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**EEE4022S - MINIONS: MarINe Internet Of Nodes Specification**

**Literature Review**

**The need for standards and specifications for IoT marine-monitoring devices**

Several papers highlight the need for industry standards for IoT devices, equipment and platforms for marine environment monitoring and protection applications [1][2].

**Requirements of IoT marine-monitoring devices**

Several papers [1][3] highlight requirements of devices being deployed in harsh marine environments.

[1] provides an assessment and review of the applications of IoT sensor networks in marine environments and lists certain requirements of such devices. [3] developed a low-cost sensor buoy network for possible use in shallow-water marine environments. This system also aimed to be relatively small enough for easy deployment, to ensure stability of the system in shifting environments, and to provide total autonomy of power supply and data recording. They identified several requirements of the system for it to be effective in its environment.

[3] highlights the following, which is supported by [1]:

* **Energy autonomy** – the system should implement software for optimal power management and should have energy harvesting devices in order to operate for long periods without human intervention.
* **Robustness and fault tolerance** – the system must have the means to ensure there is no loss of data in the event of failures of communication or power supply. In the event of a communication failure, the system should be able to continue collecting data until connection is re-established. Communications subsystems should be robust and reliable and guarantee communication between sensor nodes even in adverse weather conditions.

[3] went further to highlight:

* **Flexibility** - to facilitate different configurations of parameters to be sensed and timing of sampling and storage. Physically, the system should be flexible and customisable to accommodate a wide variety of devices and communication technologies.
* **Resource optimisation** – the system should make efficient use of resources and reduce the costs of manufacturing, deployment, operation and maintenance.
* **Scalability** – the system should be designed to function effectively regardless of the network topology and the number of buoys that will be deployed in the monitored area.
* **Mechanical design** – components should guarantee an appropriate level of insulation and corrosion-proofing. Connectors are especially sensitive to corrosion and prone to fault and should be kept to a minimum. The physical design should facilitate access to components for easy maintenance, modification and dismantling. The design should also minimise the system’s environmental impact, and considerations must be made toward sea traffic.

Requirements identified in [1] that are not identified in [3] include the need for high water resistance, careful calculation of sensor network coverage and the need to design against possible acts of vandalism.

**The need for a specification on the capture, use and sharing of ocean data**

[2] outlines several issues with current practices in the collection, storage, processing and particularly sharing of ocean data. It calls for the “development, rationalisation and uptake of standards” and investigates “how technologies, scoped by standards, best practice and communities of practice, can be deployed to change the way that ocean data is accessed, utilized, augmented and transformed into information and knowledge”. One suggestion is the need for “standard persistent identifiers for sensors, data sets, models, and products”.

[2] references “Comment: The FAIR Guiding Principles for scientific data management and stewardship” [4], which introduces the FAIR data principles, suggesting that data should be Findable, Accessible, Interoperable and Reusable. The Principles define characteristics that contemporary data resources, tools, vocabularies and infrastructures should exhibit to assist discovery and reuse by third-parties. Each principle is elaborated on in detail. [2] suggests bringing new technologies and frameworks, such as IoT, into the standards process, and to continue efforts toward building and disseminating ideas around best practice and implementing the FAIR principles for data access and use.

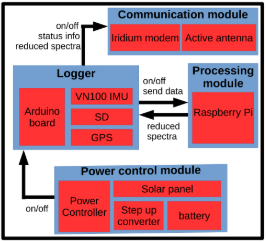
**Projects that bear similarities to MINIONs, or may be used as design inspiration**

[1] provides an assessment and review of the applications of IoT sensor networks in marine environments and provides several examples of sensor networks very similar to what MINIONs aims to achieve.

Several good examples of IoT marine monitoring sensor networks, similar in vision to MINIONs, were found [3][5][6][7], and these will serve as inspiration when developing the specification and designing prototypes of the specification.

[3] developed a low-cost sensor buoy network for possible use in shallow-water marine environments. This system also aimed to be relatively small enough for easy deployment, to ensure stability of the system in shifting environments, and to provide total autonomy of power supply and data recording.

[5] developed instruments to measure waves in sea ice. Each instrument consists of an ultra-low power unit, microcontroller-based data logger, small microcomputer for on-board data processing and an Iridium modem for satellite communications. The system uses the microcomputer to reduce the amount of data to be sent to a base station on land, thus reducing the cost of transmission via satellite. The drawback is that this is quite power-intensive, so should only be used where necessary and perhaps where energy harvesting is an option. These devices had quite a good system architecture which will form the basis of that of MINIONs.



