Title	**Embedded System for Condition Monitoring of Marine Pumps**
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Aims/research question and Objectives

This project aims to demonstrate the potential for **low-cost embedded systems to provide condition monitoring for pumps on board ships**. At present, many pumps on board ships are not monitored rigorously, resulting in inefficient maintenance schedules and a lack of data about how operating time and environmental factors affect the lifetime of pumps. As shipping looks towards an autonomous future, monitoring must be improved and at the moment it is simply too expensive to be applied to non-vital systems. Low-cost sensors and processors will be used to show the feasibility of this approach.

While much work has been done on improving diagnostic techniques, this has been focussed on offline implementations, often using an embedded system for data collection only and then processing this data on a PC. This project aims to provide **on-board processing of data** and transmission of a minimal number of key statistics related to the condition of a machine. This is in line with current approaches to node-based systems and low-energy communication.

It is important that this project is shown **operating within a live environment**. This would provide confidence for users of the system and provide a foundation for future work. The live system may be simulated within a laboratory environment or it may be possible to implement the system on board an operational ship. The features of interest, are that the runtime extends to hours or days with the system running independently and that a variety of operating conditions are experienced.

As such, the following shall be considered objectives of the project:

- Build a functioning embedded system which measures data related to the condition of a pump
- Perform on-board processing of this data and extract key statistics
- Transmit this data to another system using appropriate communication protocols
- Demonstrate the embedded system in a live environment

Summary of proposed research and analysis methodology

In order to demonstrate the effectiveness of the embedded system, it will be compared at several stages of development to other systems, for both measurements and computational methods. This will enable a quantitative comparison of data.

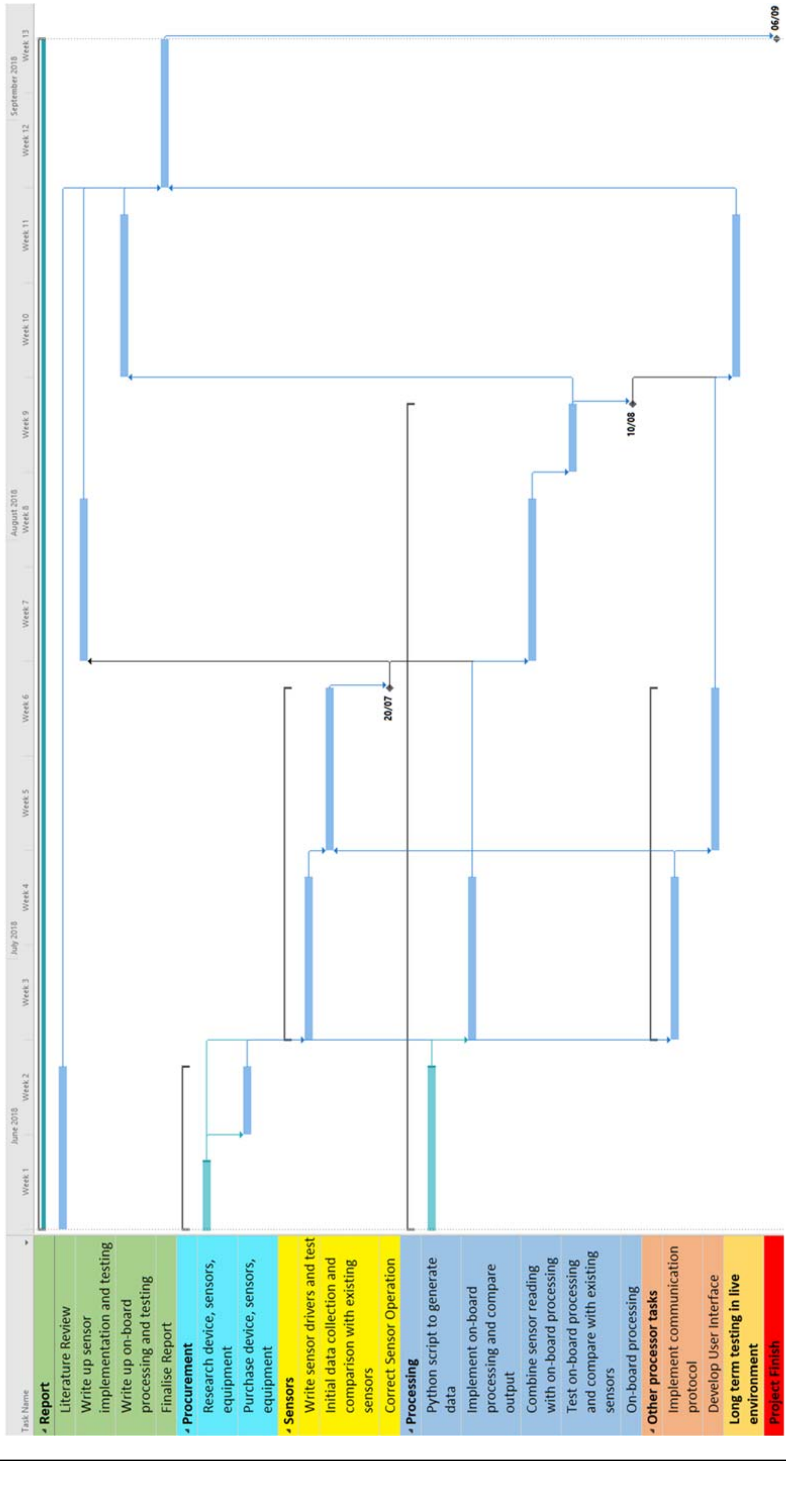
Correct computation of data will be shown by sending known data to the embedded system using a communication protocol and comparing the output of computation with the output from the same methods applied offline, using Matlab on a PC for example. This guarantees that any errors in the output are as a result of the computational implementation and not as a result of any error in sensor data. It will also serve as a demonstration of control and communication with the embedded system.

