

## WATER INTRUSION AND LEAKAGE DETECTION IN ENVIRONMENTS WITH HIGH CONDENSATION

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**Abstract** – Many technical devices but also non-technical devices and objects are sensitive to water. Excessive amounts of water may lead to a damage or even malfunction of them. Water detection can thus be a useful tool for preventive maintenance, in particular in combination with wireless sensor nodes. In addition, with respect to warranty of technical devices, water detection also helps to identify if specified operation conditions have been violated. In both cases, it is important to achieve a high detection rate whereas false alarms should be avoided. A common source of false alarms is condensation due to changing environmental temperature. In this paper, we suggest a water detection sensor that has low sensitivity to condensation yet high sensitivity to leakage water. Due to low power consumption, it is well appropriate for wireless applications.

**Keywords:** Water leakage, water intrusion, condition monitoring

### 1. BASIC INFORMATION

With respect to online condition monitoring, a water detector is an electronic device that is designed to detect the presence of water and provide an alert in time to allow the prevention of water damage. Common designs are small devices that are mounted on a floor and rely on the electrical conductivity or the permittivity of water to decrease the electrical impedance between two electrodes [1]. Depending on the application, the detector may trigger an audible alarm or other means of signalling in the presence of enough water to bridge the contacts. The devices are useful near any infrastructure that has the potential to leak water, such as heating, ventilation and air conditioning, water pipes, drain pipes, vending machines, dehumidifiers, water tanks or simply in outdoor usage, e.g. of mobile electronic devices such as mobile phones. Wireless implementations have advantages in many situations [2]. An exemplary application is shown in Figure 1.

Many sensors for the detection of moisture and water are commercially available and are state of the art. Simple sensors use switches that are actuated by a floating body. Such sensors require a comparatively high amount of water. Sensors with high sensitivity are found in dew point measuring devices, e.g. [3-4] or condensation detection,

e.g. [5] with sensing principles ranging from optical over capacitive and resistive to radioactive principles.

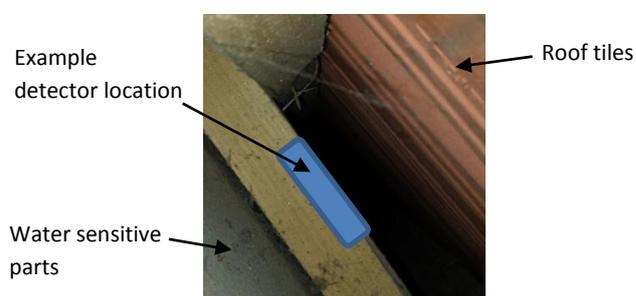


Fig. 1. Example application for water leakage detection on a roof with air insulation. If water leaks through the roof, the construction underneath can be damaged. A wireless monitoring system may detect intruding water and thus raise an alarm. Consequently, maintenance starts as early as the intrusion and major damage of water sensitive parts is avoided.

In most of the applications it is sufficient to detect the presence of water. Perhaps surprisingly – this is not necessarily the actual problem in water intrusion detection. In the latter it is important to distinguish between sources of moisture. While moderate condensation, e.g. out of the small air volume of the enclosure of an electronic device, may be uncritical or cannot be considered as operation outside of specifications, larger amounts of water - intruding from the outside - are critical or may lead to a loss of the warranty for a certain product.

### 2. SENSOR PRINCIPLE

In order to distinguish between condensation and intrusion/leakage water we need to identify differences between these two types of water. One parameter that may be the specific for each type of water is the specific conductivity. Water from condensation is usually rather pure and has a comparatively low specific conductivity. However, due to contaminations on the surface, e.g. due to dust, this low conductivity will usually not prevail. Therefore, this parameter cannot be used to distinguish between the two types of water. Another difference between condensation and intrusion/leakage water is that the latter needs to flow in some

sense to reach a point of interest. In contrast, condensing water actually forms drops at the location where it appears. This also implies that there needs to be sufficient amount of water to overcome adherence to the surface. If the amount of water due to condensation becomes large enough to overcome adherence forces, this will also lead to an alarm. This is usually a desired behaviour of the device.

