the output terminals depends on the excitation voltage applied (source voltage i.e., 5 V in this system). The excitation voltage to be applied is carefully calculated based on the available power supply because increasing the output voltage by increasing the excitation voltage, in turn, increases the energy consumption as the energy is wasted in form of heat by the resistors.

The measured output voltage from this bridge is extremely smaller (in the order of millivolts) [18]. So, a signal conditioning and amplification circuit are necessary for reading the output voltage with the controller data acquisition system. The strain gauge transducers available in the market also comes with in-built signal conditioning and amplification circuits but most professional manufacturers provide this as an addition and are usually not tailor-made.

There are two different strain gauge transducers used in this system. The first transducer is manufactured by HBK and its capacity is 200 kN. This transducer requires an external signal conditioning circuit as it is not in-built. The second transducer is manufactured by Applied Measurements Ltd., from the United Kingdom and its capacity is 50 kN. This does not require any external signal conditioning circuit. Further details about both the transducers are discussed in Section 3.5 Force transducer-1 (200 kN) and Section 3.6 Force transducer-2 (50 kN).

2.4 Choice of Controllers/ The Data Acquisition System

The Data Acquisition System (DAQ) forms the central core of electronic circuitry. Though there are several devices readily available to perform the task of data collection and storage, the choice of the device is mainly dependent on the following factors.

(a) *Low Power Consumption:*
The existing battery system in the buoy has a limited storage capacity of 1.5 kWh. So, it is necessary to limit the power consumption below 15 W to make long term measurements possible.

(b) *Software and Compatibility:*
The device should run on a popular software environment that can be programmed easily. Arduino and Raspberry Pi are easily programable and are also compatible with a wide range of sensors. Additionally, The SBG-IMU is a digital sensor with serial communication. So, the controller should be able to handle this accordingly.

(c) *Size and Cost:*
The electronics compartment of the buoy should be made waterproof and also be protected from the salty air. So, the size of the electronics compartment is planned to be limited. The controller should essentially be able to fit in such a small cabin size and also not bulky. Bulky controllers are risky under higher vibrations as the weight itself is a damaging factor for its mechanical integrity.
Since this project is not commercial, it is always necessary to have a check on the cost. The function of a controller DAQ is quite less and so low-cost controllers are very well suitable for such applications.

The Arduino based controllers, though seems a perfect choice for the application, it has a lot of stability issues. Especially the Arduino codes run into infinite loops and this is hazardous for an autonomous system that operates offshore. Under such situations, the device should be rebooted manually. But since it takes a lot of human effort to reach the buoy, it is almost impossible for frequent manual rebooting. It is also not advisable to open the electronics compartment frequently as it might expose the electronics to salty air and water sprays from the sea. So quite a stable alternative controller is required.

2.4.1 Dewesoft Systems

Considering all the conditions, requirements and functions of a controller DAQ, Dewesoft systems manufactures rugged DAQ systems, especially for marine applications. KRYPTON Central Processing Unit (CPU) is a controller DAQs from Dewesoft Systems that operate on Intel Atom Quad-core processor core and is powerful enough to handle up to 20000 samples per second. The average power consumption of the KRYPTON CPU is 14 W [19] and can handle shocks and vibrations up to 100 G [20]. Further detailed analysis can be found in [21].

(a) *Compatibility:*

Initial testing was done to ensure if the KRYPTON CPU reads the data from SBG-IMU. The connection is simple Universal Serial Bus (USB) protocol and no programming is required. The actual hardware (CPU) was not used for the testing, instead, a normal computer was used with the DewesoftX software as the core processor is the same.

(b) *DewesoftX software:*

This software acts as a platform to enable the CPU to communicate with the peripherals. The DewesoftX software is very user-friendly and doesn’t require any programming. Most of the sensor types are pre-programmed and just using the right plug-in (software extension) will make the communication possible. For example, the plug-in software required for the SBG-IMU is called SerialCom. This plug-in is downloaded from the website and enabled in the software. The device starts to communicate with the sensor and records the National Marine Electronics Association (NMEA) GPS data. A Graphical User Interface (GUI) based sample output obtained from the software is shown in Figure 5.

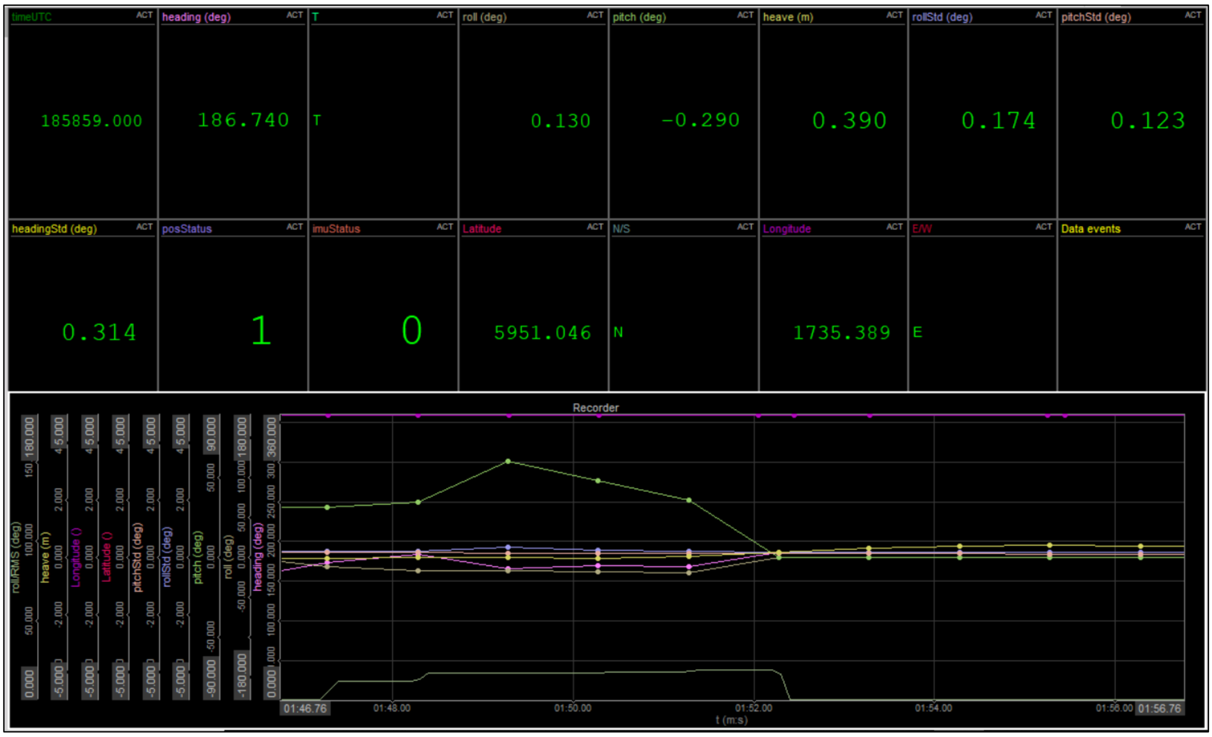

Figure 5: A sample output showing NMEA data with real-time clock and related graphs displayed.

(c) <u>*Drawbacks:*</u>

The controller DAQ though satisfies the requirements and is perfectly suitable for the application, is economically not feasible. The initial cost of the systems is around 9000€ and hence it is beyond the budget of this project.

2.4.2 Controllers from National Instruments

The controller DAQs from National Instruments are suitable and also has specific models that are built for the data storing process. Two specific models, cRIO-9040 [22] with NI-9219 [23] strain gauge interface and MyRIO [24] are found to be suitable after discussing with technicians from the National Instruments. Though the controllers are very well suitable for the primary task of data acquisition, the devices mentioned above have their demerits. The cRIO-9040 seems to consume a maximum 60 W power. This is high compared to the other controllers. Though these devices are economical, they require special LabVIEW software such as LabVIEW Professional and LabVIEW Real-Time software (by National Instruments) thus making it costlier. Though the Uppsala University provides a free student access to this software, it was still an ethical dilemma if that can be used in a funded research project. cRIO-9040 do not have analog inputs pins. Only digital signals can be given as inputs. NI-9219 is an add-on device to enable cRIO-9040 to communicate with the force transducers. NI-9219 acts as an Analog to Digital Converters (ADC) and also provides the necessary excitation current for the force transducer [25]. External ADCs can also be designed and built to communicate with the force transducers. This adds more complexity to the circuit. Additional care is to be taken to protect the external ADC circuit from the environment.

2.4.3 Raspberry Pi based DAQs

Raspberry Pi processors are powerful computers that can perform several programmed operations from small binary calculations to image processing. These computers are cheap and efficient [26]. One main advantage of the Raspberry Pi is its USB protocol for peripheral communication. The SBG sensor can easily communicate with the Raspberry Pi's USB sockets. In today's market, the Raspberry Pi core is used to build more powerful devices for industrial data acquisition and handling. One such device is the RevPi Compact from the KUNBUS GmbH.

2.5 RevPi Compact

The RevPi Compact is a powerful Raspberry Pi based processor that is used for industrial data handling applications. The control system is designed with a quad-core processor operating at a 1.2 GHz frequency. The 1 GB Random Access Memory (RAM) and 8 GB internal flash memory [27] [28] makes it more powerful than a regular Arduino based controller that is designed with a RAM of 8 kB and flash memory of 256 kB [29].

2.5.1 Operating Power and Consumption

The Rev Pi Compact is designed to operate on a wide range of voltages. It can handle from 10.8 V to 28.8 V DC and the maximum power consumption of the device is around 20 W [28]. But practically for the operation in this project, it consumes only 4-5 W. This is an important consideration because the entire system can now be operated on a standard 24 V source voltage by connecting both the Lithium Polymer (Li-Po) batteries in series.

2.6 Communication Devices

The main focus of this device depends on the data to be safely transmitted to the ground station. This can be done in the following ways:

(a) Manual data scavenging:

The data collected from the buoy can be stored in the buoy itself using high-grade storage devices. This can be later collected by manually reaching the buoy in regular intervals of three months and replacing a new storage device for the next interval. One main advantage of this method is the reduced power consumption. The power consumed by the communication devices is almost 3-5 W which is high, considering the limited available power source and storage. Storing this power increases the survivability of the buoy for a longer time frame. This main drawback of the system is the data stored is just in one point which is the buoy. So, in case if the buoy floats away from the location the entire data is lost forever. Since no information about the buoy is transmitted to the ground, it is impossible to track it without any GPS information. Another downside of this method is the requirement of manual labour. Reaching out to the buoy and replacing the storage devices on rough tide days is almost impossible.

Frequently dismantling the electronics is also not recommended as it might damage the equipment if not rightly placed.

