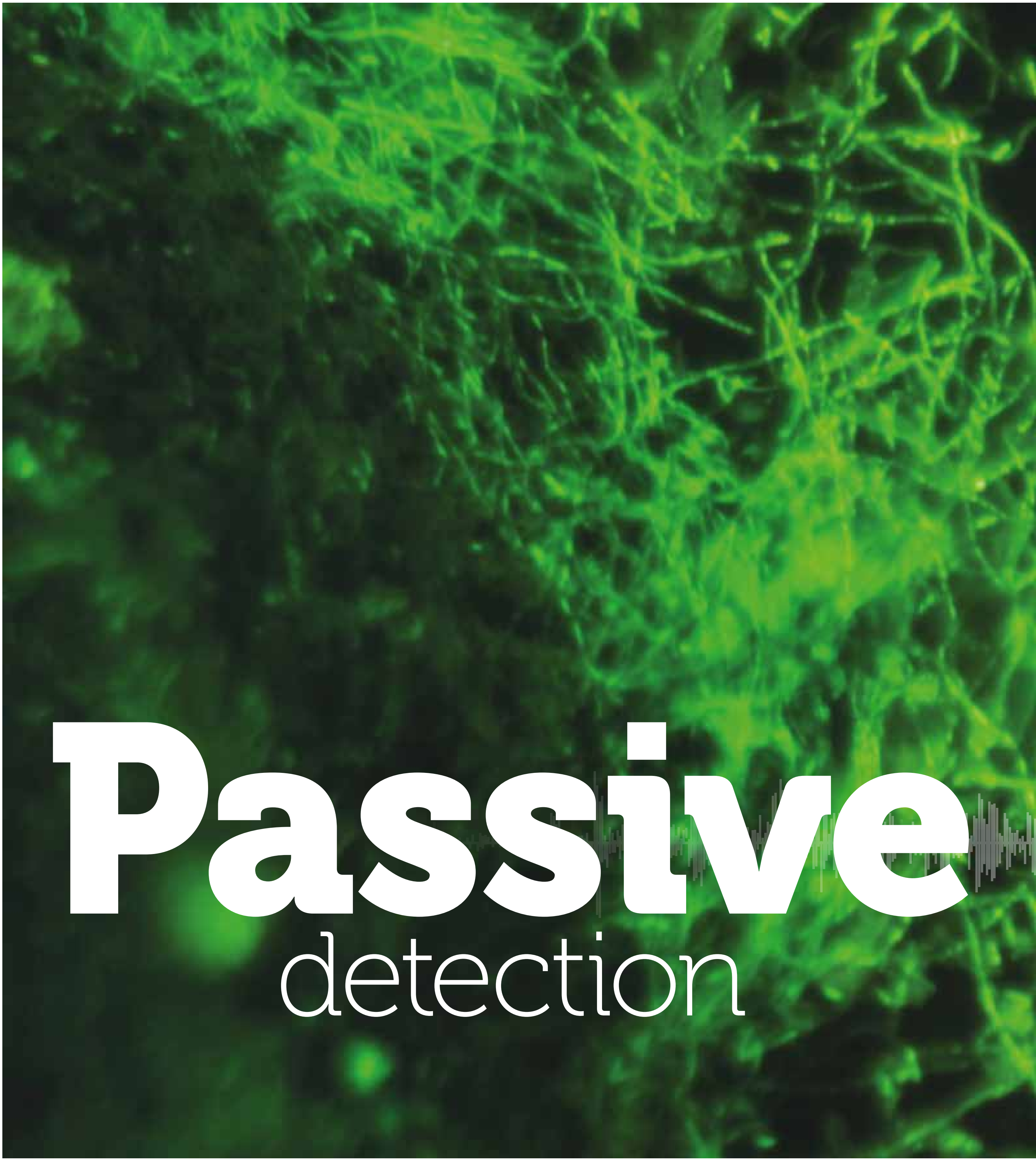
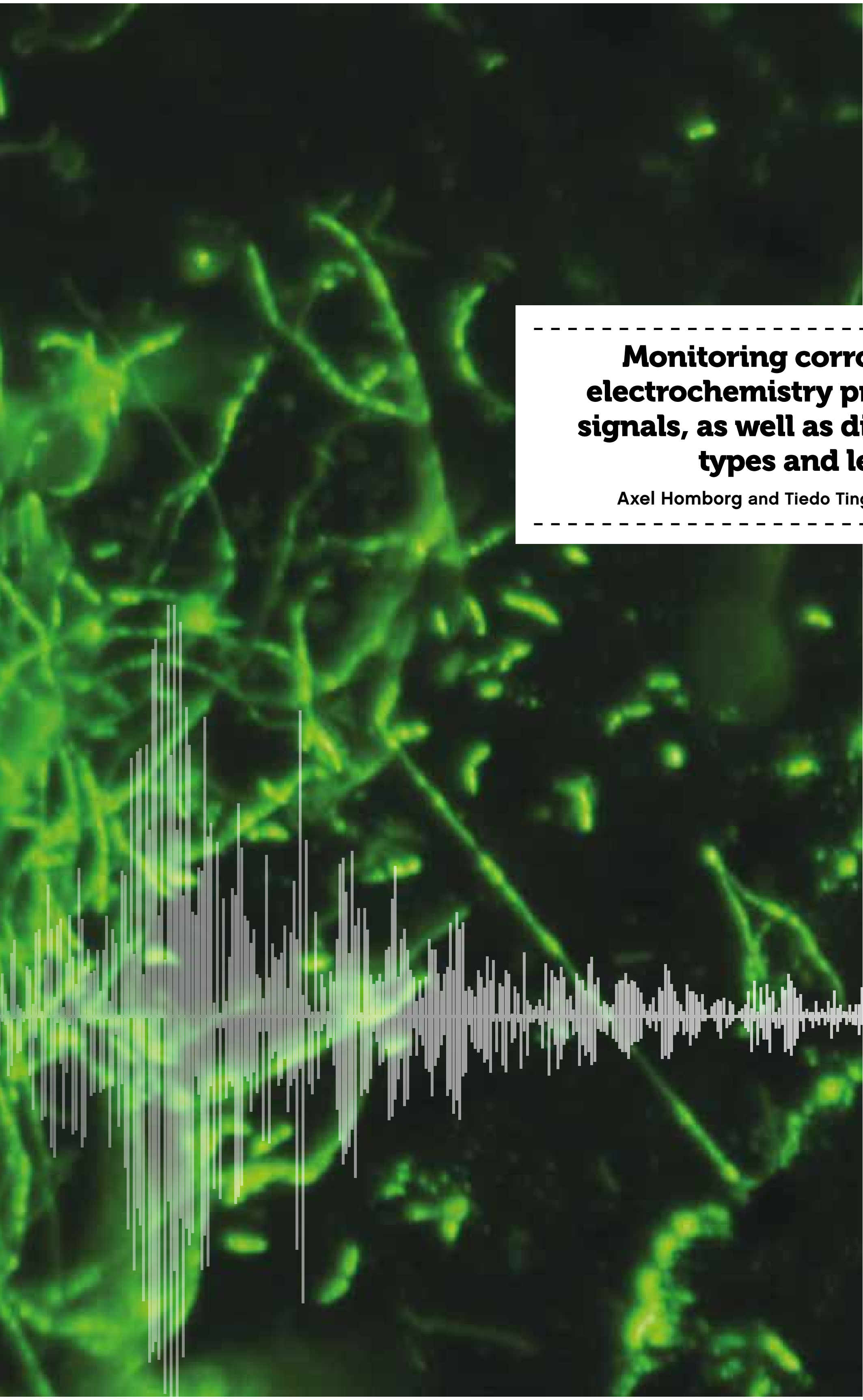