*Figure 1: Network Architecture used in [5]*

[6] proposes “A Flexible Arduino-Based Logging Platform for Long-Term Monitoring in Harsh Environments”. They aimed to build a low-cost data-logging platform to provide long-term operation in remote or submerged environments. This paper goes into quite excellent detail of the development of the sensor nodes and prioritises low cost, ease of use and development and flexibility above all else. They also go into great detail about power optimisation and the development of a robust underwater housing. Their power optimisation techniques in particular will be of great value in designing MINIONs. This project lists several benefits of using Arduino microcontrollers. While Arduino microcontrollers may not be used in MINIONs, it provides a case for selecting microcontrollers that are easy to use and allow designers to share code.

*Figures 2 and 3: Deployment of the sensor nodes developed in [6].*

[7] developed a sea-moored buoy to provide real-time seismometer data. This project is designed for use in deep, powerful seas. Several constraints dictate that MINIONs will most likely be limited to coastal applications, so this project extends quite far beyond the scope of MINIONs. However, the detail in mechanical design of this system is quite excellent, so will be referred to when developing a flexible platform for MINIONs. The use of a toroid-shaped buoy as a platform for the system will be investigated for use in MINIONs.

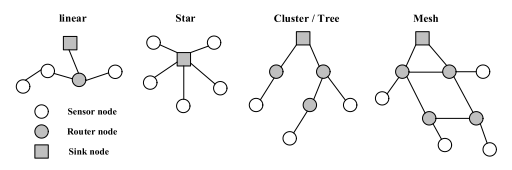


*Figure 4: The large toroid platform developed in [7].*

**Network Topologies**

[1] discusses several different network topologies, referring to the connection topology of the nodes in the network. As discussed in [3], each of these network topologies can be connected as a wired buoy network, wireless buoy network linked by radio, GPRS or both, or an underwater buoy network connected by acoustic waves.

Four typical network topologies are illustrated below:



*Figure 5: The network topologies listed in [3].*

**Specifications relevant to marine-monitoring devices**

Several marine specifications and standards exist. However, these mostly concern large steel buoys [8][9], large steel ships [10] and yachts. While these may not be directly relevant to smaller IoT-based marine-monitoring devices, they contain several sections that may be adapted for this use. For instance, [8] and [9] give insight into the structural requirements of marine buoys. [10] provides standards on thermoplastics for use at sea. This mainly concerns plastic piping on board large steel ships, but the standards may bear relevance to plastic sensor enclosures. This will be investigated further and may form part of the material specification for the MINIONs node enclosure.

[11] recommends HDPE and LDPE plastics for use at sea due to their low water absorption and high UV resistance, both physically and aesthetically. [12], [13] and [14] use ABS plastic in attempts to produce 3D-printed waterproof enclosures and list the ability to smooth and finish ABS plastics with acetone to fill any micro-gaps as an advantage. However, ABS may be less UV-resistant than HDPE and LDPE. This will have to be considered, investigated and researched further during the development of the MINIONs enclosure.

[15] provides information on a variety of metals and recommends certain alloys for use at sea. This will form the basis for the materials specification concerning fasteners, nuts, bolts etc for use on the MINIONs platform and enclosure.

Several United States Military standards (e.g. MIL-STD, MIL-DTL) exist on electrical connections and cable connectors, such as MIL-DTL-38999M [16]. These standards will be investigated further to select a connector for the specification, to facilitate wired connections between devices within a network and between multiple networks, perhaps owned by different people.

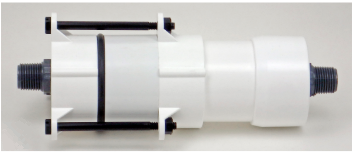
**Bus interfaces**

[17] conducted a survey on 60 launched, and 44 to-be-launched CubeSat satellites to determine the reliability of their bus interfaces. They found that the I2C data bus shows many bus lockup issues. I2C was proven to have caused a catastrophic failure for one mission, and it was hypothesised that it was the cause of catastrophic failures in two other CubeSat missions. Electrical Power Subsystems (EPS’s) were found to be a major source of in-orbit failures, but most of the failures were not related to the power bus. The paper made several recommendations on the physical interface to the power unit, but with regard to data busses, suggested only that “the data bus should have a continuous nominal behaviour, without major risk for bus lockups.” However, another paper [18] involving one of the authors of [17] went on to design a data bus architecture for CubeSats, recommending the USB, CAN and RS485 bus protocols. However, it identified RS485 as the preferred choice due to its relatively low power consumption, high achievable data rate, simplicity and reliability.

