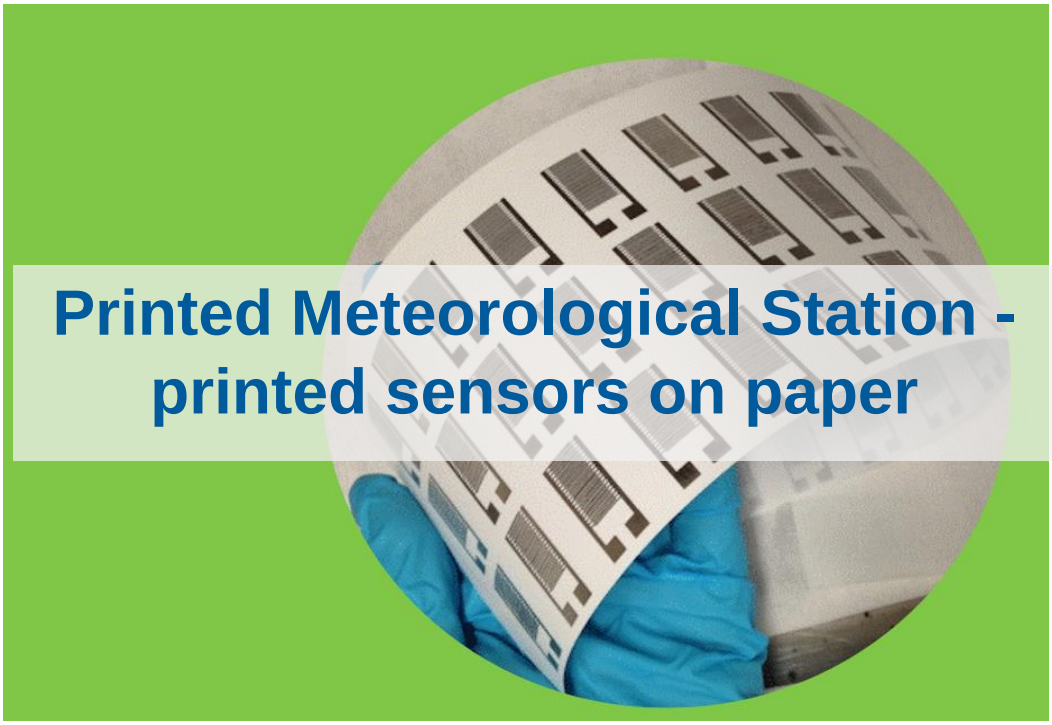
Teachers' Card



Printed Meteorological Station - printed sensors on paper

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General Introduction

The European Commission (EC) has recently established as a priority the commitment to tackle climate and environmental-related challenges – Green Deal. It defines the new growth strategy that aims to transform the European Union (EU) into a fair, sustainable and prosperous society, with a modern, resource-efficient and competitive economy. It is imperative to reinventing convectional technologies, namely high impact ones such as Information and Communication Technology (ICT) and make them more sustainable since small electronic devices already dominate the electronic waste generated nowadays.

Within this context, this is a laboratory activity where the students make their own printed sensors and perform a calibration curve so they can be used in a real context. It will give an idea of how sensors can be made and how generally a physical variation of temperature, relative humidity or UV can be indirectly determined by measuring the electrical resistance or current variation. Depending on the number of students, the "class" can be divided in several groups of three students or it can be performed in small groups of two-to-five so everyone can be able to print at least one of the layers required in this activity.

Keywords: *Sensor, temperature, humidity, UV, printed, cellulose*

Extended background information

The electronic waste, known as e-waste, is growing at a fast rate (3–4%). Just in 2016 44.7 million tonnes of e-waste were generated all over the world (Figure 1), which is equivalent to 4500 Eiffel Towers. This value is expected to reach 52.2 million tonnes by 2021. The materials present in e-waste in 2016, such as metals, ceramics, glass, and plastics have an estimated value of 55 billion Euro. Knowing that only around 15% is recycled [1], it is possible to get an idea of the value of the materials that are being wasted and not recovered. Thus, it is evident that there is an urgency to find sustainable solutions that can be implemented in some of the electronic systems in the future, envisioning a balance between well-being, environment, economy and societal acceptance [2]. Adopting a Circular Economy model will allow the increase in the value of electrical and electronic equipment's when wasted, inspiring to close the loop for these new raw materials by reusing and recycling. Business opportunities can be created around these materials and at the same time, the mitigation of environmental pollution [3]. The replacement of critical rare raw materials in modern technology with stable, cost-efficient, environmentally safe, earth-abundant alternatives is thus one of the central challenges facing humankind, being one of the priorities of the new Horizon Europe work program.