Passive detection



LEFT: **Bacteria responsible for microbiologically influenced corrosion known as (MIC)**

Monitoring corrosion using passive electrochemistry provides early warning signals, as well as differentiation between types and levels of attack

Axel Homborg and Tiedo Tinga, Netherlands Defence Academy

The operational availability of assets largely depends on the way they are used and maintained. In order to guarantee this operational availability at reasonable costs, existing maintenance concepts should be critically assessed continuously. The Netherlands Defence Academy (NLDA) performs research to novel maintenance concepts that optimize this readiness.

Novel, state-of-the-art maintenance concepts are highly responsive to the state of a system. This state is monitored either continuously or with certain intervals, depending on the expected degradation mechanisms, their rate, and their impact on operational availability. Instead of using fixed maintenance intervals, the planning of maintenance efforts is then based on those monitoring parameters, making the maintenance adaptive to a system's state. Together with the University of Twente, Delft University of Technology and Endures BV, the NLDA investigates advanced sensor techniques that enable direct measurements of the condition of a system (condition monitoring) or structure (structural health monitoring). The advantage of condition monitoring is that assumptions on the impact of a certain usage profile on local loads and the associated decrease in condition are becoming unnecessary, since direct information about the condition of a system is always available. From a known current condition, more reliable estimates of the remaining lifetime can be done, potentially resulting in less unexpected downtime.

One of the most important failure mechanisms in terms of costs and reduction of operational availability is corrosion.