(b) Radiofrequency transmitters and receivers:
Radio Frequency (RF) is the electromagnetic spectrum that ranges from 20 kHz to 300 GHz, above the infrared spectral region. In the previous project [8] the Adeunis was used for communication. The RF transmitter is placed in the buoy and the receiver device is placed in the ground station. The receiver device is connected to a microcontroller (Arduino) which is programmed to decode the RF signals and convert them into user-readable data. The transmission speed was set at 57.6 kbit/s but it decreases with the increase in the distance between transmitter and receiver.
The main disadvantage of this communication setup is that the maximum achievable range of communication under test conditions was 3.3 km [8]. So, the performance of this system will decrease under a highly variable marine environment. One more disadvantage of this setup is the need for a ground station within 3.3 km from the buoy. The ground station with the transmitter should be equipped with a stable power source, controllers like Arduinos or processors like Raspberry pi and computers to upload the data. This adds one more link in the chain increasing the probability of failures.

(c) 4G Internet Communication:
This method uses the existing mobile data network from the local service providers to transmit data from the buoy. The 4^{th} Generation-Long Term Evolution (4G LTE) is the present-day network used for internet communication in all mobile devices. The main advantage of using internet communication for this system is that the data becomes accessible from any point on the planet. This does not necessarily affect data security because the username and password are required for access. The buoy and the measured data can be tracked in real-time and the data can be uploaded on a cloud instantaneously. An interruption in the network for a few minutes will still not affect the transmitted data as the data stored in the buffer will be transferred to the cloud whenever the connection stabilizes. The measured data is stored in two different locations by this technique. One is the onboard storage and the second location is the network cloud. Hence, the data is very well secured in comparison with methods a and b mentioned above.

2.6.1 Choice of network

The location of the buoy is the first major deciding factor for choosing the network. Several networks like Telenor^{TM}, Comviq^{TM}, Telia^{TM} etc are available in the area. It is necessary to ensure that these operators can provide a stable network in the coordinates between ($58^0$11’850 N $11^0$22’460 E) northern and southern navigational markers ($58^0$11’850 N $11^0$22’460 E). More details on the Lysekil test site can be found in [7] section 2. On enquiry, the network operator Tenenor^{TM} and Telia^{TM} provides a highly stable 4G signal with signal strength 4 out of 6. The website of Telenor^{TM} provides a clear interactive map of the area and the signal strengths represented in Figure 6.

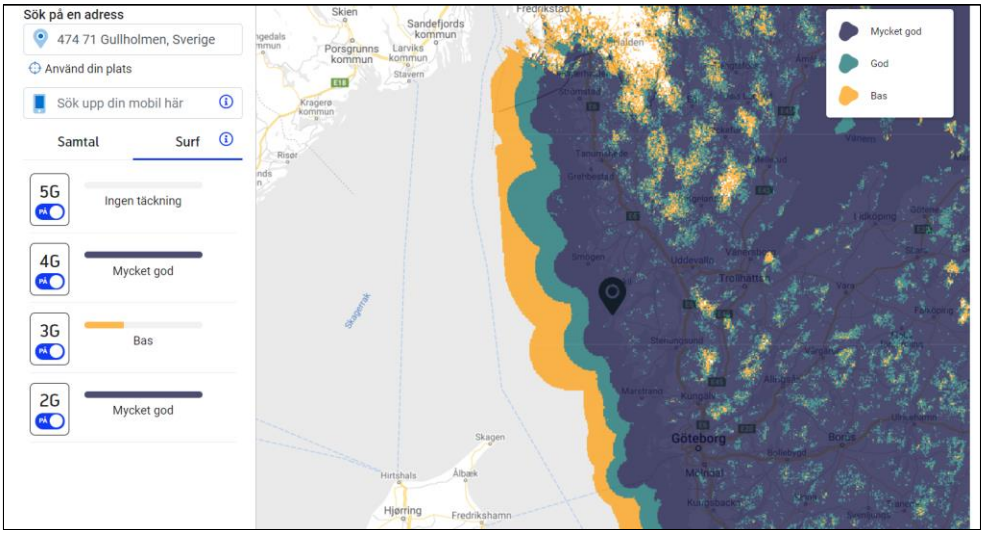

Figure 6: Real-time map for signal strength in a given location on Tenenor™ website[4]

2.7 Electronics Chamber Planning

The central core of the buoy is the container in which all the electronics are housed. This chamber should be designed in such a way that it protects the devices from the salty humid marine atmosphere. The chamber should not be small as it can cause ventilation issues and not too large. The individual devices are placed in a way such that a small clearance is available in between. This ensures air circulation and also protection from Electro-Magnetic Interference (EMI).

2.7.1 Planning

The IKEA® Kitchen tool is used to design the arrangement of the electronics chamber. The tool does not allow the chamber to be lesser than 90000 mm^2 in the area and hence the sizes are scaled up to twice the original. The design is shown in Figure 7.

[4] https://www.telenor.se/support/driftinformation/mobiltelefoni-och-mobilt-bredband/mobiltackning-i-sverige/

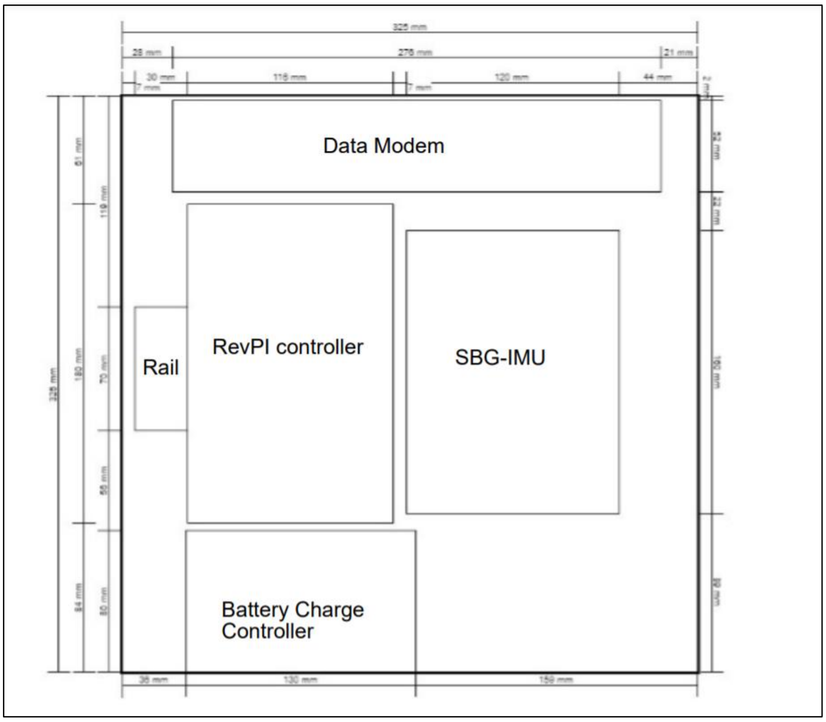

Figure 7: The blueprint of the electronics compartment with individual devices.

Figure 7 shows the devices inside the electronics compartment. The batteries do not belong to the electronics compartment and they are placed inside the cabins on the sides of the electronics compartment. By isolating the batteries from other electronics, the heat from the batteries is dissipated properly ensuring the safety of other electronic devices from this heat. Connection cables from the battery cabins enter the electronics compartment through small holes placed on the walls of the compartment as shown in Figure 8.

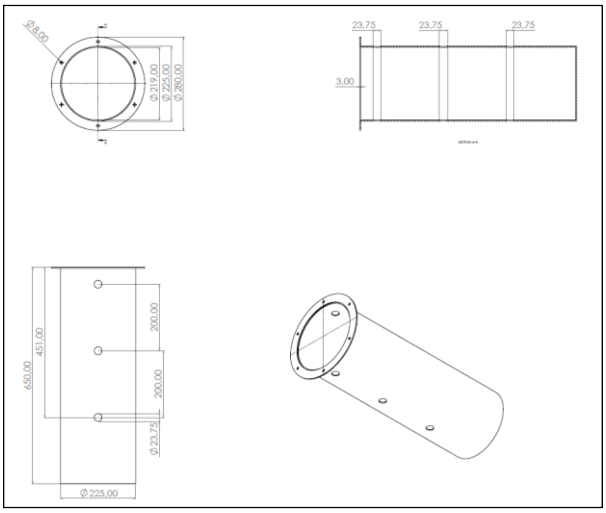

Figure 8: Design of the electronics compartment with the measurements.

A top-view of the buoy is shown in Figure 9 consisting of slots to mount solar panels and the battery cabins visible.

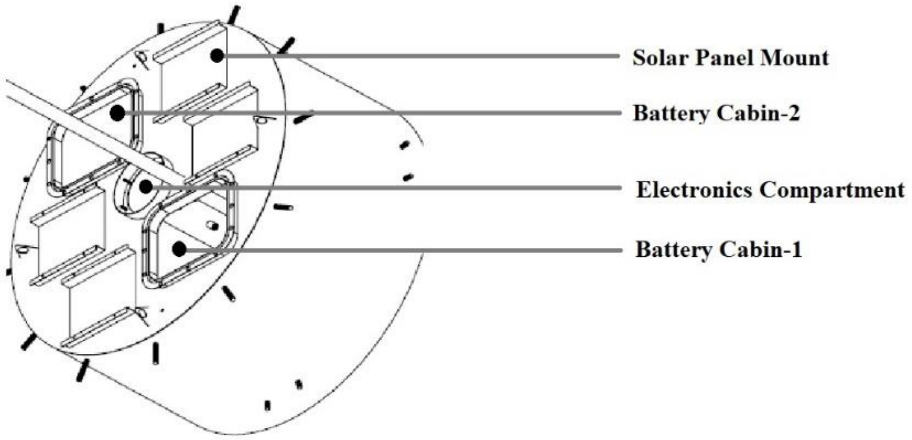

Figure 9: Design of the buoy housing the battery cabin and electronics compartment.

3. <u>Method</u>

This section gives a detailed insight about interfacing the electronic devices and operating them in coordination to bring the necessary output.

3.1 Electronic connection ports in RevPi Compact

The device operates on a Broadcom BCM2837B0 quad-core ARM Cortex A53 processor. The motherboard has some peripheral device connector capabilities. It has a High-Definition Multimedia Interface (HDMI) port, one Micro USB port and one RS-485 port. Additionally, there are four USB-A type ports to connect peripheral devices and sensors. Initially, the HDMI and USB-A ports together are useful in communicating with the device itself with monitor, keyboard and mouse.

