Investigating Reed Sensors for Monitoring Closing Mechanisms of Flood Protection Gates

Timon Rupelt

Hamburg University of Applied Sciences, Berliner Tor 7, 20099 Hamburg, Germany
Timon.Rupelt@haw-hamburg.de

Abstract. The RESCUE-MATE research project aims to improve the situational assessment and optimization of the communication from the scene to the rescue services for the scenario of a storm flood in Hamburg. This includes the monitoring of flood protection gates of port polders. The various sizes and closing mechanisms of these gates place a variety of requirements on possible sensors. One possible option are reed sensors, which are simple and versatile magnetic proximity sensors. This work outlines an investigation of the suitability of reed sensors for this application by evaluating whether the requirements are met and how they compare to other sensor types.

Keywords: reed sensor, proximity sensor, flood gate monitoring, riot, resuce-mate

1 Introduction

Flooding is not uncommon in Hamburg or many other places near a body of water affected by the tides or heavy rainfall. Even when prepared, floods continues to present a variety of risks and challenges for residents and emergency responders. High water levels can damage dikes and create a risk of a breach [13]. It is necessary to detect this in time to be able to react. Strong winds and high waves can cause ships to become loose and drift, posing a risk of damaging other ships and bridges. Slowly rising water levels can leave uninformed and onlookers cut off from the mainland. These and residents in endangered areas must be evacuated in a timely and efficient manner [13]. Clear escape routes and the availability of spaces in emergency shelters must be known at all times to avoid overloading them.

The motivation of the research project *RESCUE-MATE*, is to investigate the challenges of creating a situation overview and the optimization of communication from the scene to the responsible personnel for the scenario of a storm flood in Hamburg [13]. The primary objective ist to construct a dynamic and comprehensive situation overview, to serve as a basis for orientation and assessment for emergency services and decision-makers. The overview will continuously integrated with real-time data from sources, such as rescue radio, environmental and traffic sensor data, social media, and drones.

To this end, the Hamburg Port Authority (HPA), the Hamburg ministry for interiors and sports (Behörde für Inneres und Sport) and 24 other partners including the University of Applied Sciences Hamburg (HAW) are working together [13]. The project is funded by the federal ministry of education and research (Bundesministerium für Bildung und Forschung (BMBF)) as part of the "Research for Civil Security" program.

The research group INET of the HAW is involved in the subproject "Resilient Sensor Networks for Dike Monitoring and Emergency Communication" to expand and accelerate the access to information about dikes and floodgates [8]. Goals and contributions include the concept of efficient and robust sensors to monitor critical locations and the design and testing of an autonomous, energy-efficient sensor box for long-term use. In addition, methods for coordinating long-range radio communication and collision recovery will be investigated, and a robust, secure, and fault-tolerant sensor network will be designed and tested.

In the context of this project, this work outlines an investigation of the suitability of reed sensors for the monitoring of closing mechanisms of flood protection gates. Section 2 discusses the requirements the application places on a sensor and the steps to evaluate the suitability. Section 3 introduces reed sensors and the how to use them. Finally, Section 4 gives a conclusion and outlook for the future of the investigation.

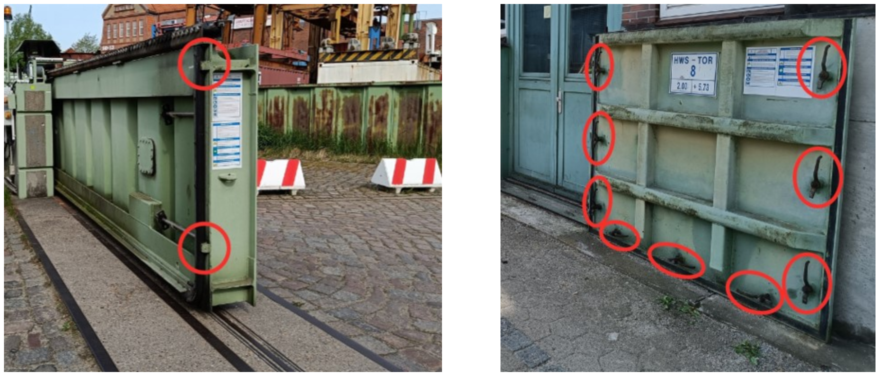
2 Floodgate Monitoring

In the port of Hamburg the concept of *polders* are used to protect areas from the flood [13]. Polders or port polders are areas secured by flood protection systems [5]. By closing all flood protection gates, an area can be completely sealed off. So-called *polder pilots* are in charge of the polders. They have to close and monitor the gates in case of flooding. The construction and management of polders can be undertaken by private individuals or companies, so that land users can determine the extent of protection themselves.

