CHAPTER 1

INTRODUCTION

1.1 Automatic condition monitoring

This thesis deals with maintenance of large marine diesel engines, which is a very important area in the ship industry. The more effective and reliable the engines are, the less expensive are the costs for the shipping company. Several cost expensive situations exist, e.g. if a ship is traveling from Europe to USA with a valuable cargo, but in the middle of the Atlantic Ocean the engines break down. What do the crew do in this serious situation? In fact, the possibilities of solving the problem are few. They can try to fix the problem them selves, but the probability of being a success is very small, since it is very unlikely that the crew has the necessary knowledge and experience of solving the exact problem. This means that the ship must have assistance from specialists, but they are very rarely located in the middle of the Atlantic Ocean. Therefore, assistance must be brought to the ship from locations far away.

1.1.1 Inspections

The situation described above is a worst case scenario, but occasionally this is reality for shipping companies. Well-known changes within the engine cause its lifetime to be shorter than expected. One way to detect these changes is to execute frequent inspections on the engines. The purpose of the inspections is to detect the changes or errors while they still are insignificant, and repair these errors before they cause an engine breakdown.

However, some errors are related to cracks in the crucial parts of the engine, and during inspections there is a potential high risk of inducing such cracks in the engine. This is because the inspections usually include that the engines are separated and assembled, so that the inspectors can gain access to the parts, which are to be inspected. The inspectors can accidentally induce small cracks, and these small cracks will evolve into large cracks during time. When the inspectors send the ship back on the ocean, rather than having improved the risk of breakdown, it has been enhanced

1.1.2 Preventing fatal errors

The purpose of inspections is that “it is better to prevent than to cure”. If small errors are detected before they evolve to fatal errors, they can be fixed, or precautions can be taken. E.g. wear on a gear wheel can be reduced if more oil is lubricated on the gear wheel. Imagine the worst case scenario where a ship was exposed to engine breakdown causing the ship to float around out of control in the middle of the Atlantic Ocean. If the engine breakdown was caused by too much wear on a gear wheel, the accident could have been avoided if the wear was detected in time. If almost all errors can be detected in time, then the frequently inspections and reparations can be planned more efficiently, i.e. fewer inspections and only reparations when they are needed. This is the motivation behind automatic condition monitoring of large diesel engines, which is what this thesis is about.

1.1.3 Automatic condition monitoring of engines

Condition monitoring of engines has existed for many years, but initially the monitoring was performed manually by a technician. This is expensive, since the technician has to spend most of the time monitoring the engines, but the main disadvantage is that the technician is not capable of detecting all errors on their non-critical level before they evolve to fatal errors. Also the sound pressure level in the engine room is way too high for a human being.

Automatic condition monitoring is a concept that is similar to the traditional condition monitoring, but here the technician is replaced by a system of sensors, change detectors and change classifiers. Figure 1 shows the basic principles in the automatic condition monitoring system. Sensors are placed at different locations on the engine in order to sense the responses on the activities happening within the engine. Since the sensor signals are analog and the signal processing is digital, analog to digital conversion is performed by an A/D converter before the sensor signals are transferred to a personal computer (PC). The PC monitors the digital sensor signals and displays information on a screen about the actual engine condition. When an alarm occurs, information about the engine change time and cause is given, in order to alert the crew that they have to take precautions.

1.1.4 Sensors

The choice of sensor types is crucial, since different sensor types sense different engine activities. E.g. temperature sensors sense temperature, and vibration sensors sense vibrations. These two sensors along with a third type, pressure sensors, account for the traditional sensor types, but in recent years a new sensor type has shown a superior performance compared to three traditional types. These sensors are classified as acoustic emission sensors, or simply AE sensors. The main difference of the sensor types is the bandwidth, which is significant lower for the traditional sensor types. The focus of acoustic emission is on waves with ultrasonic frequencies, i.e. from app. 100 kHz to a few MHz, [17]. Research has shown, that small cracks generate AE’s, [15], and with AE sensors it is possible to detect an error before it becomes fatal. The placement of the AE sensors on the engine is also very crucial, because AE’s contain a small amount of energy, causing it to decline dramatically with distance from the point of generation, [15]. Therefore, in order to sense AE’s, the sensors must be placed quite near the point of origin. However, the dramatical declining also reduces the cross-talk between cylinders, thus improving localization of the AE’s.