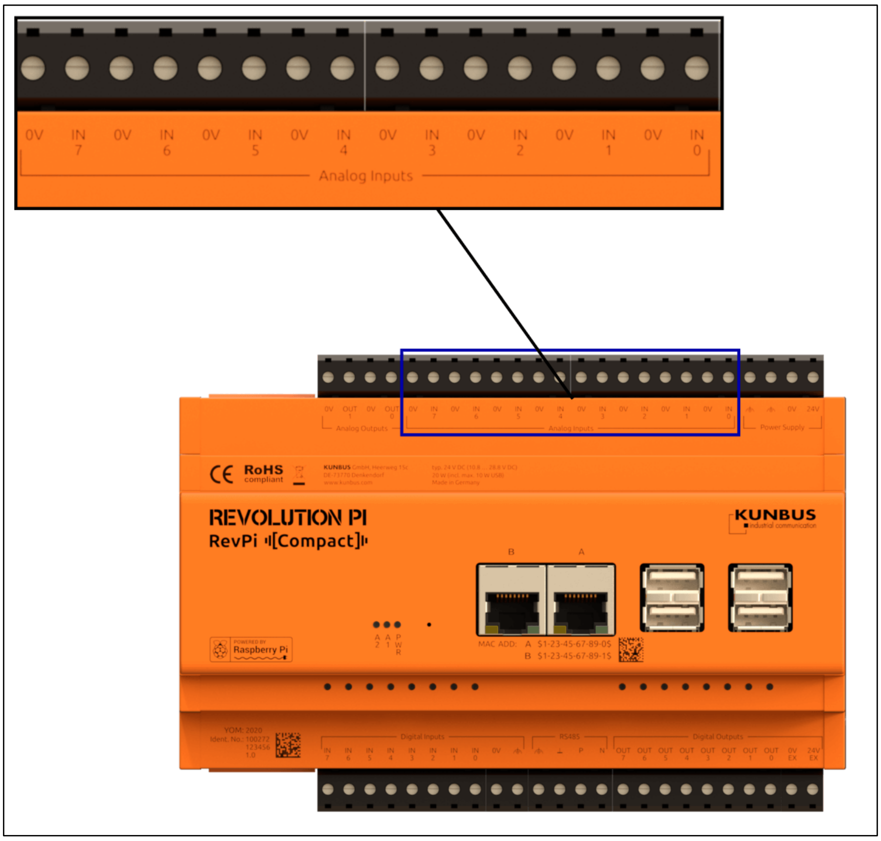

Figure 10: Rev Pi Compact (front view) with USB ports, digital and analog I/O pins with an enlarged view of analog pins from 0 to 7 [30].

One important feature of this device is the analog inputs. There are 8 analog inputs with the pins are numbered from 0 to 7 as shown in Figure 10 and two analog outputs enabled in the device. The input and output pins are collectively referred to as I/O pins. Generally, Raspberry Pi models do not support analog inputs directly [31]. The analog sensors are interfaced with the core device with the help of ADCs. The most commonly used ADC is MCP3008 with a 10-bit resolution [32]. But the advantage of the RevPi Compact is its inbuilt ADC. The resolution of the ADC is 21-bits [33]. MCP 3550-50 chip [34] is used as an ADC in the device.

The pins, as shown in Figure 10, are designed as slots with screws to secure the connections in place. Every measurement pin (0-7) comes along with a 0 V pair as a reference (ground) to the measurement pin. But since the device has internal pull-up resistors enabled, the measurements can be made even without the connection in the 0 V pin.

Raspberry Pi models have onboard Wi-Fi enabled to access the internet. But RevPi Compact does not have onboard Wi-Fi. So, the device has two ethernet ports to connect to the Local Area Network (LAN). This is not very advantageous as it might induce connection errors in the ethernet cable during extreme vibrations. But the cable connection over short distances enables faster data transfers and are more reliable.

The ethernet port A shares bandwidth with the USB devices and can achieve data transfer speeds up to 11.2 Mbps (Bytes Per Second) [35]. But since the device shares the bandwidth with USB, it might have an adverse effect on the data transfer rate, thus slowing it down. The ethernet port B shares bandwidth with Serial Peripheral Interface (SPI). The maximum throughput of this port can be up to 2.1 Mbps [35]. The data transfer speeds can be decided only after testing the communication network setup.

3.2 Mechanical Installation

The device is housed in a polycarbonate material and weighs 0.3 kg approximately. The dimensions are 160.6 mm x 90 mm x 58 mm [27]. The device can be easily mounted by sliding into a Deutsches Institut für Normung (DIN) rail of 35 mm width as shown in Figure 11.

Figure 11: RevPi Compact mounted on a DIN rail [36].

3.3 Sensor interfacing and data flow path

This section explains the flow of data from the transducers to the communication device through the controller.

The strain gauge transducers are connected to the analog input pins. The 200 kN force transducer is connected to analog input pin 2 that is addressed as Ain_3 and the 50 kN force transducer is connected to pin number 1 that is addressed as Ain_2. A small portion of unshielded copper wire is inserted into slots and screws to ensure contact. The SBG-IMU is connected to one of the USB-A ports. The IMU can communicate directly with RevPi Compact through the USB protocol with its RS-232 to USB converter. The data collected from all three sensors is processed by the controller and safely logged into the memory device.

The ethernet port A is connected to the Huawei modem through a LAN cable. A copy of the stored data is transmitted to the cloud (internet) through the modem periodically. All the data receiving and transmitting ports are highlighted as green spots in Figure 12.

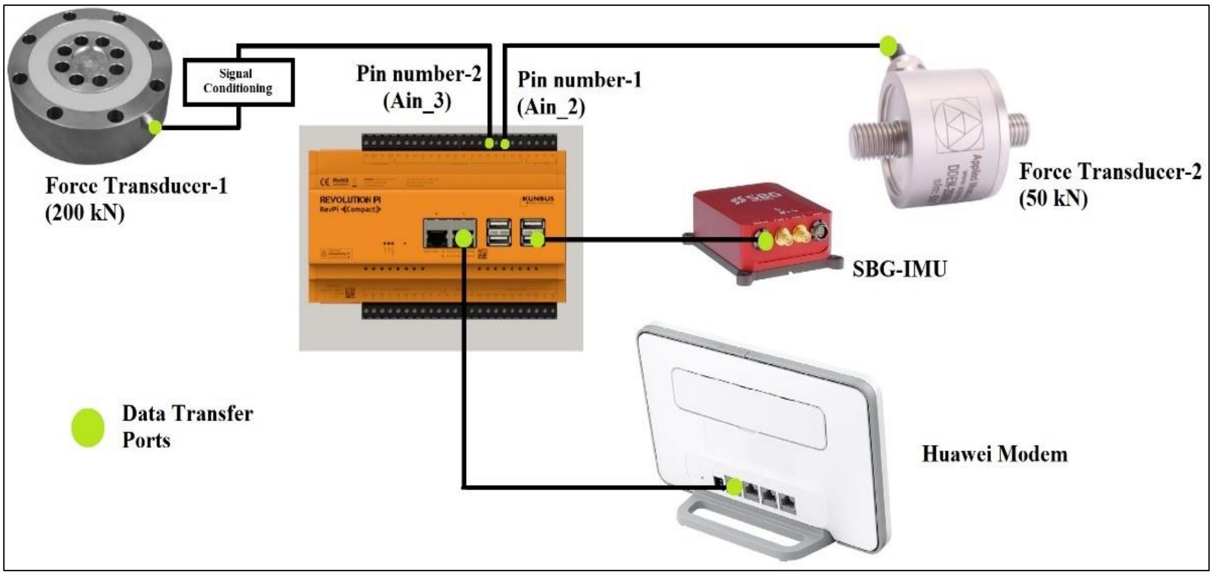

Figure 12: Pictorial representation of data flow points in the circuit [27] [17] [37] [38] [39].

3.3.1 Software Settings

The PiCtory[5] is the application that runs on a browser to enable or disable the I/O pins in any RevPi device. This application is pre-installed in the RevPi device that can be accessed from the applications tab on the top-right corner in the desktop. One other way is to type the IP address of the network connected on the browser search tab. The screenshot of the Pictory application is provided in the Appendix section. The Configuration Board of the Pictory application enables us to arrange and connect different devices like how they are arranged physically. The RevPi Compact device is selected from the list provided and dragged into the main working window. The 'Device Data' box immediately displays the type of the device and its details. The next important step is to decide the types and number of input pins required for operation. For communicating with the analog sensors, two analog input pins are enabled from the 'Value Editor' box in the bottom right corner of the window. The frequency of measurement can be selected from input debounce tab and the name of the pins can also be changed if necessary. After the necessary steps are done, the changes can be saved by selecting the Reset Driver option from the Tools tab. The device can be restarted for these settings to be implemented.

To read the sensor data, the piTest[6] shell command is used. Though this command has many functionalities, the piTest-r command followed by the pin name, reads the data from sensors. Delays can be introduced to vary the frequency of the data measured (sampling rate). A Python code can also be used to carry out this operation instead of shell script. Python programming can be written using the Python 3 environment available as one of the menus in the GUI desktop as shown in Figure 13 can be called as a python file inside a shell script.

[5] *https://revolutionpi.com/tutorials/was-ist-pictory-3/*
[6] *https://revolutionpi.com/tutorials/__trashed/*

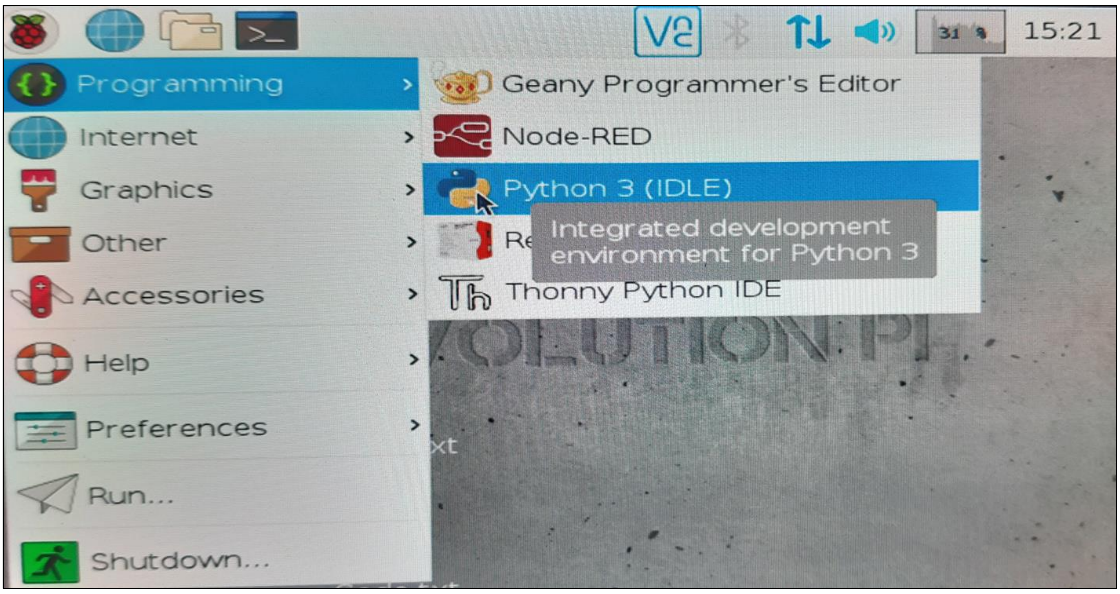

Figure 13: The Python 3 IDE in the GUI desktop from the drop-down menu.

Using regular shell commands, it is easier to test the data measurement along with monitoring value variations and storage. A simple shell script is coded for both strain gauge transducers to monitor and store the measured data. The script is shown below:

Line 1: cd /media/pi/A0AB-1433/Data //This opens up the destination where the data file is to be stored.
Line 2: while [1 -eq 1]; do piTest -1 -r AIn_2 >> Data1.txt; sleep 0.5 ; done //A loop that creates a file (here 'Data1') to log the data. 'AIn_2' is the name of the pin that one of the two force transducers are connected.