Floodgates differ in size and the way they close. Common variations include rolling gates (see figure 1a) that are motorized and move linearly on a rail, motorized swing gates on rails and swing gates with multiple latches that are manually locked (see figure 1b). Different closing mechanisms present a challenge to the task of monitoring these gates, because different things need to be sensed to ensure proper monitoring. There is no one-size-fits-all solution.

Reed sensors are simple but versatile proximity sensors that could be used to handle the various mechanisms. The following six research questions are formulated to guide the evaluation of reed sensors for this use case.

RQ1. How can reed sensors be used to monitor the various locking mechanisms?
RQ2. How reliable are the sensors and can errors be quantified?
RQ3. How to handle ambiguous signals from multiple sensors on a gate?
RQ4. How to mount the sensors to ensure proper operation and protection?
RQ5. How can wear and tear be reduced?



(a) A motorized rolling gate. (b) A manually closeable swing gate.

Fig. 1: Images of two variations of flood protection gates.

RQ6. What resources do reed sensors require and how can they be optimized for constrained devices?

These research questions will serve as the basis for further investigation.

2.1 Suitability Evaluation

In order to address these research questions, a more detailed examination of the various floodgates and the reed sensors are required. First, the existing locking mechanisms of the floodgates need to be determined and how reed sensors can be used to detect opening and closing. When a gate is considered correctly closed, depends on how many steps need to be performed to close it. Therefore, multiple points may need to be monitored with separate sensors to cover all these steps. Furthermore, it is required to check, whether reed sensors support the required sensing distances for this. By building models of the gate closing mechanisms, it will be possible to test different configurations and mounting options with the sensors.

It is also necessary to perform a detailed evaluation of the sensors themselves to quantify the sensor errors. To determine if there are variations in the actuation distance or if false triggers are occurring, a test setup can be created, in which a reed sensor can be repeatedly tested under the same conditions. A magnet can be moved to a specified distance from the switch, thereby activating it if the magnet is within the supported operational range. The magnet can then be moved back to deactivate the switch again. This process is then repeated for a large number of operations while recording whether the switch is in the correct state or if a false trigger has occurred, which is when the switch is actuated when it should not be. With the recorded data, the error rate of the switch can be determined. This can be performed at different distances within and outside of the supported operational range of the sensor.

The same test setup can also be used to evaluate the number of supported fault-free operations before a sensor fails due to wear, if the numbers provided by the manufacturer are not to be trusted. Performing the actuation cycle of the switch for a large number of times, it can be determined when the error rate exceeds an acceptable threshold or the switch fails completely. This information is important when considering when and how often to replace a sensor.

In addition, the aforementioned test setup can be used to test the influence of surrounding metal objects by checking the distance at which the switch is incorrectly triggered or is unable to switch between states correctly. This information is necessary for the correct mounting of the sensors and for designing a housing for protection against interference, tampering and also environmental influences.

To evaluate whether reed sensors are the more suitable sensor type for this application, other proximity sensor types can be evaluated under the same conditions for comparison. Possible alternatives include sensor types like other magnetic field sensors, inductive, optical, capacitive and ultrasonic proximity sensors.

Another variant of magnetic field sensor is the hall (effect) sensor. Hall sensors have no moving parts and can be digital or analog returning a voltage depending on the distance of the magnetic field. However, they require an electrical circuit to operate, which consumes power even when in its passive state [18].

Inductive proximity sensors detect objects by measuring the reduction in inductance caused by their magnetic field [1]. As with hall sensors, they have no moving parts and a high switching frequency but require power to operate and are generally more expensive.

Optical proximity sensor detect the presence or absence of visible or infrared light to detect an object that either obstructs the path of the light or reflects it back to a receiver. They can detect most materials but are susceptible to environmental influences such as ambient lighting or dust [15].

Capacitive proximity sensors work in a similar way to inductive sensors, except that they measure the change in capacitance caused by a nearby object. They can detect metallic and non-metallic materials in solid, liquid, granulate and powder form but generally have a lower accuracy than inductive proximity sensors [15].

Ultrasonic proximity sensors measure the time of flight of emitted ultrasonic pulses to detect targets. They can also be used like a light barrier detecting the obstruction of the emitted pulse [6]. Ultrasonic proximity sensors can detect targets of various materials and shapes and have high ranges [15].

Different sensors have different advantages and disadvantages depending on the application they should be used in. It is important to determine whether there is a better option than a reed sensor for this particular application.