It seems clear that to fulfil the aims of the "Green Deal" of transforming the European Union (EU) into a fair, sustainable, and prosperous society, with a modern, resource-efficient and competitive economy, the development of new emerging technologies, such as those

supporting our "digitalized" society, cannot just focus on the performance/cost ratio. It will necessarily consider the technology's environmental impact and sustainability, which includes materials, processes and product end of life. When conceptualizing a circular economy, three fundamental principles must be considered: (i) eco-design out of waste and pollution, (ii) keep products and materials in use, (iii) regenerate natural systems. Thus, it seems evident that the future will consist of mixed and hybrid technologies, which represents a change in the actual paradigm of dominant technologies as it is the case of silicon integrated circuits (ICs) and related production techniques in the electronics industry. Although the electronic products become more and more energy-efficient when in use, it is not their power consumption that creates an energy imbalance, but the energy expended in the production phase and stored (embodied) in their internal constituents (i.e. microchips, processors, displays, etc).

Given this scenario, it seems evident that the same will happen in the electronics industry serving Information and Communication Technology (ICT). High-performance levels will continue to be satisfied by silicon ICs and other crystalline semiconductors. At the same time, some new devices and systems in the future, without the need for such high performance, will be covered by hybrid technologies and low-cost processes. This will be of particular interest for devices that are used for short periods and with low added value, such as biosensors, smart packaging, wearables, all of them serving the demands of the Internet of Things (IoT) concept. While ARM predicted that by 2035 one trillion IoT devices would be connected to the Internet , Global System for Mobile Communications association set a new lower estimate to 25 billion by 2025 . In any case, these numbers surpass considerably the current number of connected IoT devices, estimated in 7 Billion, which confirms the slower-than-expected progress of the technology required for its deployment. Several reasons can explain this, but for sure solutions to powering them, materials scarcity and management of e-waste generated by billions of devices, are some of the most challenging bottlenecks in achieving the future vision of IoT.

Key Competence European Framework

Literacy competence
S4. Ability to interact in an appropriate and creative way in any situation.
Multilingual competence
S4. Ability to interact in an appropriate and creative way in any situation.
S7. Ability to use technical language accordingly to the field of work.
Mathematical competence and competence in science, technology and engineering
S1. Ability to use constructed thinking in order to solve a problem in every situation.
S2. Understanding of mathematical term and concept and know how to apply it.

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S3. Ability to model mathematically a situation from the real world and to transfer mathematical expertise to non mathematical contexts.
S4. Readiness to address new problems from new areas.
S5. Capacity for quantitative thinking.
S6. Ability to extract qualitative information from quantitative data
S8. Ability to design experimental and observational studies and analyse data resulting from them.
Digital competence
S2. Basic skills in ICT
S3. Understanding the role, opportunity and risks related to ICT in everyday life.
S4. Ability to use and handle technological tools and machines
Personal, social and learning to learn competence
S3. Ability to gain process and assimilate new knowledge, skills and qualification required for career goals.
Citizen competence
S3. Ability to work effectively and collaborate with other team members
Cultural awareness and expression competence
S3. Ability to plan and manage tasks

United Nations' Sustainable Development Goals

The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice.

Please indicate which goal/s can be linked to this activity

	1 NO POVERTY, 2 ZERO HUNGER — Enable access to basic services		10 REDUCED INEQUALITIES — Equal access to global expertise
	3 GOOD HEALTH AND WELL-BEING — Safe medical devices	✓	11 SUSTAINABLE CITIES AND COMMUNITIES — Sustainable urbanization
	4 QUALITY EDUCATION — Access to education	✓	12 RESPONSIBLE CONSUMPTION AND PRODUCTION — Responsible consumption and production
	5 GENDER EQUALITY — Less hardship, more opportunities		13 CLIMATE ACTION — Strengthen resilience, reduce disaster impact
	6 CLEAN WATER AND SANITATION — Safe and affordable water		14 LIFE BELOW WATER — Reduce marine pollution

