The design and construction of a prototype WASP - a novel wave measuring buoy

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Abstract—**In order to assess the viability of locations for proposed wave energy farms, and design optimal wave energy converters and wave farm layouts, wave farm developers will need knowledge of local wave regimes. Furthermore, with the increasing occurrence of extreme weather events, coupled with rising sea-levels as a result of climate change, local authorities will also require knowledge of wave regimes in order to design effective coastal protection measures. Wave conditions at a point may be measured using existing buoys. However, such devices are expensive. The Wave Activated Sensor Power Buoy (WASP) is a proposed, low-cost wave powered device currently under development. The WASP comprises a floating body with a centre moonpool, and it is proposed to use measurements of the pressure of the air above the water column to estimate the incident wave spectrum. The concept has been investigated through tank testing of a 1:20 scale model. This paper describes the process of the design and construction of a full-scale prototype and focuses on the physical, electrical and electronic, communications and programming aspects of the prototype buoy. The rationale behind design decisions is explored. Pre-deployment testing of the prototype on land is described. A number of issues which arose during the on land testing, and the steps taken to overcome the issues, are discussed.**

Index Terms—**Data acquisition, Oscillating water column, Prototype design, Wave measurement, Wave regime.**

I. Introduction

THE work described in this paper has been undertaken as part of an effort to develop a low-cost, wave-powering buoy to measure wave conditions to meet the needs of both developers and local authorities, christened the *W*ave *A*ctivated *S*ensor *P*ower Buoy (WASP). A number of such low-cost buoys may potentially be deployed at a location to measure the local wave climate both temporally and spatially. The proposed device, christened the Wave-Activated Sensor Power Buoy (WASP) will comprise a floating body with a centre moonpool. The relative motion of the water level in the moonpool to the buoy will pressurise and depressurise the air above the water column. The air flows generated by the change in pressure will, in the final design of the device, be used to drive a bidirectional turbine in the manner of an oscillating water column, which will be used in conjunction with a generator to recharge an on-board battery pack. It is intended that, once the WASP has been suitably calibrated, the wave spectrum may be estimated from measurements of the pressure of the air above the water column. Important statistical parameters relating to the sea-state, such as the significant wave height, zero-cross period etc. may then be estimated from the spectral moments of the wave spectrum. Note that, at this time, a single WASP device will provide no information on the directional characteristics of the spectrum, and can, at best, be used to estimate a wave spectrum to the same level of accuracy as may be obtained by whatever existing wave measurement device is used to calibrate the WASP. Mathematical techniques may be used to determine sea-sates from the time series of the air pressure. Such techniques include inverse transfer functions, neural networks and numerical estimators, each of which is currently the subject of further investigation, once the WASP has been calibrated. The concept has been investigated through tank testing of a 1:20 scale model. The initial full-scale prototype of the WASP uses a modified, off-the-shelf buoy, the Seagull navigation buoy manufactured by JFC Manufacturing Company Ltd., Ireland, and is to be tested and calibrated at the SmartBAY Marine and Renewable Energy test site off the West coast of Ireland. The purpose of the prototype is to investigate the use of the pressure time series to estimate sea-state parameters in the real world at full scale. To this end, the device must be deployed at a location where the wave regime is independently measured. The SmartBAY test site provides such a location. The prototype is not wave powered, and the air chamber above the water column is intentionally sealed from atmosphere.

This paper describes the construction of the prototype with reference to the buoy, the data measurement and recording equipment, the transmission of data to shore and the powering of the electronic and communication apparatus while the device is under test while deployed. Initial testing of the subsystems of the buoy onshore, and then offshore in a benign location are described. A number of issues arose during this testing, and the steps taken to address these issues are described.

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II. Construction

A. The Buoy

Conventional wave regime measurement buoys operate by 'following' the free surface of the ocean at a deployment site. On-board accelerometers measure the acceleration of the buoy, and the displacement of the buoy is determined from the double integration of the accelerometer data. Hence, the time series of the motion of the buoy can be obtained, and by assuming the motion of the buoy matches the free surface elevation, the wave spectrum as the deployment site may be estimated. Unlike wave-following buoys, the operational principle of the WASP depends on the interaction of the WASP with the ocean waves in order to pressurise and depressurise the air above the water column. For reasons discussed herein, the air chamber above the water column in the prototype WASP is sealed. The time series of the pressure in the air volume above the water column is measured and recorded. The prototype samples data at a rate of 8 Hz. The power density spectrum of the pressure time series is computed, and may be used to estimate statistical parameters of the wave spectrum at a deployment site, once the relationship between the power density spectrum of the air pressure signal for the WASP and a corresponding wave spectrum which generates the air pressure time series, is known. The relationship may be established through a calibration process where the buoy is deployed at a site where the wave regime is independently measured for a period of time sufficient to capture multiple sea-states.