The second approach can be found in water indicator labels, which many manufacturers of electronic devices include into their products. These tapes change their colour when they get into contact with water. As the exposure of electronic devices to a large amount of liquid will void the warranty, the manufactures (or the repair centre) can use a stained water contact indicator label to justify refusing replacement or the repairing of the device. However - as mentioned above - sole condensation from humidity due to a change of temperature should not lead to a loss of warranty because this can occur during normal operation of such devices.

An approach to improve the robustness with respect to high humidity and/or condensation is to include a protective sheet into the water indicator tape. A realization of this approach is the water contact indicator tape 5557 from 3M [6,7] (Figure 2). Water condensing on top of the tape is separated from the dye in the indicator layer by a transparent PET layer so that the water on top does not stain (or wet) the indicator layer. However, when a larger amount of water is present at the edges of the tape, it gets absorbed into the hydrophilic water indicator layer thus leading to a colour change.

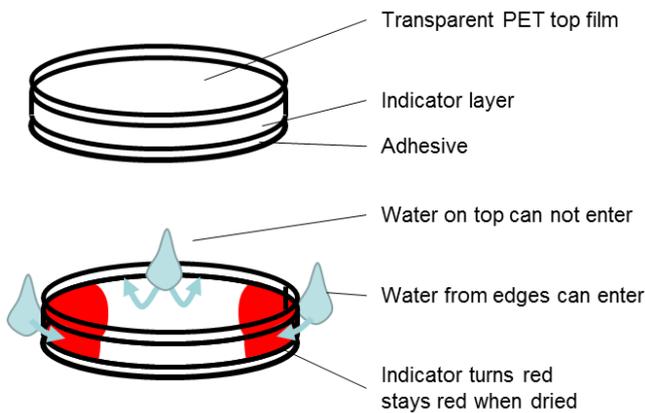


Fig. 2. Illustration of a water indication tape [6]. A transparent top film is used to protect the indicator layer and thus also direct condensation is avoided. Water that enters into the indicator layer from the edges leads to a colour change of the same. The change remains after the exposure to water is over.

With respect to online condition monitoring, we are interested in an electronic readout of the water indication information. This could be achieved, e.g. with the water contact indicator tape 5557 from 3M combined with a light source and an optical sensor. However, in online condition monitoring we want to use the indication to prevent further harm to the device. Consequently, it is aimed that the water intrusion is

eliminated. In this case, we want the sensor to have the ability to recover. Additionally, a wet water absorption layer can also easily be evaluated electronically using capacitive or resistive principle, which will typically be more compact in size and also of lower cost than an optical approach. Therefore, we suggest to combine the concept of water contact indicators and resistive readout to obtain a robust detector principle.

It should be noted that although the indicator tape has a low sensitivity towards humidity, it may still cause false alarms. A study on aging effects has recently been presented in [8]. While this is a major concern with respect to warranty claims, it is of lower importance in the present application. First, no permanent colour change occurs in the suggested sensor as the sensor recovers from moisture. Second, excessive moisture due to condensation will frequently be accepted as a reason for an alarm.

Our proposed detector design is based on the common water detectors principle utilizing the conductivity of water. Electrodes are embedded into a hydrophilic material. When water is present, the hydrophilic material becomes wet and due to the conductivity of the water the resistance between the electrodes decreases.