Impact of corrosion

In its various forms, corrosion mechanisms are often very hard to predict, whereas their consequences for the asset can be quite severe. This especially holds for assets operating in a maritime environment, which is generally considered as being one of the most aggressive environments. As an example, the US Department of Defense estimates that approximately 27% of the maintenance costs for their vessels can be attributed to corrosion.

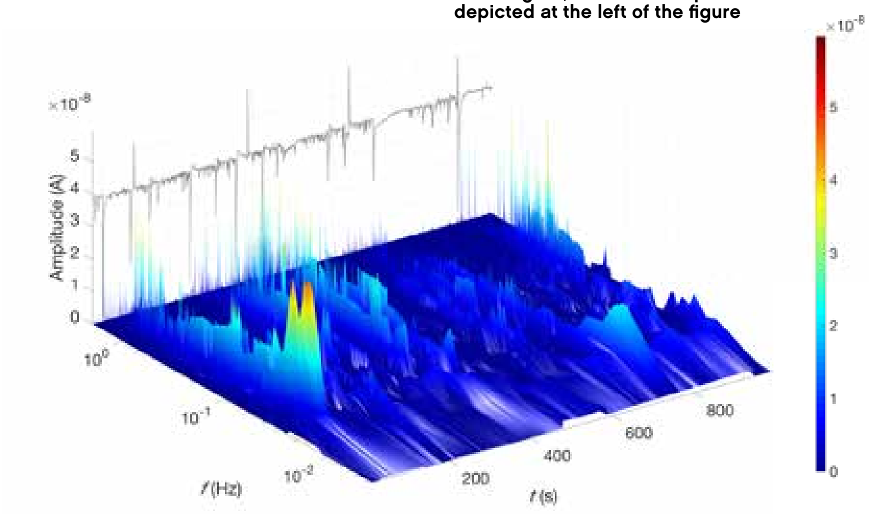
An even more critical aspect is safety. In some cases, corrosion can unexpectedly lead to system failure, with potentially severe consequences. An increased understanding of the corrosion mechanisms and proper monitoring and/or modeling will lead to a more careful selection of corrosion protection and the prevention of both system failures and unnecessary corrective maintenance procedures.

The consequences of corrosion largely depend on the function of a system; a corrosion pit in a fuel tank can be a much bigger problem than a similar pit in a ship's railing. The timing, location and rate, together with the typical unpredictable nature of localized corrosion mechanisms (such as pitting under specific conditions), make it very hard to anticipate these kinds of problems.

Corrosion detection

Monitoring is an effective solution for something that is difficult to predict and that potentially leads to severe consequences. In most cases, periodic corrosion inspections are performed visually, sometimes with the aid of more advanced techniques that can quantify corrosion damage, for example ultrasonic devices. A more advanced approach is online (continuous) corrosion monitoring, enabling a more carefully adapted maintenance policy, which takes into account the actual state of a system and the performance of preventive measures, e.g. a protective coating. However, the disadvantage of many monitoring techniques is their low reaction speed, i.e. the long delay between the indication and the actual occurrence of the corrosion. Moreover, the probability of detection is often directly proportional to the amount of corrosion damage, provided that the specific corrosion problem can be detected at all. In fact, localized corrosion problems typically remain undetected until it's too late and failure occurs.

Corrosion is actually the deterioration of a material that results from an electrochemical reaction with its environment. Usually this involves

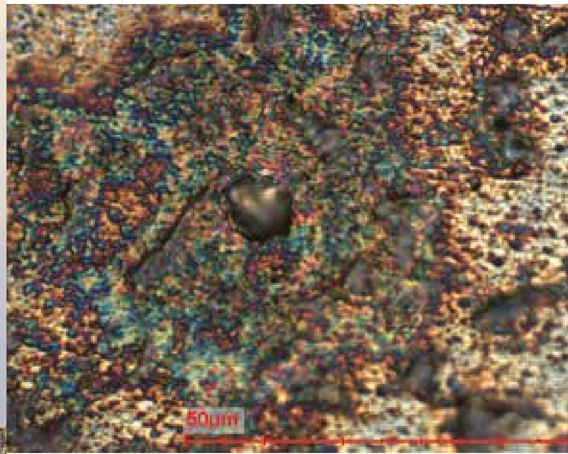


BELOW: **Example of the characteristic 'fingerprints' of corrosion pits, visible as transients in the signal at the back of the figure, with their frequencies depicted at the left of the figure**

The US Department of Defense estimates that approximately 27% of the maintenance costs for their vessels can be attributed to corrosion

LEFT: **Fixing corrosion problems can take expensive national assets out of service for repairs, such as this US Navy ship preparing to enter a San Diego shipyard**

BELOW: **Corrosion pit on plain carbon steel, resulting from MIC**



Localized corrosion problems typically remain undetected until it's too late and failure occurs

Axel Homborg, Netherlands Defence Academy

metals, although other materials can also corrode. Corrosion is easily misinterpreted and very difficult to model, because it is a multidisciplinary problem. To fully understand the phenomenon requires at least a proper understanding of material properties and electrochemistry, but also of the influence of environmental parameters on corrosion characteristics.