The buoy must fulfill a number of roles. It must contain a moonpool. It must provide a platform to house the sensing and data acquisition equipment, and the communication equipment. It must also provide a platform where power generation and storage may be placed to power the electronic equipment. Further, in order to generate large pressure variations which may be reliably measured and used to estimate sea states, and potentially be used to drive a bi-directional turbine to generate electrical energy from the wave action on the buoy, either the buoy itself, or the water column it houses, must be significantly excited by the frequencies contained within the wave spectrum encountered at the deployment location. Within the confines of the current budget, it was not possible to construct a customised buoy. However, a number of existing companies manufacture buoys which meet a number of the required attributes. One such company is JFC Manufacturing Co Ltd, who produce a range of buoys in a number of sizes including the *Seagull* buoy [1]. One 3-meter diameter *Seagull* has been rented for the duration of the current WASP project, and an exploded schematic of the [1], provided by the manufacturer, is shown in Figure 1. Note the centrally located moonpool. The *Seagull* provides a centrally-located moonpool, and modular daymarks, which may be added to the top of the buoy to provide secure and water-tight housing for the electronics and battery storage required. Further, the daymarks provide a location where power generation and communication antennae may be located. In the current configuration of the WASP prototype, two daymarks are added to the base buoy so that the electronics, power generation system and communication antennae are located well above the sea level.

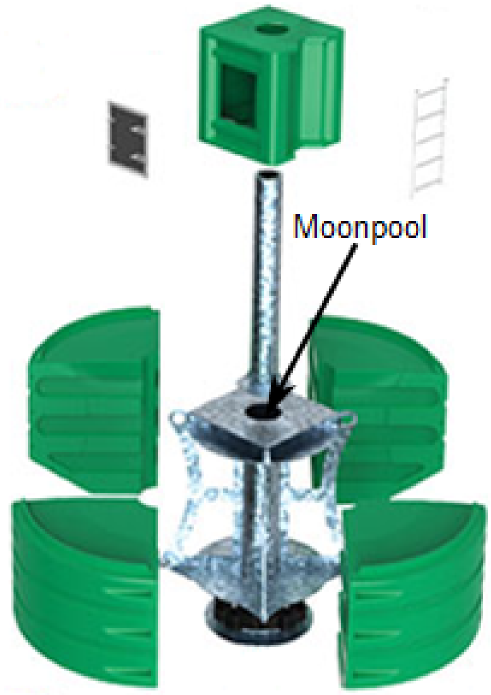

Fig. 1. Exploded schematic of the Seagull buoy, courtesy of JFC Ltd.

However, the *Seagull* has not be designed to optimise pressure generation within the moonpool, (and hence the potential to capture wave power to power the bouy). As a result, the prototype WASP required a power generation system that is not based on wave energy as discussed in Section II-E. Future iterations of the WASP which will include wave power generation will be designed so that the wave power absorbed by the buoy is increased (e.g. through changes in buoy geometery and water column length). However, supplementary power generation (e.g. through solar panels or marine wind turbines) may still be required. A further consequence of the current design of the *Seagull* is that the pressures generated in the air above the water column in the prototype WASP are likely to be relatively low. Initially, it was intended that a plate containing an orifice be placed over the top of the opening of the moonpool. The planned purpose of the orifice was to simulate the effect on the air flow into, and out of, the moonpool chamber that would be had if a bi-directional turbine, such as a bi-directional impulse turbine, were installed. However, in order to ensure the maximum variation in the pressure in the air above the water column, the plate ultimately installed contained only a small breather hole of 2 mm in diameter. The 2 mm hole allows water to gradually fill the water column over approximately 10 minutes during deployment. When in operation, the air pressure above the water column of the WASP

will vary above and below atmospheric pressure in the time scale of a number of seconds, thus airflow through the 2 mm hole will be minimal, and the air pressure in the chamber will be close to the maximum possible, ensuring the best possible measurements for the prototype.
The prototype WASP is to be deployed using single-point mooring during testing.