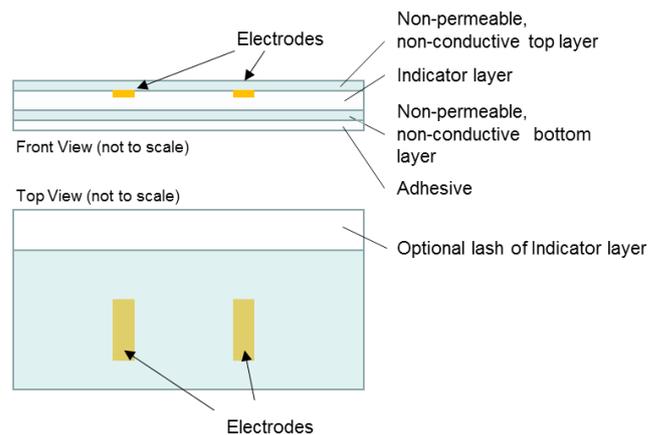


Fig. 3. Illustration of the topology of a resistive water detector. In analogy to Figure 2, a water absorbing indicator layer is covered by non-permeable, non-conductive top and bottom layers. The detector can be attached to a surface, e.g. aluminium, steel or plastic by means of an adhesive. As the electrodes are covered, a conductive bridge can only be formed when water is absorbed from the edge of the detector. An optional lash may be used to facilitate faster drying of a wet sensor.

### 3. EXPERIMENTAL SETUPS AND RESULTS

Based on the principle described in Section 2 prototypes were built and the sensitivity with respect to water and condensation was investigated. Figure 4 shows results for water intrusion. Here, we let a drop get into touch with the edge of the sensor. The hydrophilic layer absorbs the water and brings it to the electrodes. As soon as it reaches both electrodes of the sensor, a conductive connection is formed and the resistance between the sensor electrodes decreases rapidly. The drop distributes itself in the hydrophilic material

leading to a further decrease of the resistance. Consequently, the drop is easily detected by measuring the electrical resistance between the electrodes. Once the resistance drops under a certain threshold, the presence of water is indicated.

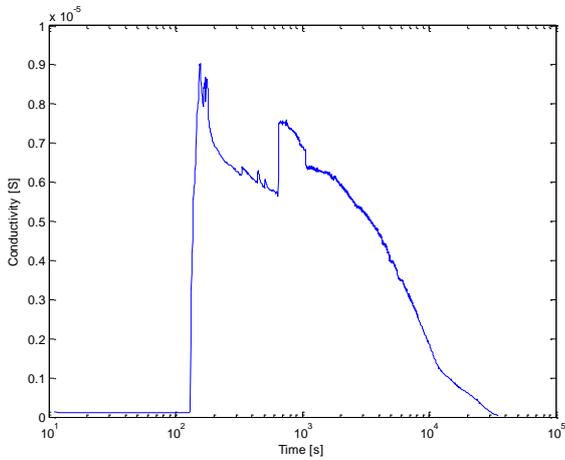


Fig. 4. Conductivity change due to a water drop placed at the edge of the water detector. The conductivity changes rapidly within seconds to a maximum close to  $10 \mu\text{S}$ . Please note the logarithmic scale on the time axis: It takes several hours until the device fully dries and recovers to the original low conductance.

As mentioned above, it is also desirable that the detector recovers after exposure to water. This implies for the use with respect to validating warranty, the information must be stored electronically, e.g. in an RFID enabled memory. The resistance change during the recovery of the sensor is also shown in Figure 4. Figure 5 shows a snapshot obtained with a thermal camera during this process. By this, the evaporation process can be visualized. Due to the enthalpy of vaporization of water, the lash gets cooler than the surrounding. In contrast, the part of the hydrophilic material that is covered with a water proof material, does not experience the same cooling. Instead, the water inside this part of the sensor has to first migrate towards the uncovered area, i.e. the lash.

In order to assess the robustness with respect to condensation the sensor was cooled in a climate chamber to a temperature below 0 degrees Celsius. Then it was removed from the climate chamber. The results for the conductance are shown in Figure 6. Immediately after the removal from the climate chamber condensation occurred on the surface. However, the resistance remained high and only started to decrease slightly after several minutes. The reason for this is that the hydrophilic material also absorbs some of the condensing water near the edge and also from the lash. However, the resistance remains significantly higher than for the experiment shown in Figure 4. As the resistance remains high in the condensation experiment, it can be expected that the probability of false alarms remains low.