3 Reed Sensors

A reed switch is an electromagnetic switch operated by an external magnetic field. [19] Instead of using mechanical force as with tactile switches, magnetic force is used to close or open two contacts. Reed switches can be operated without physical interaction or direct access to the switch. They presents a simple form of a magnetic field proximity sensor to detect the presence of a magnetic field. When used for sensing, reed switches are often encased in a housing for protection and mounting, which is altogether often referred to as a reed sensor [12,19].

The switch consists of two or three ferromagnetic blades which are hermetically sealed in a glas tube. Inside the glas tube is either an inert gas like nitrogen or a vacuum [19]. The blades are positioned to overlap slightly but are separated by a small gap. Applying an external magnetic field to the switch, will move the blades together and close the contact. This requires the magnetic force to exceed the spring forces of the blades [19]. Removing the magnetic field will cause the blades to return to their original positions and reopen the contact.

3.1 Characteristics

There are several variations of reed switches with different *contact forms* [19]. They differ in number of blades and the switching behavior. The basic variant is the *form A* or *Normally Open (NO)* switch [7]. It has two blades that are not connected by default. Activating it will close the connection. It is a *Single Pole, Single Throw (SPST)* switch, which means it controls a single electrical circuit [4]. A sketch of the structure of a form A reed switch is depicted in figure 2a.

The function of the *form B* or *Normally Closed (NC)* variant is inverted to the form A reed switch. The contact is closed when not activated, otherwise it is open. The structure is the same to form A shown in figure 2a except for the closed default state.

The third most common variant is the *form C* or *Changeover* switch, which combines the previous variants into one. It has three blades - the common blade, the NO blade and the NC blade. The common blade is the only one that moves and is normally connected to the NC contact and switches to the NO contact when activated. It is a *Single Pole, Double Throw* switch meaning that it controls two electrical circuits by switching states. A sketch of the structure of a form C reed switch is shown in figure 2b. Another variant is the *form E* or *Latch* switch, which locks in either position and remains in the activated state when the magnetic field is removed [7,19].

A magnetic field is required to operate the switch, which can be provided by either a permanent magnet or an electromagnetic coil. How close the magnetic field has to be to the switch depends on the strength of the magnetic field and the activation point of the switch, the so called *Pull-In* [19]. The point of release where the contacts open again is called the *Drop-Out*. When using a magnet both is usually measured as a distance from the switch to the magnet in millimeters (inches) or in field strength usually ampere-turns, mTesla or Gauss. For a coil,

(a) Form A

(b) Form C

Fig. 2: Sketch of a form A (a) and a form C (b) reed switch (from [19]).

it is measured either in volts across the coil, milliamps flowing through the coil, or ampere-turns.

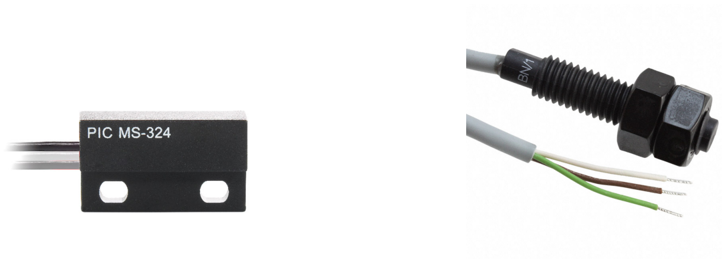
Ampere-Turns (AT) describes the amount of current passing through a specific number of turns of a coil [7]. It is calculated as the product of the current in amperes and the number of windings [19]. The Pull-In is closer to the switch than the Drop-Out, which is referred to as *Hysteresis* and is expressed in the ratio DO/PI in percent [19]. The ratio may vary depending on the design and materials of the reed switch. This prevents a *floating state*, where the switch is rapidly changing states when the magnet is at the pull-in point.

The relationship between the actuation distance and the sensitivity of the reed switch and the strength of the magnet depends on the size, shape and material of the magnet [7]. There are also multiple ways to move a magnet around a reed sensor passing the pull-in point and activating the switch. Moving the magnet parallel to the switch, toward the main body, or toward the outer contacts will activate the switch depending on its range. A magnet can also be rotated so that the magnetic poles facing the switch change, thereby actuating the switch. Another option is to use a magnetic shield which will divert the magnetic field away from the switch when moved between the magnet and the switch [7].

Instead of using a permanent magnet, an electromagnetic coil can also be used. The switch can be surrounded by the coil and actuated by passing current through the coil, creating a magnetic field. This is the principle used in a *Reed Relay* [19].