B. Stability Calculations

In order to calculate the ballast required to ensure the stability of the prototype WASP, and set the draft of the prototype WASP as desired, calculations were performed independently by both the team at DkIT, and the manufacturers of the Seagull buoy. A custom spreadsheet was developed for the purpose. SmartBay provided information regarding the local tidal currents at the test site. Wind data for the site is readily available. The calculations considered the maximum wind drag on the daymarks, the maximum thrust acting on the wind turbine, and the maximum tidal drag acting on the buoy. Following standard practice, (see, for example [2]), the masses of the battery pack were considered as acting at one point. Likewise, the mass of the turbine is considered a point mass. The mass of the total daymarks and associated components was found using a weighbridge, and hence the mass of the various fittings could be found (notably the custom–made frame for the wind turbine) and located as appropriate. With appropriate ballast, the meta-centric height of the buoy was estimated, and stability under extreme conditions confirmed. A maximum heel angle of 36-degrees is estimated in a worse-case scenario.

C. Data Acquisition

1) Sensing Equipment: In order to measure the pressure in the air above the water column, the prototype WASP uses two PD-23, piezo-resistive, differential pressure sensors, manufactured by Keller [3]. The full-scale ranges of the two sensors are 200 mBar and 1 Bar respectively. The 200 mBar range was selected to ensure precision during typical operation, while the 1 Bar sensor is intended to capture extreme pressure events. The accuracy of the sensors is $\pm 0.2\%$ of the full scale value. The output signal from both sensors is an analog voltage between 0-10 V. To measure the ambient temperature of the electronic enclosure a LM35 sensor is used. The data acquisition system (DAQ) monitors and records the voltage of the battery at a sampling rate of 8 Hz. As the DAQs maximum input range is ± 10 V, it could not accept the 24 Vdc supplied by the batteries directly (see Section II-E). So a simple voltage divider in conjunction with a buffer is implemented which provides a voltage between 0-5 V which is proportional to the real battery level.

2) Data Recording Equipment: The data is collected and recorded using a National Instruments NI9133 Compact DAQ (cDAQ) controller [4], powered by a 15 Vdc regulator, which in turn takes power from the battery bank. The controller has an Integrated 1.33 Ghz multi-core processor with 8 slots of modular I/O. These slots can be used with C Series modules, including analog and digital I/O. The cDAQ also has 16 GB of non-volatile storage and a removable SD card slot, allowing data logging of large amounts of data. It runs both Windows Embedded Standard 7 and NI Linux Real-Time OS. The cDAQ allows further connectivity using USB and Ethernet. The prototype uses two C series modules, NI-9201 8 channel analog input and a NI-9485 solid state relay.

3) Data Acquisition Coding: The code used to control the NI cDAQ essentially comprises two separate *while* loops. The first loop stores the measured data from the sensors, which is sampled at a rate of 8 Hz, to a *National Instruments* TDMS file. Each file represents 24 hours of data. At midnight each day, the file is closed and a new file created. The file is saved to a SD card installed on the cDAQ. A second loop compresses the TDMS data file created the previous day. Each TDMS file is approximately 360 MB in size, and is compressed to 5MB. Once a second, compressed, version of the data file created the previous day is generated, the original TDMS file is deleted to save memory space on the SD card. The file is then uploaded to the Microsoft Azure cloud service. The default upload time is set to 08:00 AM. To accommodate this upload, a 4G Module (see Section II-D) is switched on by a Solid State Relay (SSD) before the file is uploaded. The 4G module is switched off once the upload is complete to reduce power consumption. At this time, the 4G module is switched on 30 minutes prior to the chosen upload time, and switches of 30 minutes after the upload time. Uploading the compressed data file requires approximately 5 minutes.

D. Data Transmission

While the data measured and recorded by the WASP device is stored on-board the cDAQ using an SD card, the proposed test location makes regular physical retrieval of the data impractical. Two methods for transmission of data from the buoy to shore were explored. The first method investigated proposed using the on-site Wi-Fi system. SmartBay maintain a number of Mobilis DB8000 buoys which host a variety of communications protocols to shore, including Wi-Fi. However, this system does not have the capacity required. A second Wi-Fi option was to use a 5.2 GHz link from Spiddal to the test site. However, the 5.2 GHz link is very directional, and not suitable for buoys with a single point mooring such as is to be used for the prototype WASP.