3.4 Storage

Since the controller has four USB-A slots, it can be used to plug-in USB memory devices (such as pen drives) to expand the storage capacity of the RevPi Compact. The size of the memory device is determined by the amount of data recorded over a definite time period. The calculation of data size cannot be predicted 100% accurate because it depends on the instantaneous data recorded by the transducers. But considering a sampling rate of 100 Hz, which is 5 times higher than the practical sampling rate, the maximum memory required per day can be predicted.

IMU data sample size= 204 bytes

Force data sample = 2 bytes (8-bit information from every sensor)

Total instantaneous data size = 206 bytes

206*100=20,600 bytes/second

=1,779,840,000 bytes/day

=1.78 Gb/day

A 16 Gb memory card is sufficient to store 9 days of data

A 512 Gb USB storage can be used to store data for 300 days.

But practically, the sampling rate is in the range of 15 to 25 samples per second. So, the weight of the measured data will be 4 to 5 times less than 1.7 Gb/day.

SanDisk UltraFit 512 Gb USB stick is used for this purpose. It is extremely compact and weighs about 1.2 g [40]. It almost becomes a part of the main body of RevPi Compact once plugged in and hence the connection is not susceptible to the effects of vibrations.

3.5 Force transducer-1 (200 kN)

This strain gauge transducer is manufactured by HBK (renamed from HBM in 2020) [41]. The maximum load capacity of this transducer is 200 kN and the sensitivity of the transducer is 2mV/V [37]. This transducer is attached to the base of the buoy as shown in Figure 14, facing the seabed. This alignment with the buoy allows the transducer to move along with the buoy and measures the forces acting perpendicular to the base of the buoy.

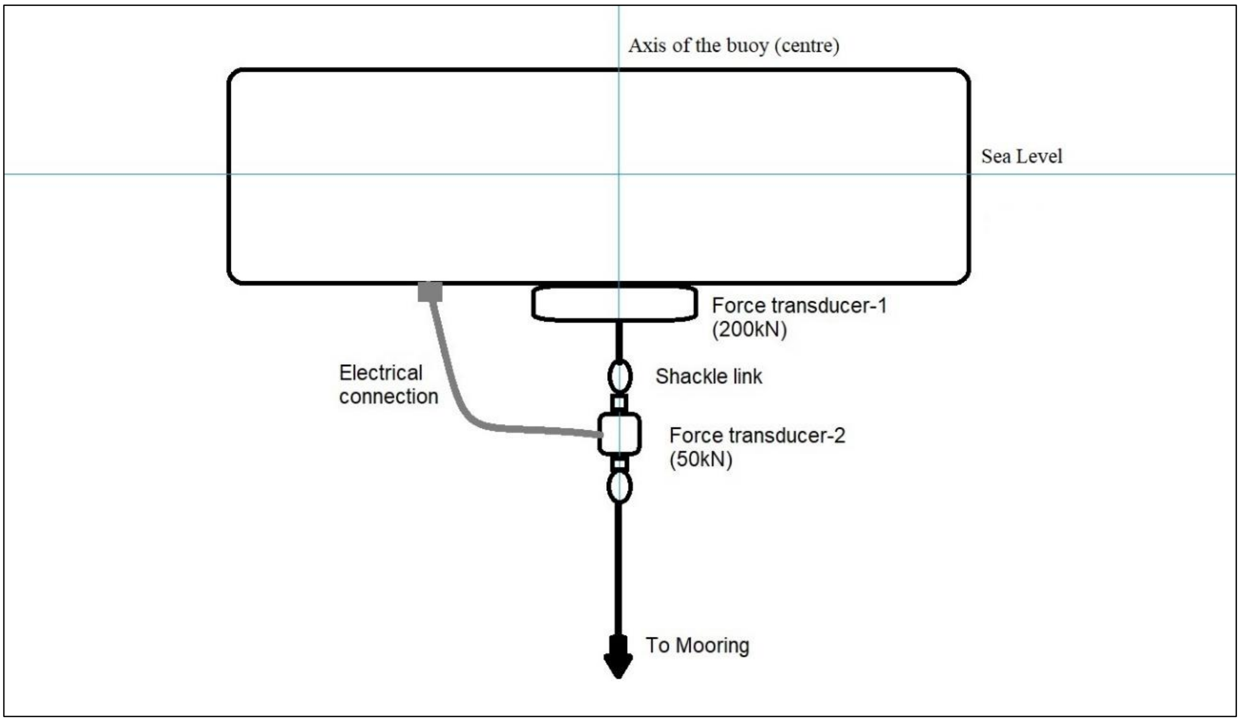

Figure 14: Mechanical installation of force transducers under the buoy (front view) under stable conditions.

3.5.1 Amplification Circuit for Force Transducer-1

The transducer does not contain an internal amplification circuit and so an external amplification circuit is designed to get the voltage output from the range of millivolts to 0 to 5V. This amplification of voltage is necessary as 0 to 10 V is the readable range of Rev Pi Compact’s analog input pins.

The DC-DC converter is used to step down the 24 V DC voltage from the battery supply to a stable 5 V DC supply that feeds the force transducer with excitation voltage and the amplifier source voltage. Any disturbances, noise or instability in the source voltage will affect the output measured from the transducer. So, additionally, a uA7805 voltage regulator IC [42] is added to obtain a more stable source voltage.

The INA-126P instrumentation amplifier [43] operating in differential mode is used to amplify the low voltage signals from the force transducer in the range of millivolts to volts.

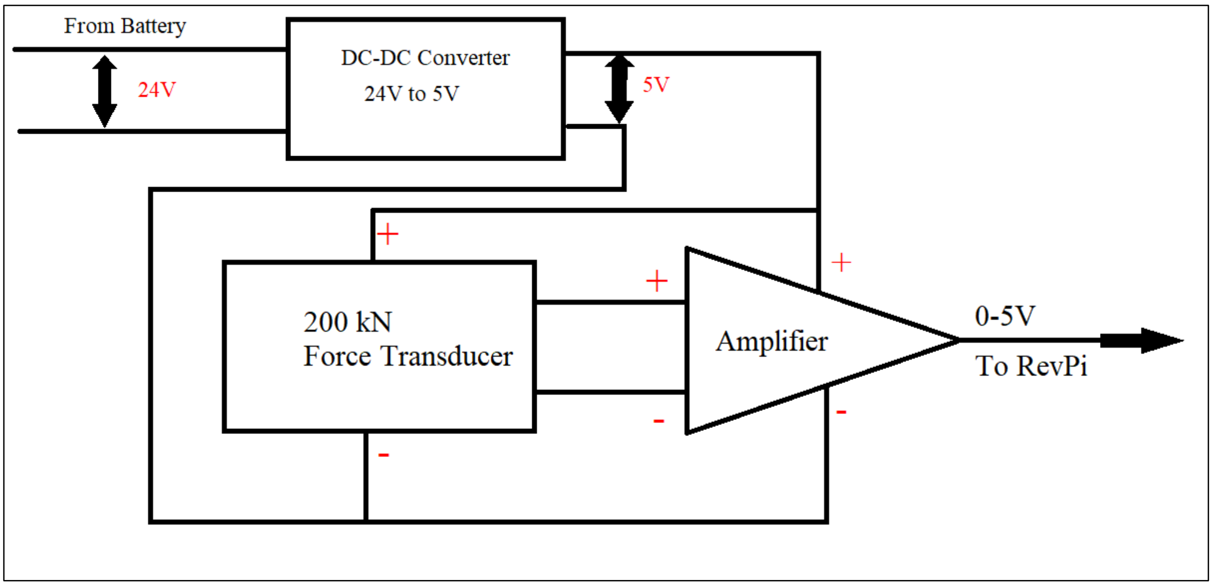

Figure 15: Amplifier Circuit for 200kN force sensor.

The amplification circuit as shown in Figure 15 provides output voltage proportionate to the input force, that is, 0 V corresponds to 0 N and 5 V corresponds to 200 kN. Since the RevPi Compact can measure in the order of millivolts, every millivolt corresponds to a change of 40 N force which is the maximum obtainable resolution of this system. The sampling rate can be adjusted in the programming.

3.6 Force transducer-2 (50 kN)

Unlike the first force transducer, which is attached to the buoy, the second force sensor is attached below the first transducer in the mooring line. Two shackles hold the sensor in place and it moves along with the mooring line. This sensor measures the force that acts on the buoy parallel to the mooring line.

The force transducer used is from Applied Instruments, model DDENA2H. The force sensor is capable of measuring 0-50 kN [38]. The built-in amplifier converts the measured voltage which is in the order of millivolts to 0-5 V. Hence, an external amplification circuit is not necessary. Considering the force-voltage proportion, the resolution of this sensor is 10N/millivolt.

With the values recorded, a Matlab plot (see Figure 16) is obtained. Since the relationship of the force measured and the voltage output is linear, the plot is used to calculate the force values in between two voltage values.

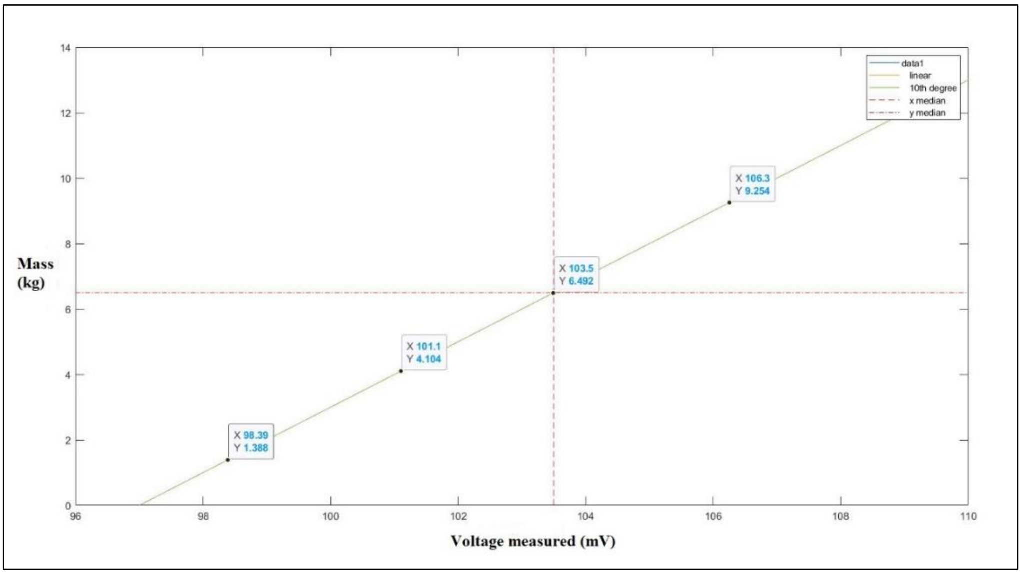

Figure 16: Linear relationship between force and output voltage used to measure force values in between millivolts.