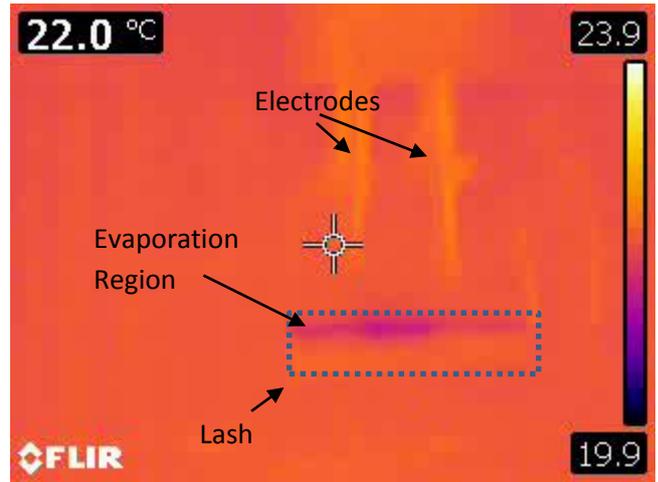


Fig. 5. Infrared thermography image as obtained during the drying/recovery of the detector. The temperature is fairly constant over the entire area. A lower temperature is only observed at the sensor lashes, close to the edge of the protective layer, the temperature is lower. This is due to the enthalpy of vaporization of water.

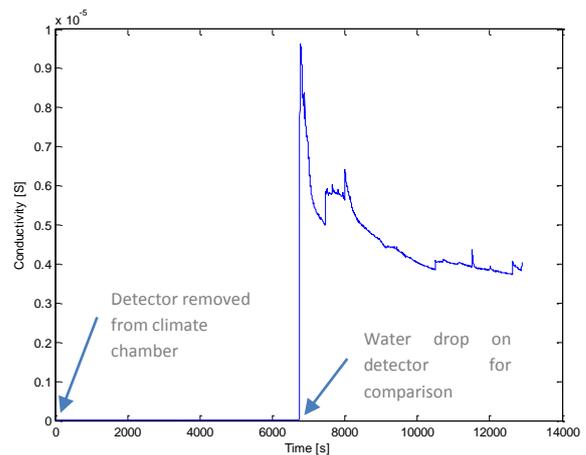


Fig. 6. Investigation on conductivity changes due to condensation. The detector is cooled in a climate chamber to below  $0^{\circ}\text{C}$  and then exposed to room temperature. The changes are orders of magnitude below the changes caused by a water drop.

Figure 7 illustrates how the poor thermal conductivity of the hydrophilic material contributes to the reduced sensitivity towards condensation. Besides the warm air, the enthalpy released during condensation of the water warms the surface. Consequently, the part that has a poor thermal conductivity attains a higher temperature. Assuming that the surface of the surrounding material will attain the dew point temperature, it can be assumed that the temperature of the sensor area will soon exceed the dew point and no more condensation takes place on the hydrophilic material.