Collection of data will use motor rigs available on campus, which have known and controllable operating conditions. In particular, a Condition Monitoring Demonstrator in the Tribology Laboratory will be made available for this project. Measurements from the existing system can be extracted, to test computation with real data. The embedded system performance using sensors can then be directly compared to the existing measurement system. In addition to basic data collection, the rig can be modified to provide healthy and unhealthy conditions, through the use of damaged bearings and inducing a bend in the shaft. This is an established method for demonstrating diagnosis capabilities of condition monitoring systems [1].

Once the embedded system has reached a suitable stage of development, it should be tested within a live environment for an extended amount of time, operating independently but with supervision. Initially, the Condition Monitoring Demonstrator will be used. Opportunities for testing on board an operational ship are being investigated through Lloyd's Register, who are assisting this project. This would demonstrate the capability and utility of the system beyond simple experiments.

[1] A. Moosavian, M. Khazaee, H. Ahmadi, M. Khazaee and G. Najafi, "Fault diagnosis and classification of water pump using adaptive neurofuzzy inference system based on vibration signals", Structural Health Monitoring: An International Journal, vol. 14, no. 5, pp. 402-410, 2015

Research plan – Gantt chart or Pert chart



Ethical statement

Testing for this project will be carried out in a laboratory at the University of Southampton. Before testing can be carried out, I will undergo initial training on how to use the equipment safely within the laboratory. The procedures in place will be followed carefully for my own safety and the safety of other students and staff.

As condition monitoring systems are implemented on board ships, they will be relied upon to provide accurate information. Failure to do so could result in unexpected failures, which in the worst instance would be catastrophic. Therefore, the systems should be built to a high standard and the exact capabilities of systems should be outlined before implementation, including detailing the limitations of the system. There already exist standards related to condition monitoring of machines: ISO 13374, ISO 13379 and ISO 18436. There is also a working group developing a standard for smart shipping, ISO/TC 8/WG 10. These standards should be adhered to in systems which aim to provide condition monitoring in the marine environment.

A natural extension to this project would be to create a connected condition monitoring system, part of the Internet of Things (IoT). This would allow data collection of all ships owned by a company, for instance, for better diagnosis and prognosis. However, care should always be taken when connecting a device to the internet, and embedded devices in particular have been used as attack vectors for Distributed Denial of Service (DDoS) attacks and to extract private information. In this context, commercially sensitive information could potentially be extracted directly or indirectly from a connected system. Employing simple safeguards, such as data encryption, can have a beneficial effect here and should be designed into the system as early as possible.

To ensure the system operates within the specification and to enable future development of the system, a coding standard will be employed. This helps to catch common bugs and to prevent misunderstanding of the code. In turn, this makes the system safer and more reliable. It is also good practice for embedded systems engineers.

Legal and commercial aspects

The aim of this project is to develop an embedded system which ultimately provides a reduction in maintenance costs and improvement in safety for shipping. The project is set in this industrial context and provides the groundwork for a connected, low-cost condition monitoring device. As such, it is likely that Intellectual Property (IP) will be generated during the project. This IP is fully owned by the university. It may eventually be spun off into a limited company or licensed, at which point compensation may be awarded appropriately. This is detailed in the University Calendar Section IV: General Information and Regulations, Intellectual Property Regulations.

The project is also being assisted by Lloyd's Register, who are interested in proving to their clients the possibility of low-cost condition monitoring. Lloyd's Register does not manufacture components but if this project is successful, they may begin including it as an option in their matrix of solutions for their clients. This is one route to commercialisation.

Other routes to commercialisation are through smart shipping and autonomous shipping. Both of these technologies are dependent on having many sensors which give reliable data over the lifetime of a ship. The technology may be adopted by third-party manufacturers who create specialist condition monitoring systems which are attached or retrofitted to motors and pumps, or it may be included by motor and pump manufacturers themselves in new models. It is likely that a combination of these scenarios will occur, as many ships with older systems will continue to operate and will desire retrofitted solutions, while ships built from the ground up with such monitoring in mind may prefer an integrated solution.

As autonomous ships are developed and made possible through systems similar to the embedded system being focussed on in this project, there are legal issues which are yet to be settled by legislation. By definition, there is no human in charge of an autonomous ship and it may make decisions which result in a large accident and environmental, material or human damage. If this is the result of an error made by a condition monitoring system, it is possible that the designer of that system would be held responsible. This could result in lawsuits or criminal charges being pressed. Such legislative questions are likely to be answered for autonomous automobiles first, as this is more pressing in the minds of the public. This legislation will then be adapted for autonomous shipping. Therefore, designers of subsystems, such as condition monitoring systems should design their products to the highest standards in the first instance, to avoid costly redesigns if legislation is more stringent than predicted or compensation being demanded retroactively. A good case study for designing highly redundant and reliable electronic systems is commercial aviation.