The sensor is initially tested to monitor the change in the voltage output and periodically inducing some mock force. The sample output displayed on the screen of RevPi Compact is shown in Figure 17. The test was carried out for 18 hours and the values were tabulated. A graph was plotted with the obtained values and this is shown in Figure 18. The large spikes in the graphs are due to the mock loads applied by human hands. For most of the time, the output was stable at 97 mV. There are little deviations in some parts (small spikes in the graph). These variations are ±2 mV. This is due to the variation in operating temperature and also disturbances in the excitation voltage. So, the accuracy of the output from the sensor and amplification system is ±20 N (or 2 kg). But considering the measurement range of 50 kN, an error of 0.04% is almost negligible. This accuracy also matches the sensor's datasheet value of 0.05% [38].

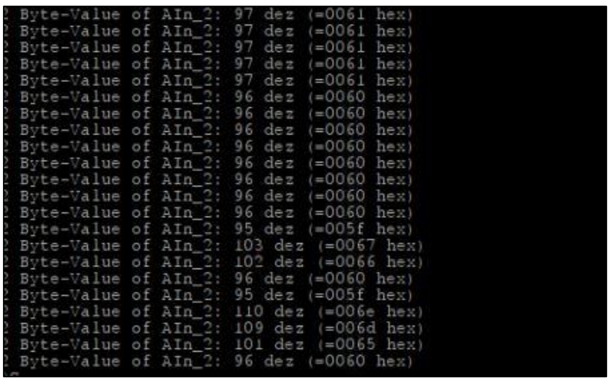

Figure 17: Output values from 50kN force transducer measured by RevPi Compact.

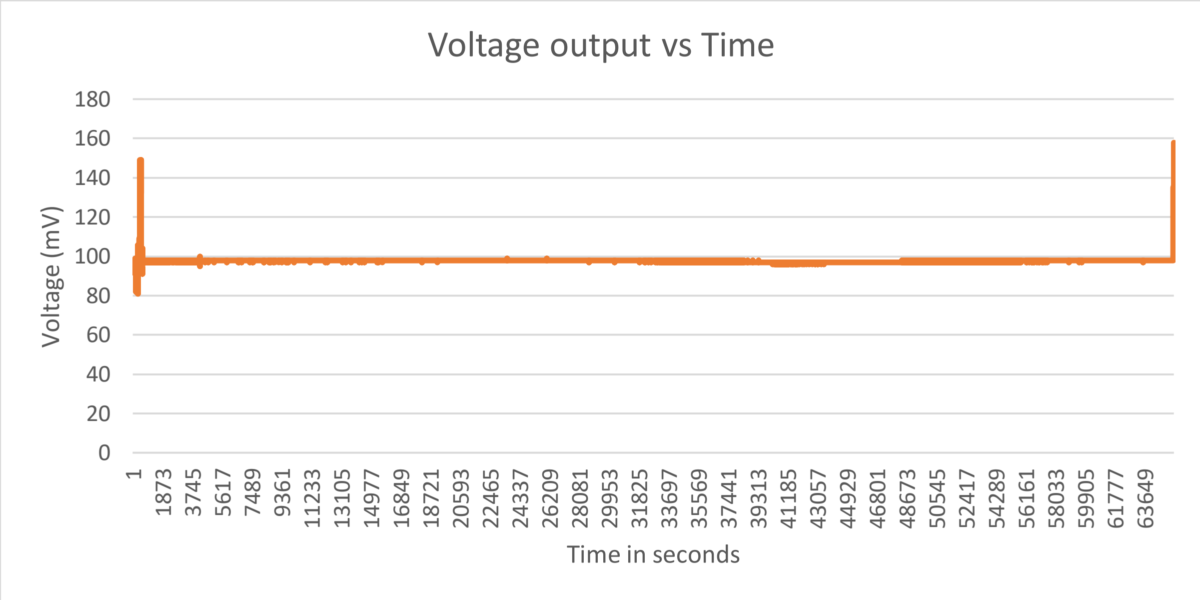

Figure 18: Voltage vs Time plot with recorded data from the force transducer

4. Results and Discussion

4.1 Measuring an unknown load using the force transducers

A bridge crane is used to suspend the transducers and the loads. Nylon cables are used to secure the 200 kN transducer. The 200 kN transducer is hooked to the crane by nylon cables looped several times through the eight inner holes (shown in Figure 19). The ends of the nylon rope are fastened by a bowline knot. Similarly, several loops of the nylon cables are run through eight outer holes which connect the second (50 kN) force transducer through shackles. The second force transducer has two heads with threads. The diameter of the head is 16 mm. Two M16x2 shackles are screwed to the heads of the transducer. Additional shackles are used to connect the nylon cables along with the 50 kN transducer. The unknown load is used for testing the working of the transducers. Heavy metallic materials are loaded into a wooden box with supporting slots used for forklifts. Broad nylon straps are carefully fastened and inspected for loose ends. The ends of the straps are then connected to the loading shackle attached to the bottom head of the 50 kN transducer-2. A known load (not used initially) of 70 kgs is used for calibration of the transducers and later calculate the unknown load.

It is necessary to ensure that the load is perfectly balanced to obtain accurate values from the sensor. This can be inspected by visually checking if the base of the wooden load box is perfectly parallel to the ground and not inclined.

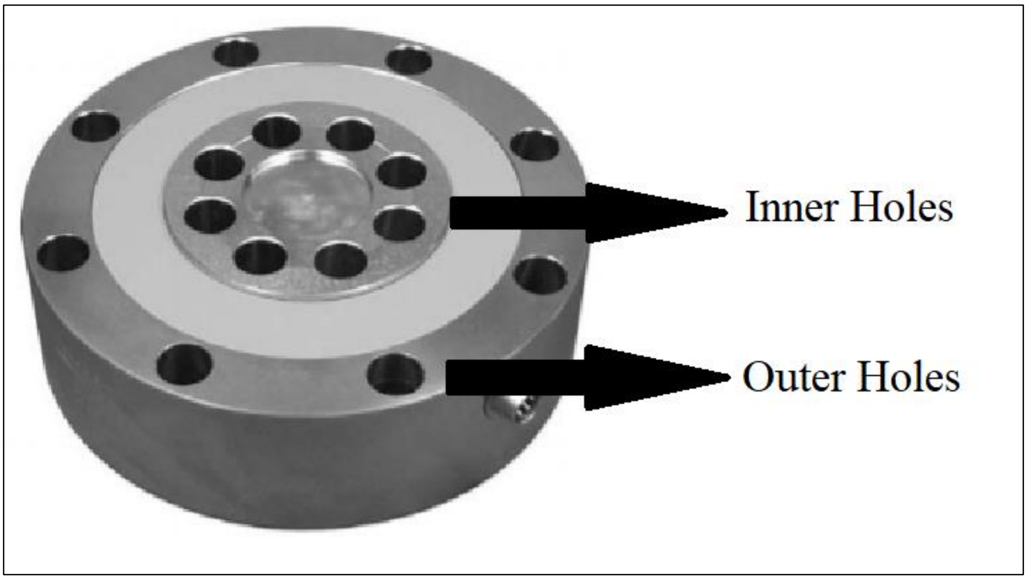

Figure 19: 200kN Force transducer with inner holes and outer holes [37].

Mechanically, the outer holes are used to fix the transducer onto the body of the buoy. The inner holes are used to connect the transducer to the mooring line (in series with the next transducer).

After mechanically assembling the force transducers and load as discussed earlier, the test setup is shown in Figure 20.

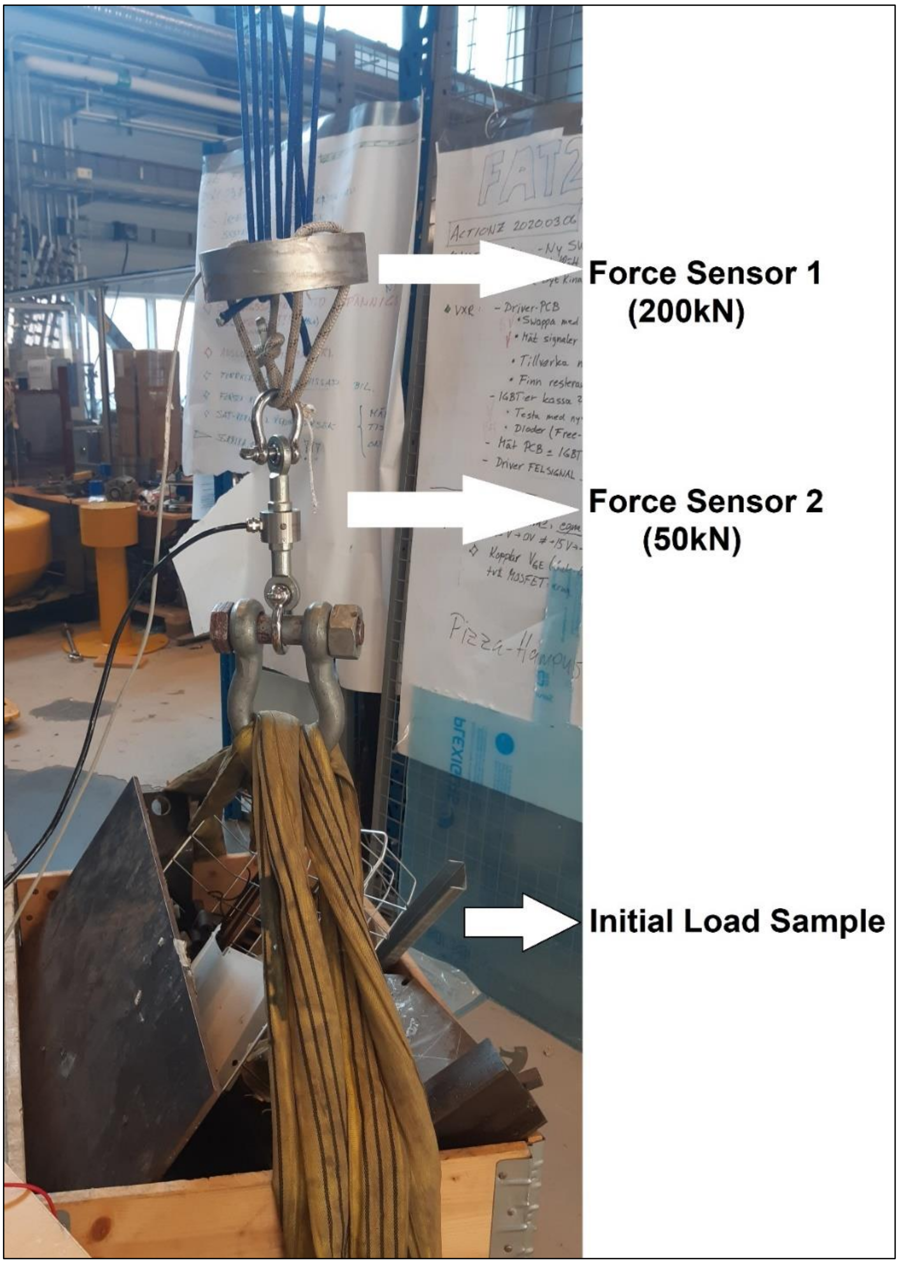

Figure 20: Initial test setup with force transducers and an unknown sample load.

4.2 Electrical Connections

The whole system is designed to operate on a standard 24 V supply and for the lab tests, it is provided by a bench power supply for this testing. The electrical wirings for the individual transducers are explained in the sections below.