Following discussions with SmartBay, the prototype WASP will instead use 4G communications to connect to cloud computing services. Conveniently, National Instruments software includes a number of toolkits which allow connection to commercial cloud computing services. These services include Amazon Web Services (AWS), IBM Bluemix, PTC ThingWorx and Microsoft Azure. Each service has strengths and weakness. Initially, it was intended that the Amazon Web

Services be used as the authors had previous experience with this service, and the intial implementation (which was preformed using a Windows-based desktop computer) proved robust. However, after sometime developing the WASP software to use the AWS toolkit, a compatibility issue between LabVIEW's real-time Linux operating system and AWS arose.

Following an assessment of a number of other cloud computing services, the Microsoft Azure service was chosen for use with the prototype WASP. Azure Blob storage is Microsoft's object storage solution for the cloud. Blob storage is optimized for storing large amounts of unstructured data, such as text or binary data. All access to data objects in Azure Storage happens through a storage account. All blobs reside within a container, which is similar to a folder. Once uploaded to the service, data may then be downloaded to any computer with an internet connection. No compatibility issues were found to exist between the Azure service and the real-time Linux operating system. Implementation of data transfer from the WASP to the Microsoft Azure service has been extensively tested, and proven to be robust. The upload of the data is achieved via a 4G (LTE) module from Digital Yacht [5]. Following advice from Smartbay, the 4G module was equipped with a Vodafone SIM card. Dual high-gain antennas are used to transmit data to allow for fast, long range capability. The 4G module also allows remote connection to the cDAQ via Wi-fi which would allow for reprogramming of the cDAQ, if necessary.
All DAQ, communications and sensing equipment is mounted in an IP66-rated cabinet, which in turn is located within the top daymark behind a water-tight access hatch. Figure 2 illustrates the layout of the electronic, DAQ and sensors installed in the IP66 cabinet, and Figure 3 is a schematic of the electronics.

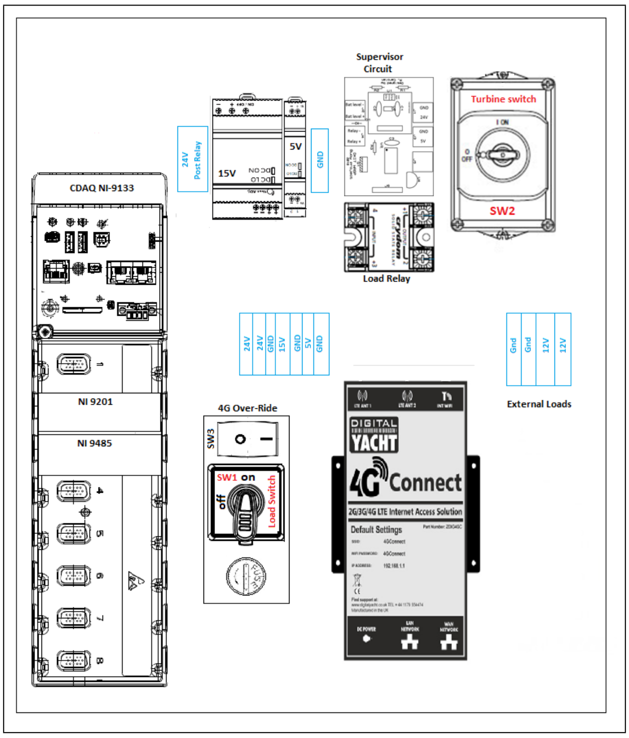

Fig. 2. Layout of the electronics board housed with an IP66 cabinet.