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	7 AFFORDABLE AND CLEAN ENERGY — Energy – the golden thread	✓	15 LIFE ON LAND — Sustainable use of terrestrial ecosystems
	8 DECENT WORK AND ECONOMIC GROWTH — Safety of workers and economic growth		16 PEACE, JUSTICE AND STRONG INSTITUTIONS — Promote peaceful and inclusive societies
✓	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE — Resilient infrastructure and sustainable industrialization	✓	17 PARTNERSHIPS FOR THE GOALS — Better access to technology and innovation

Contents – Theoretical principles

In this activity, students will get to know the basic transduction principal behind resistive temperature, relative humidity, and UV sensors. All sensors where prepared using conventional printing technologies and flexible substrates as paper and Kapton foil and functionalized inks. Conductive silver patterns where used to create a temperature sensor as electric resistance responds to temperature variations. A functional humidity sensitive films was specially created by using an ink formulated using cellulose as binding agent of chopped carbon fibers to create a film that responds to humidity variations by swelling and promoting/cancelling percolation paths and alter its electrical resistance. An ultraviolet (UV) light sensitive nanoparticle-based ink was formulated using cellulose as a binding agent of zinc oxide (ZnO) nanoparticles to create a film where the electrical resistance decreases when exposed to UV light because of a surface phenomenon of photogeneration of electron-holes pairs.

The printed temperature sensor consists in a sensitive layer made of silver and the operation principle is based on the characteristic increase of electrical resistance with temperature in metals. This is called the positive temperature coefficient (PTC), and it can be calculated using the following expression:

$$\alpha = \frac{\Delta R / R_0}{\Delta T}$$

where ΔR is the resistance variation, R_0 the initial resistance, and ΔT is the temperature variation.

The printed relative humidity sensor working principle is based on the absorption of moisture by the hygroscopic cellulose derivate present in the sensitive layer (the carboxymethyl cellulose, CMC). The sensitive layer in this case is a mixture of CMC and chopped carbon fibers randomly mixed in the cellulose matrix aiming to promote some electrical conductive paths whenever contact points between this fibers are established (percolation paths) While this matrix swells by absorbing humidity from the atmosphere, the percolation points decrease because the CMC matrix expands, pushing the fibers further apart, which translates in an increase of its electrical resistance. The opposite happens with the relative humidity decreases.

Finally, the printed UV sensor is based on the internal photoelectric effect in which an electron-hole pair is created due to the excitation of an electron from the valence band to the conduction band, provided by the absorption of a photon by the semiconductor. In this case the sensitive layer is made of zinc oxide (ZnO) nanoparticles that have a band gap above 3 eV, that is, in the ultraviolet region of the electromagnetic spectrum. Providing an electric field, the movement of the free charges starts and creates a current in the detector. The photosensitivity (p_s) of the sensor can be calculated using the following expression:

$$p_s = \frac{I_{ON}}{I_{OFF}}$$

where I_{ON} is the current under UV irradiation and I_{OFF} the current in the dark.

Lab Procedure/Activity

In this activity, students will learn the principle of electric resistance transduction while using temperature, relative humidity, and UV radiation sensors printed on flexible substrates, including paper.

Temperature Sensor

To observe the sensor response to temperature variations, begin by identifying the correct multimeter terminals and the sensor electrodes, by observing Figure 1 *and* Figure 2*. It is irrelevant whether you connect the red or black probes in the order indicated in* Figure 2*.*

- *Start by connecting the multimeter probes in the sensor terminals for resistance measuring mode.*
- *Measure and register the resistance value in the printed temperature sensor. Use the commercial/laboratory thermometer to register the ambient temperature.*
- *Put the printed temperature sensor on the outer side wall of the metallic container. You can use scotch-tape to fix it leaving the printing layers facing you.*
- *Read and register the resistance on the temperature sensor using the multimeter. Use the commercial thermometer to measure the temperature on the surface of the sensor. (Be careful to not damage the printed layer)*
- *Use the electric kettle to boil enough water to fill the container. Make sure you have enough water to reach a level that allow to heat the side walls.*

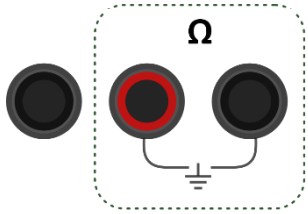

Figure 1

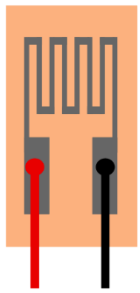

Figure 2

- *Wait a couple of minutes to allow the temperature in the side wall of the contained to stabilize.*
- *Read and register the resistance on the temperature sensor using the multimeter. Use the commercial thermometer to measure the temperature on the surface of the sensor. (Be careful to not damage the printed layer)*
- *Discard the warm water and now use the ice cubes and enough water for the temperature of the ice bath being as close to zero degrees celsius as possible.*
- *As before, wait some minutes for stabilizations of temperature before reading and registering the resistance at the temperature sensor.*