1.1.5 Digital signal processing

The PC processes the digital AE signals in several ways to obtain statements on the engine condition. Giving statements on the engine condition is also referred to as giving a *diagnosis*. This is a term, which is borrowed from the medical world where the doctor investigates the patient and gives his opinion on what is wrong with the patient. So in automatic condition monitoring on engines one can regard the engine as the patient and the PC (or the digital signal processing task) as the doctor.

The digital signal processing task can be split into three main tasks, pre-processing and feature extraction, segmentation of signals, and classification of engine conditions. This is shown in figure 2. Usually the incoming data to the digital signal processing is too large and carries a lot of redundant information. This is also the case with this project. Four AE sensors are placed on the engine, giving four analog sensor signals. The A/D converter samples these analog signals at a 20 kHz sample frequency, [16]. After the sampling, the digital signals

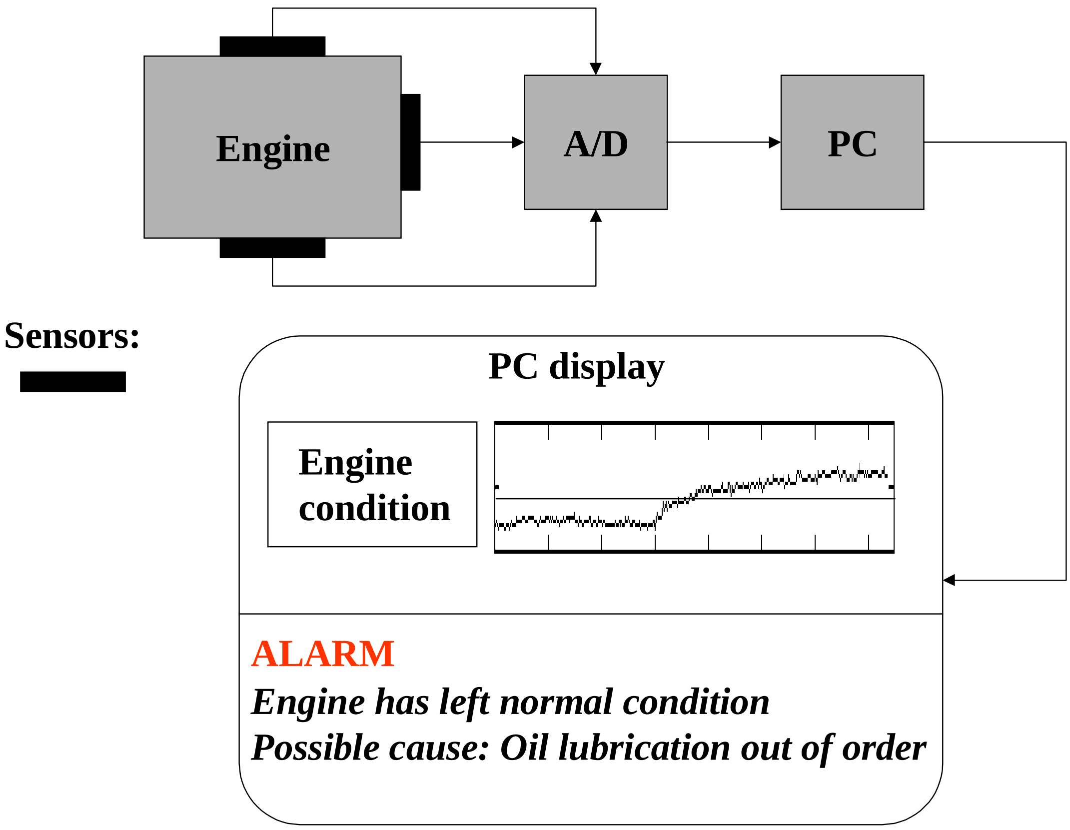

Figure 1: Illustrating the basic principles in automatic condition monitoring on engines. Sensors placed on the engine sense the responses on the activities taking action within the engine. The sensor signals are A/D converted and transferred to a PC, which performs change detection and classification and displays the engine condition and information about alarms on a screen.

are re-sampled into the crank angle domain in order to get the relation between the fluctuations in the sensor signals and the specific ranges of the engine revolution. The re-sampling causes the digital sensors signals to consist of 2,048 samples per engine revolution, thus N in the figure is equal to 2,048.