**Waterproof Enclosures**

Ingress Protection (IP) Ratings, as defined in the international standard IEC60529, classify the degrees of protection provided against the intrusion of solid objects, dust, accidental contact, and water in electrical enclosures. IP68 and IP69K, the highest IP ratings, both specify that the enclosure is protected from total dust ingress. Additionally, IP68 specifies that the enclosure is protected from long-term immersion “up to a specified pressure” (specified by the manufacturer), while IP69K specifies that the enclosure is protected from steam-jet cleaning [19]. The IP ratings are thus quite limited for specifying the waterproof rating of devices for use in deep-sea environments. Further research will be done to include a clearer, well-established standard concerning waterproofing into the MINIONs specification. If this can not be found, IP68 will be adopted and a depth requirement will be specified.

Several projects have aimed to develop low-cost, waterproof sensor enclosures that are easy to replicate [6][12][13]. [6] based their system on cheap and readily available PVC piping and fittings. PVC is waterproof and chemically resistant but has poor UV resistance. To get around this, they applied a protective coating of water-based exterior latex paint. This solution is not ideal, as it is effectively applying a semi-permanent seal that would have to be broken and reapplied for maintenance. This contradicts the requirement set out in [3] that the system should “facilitate access to components for easy maintenance, modification and dismantling”.



*Figure 6: The PVC enclosure developed in [6].*

[12] and [13] endeavoured to 3D print a waterproof enclosure. Both provided good insight, advice and lessons learnt in their endeavours. The both used ABS plastic and mentioned the use of acetone to smooth the outer surface and fill in any small gaps. [12] did not manage to achieve the objective but made good recommendations for future work. [13] made beautiful, naturally-shaped, waterproof enclosures in order to gather data on the forces experienced by mobile river sediment grains. Their system consists of an internal, pill-shaped enclosure to house the sensors. This inner case was designed to hold the electronics firmly in place. This was then enclosed in a larger case that mimicked the form of natural sediment. Each external case was designed to enclose the same internal case, meaning that the external case of a sensor could be changed at will. They used clever design to interlock two halves of each case, but information on the seals they created is unfortunately quite vague, although they do mention the use of o-rings. All three of these projects will be considered when designing an enclosure for MINIONs. [20] provides an excellent guide to making waterproof enclosures using static o-ring and gasket seals. This guide also mentions the use of 3D printing to make enclosures, and recommends using high-resolution printing materials such as ABS in order to seal against o-rings and gaskets.



*Figure 7: The 3D-printed enclosure in [12]. Figure 8: The 3D-printed enclosure in [13].*

**Microcontrollers for use in IoT marine-monitoring sensor networks**

[1] lists a large number of IoT marine-monitoring sensor networks. A wide variety of microcontrollers was used in each of the projects, depending on the requirements of the node and the competencies and preferences of the designers. Many of these used Arduino microcontrollers because of their ease of use and well-developed libraries and examples, and several projects were able to optimise their power usage [5][6]. Various requirements of the microcontroller such as memory, clock speed, power usage and ability to optimise power usage, bus interfaces, number of ADC, DAC, PWM-capable and GPIO pins, size and ease of use will be considered before selecting a suitable microcontroller.

**Discussions with Mr. Rick Harding**

I contacted Mr. Rick Harding, a retired Marine Biologist with vast experience in designing moored buoys and drifters and gathering data on board research vessels such as the S.A. Agulhas. He made several suggestions to the mechanical and electrical design of MINIONs, and also provided insight into the wealth of knowledge he has gained throughout his career. He recalled how one of his projects mysteriously made its way several kilometres inland of Mozambique, and how they had to negotiate with the Naval Academy in Gordon’s Bay to test one of their devices within their harbour to prevent it being stolen. He told these stories jokingly but highlighted the need to make serious considerations regarding security, as he has experienced several incidents of theft and vandalism. These considerations are less of a concern when operating far out at sea but become more important in coastal applications. This corroborates the need identified in [1] to design against possible acts of vandalism.

He offered great insight into mooring systems and suggested a simple system for MINIONs. One of the key takeaways was to keep the mechanical design as simple and structurally solid as possible. He suggested to avoid underwater cabling and complicated rigging systems, as he has seen many of these tangled and destroyed by the intense storms and swells in the Western Cape.

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