Humidity sensor

In this activity, switch the previously used probes in the multimeter to crocodile terminals. The sensors are inside zip bags to keep the initial humidity close to zero so make sure to only open the bags when you are ready to measure and register its initial resistance. Alternatively, place the sensors in a room where there is a low humidity level for at least some hours before performing this experiment.

- *Using scotch-tape, fixe the humidity sensor to the piece of glass, or the credit card (any rigid and thin small object will do) like shown in* Figure 3*. This will help when handling the sensor with the crocodile terminals attached.*
- *Place the crocodile terminals in the sensor and make sure there is a good electrical connection.*
- *Measure and register the resistance right away, as the sensor will readily absorb any humidity in the room and shift resistance values accordingly.*

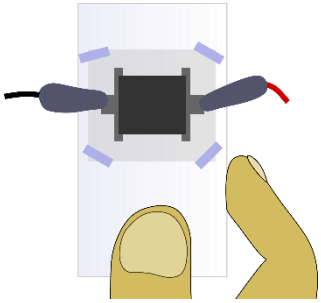

Figure 3

- *Prepare some steamy boiling water using the kettle and place the sensor facing the steam some minutes, while monitoring and registering the resistance value in the multimeter.*
- *You can either register the variation of the electrical resistance for a regular period of time (5 sec interval, for instance) of just wait some minutes until it eventually stabilizes.*

UV Sensor

To observe the sensor response to different UV variations/intensities, begin by again identifying the correct multimeter terminals and the sensor electrodes, by observing Figure 1 *and* Figure 2*.*

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- *Using scotch-tape, attach the UV sensor to the piece of glass, cardboard or credit card (any rigid and thin small object will do) like it is shown in* Figure 4*. This will help when handling the sensor with the crocodile terminals attached.*
- *Place the crocodile terminals in the sensor and make sure there is a good electrical connection.*
- *Measure and register the resistance values with the UV light OFF and then ON. Repeat it for some OFF/ON cycles (between 3 to 5), with a fixed time step of about 20/30 seconds if possible, registering the measured resistance values.*
- *Use a glass slide or a plastic ruler to reduce the distance between the UV sensor and the UV light source and measure the same way, decreasing each time the distance between the sensor and the UV light source*.*

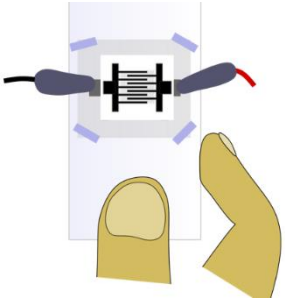

Figure 4

**- the UV light may be either a controllable one or a small circuit made of the 6V battery pack in series with the resistors and the UV LED. Please assure that you connect the UV LED with the right polarity. By changing the resistors will you change the current in the circuits, thus, the light intensity. In this case you do not need to change the distance to the source.*

Learning Pathway

Step 1- Time & Activity: i.e. 15 minutes: Teachers do a short introduction with a prepared PowerPoint presentation.

Step 2 – Time& Activity: i.e. 10 minutes: Students are divided into groups (preferably the number of students in one group is 3-4). The student become familiar with lab material.

Step 3 – Time& Activity 30 minutes: Each group characterize one of the sensors as it is described in previous section.

Step 4 – Time& Activity 45 minutes: Each group make data treatment and present it to the other groups.

Step 5 – Time& Activity 20 minutes: General discussion.

Evaluation

The evaluation will consist in the preparation of a PowerPoint presentation describing the experimental procedure, main results and data presentation, and discussion. The teacher must make a first assessment. Opinions from other students about the presentation made by each group should be also considered. The behaviour of the students during the lab work should be evaluated as well. Suggested weighing factors may be: interest and behaviour of the student during the work 30% (assessed by the teacher), presentation and data collection/treatment, 40% (assessed by the teacher), evaluation made by the other students 30%.

Description of Student's Cards

Student's Card 1 - Printed Meteorological Station - printed sensors on paper

Sources

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