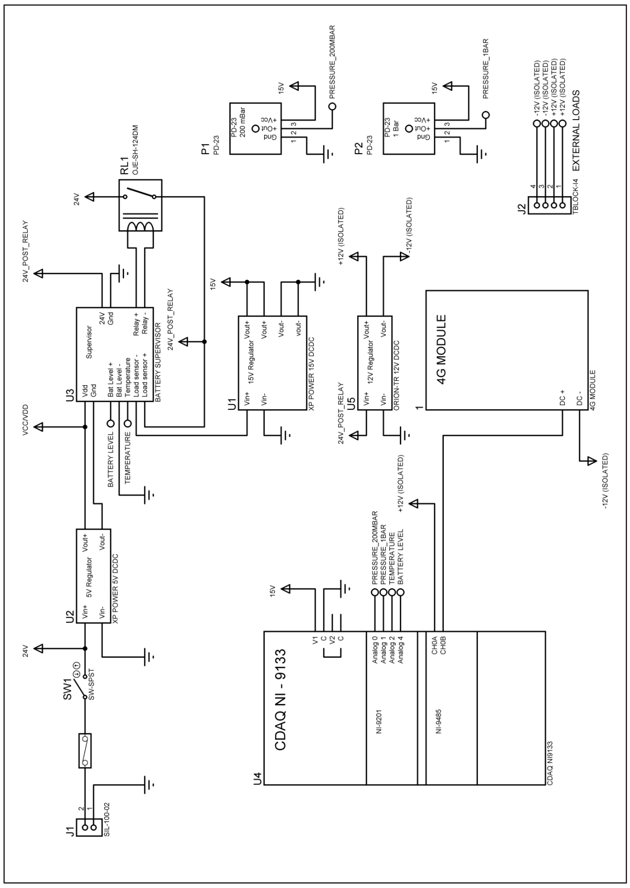

Fig. 3. Schematic of the electronics board.

E. Power

1) Storage: On-board power storage is provided by six 12Vdc, 80Ah sealed lead acid batteries, manufactured by Haze Batteries. The batteries are located in bays located in integrated compartments positioned at the bottom of the upper daymark. The bank of batteries is connected in a series-parallel configuration so as to produce 240Ah of storage operating at 24Vdc. The system voltage level was chosen so as to match the output voltage of a Zephyr Airdolphin 1 KW wind turbine, which was to be used to recharge the batteries (see Section II-E2). The DAQ and pressure sensors are powered by a 15Vdv regulator (U1 in Figure 3) and the battery supervisor circuit is powered from the 5V regulator (U5 in Figure 3). The 4G module is powered by an isolated 12Vdc regulator to prevent noise in the more sensitive components, an issue which arose during early testing of the system, see Section III-F. A GPS tracker, which Smartbay require be installed on all equipment to be deployed at the test site, is also attached to the isolated 12Vdc regulator to isolate any noise it ay generate from the rest of the system. The GPS tracker transmits its location once every hour. The power consumption of the electronics in the prototype varies depending on the time of day. The main electronics package draws a current of approximately 500mA for 23 hours a day, which increases to 600mA for 1 hour each day while the 4G module is powered on and transmitting data. Additionally, the GPS tracker draws a continuous 70mA in standby, a current which increases to 1.9A during a transmission period of approximately 60 seconds once each hour. When the batteries are fully charged the prototype should provide data up to 8 days approximately. Prior to deployment, the batteries in the WASP will be fully charged from mains electricity.

2) Generation: As noted in Section II-E1, when fully charged, the batteries in the prototype WASP are expected to provide a minimum of 8 days of continuous operation. Thus, some means of recharging the batteries while the WASP is under test offshore is required. While it intended that the final WASP device be wave-powered, the current prototype is intended to investigate the relationship between the pressure in an OWC chamber and the wave regime, and hence is not wave powered. A number of potential charging options were investigated, and it was decided to install a small wind turbine atop of the daymarks to recharge the batteries during the current phase of testing. To save costs, a Zephyr Airdolphin turbine, which was available at no cost to the project, was selected. A charge controller is incorporated in the nacelle of the Airdolphin turbine, and the output from the turbine is 24 Vdc. The turbine output voltage dictated the voltage used throughout the system. A custom-made frame to mount the turbine to the daymark was constructed, which also provided a convenient location to mount the communication antennas. The turbine is rated at 1 KW with a rated wind speed of 12 m/s. It has a rotor diameter a rotor diameter is 1.8 metres. One of its main selling points is its low wind speed start-up at 2.5 ms. It does this by using it's so called "power assist function". If there is no wind the turbine uses power from the batteries to self-rotate for 10 s every minute. This also protects the turbine from icing. In normal circumstances this feature may be seen as an advantage but in a solely battery powered offshore project it would be more of a hindrance. This meant that some energy would be lost to the turbine. Another issue with this is if one or more blades where damaged by potential wave strikes, battery charging would cease but the damaged blades would still spin every minute. This would quickly drain the battery and almost certainly over discharge them. During initial testing, it was found that the turbine was capable of generating far more power than required to operate the prototype WASP in typical wind conditions.