4.2.1 Wiring scheme of 200 kN Transducer

The wiring scheme according to the datasheet [37] of the transducer is shown in Figure 21. The sensor is excited by a 5 V signal from the amplification circuit shown in Figure 15. The output of the bridge is measured across the white and red wires as shown in Figure 21. This output, in the order of millivolts, is directly fed into the amplifier chip and corresponding output in the range of 0 to 5 V is obtained. This amplified output is directly measured by a multi-meter and parallelly connected to the analog input 3 (Ain_3) of the RevPi Compact. This is to ensure that the values measured by the RevPi Compact are in accordance with the physically measured voltage values from the multi-meter.

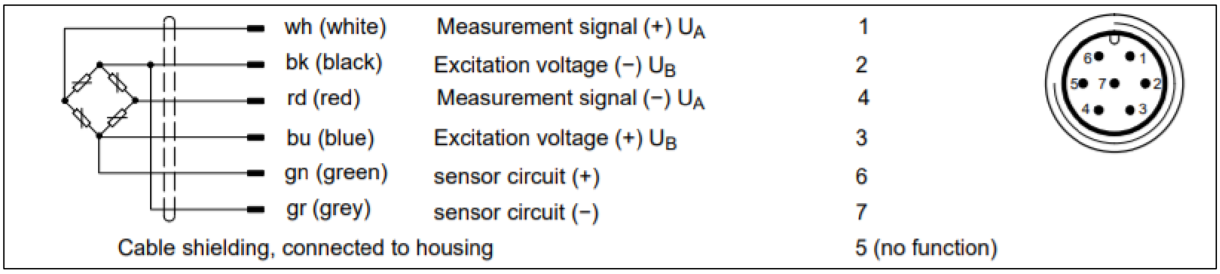

Figure 21: Wiring scheme of force transducer-1 (200kN) [37]

4.2.2 Wiring scheme of 50 kN Transducer

The wiring scheme of the DDENA2H transducer is simpler due to its built-in amplification circuit. The red and blue wires are connected to the positive and negative terminals of the 24V power supply respectively. The white cable is the data line and it is connected to the analog input slot 1 of RevPi Compact which corresponds to AIn_2. All the relevant wiring schemes are listed in the datasheet of the DDENA2H and it is shown in Figure 22.

Wiring Diagram:

Wire	mV/V Output	3-Wire Voltage or Current Otput	4-Wire Voltage Output	2-Wire Current	RS485 Digital
Red	+ve excitation	+ve supply	+ve supply	+ve supply	+5.4 to +18Vdc supply
Blue	-ve excitation	0V common	-ve supply	-ve supply / signal	-ve supply
White	+ve signal (tension)*	+ve signal	+ve signal	N/C	RS485 (B) Data -ve
Yellow	-ve signal	N/C	-ve signal	N/C	RS485 (A) Data +ve
Screen	To ground - not connected to load cell body				

* +ve signal in tension is standard, +ve signal in compression can also be offered.

Figure 22: Wiring scheme of a DDENA2H force transducer (50kN) highlighted [38]; 3-wire voltage output.

4.3 Testing the Force Transducers

This section explains the two different tests carried out using the force transducers.

a. *Initial test (Unknown load measure)*

The initial testing of the force senor is done to measure the output voltage proportionate to the loaded weights. The change in the output voltage has a direct linear relationship with the change in load. This is important to test in the first stage to ensure that the sensors are connected properly and the measurement is as expected. All the shackles are thoroughly inspected ensuring safety. The nylon straps and ropes are checked and then the test is started. The crane is operated and the load is slowly lifted above the ground. The change in the output voltage value is carefully observed. The output voltages from both the transducers gradually increase indicating that the sensors are working as expected. After the load 10 cm off the ground, the crane is stopped. At this point, it is important to arrest the oscillation of the suspended load because this will induce an error in the measured output voltage and is also highly unsafe. The final voltage readings of both the transducers are carefully monitored for any changes and once a stable value is displayed, the values are recorded.

b. *Load Test (70kg)*

After measuring the voltage values of the unknown load, the crane operated and the wooden load box is safely placed on the ground. A known mass of 70 kg is placed on the box such that the orientation of the box is not disturbed. After loading the crane is operated and the box is suspended with a ground clearance of 10 cm similar to the previous test case. As expected, there is a proportionate increase in the output voltage. The voltage readings are tabulated and shown in Table 1.

Table 1: Voltage readings output measured from force transducers for different loading cases

Case	Output - 50kN (mV)	Output - 200kN (V)	Comments
No Load	107	0.9786	The default value displayed (may vary by + or - 3mV) depending on factors like temperature etc So, this is considered to be 0N.
Load (unknown mass)	517	1.0895	Change in voltage as the unknown load is slowly lifted above the ground.
Load (known mass 70kg or 700N)	588	1.1063	Change in voltage as the known mass of 70kg loaded.

From this setup, it is also essential to note that the dead load of the force transducer-1 is the weights of shackles, chain links, hooks and the force transducer-2. So, if at all the weight suspended on the first transducer is measured, the dead load should be subtracted. Practically, once the whole system is installed in the buoy, the sensor readings should be calibrated accordingly.

4.4 Testing the Ellipse2-D IMU

Note: Since detailed testing of SBG-IMU is already discussed and performed in the previous project [8]*, this section focuses on the interfacing of SBG and RevPi Compact.*

The Ellipse2-D, is a digital sensor as explained in Section 2.2 Inertial Measurement Unitthough it is designed to communicate through an RS-232 protocol, it has an external converter cable. This cable is useful in converting the RS-232 to USB so that it can be directly connected to one of the four USB-A ports available in the RevPi Compact.

Once the IMU is powered, it starts to measure and send the data to the connected device. The settings for Ellipse2-D are first done by connecting the IMU to a computer with sbgCenter software installed. The software detects the connected device once refreshed as shown in Figure 23.

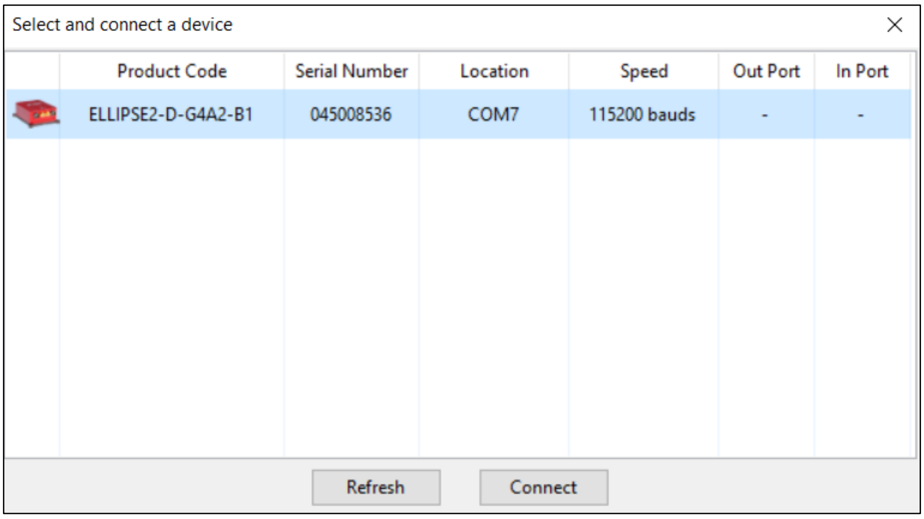

Figure 23: The sbgCenter application dialogue box that opens up to show connected devices and details.

Once the connection is established, the device details and information are separately displayed in another dialogue box as shown in Figure 24.

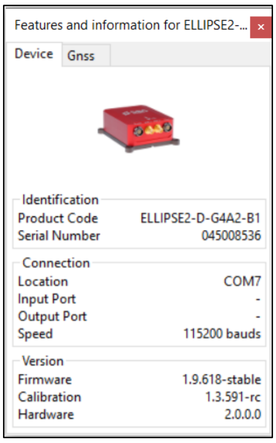

Figure 24: Device information box that shows important details including port number and baud rates.

After device detection, it is important to make sure that the required data to be measured are properly selected and the baud rate is set to 115200. For this project, to measure the raw data and the real-time data, it is necessary to enable 2 ports. Port A and Port E are enabled at 115200 bauds each from the settings window as shown in Figure 25.

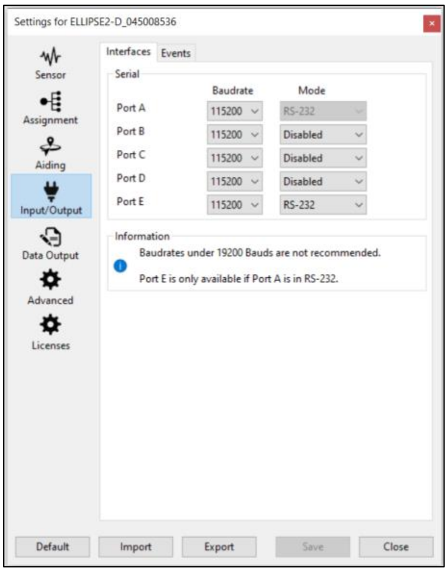

Figure 25: Settings window in sbgCenter for enabling/disabling serial ports.

After choosing the number of ports, the next step is to select the data types to be measured. For example, accelerometers, gyroscopes, magnetometers, GPS etc., can be enabled or disabled depending on the requirement. Along with this, the frequency at which these data are to be measured can also be fixed from the Data Output tab as shown in Figure 26.

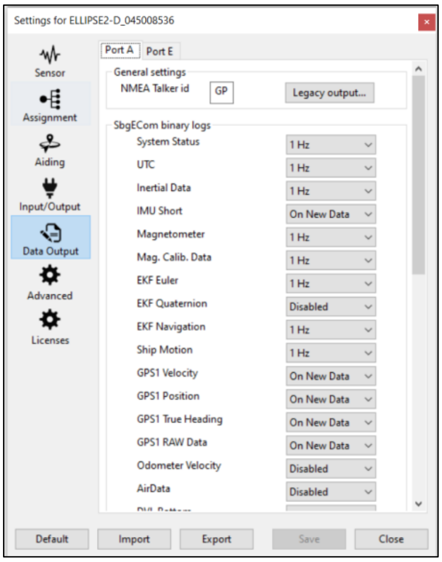

Figure 26: Data Output settings box that is used to fix the types of data to be measured and their respective sampling rates.

After all the necessary data and their sampling rates are selected and fixed, these settings can be saved in the sensor. These settings can also be exported as a separate '.bin' file so that the same can be imported into the sensor in the future. Now the IMU device can be disconnected from the computer and the USB can be connected to the RevPi Compact device.

The serial communication between Ellipse2-D and the RevPi Compact device is established by a software called GTK Terminal. The GTK terminal can be opened from the Accessories Tab in the applications menu from the GUI desktop as shown in Figure 27.