In addition, particularly in a maritime context, knowledge about microbiology can be very important. Microbiologically influenced corrosion (MIC) is little known, often misunderstood, and can lead to severe pitting problems.

Many forms of corrosion exist, but in general the distinction between general (or uniform) and localized corrosion (e.g. pitting) is made. If proper care is taken, in most cases general corrosion can be predicted and prevented to a reasonable extent, whereas localized corrosion in many cases cannot. Because the total material losses in the case of localized corrosion are often quite small, it is hard to monitor and detect these types of corrosion. In the case of MIC, in many cases no, or perhaps limited general corrosion damage would be expected. This potentially leads to severe consequences: think about small penetrations of a ballast tank in a ship's hull that can act as crack initiations.

Sensor technology

The sensor technology that is being developed at the NLDA is based on electrochemical noise (EN). Energy that was initially captured in the metal through the refining process is released again during corrosion. EN is based on the measurement of this corrosion signature, i.e. the small fluctuations in current and potential (hence their original designation as 'noise'), spontaneously generated by corrosion processes. Measuring EN is a passive technology, which means that no external signal is applied. This can be regarded as an important advantage compared with other techniques, since any external perturbation may accelerate the corrosion process, damage a protective coating, and further reduce its lifetime. It is therefore considered to be a non-intrusive technique. EN measurements (ENM) detect corrosion at its early stages, before any significant corrosion damage has taken place. Therefore, EN-based sensors are likely to provide a warning for any potential corrosion problem earlier than sensors based on other techniques.

The power of this technology lies in its simplicity: because it is a passive method, based on a minimum of two fixed electrodes, it contains no moving parts. This makes it a robust monitoring solution that can be used in a wide variety of applications. Moreover, because the electrodes can be made of inexpensive materials, it is relatively cheap.

LEFT: **Corrosion blisters underneath a protective organic coating inside a ship's ballast tank**

BELOW: **The cure for corrosion problems is often sandblasting work and recoating**

> **Using corrosion sensors based on electrochemical noise, the inspection or monitoring process can deliver more information**

Dr Axel Homborg, Netherlands Defence Academy

Sensors can either be integrated in newly built assets at locations that are otherwise hard to reach, or a handheld solution can be chosen. A network of sensors could be placed to increase the probability of detection of localized corrosion. Tests in ballast tanks and fuel tanks of Dutch navy ships have already proven the effectiveness of this sensor technology. Here, a comparison was made between this novel technique and an existing corrosion monitoring technique that is used in practice: electrochemical impedance spectroscopy (EIS).

Besides the advantages mentioned earlier, what makes the EN technique particularly attractive compared with its rivals is the ability to not only detect, but also qualify the corrosion problem. By using corrosion sensors based on EN, the inspection or monitoring process can deliver more information than conventional techniques. EN is actually based on a principle known since the early 1960s. The novelty in this case is the way the measured signal is treated.

Because the technique is passive, all information should be obtained from the spontaneously generated current and potential. The largest challenge lies in the detection and classification of localized corrosion. Localized corrosion processes such as pitting do not occur continuously over time. Instead, they occur intermittently

as a brief (and potentially quite severe) instantaneous corrosion attack. This implies that their EN signature is also highly localized in time.

Any pitting process generates so-called 'transients' in the EN signal. These contain information about the formation and progress of the pits in the material. This is captured in the localized frequency information of the transients. The data analysis procedure that is used to extract these localized frequencies uses time-frequency algorithms that enable the maintainer to obtain information about the moment of occurrence of corrosion attack, as well as the specific type of attack. This can best be considered as the corrosion pits leaving behind a 'fingerprint' in the EN signal. By applying an analysis procedure, each transient is analyzed individually. In case the type of corrosion attack changes over time, this will be detected by the EN technology. If, for example, a change from general corrosion to more aggressive pitting corrosion occurs, the EN transient analysis procedure can inform the maintainer in time about this change. Also, in case of corrosion inhibition, EN can indicate the effectiveness of the inhibition by detecting the change in corrosion signature.

Conclusion

With its partners, the NLDA is developing a promising new condition monitoring solution for corrosion problems in a large variety of assets. This is not only limited to the maritime industry, but the technique is, in principle, also suitable for many more types of applications. The early-warning possibility and the ability to differentiate between various types and levels of corrosion attack, combined with the simplicity of the sensor and passive nature of the measurement, make ENM an interesting option for any asset manager facing corrosion problems. \\