However, following transportation of the top section of the prototype WASP to Galway docks for final assemble, benign site testing and deployment, an issue arose with the wind turbine, and it is no longer intended that the batteries in the WASP be recharged by this turbine. Instead, six 80 W solar panels, manufactured by BP Solar, will be used, see Section III-G.

3) The Supervisory circuit: When deployed, the data acquisition and communication systems are powered from the 24 Vdc battery bank. The cDAQ has no low power mode, and in the event that power consumption exceeds power generation over along period of time, a possibility exists that the rechargeable batteries may be over–discharged, resulting in damage to the batteries. In order to prevent over–discharge and protect the batteries, a microcontroller–based supervisory circuit is used. A schematic of the supervisory circuit is illustrated in Figure 4. The battery voltage is inputted to a voltage divider via R1 and R2 to produce a voltage between 0-5V so the voltage can be accepted by the DAQ analog input and the microcontroller via buffers (U2). The supervisory circuit continuously monitors the voltage level of the battery bank via the 0-5 V output from the voltage divider. If the voltage level drops below a predetermined value, the supervisory circuit switches off all loads, except the load to the supervisor circuit itself. The shut-off voltage level has been set to a battery bank voltage of 21.5 V (equivalent to 3.5 V from the voltage divider), and if this threshold is reached, a load relay is switched off to power down the system. The supervisory circuit itself then enters a low–power state, in which the circuit may remain active for a number of months before using sufficient power to over–discharge the batteries.

However, the cDAQ Controller is essentially a computer, and, like any modern computer, it is recommended that the cDAQ be allowed to shutdown in accordance with normal operations, rather than be abruptly powered off. If the battery level reaches a critical point of discharge, the cDAQ programmatically shuts itself down safely. The current draw of the 15 Vdc load, which includes the cDAQ, is approximately 450 mA under normal operating conditions, and approximately 150 mA when the cDAQ is shutdown. The microcontroller (U3 in Figure 4) uses a current sensor INA169 (U1 in Figure 4) to monitor the current draw to the 15 Vdc load to decide when to switch off the load. The microcontroller reads the current sensor via an analog-to-digital converter every minute. If the reading is below 200 mA for 10 minutes, the cDAQ is presumed shutdown, and the 15 Vdc load is switched off via a MOSFET transistor and a solid state relay, (Q1 and RL1 in Figure 4 respectively).

Due to the high output from the wind turbine, significantly higher than power usage in typical wind conditions, the microcontroller was initially programmed to switch the system back on after 24 hours. It was considered likely that, after 24 hours, the battery bank would likely have reached an acceptable high level of charge to resume normal operations. If it was not the case that the battery bank charge level had recovered, and hence the voltage was above the shutdown threshold, the cDAQ would once again switch off, the microcontroller would switch off the 15 Vdc load after 10 minutes, and start the 24 hour timer again. This cycle would repeat until the battery charge was sufficient to resume normal operations. However, prior to deployment, the Airdolphin wind turbine was replaced with six 80 W solar panels. While the panels should provide sufficient power to maintain operation of the WASP, the recharging rate is significantly lower than that should the Airdolphin turbine continued to operate. A concern arose that sufficient charge may accrue over the course of 24 hours to allow the battery pack voltage exceed the 21.5 V threshold, while not allowing enough charge to accrue to run the DAQ and communication system for 24 hours. This raises the possibility that the system may power up, run for a sufficient length of time to cause the battery pack voltage to drop below the threshold, and hence shutting down the system for a further 24 hours, without any data transfer taking place. Such a low-charge cycle could happen repeatedly, effectively preventing any data transmission from occurring. In order to prevent this scenario, the time between shutdown and automatic restart was increased to 5 days. While this may result in a large gap in the data, it will ensure that the battery pack is well charged between shutdown and restart, eliminating the danger of the WASP entering a low-charge cycle.