2,048 samples per revolution times four sensors gives a high number of data points to the digital signal processing task. If all 2,048 data points for each sensor are processed during every revolution, the system is quite certain too slow. Another disadvantage is that the classification task demands a very high training set if the amount of input data is high. This is due to the "curse of dimensionality", [2]. Thus it is necessary to reduce the amount of input data points, but at the same time keeping as much information as possible. This procedure is referred to as feature extraction, where the idea is to look at the input data and find appropriate features, which are then extracted and send to further signal processing. Feature extraction is shown as the second block in figure 2, where M is the number of features, and M should be much less than N.

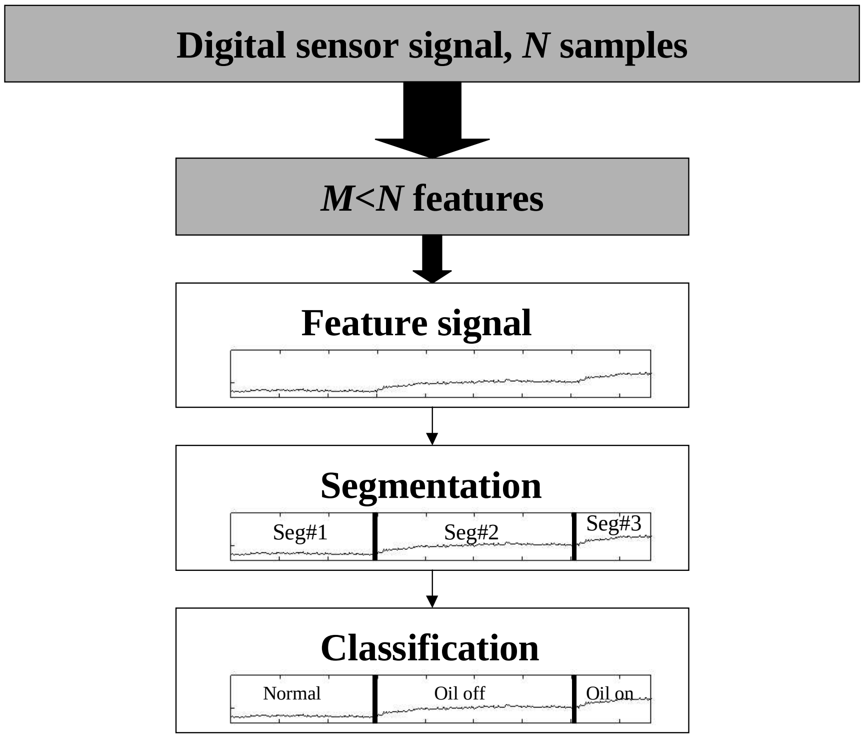

Figure 2:. The three main steps in the digital signal processing of the sensor signals. The first three blocks are the pre-processing and feature extraction tasks, where the aim is to generate a feature signal with dimensions smaller than the digital sensor signals without loosing significant information of the digital sensor signal. The fourth block segments the feature signal so that the last block, classification, can be executed on the segments.

The pre-processing and feature extraction task generates features for each engine revolution. These features are collected into feature signals as a function of the engine revolutions, on which the actual change detection system, is applied. Several feature signals can be generated but in figure 2 only one single feature signal is shown for convenience. The next step in the change detection system is to segment the feature signals, i.e. estimate the change points. Use of segmentation will make the system more efficient when looking at the number of calculations, since it only will be necessary to perform classification when the feature signal enters a new segment. This stems from the intuitively point of view that if a feature is similar to the previous features, then it probable belongs to the same class (or segment).

When the feature signal has been segmented, the segments are classified. Examples on classes are:

- "The engine works normally".
- "The oil lubrication is *off*".

- “The oil lubrication is *on*”.

These examples are also found in figure 2. Pre-processing, feature extraction and segmentation play the most important roles in the thesis, and specifically focus is on the segmentation task. In order to restrict the size of the project, this thesis will not include the classification task. However, during the litterature study, several proposals were given, [6], [8], [9], [11], [14], [15], [18] The focus is not on the sensors either, and this is also true with the generation of the digital signals.