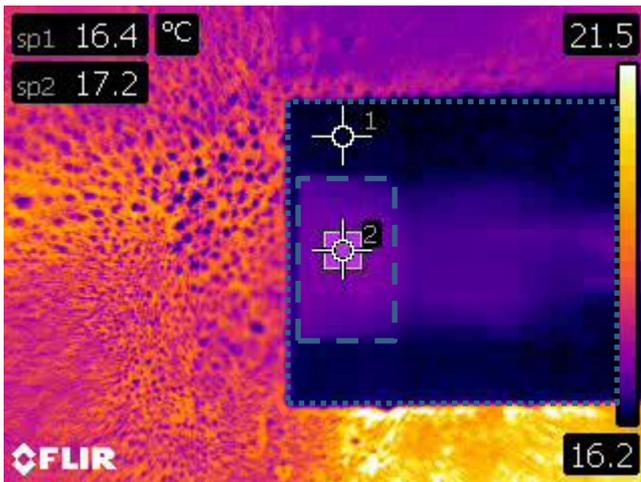


Fig. 7. Infrared thermography image as obtained during the condensation experiment. The detector (dotted rectangle) is placed on an aluminium carrier. Marker one is located on the lash of the detector. Due to the low thermal conductivity of the lash, the temperature on the lash is higher compared to the environment. Therefore, less condensation will occur. Please note that the temperature on the aluminium is not correct due to the high reflectivity.

#### 4. WIRELESS OPERATION

In order to use the sensor in a condition monitoring system, it needs to be combined with a wireless sensor node. Due to the simple evaluation of the sensor signal, many wireless node platforms may be used. For our laboratory demonstration we make use of the nRF51822 Evaluation Kit from Nordic Semiconductor [9]. A photograph of the setup, and a sketch of the circuitry are shown in Figure 8. Instead of measuring the impedance, the current across a shunt resistor is determined. Consequently, a drop of the resistance will lead to an increased current. Experimental results are shown in Figure 9. The addition of water to the sensor is clearly visible as an increase of the current. However, the absolute values still remain low, therefore the setup is perfectly suitable for low power wireless sensors.

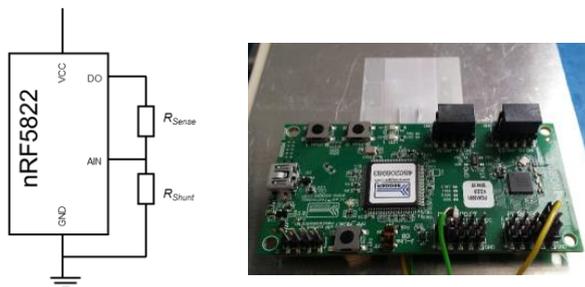


Figure 8. Left: Illustration of the connection of the sensor to a wireless sensor node, e.g. the nRF51822 evaluation kit. Right: Laboratory setup with a wireless sensor evaluation kit as used for the experimental result shown in Figure 9.

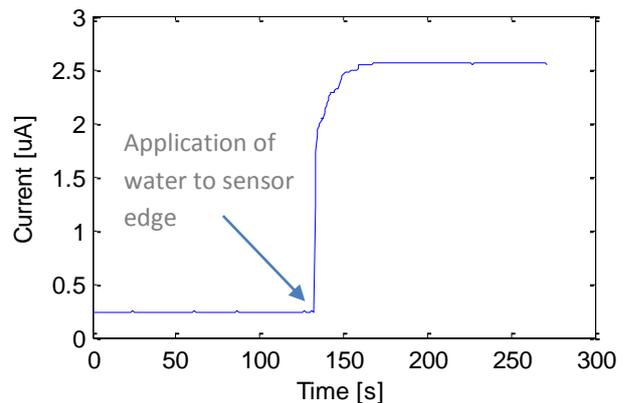


Figure 9. Example for the detection of water with a wireless sensor node in a laboratory prototype. After the application of a drop to the edge, the water gets absorbed and reaches the electrodes. The conductivity increases and attains the maximum when the entire layer is wet.

#### CONCLUSIONS

We present a resistive sensor for water intrusion and leakage detection. It is based on the change of the electrical impedance between electrodes that are embedded in hydrophilic material when this material becomes wet. In order to reduce the impact of condensing moisture, the hydrophilic material is partially covered by a waterproof material. Our experiments show that normal occurrence of condensation does not lead to an alarm whereas even small amounts of water intrusions are detected. Due to extreme impedance change and the high impedance in case that no water is present, the sensor requires very low power. Therefore, the device can be used for continuous monitoring of water intrusion, e.g. in wireless mobile electronic devices and for long term remote monitoring of various infrastructure.

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