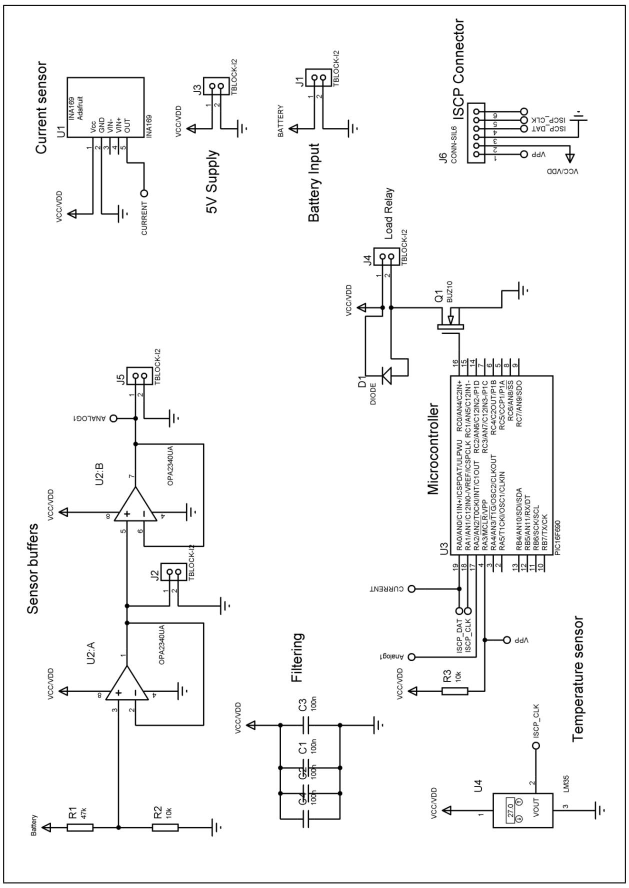

Fig. 4. Schematic of the supervisor circuit.

III. Testing

F. Dry testing

Various sub-components of the WASP were tested at DkIT prior to final assembly and transportation to the Galway docks for deployment to the SmartBay test site. The data acquisition and communication systems were benched–tested to ensure data was logged and uploaded to the Microsoft Azure cloud service, and that the in–house code performed as expected. The system was tested for a week, and data logging and communication system performed successfully. However, a number of issues were identified and rectified during this time. The first issue which arose was that noise created by the 4G module was interfering with output voltages from the pressure sensor during the hour each day when the 4G module was active. This issue arose as when initially installed, the 4G module shared a common ground with the rest of the system, including the pressure sensors. The issue was remedied by adding a 12 Vdc regulator to power the 4G module any other potentially 'dirty' load, such as a transponder. The 12 Vdc regulator is kept isolated from the rest of the electronics. A second issue identified was one of memory space on the SD Card. Data is stored locally on-board the WASP as well as being uploaded to the cloud. The raw data is first recorded in the native, National Instrument, TDMS format. The storage required for one day of data in this format is approximately 365 MB. In order to reduce transmission time, and prevent the SD card from running out of memory, the TDMS files are compressed. The compressed files require approximately 5 MB of storage, and it is these files that are uploaded to the cloud service. Once one day of data is compressed into a single file, the unzipped data is deleted to free up space on the SD card.

Fig. 5. The prototype WASP prior to testing at a benign site (Galway Marina).

Once the changes outlined above, the complete electronics/DAQ/communication and power system (including wind turbine) was installed in the daymarks. Two daymarks are used, and all components described herein were installed in the upper of the two so as to reduce the likelihood of submergence, and to prevent breaking waves damaging wind turbine blades. The assembly was mounted on a trailer, and tested outside for a number of weeks, during which time the wind turbine charged the batteries successfully, and data was recorded and uploaded to the cloud without issue. The daymarks were then transported to Galway for final assembly and subsequent deployment.

G. Benign site testing

Once the daymarks and associated components were transported to Galway port, the final assembly of the WASP could take place. A custom-made plate was installed to seal the top of the moonpool in the buoy. Two 1/4 BSP connectors, which had been installed in the plate, allow gas lines to connect between the air chamber of the moonpool and the pressure sensors, so that the pressure in the air chamber may be measured and recorded. The daymarks were hoisted onto the Seagull buoy, and the gas lines connected. The prototype was then transported to the Galway marina, where a crane lifted the WASP into the water. The device as switched on, and over a number of days, the prototype acted as expected, with data files uploading at the appointed time each day. However, a major issue arose. The tail of the wind turbine had damaged during transport, and it proved impossible to source a replacement. A new tail was designed by the authors and was fabricated by the deployment contractors. Once installed, the replacement tail functioned as hoped, but it was then discovered that the internal turbine control circuit was no longer functioning correctly, and it is assumed this circuit was damaged during transport. While a number of alternative turbines were investigated, to save costs, six 80 W solar PV panels, with suitable power regulators, were installed on the WASP, providing a total maximum power of 240 W at 24 Vdc. For safety reasons, the prototype was removed from the marina, and the daymarks were split from the buoy while the turbine was removed and the solar panels installed. Once the solar panels were installed, the system was tested in the dry for a week, before the daymarks and buoy were reassembled. The protoype WASP was then returned to the marina, were it was successfully tested for a number of days.