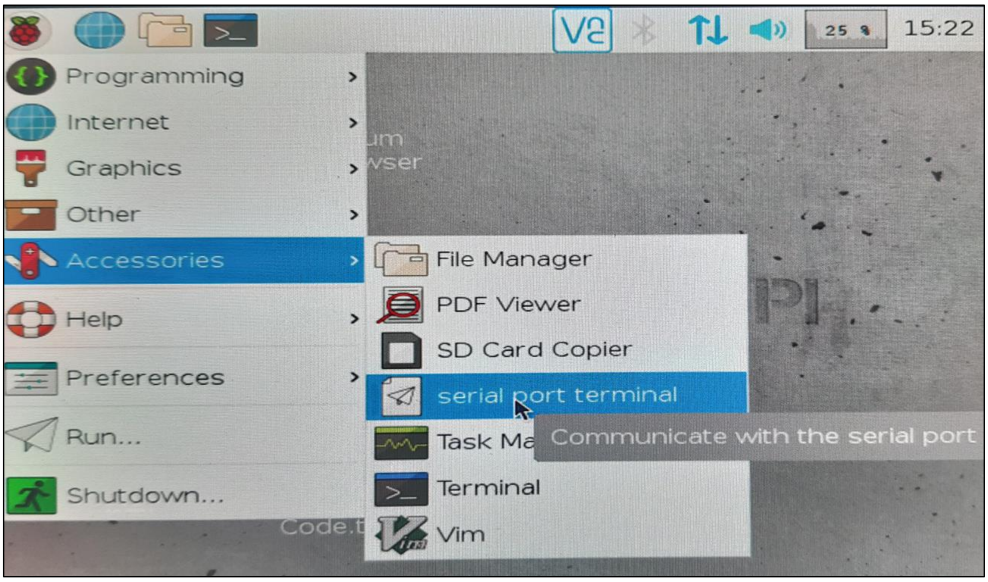

Figure 27: Opening the GTK terminal in a Raspberry Pi GUI desktop.

The next step is to setup the communication protocol. From the configuration tab, the port menu is selected (shown in Figure 28).

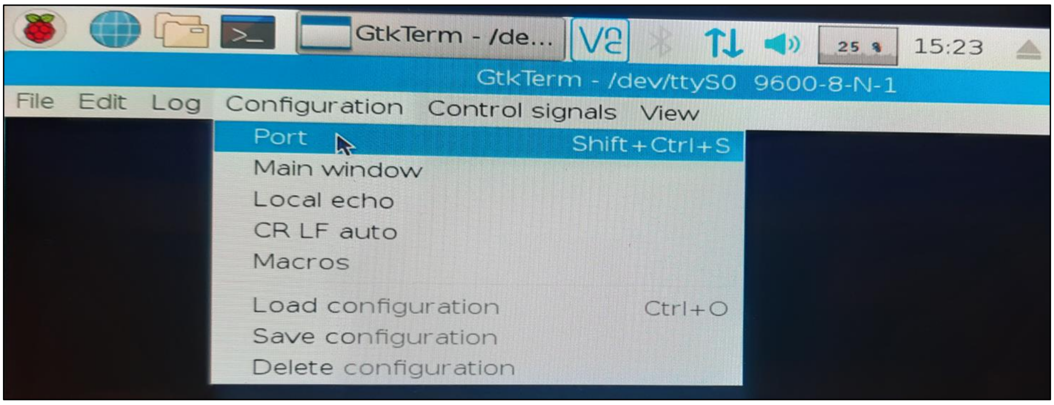

Figure 28: Port menu to enable the communication.

The port is selected as /dev/ttyUSB0 and the baud rate is set as 115,200 as shown in Figure 29.

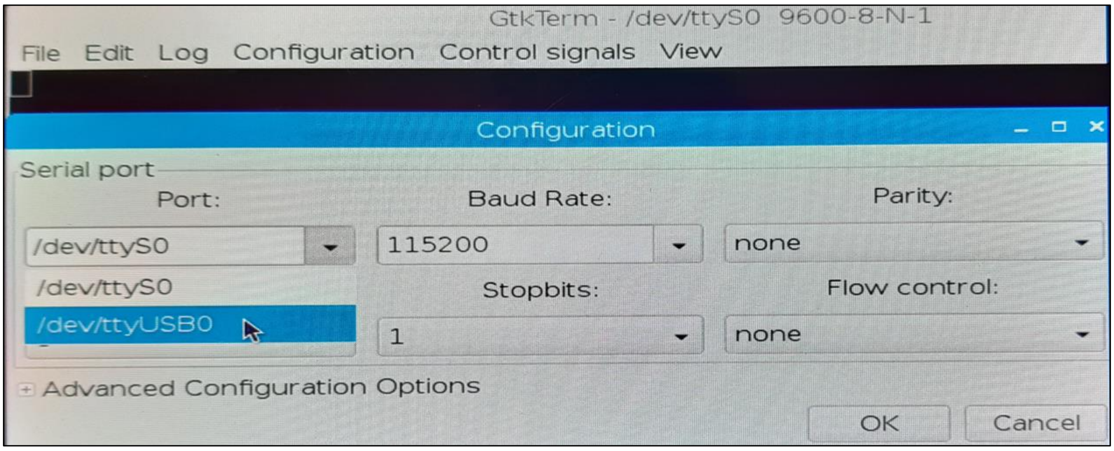

Figure 29: Configuration Window where all the necessary details are set, including the Port address and the Baud Rate.

Once all the above steps are done, the software starts to log the data in the pre-set location addressed in the memory. The data is not readily readable and it is logged just as meaningless characters as shown in Figure 30.

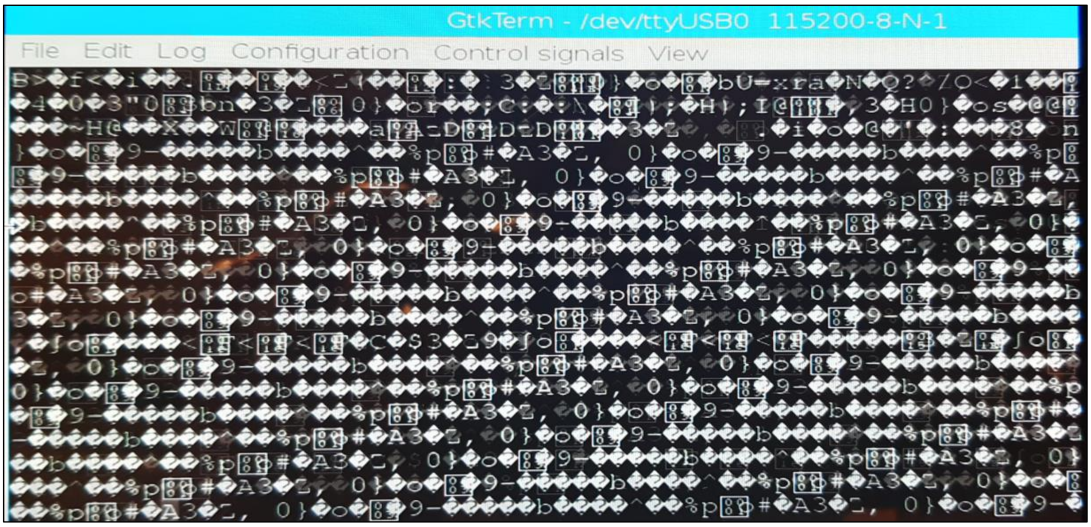

Figure 30: The junk character data logged as the output from the Ellipse2-D in the RevPi Compact with GTK Terminal.

This raw file is then converted in sbgCenter software available in a remote computer. A sample data that is recorded and converted is shown in Figure 31

UTC Date (YYYY-MM-DD)	UTC Time (HH:MM:SS.SS	Roll (°)	Pitch (°)	Heave (m)	Accelerometer X (m.s^-2)	Accelerometer Y (m.s^-2)	Accelerometer Z (m.s^-2)
2015-05-02	12:27:57.000	0.047776	-0.173830	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:57.200	0.047618	-0.173306	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:57.400	0.047459	-0.172782	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:57.600	0.047301	-0.172258	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:57.800	0.047143	-0.171735	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:58.000	0.046984	-0.171211	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:58.200	0.046826	-0.170688	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:58.400	0.046667	-0.170164	0.000	-0.037	-0.008	-9.821
2015-05-02	12:27:58.600	0.046508	-0.169641	0.000	-0.037	-0.008	-9.821

Figure 31: Sample data recorded from SBG-IMU. (Note: The values are not calibrated as the antennas are not connected during this test).

The sbgCenter software application also provides graphs based on the recorded values that can be used in the data analysis in future. The graphs plotted by the software based on a sample recording is shown in Figure 32. In the application software, minute details (up to a range of 10^{-3}) can be observed by zooming in. this is shown in the plot of the accelerometer in Figure 32.

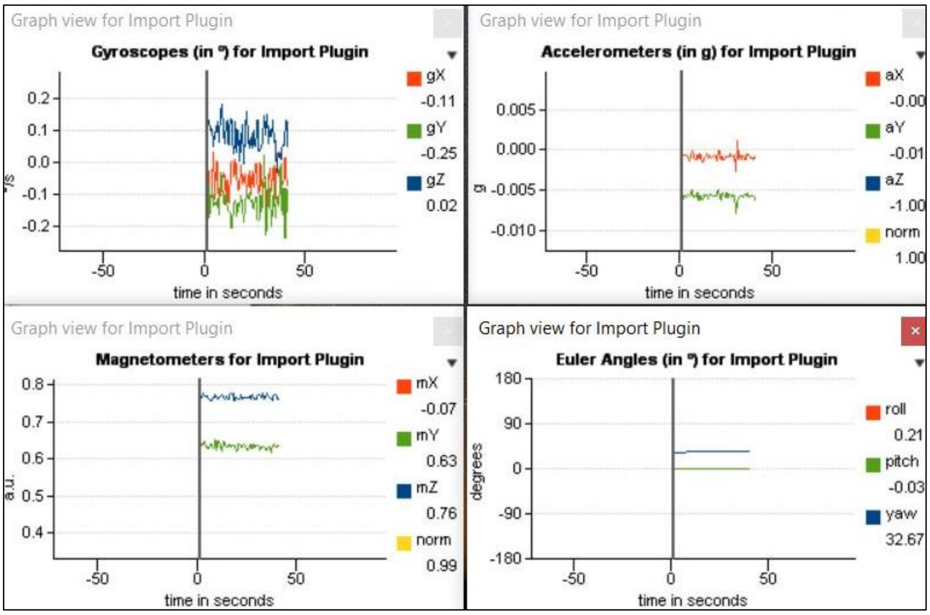

Figure 32: Graph output provided by sbgCenter software application with the sample input.

4.4.1 Issues in Large Data Conversion

Though the sbgCenter application is powerful enough in converting the recorded data into various readable formats like '.txt', '.csv' etc., and also providing graphical outputs, there is an issue observed while converting large memory files. The time taken by the application to process the data is proportional to the size of the data. But when the file size exceeds 300 Mb, the software, running on a regular 64-bit processing laptop, crashes. The application stops working and sometimes closes automatically. This issue has to be resolved because the recorded raw data can be made meaningful only after being processed in the application. So, to overcome this issue, it is essential to split the recorded data into several small files of lesser size without any loss in the data. Instead of splitting a bigger file into several parts, it is better to log data in different files at definite time intervals. Then these small files can be transmitted to the ground station for post-processing. A shell script is run in order to ensure the data is logged in different files. The files are named according to the date and time recorded. The naming method can also be changed by making modifications in the shell script.