When using a reed switch in a circuit, there are a few other characteristics to consider. The *switching* or *operating voltage* is the maximum allowable voltage across the open contacts [7]. A higher voltage is more likely to cause electrical arcing. The *switching current* is the current measured when the contacts are closed or open. Exceeding the maximum rating for the switch will result in more arcing at the opening and closing. When the contacts are closed, a higher maximum current is allowed, which is called the *operating* or *carry current*. The *switching load* or *power* refers to the maximum combined voltage and current at the time of closure without damaging the contacts [19,7].

Reed switches can have a varying amount of *contact* or *total resistance*, which is the resistance at closed contacts. The *insulation resistance* refers to the measure of insulation across the contacts of a switch, which should prevent current leakage. The *operating time* indicates the time it takes to close the contacts



(a) A flatpack reed sensor (from [12]).

(b) A cylindrical threaded reed sensor (from [20]).

Fig. 3: A flatpack (a) and a cylindrical threaded (b) reed sensor.

and stop bouncing, while the *release time* refers to the time it takes for the contacts to open and stop bouncing [7]. Other attributes include the operating temperature range, the shock and vibration resistance.

For better protection and mounting options, manufacturer provide different types of housing mostly made of metal or plastic with wiring [12]. The most common housing variants are flat(-pack)/screw mount, tubular/cylindrical, tubular/cylindrical threaded [12,20]. The flatpack or screw mount is a rectangular housing with one flat side and two screw holes with little room for fine adjustment. The tubular or cylindrical housing can be very small in size, allowing mounting in small holes. Tubular or cylindrical threaded housings have a external thread around the outside that allow for precise positioning and fine adjustment [12]. A flatpack and cylindrical thread reed sensor are shown in figure 3a and 3b respectively.

3.2 Use cases

One of the advantages of using reed switches/sensors is not needing direct access to the switch. It can therefore be operated from outside of an enclosure and from a distance. Reed sensors have no power consumption of their own, making them an good choice for low power applications. With very little wear and tear, they can support up to tens of millions of operation cycles, if the rated values are adhered to [7,19]. The hermetically sealed contacts make reed sensors suitable for use in hazardous environments such as with flammable gases, without the risk of sparking. It also prevents contact corrosion and other environmental damage.

Reed switches are generally used for anything that turns on and off, opens and closes, requires power transfer, starting, measuring or detecting [19]. These basic tasks are found almost everywhere, which is why reed switches find application in areas like in automotive and transportation, smart homes, medical, test and measurement equipment. Some specific examples include liquid level detection, brake pedal position sensing, and door detection for automobiles, homes, or appliances.

In research, reed switches are used in areas like enhanced overcurrent protection [11,9], in activity recognition systems [14,16] and to enhance RFID tags, often in the context of home security [17,2,10].

3.3 Integration with RIOT

The interaction with the sensors and the evaluation of their values will be handled by an embedded device. The devices will use the real-time operating system RIOT [3], which is designed for resource-constrained embedded devices. For optimal and future-oriented usage, a driver for reed sensors needs to be developed. Connecting a reed sensor to a RIOT node requires only one digital input pin for form A and B variants and 2 pins for form C switches.

For low-power applications where events occur infrequently, reading sensor values via interrupts is a better option than with polling. Thereby, an interrupt can be registered for these pins to execute code whenever the sensor state changes. To increase the stability of the values measured at the pins, an internal or external pull-up or pull-down resistor can be used. A basic schematic of using a pull-up resistor is shown in figure 4.

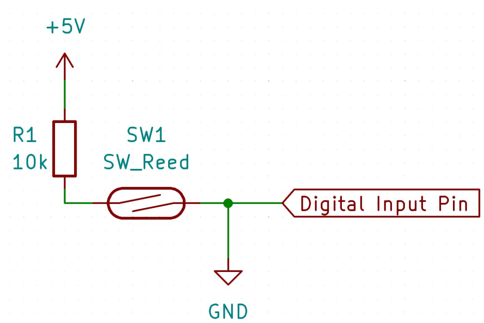


Fig. 4: Basic schematic for using a reed switch with a pull-up resistor.

4 Conclusion and Outlook

This work outlined the function of reed sensors and the necessary steps to investigate their suitability for the specific use case of monitoring closing mechanisms of flood protection gates. Reed sensors are simplistic magnetic proximity sensors with the advantages of contactless sensing, no power consumption and usability in a variety of environments and applications. They are easy to integrate into a circuit requiring no further circuitry to convert the signal.

However, the application places high demands on the sensors. Whether reed sensors are suitable for the presented use case will be determined in the following work. The first stage involves laboratory testing, the results of which will determine whether to proceed to field testing. The field tests are the second stage, in which the sensors are tested on site at actual flood gates. This will determine whether the specified requirements are fulfilled and whether alternative proximity sensor types are more suitable.

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