The likely reduced power generation by the solar panels when compared to the wind turbine increases the likelihood of the supervisory circuit switching to a low power mode, and introduces the possibility of the low-charge cycle described in Section II-E3. As described, the waiting period between low-charge shutdown conditions and subsequent re-powering up of the system was increased after benign site testing. However, an advantage of the solar panels is that the risk of possible blade damage due to high waves is eliminated. Another advantage is that the maximum heel angle of the buoy will be reduced, as the trust from the turbine will no longer contribute over-turning moments. One final possible advantage of the solar panels when compared to a wind turbine is the reduction in moving parts potentially increasing long-term reliability of the system.

IV. CONCLUSION

At the time of writing, the final stage of pre-deployment testing of the prototype WASP device have been completed. This testing verified operation of the solar panels which replace the damaged wind turbine. The rated output from the solar panels is such that the operation of the WASP may be intermittent, resulting in gaps in the recorded data. However, the authors are confident that sufficient data will be obtained to verify, or otherwise, the principle of using pressure in an oscillating water column to estimate the spectral parameters of a sea-state.

Fig. 6. Solar panels installed on the daymarks following removal of the wind turbine.

Upon completion of benign testing, the buoy was deployed at the test site on the 27th February 2019. The operation of the data acquisition and transmission subsystems have operated to the time of writing. The results obtained from the testing of the prototype device will be the subject of future publications.

The deployment of the prototype WASP is one phase in a planned multiphase development programme. Subsequent phases will focus on using cheaper electronic and sensing equipment with lower power requirements. The use of the variation of air pressure in a non-sealed oscillating water column to estimate sea-states will be investigated, and the use air flow from the oscillating water column to part-power the device in conjunction with other renewable energy sources explored. Alternative methods by which the WASP may be calibrated, for example using large wave tanks where the time series of the free surface elevation at a point is known, will be considered. Further research into obtaining wave direction information from a single device using pressure measurements is also proposed. Such research may focus on measurements from multiple OWCs on a single buoy, or on the potential to exploit the relationship between wave non-linearity and wave directionality [6].

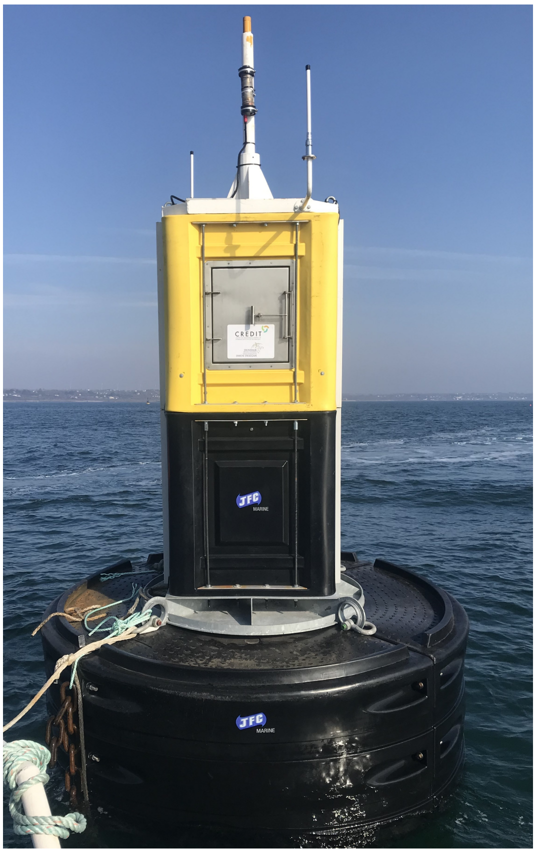

Fig. 7. The prototype WASP deployed at the SmartBay test facility.

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