4.5 Communication Circuit

The communication setup consists of the following devices

a. Huawei B535 portable modem with a Subscriber Identification Module (SIM) card. The modem is usually used in locations where mobile data networks are needed for internet facility. A SIM card is inserted into the modem and it immediately communicates with the service provider's network. The modem has four Local Area Network (LAN) sockets for wired/cable internet connections. It also provides a Wireless Fidelity (WiFi) hotspot that can support a maximum of 64 devices and a maximum speed of 867 Mbps [39]. The device consumes a maximum of 12 W and works on a 12 V DC supply.

b. Antenna (placed on top of the buoy) connected to the modem. [44]
The eternal antenna plays a very important role in increasing the modem's connectivity and signal pickup. The addition of antennas increases the speed of the internet as well as increases the probability of connecting to towers that are farther away.

   The antenna required should be omnidirectional because the movement of the buoy in all directions should not interrupt the communication. The Poynting OMNI-A0121 is found to be suitable for this application. The antenna is 500 mm in length that gives a higher range and it is also rugged in design to handle the rough sea environment.

4.6 Energy Consumption

It is important to calculate the total power consumed by all the electronic devices to know the energy consumed over a time period. This is done to predict how long the system can survive with the available batteries without being recharged. Since the solar panels are the only onboard power source to recharge the batteries, the data from this worst-case scenario is useful in calculating the system's operating time during the dark winter days. For example, if the operating time of the system without recharging is 5 days and there are 15 days with very minimal or no sunlight ahead, the service team can immediately replace the batteries with freshly charged ones and get the old batteries to the ground station to recharge.

Table 2: The power consumption of individual devices and the daily energy consumption is calculated.

SNo.	Component	Max. Power (W)	Working Hours/day	Approximate Energy (Wh/day)
1	Ellipse2-D	1.5	24	36
2	Force Transducer -1 (With the amplification circuits)	0.264	24	6
3	Force Transducer -2	0.2	24	5
4	RevPi Compact	4	24	96
5	4-G modem	3	24	72
	Total			**215Wh/day**

The total capacity of the batteries on board is 1536 Wh. From the above values, it can be predicted that the system can run for more than 7 days just with the stored energy in batteries and without being recharged.

4.7 Data Transmission Test

As discussed in Section 2.6 Communication Devicesthe data measured from the system is planned to be transmitted via 4G internet. Instead of transmitting data in batches periodically, the 4G internet facility enables remote access possible on a Raspberry Pi computer. Since RevPi Compact is also a system based on Raspberry Pi, it is possible to take over remote access from a computer anywhere onshore. Security is also ensured by the login facility. The RevPi Compact is pre-programmed such that only a specific username can log in with a pre-set password. Once the login is successful, the complete onboard control can be done by a user onshore. The files are saved in batches of data logged in intervals of 2 hours (for testing). The files are named according to the type and chronology of the data recorded. This can be downloaded to the remote computer by logging in.

The test was conducted by connecting the RevPi Compact device to Telenor^{TM} internet by inserting the sim card into the Huawei 4G internet modem. The communication between the RevPi Compact and the Huawei 4G internet modem is established by a regular LAN cable. A personal computer acts as the remote onshore computer. This personal computer is connected to a different internet network and not in the same Telenor^{TM} network.

4.8 Stability Test

This test is important to check if the RevPi Compact is able to work with all the sensor peripherals connected for a long time without crashing. The SBG-IMU along with the two force transducers are connected to the RevPi Compact. The system is powered by a bench power supply with a set voltage 24 V. The data recorded is monitored on the screen connected. The test is run continuously for 48 hours and 1.8 GB data is collected and stored in the external storage drive (SanDisk) connected. Throughout this test, the IMU data was recorded at 20 Hz and Force data was sampled at 4 Hz frequency. There was no system crash experienced. The data was moved to a personal computer through VNC remote view software for further processing.

5. Conclusion

The data acquisition system based on the RevPi Compact is designed to control the three sensors and coordinate the data storage and communication devices. The 4G communication network is implemented for transmitting large volumes of data at high speeds and real-time monitoring is made possible.

The amplifier and signal conditioning circuits are designed to connect the 200kN force transducer to the RevPi Compact. The two strain gauge transducers were mechanically connected in series and their data was recorded using the RevPi Compact as a part of lab tests.

The Ellipse2-D IMU is programmed to measure the pitch, roll, heave, accelerometer, gyroscopic and GPS data. This is recorded in batch files for a specific time period. This can be later converted into user readable .txt or .csv files using the sbgCenter application.

The outputs obtained under laboratory test conditions are presented in the form of screenshots and graphs. All these outputs are gathered from the RevPi Compact that is operated through remote access software. Under the same test conditions, these outputs can be replicated.

This data acquisition and communication setup will be installed in the metallic buoy that is currently under its design phase and will be tested at the Lysekil site.

6. Future Work

This section elaborates on the further improvements, upgrades and modifications to be done in this DAQ system so that it remains more stable and can be operated non-stop throughout the year.

Power supply and management is one main concern throughout this design. Though the batteries chosen are very well capable of running the device for longer periods, the power source to charge these batteries (solar power) is still unstable. So, during the dark days of the winter, it is essential to keep the batteries charged. A power monitoring system can be included to sense the power levels in the batteries. This data can be monitored by the operators onshore and necessary steps can be taken if necessary. Apart from this, power from other stable sources such as wave energy itself can also be tapped to power the buoy.

Though the RevPi Compact is stable under laboratory conditions, it might still run into indefinite loops or crashes due to several internal factors (such as processor overloading) and external factors (such as temperature, ventilation failure etc). Under such conditions, a secondary controller is necessary which is intended to restart the RevPi Compact. A relay can be used as an actuator that momentarily interrupts the main supply power to the RevPi Compact, thus restarting the system. This controller can also be designed in such a way that it restarts the RevPi Compact when it receives a command from the onshore operators.

A cloud storage facility can be included to store a large volume of data in a secured and can be accessed by any authorised user around the world using the login credentials.

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8. Appendix

Software operation in RevPi Compact

The setting up of the input and output channels in the RevPi Compact device and the engagement of peripherals (if used) is done through a portal called Pictory. This can be directly accessed from the Raspberry Pi's desktop options. Through a computer connected in the same LAN, this page can be accessed just by browsing the IP address of the RevPi Compact device.

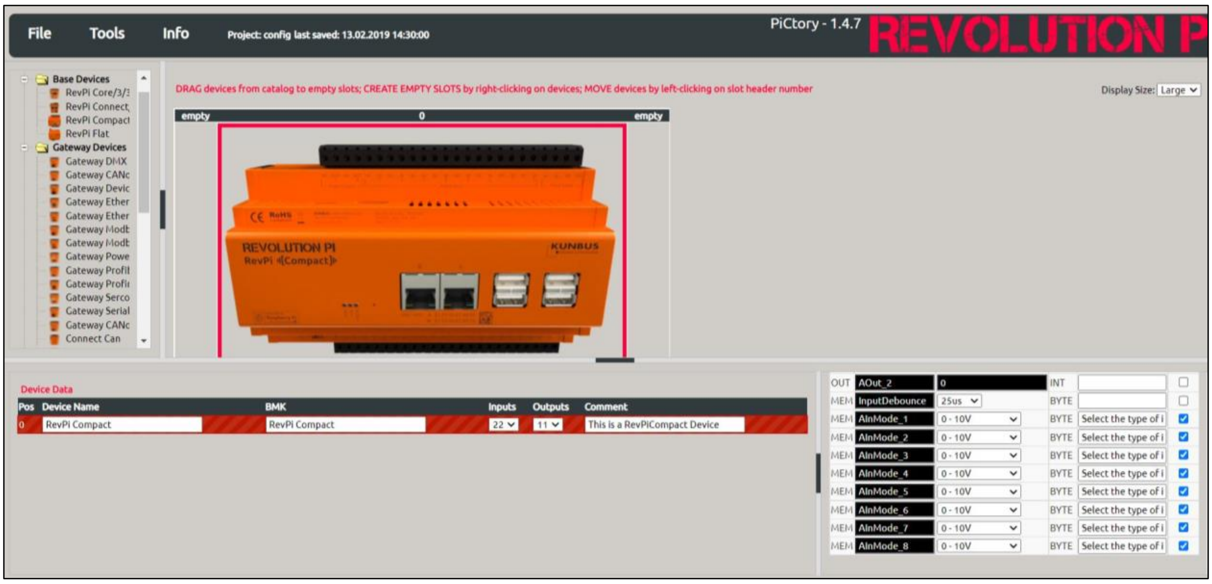

Figure 33: Pictory page to enable/disable the input/output pins.

The Figure 33 shows the home page of the Pictory software and the box in the bottom right corner is used to enable/disable pins. The device type is just selected from the list available in the left and can just be dragged into the centre to bring into operation.

A text version of these settings can be downloaded from Pictory and it is shown below.

Core_Temperature		0	//BYTE
Core_Frequency		1	//BYTE
AIn_1	3	//INT	
AIn_2	5	//INT	
AIn_3	7	//INT	
AIn_4	9	//INT	
AIn_5	11	//INT	
AIn_6	13	//INT	
AIn_7	15	//INT	
AIn_8	17	//INT	
AIn_Status	21	//BYTE	
AOut_Status		22	//BYTE
RevPiLED	23	//BYTE	
DOutBit_1		24.0	//BOOL
DOutBit_2		24.1	//BOOL
DOutBit_3		24.2	//BOOL
DOutBit_4		24.3	//BOOL
DOutBit_5		24.4	//BOOL
DOutBit_6		24.5	//BOOL
DOutBit_7		24.6	//BOOL
DOutBit_8		24.7	//BOOL
AInMode_1		30	//Select the type of input signal ##ATTR_COMMENT##
AInMode_2		31	//Select the type of input signal ##ATTR_COMMENT##
AInMode_3		32	//Select the type of input signal ##ATTR_COMMENT##
AInMode_4		33	//Select the type of input signal ##ATTR_COMMENT##
AInMode_5		34	//Select the type of input signal ##ATTR_COMMENT##
AInMode_6		35	//Select the type of input signal ##ATTR_COMMENT##
AInMode_7		36	//Select the type of input signal ##ATTR_COMMENT##
AInMode_8		37	//Select the type of input signal ##ATTR_COMMENT##

The first column indicates the name of the pin. This is helpful to be addressed in a program to get input. The second and third column indicates the pin number in the device. The last column indicates the type of data the input or output signal is read.

Program:

To save the data in parts and name them according to date and time:

```
date_time_var=`date +"%d_%m_%Y_%H_%M_%S"`
file_name_var="/home/pi/Desktop/Test_${date_time_var}.bin" //Creating a file to save
cp /home/pi/Desktop/test_file123.bin $file_name_var

if [[ $? -eq 0 ]]
then
cat /dev/null > /home/pi/Desktop/test_file123.bin
fi

0 */2 * * * /home/pi/new_file_script.sh
```

ls