IoT with a Soft Touch: A Modular Remote Sensing Platform for STE(A)M Applications

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Abstract—Besides wide attraction in industry, Internet of Things (IoT) is being used to advance Science, Technology, Engineering, (Arts) and Mathematics (STE(A)M) education across a range of education levels. This work presents a remote sensing platform, named IoT with a Soft Touch, developed to achieve two goals. First, it aims to lower the technicality, stimulating the students to do STE(A)M. Second, the technology is to be used in “softer” applications (e.g., environmental and health care), thereby aiming to attract a more diverse set of student profiles. Students can easily build a wireless sensing device, minding a specific application. The modular design of the platform and an intuitive graphical configurator tool allows them to tailor the device’s functionality to their needs. Unlike existing solutions, where integration is hard to achieve due to the combination of pre-made sensor nodes, our solution features full hardware and software integration. The sensor’s data, transmitted wirelessly through a long-range wide-area network (LoRaWAN), can be viewed and analyzed on a dashboard, or the raw data can be extracted for further processing, e.g., as part of the school’s STE(A)M curriculum. This work elaborates on the low-power and modular design challenges, and how the platform is used in education.

I. INTRODUCTION

The ROSE study [1] showed that pupils hold positive attitudes towards science and technology, but skepticism towards Science, Technology, Engineering, and Mathematics (STEM) is growing amongst youngsters, especially in the richest countries, such as Northern Europe and Japan. Furthermore, girls are more negative or ambivalent towards the role of science and technology in our society than boys. Especially in developed countries, youngsters are not enthusiastic about school science, do not believe that school science will advance their careers, or even think that school science has opened their eyes to new and exciting jobs. Large gender differences exist in the STEM topics that interest boys and girls: where boys are more attracted towards technical, mechanical, electrical topics and spectacular experiments, girls are mainly interested in health and medicine, the human body, ethics, and societally relevant topics. As studied in [2], to attract more girls/women to STEM, we need to increase the visibility of areas that are attractive to the female gender and build a welcoming environment to achieve a long-term change. This was one of the key principles behind the presented platform.

Internet of Things (IoT) provides new possibilities and opportunities to acquire a certain skill-set and knowledge, and therefore has a crucial role to play in education, as elaborated in [3], [4]. We designed an open-ended IoT STEM project according to integrated STEM instructional practices [5], especially incorporating problem-centered learning (PCL), integration between STEM disciplines (INT), modeling (MOD), and inquiry- and design-based learning (IBL and DBL).

In an effort to show the societal relevance of science and technology and to enhance their research skills, students are challenged to investigate an ecologically or societal relevant problem in their school environment with our plug-and-play IoT set (PCL). This paper will focus on the design and technical challenges when making the IoT set and platform (Fig. 1).

Sensor metrics (i.e., temperature, air pressure, air humidity, air quality, sound level, light intensity, and button presses) were selected such that students can study sound pollution and environmental conditions in their everyday surroundings. As societally relevant topics are more attractive to girls [2], we decided to study IoT sensor outputs relating to these type of problems in the daily (school) environment. This setting is likely more attractive to girls than investigating a company or industrial environment. With the environmental sensor that measures temperature, air quality and humidity, global challenges such as livable cities, heat island effect and climate change may be studied - albeit on a small scale. With the sound sensor, sound pollution may be investigated. By combining the two sensors, interactions between both may be investigated, e.g., the effect of warmer classroom environment on the noise level. Still, it was ensured that the selected sensor metrics related sufficiently to the curriculum learning goals defined by the Flemish government. The chosen IoT wireless communication technology, long-range wide-area network (LoRaWAN), poses important preconditions, such as...
maximum signal range, transmission frequency, etc. for the students’ chosen problem statement. Teachers can elaborate on mathematical topics ((statistical) data processing), technical topics (wireless communication, sensor technology), science topics (problem statement, sound vibrations and waves, resistive sensor technology) (INT). Based on their self-formulated research questions (IBL), students are encouraged to select the appropriate sensor metrics and configuration (DBL) and report appropriate conclusions after data collection and processing (IBL). The design team focused on designing and assembling IoT sensor modules and configuring the wireless communication link, as secondary school students generally do not have the necessary technical baggage.

In existing systems, such as [6], [7], integration is hard to achieve due to the use of pre-made sensor nodes. Either, processing and wireless communication is implemented on all sensor nodes, or sensors need to be connected in different ways, to the detriment of ease of use. Typically some sort of programming is still required to get the system operational.

We here below summarize the main contributions of this work.

- The embedding of a technical system in a secondary school Science, Technology, Engineering, (Arts) and Mathematics (STE(A)M) context, relating to Flemish curriculum guidelines and according to iSTEM instructional practices
- The ease of use the system provides, thanks to a configurator tool (no programming required) and modular, flexible design
- The upgradability and adaptability of the system
- We explain the challenges in the design of a modular and low-power platform

The remainder of the paper is structured as follows. First, an overview of the full IWAST system is given, and the individual components are elaborated. In Section III, we describe the approaches taken to increase the autonomy of the remote sensing modular platform. Two applications studied by the students are described in Section IV. The conclusions and the future work are presented in Section V.

II. IWAST PLATFORM

The presented IoT With a Soft Touch (IWAST) platform consists of both hardware modules and supporting software packages. This is illustrated in Fig. 2. The hardware platform consists of several hexagon-shaped boards. The central board, is the dedicated main controller, i.e., the motherboard. The other hexagon-shaped boards (the sensor boards) can be connected to all faces of the motherboard. The motherboard reads all connected sensors and wirelessly connects to the cloud. The internal processing of an IWAST set can be adjusted to a specific use case via the dedicated configurator on a computer via USB. There, depending on the connected sensor boards, different parameters can be configured. For example, only when a sensor value drops below or exceeds a certain level (i.e., threshold), the sensor value will be transmitted. In contrast, the sensor module can be requested to read out its sensor(s) at specific intervals. The choice between these distinct measuring operations, i.e., polling- and threshold-based measuring, has a large impact on the energy consumption, which is discussed in Section III.

After the configuration stage, the sensor measurements are sent wirelessly over LoRaWAN via The Things Network. On our cloud platform, all measurements are stored in a local database and can be accessed through our IWAST dashboard. There, students have a clear overview of all sensor data. In addition, the raw sensor measurements can be downloaded for further offline processing. In what follows, the different components in the IWAST system are elaborated in more detail.

A. Motherboard

The IWAST motherboard, the central controller of an IWAST set, automatically discovers and connects to all connected sensor boards. The motherboard features a built-in USB connection, which makes for easy communication with our accompanying configuration software. There, all use case parameters (e.g., polling interval, thresholds) can be configured. The motherboard is equipped with a LoRaWAN radio to connect a IWAST set to the cloud. The motherboard can be powered from either the computer’s USB connection or by the power sensor board featuring an internal battery.

B. Sensor Boards

A distinction is made between the sensor, the sensor board, and the sensor metric. A sensor board comprises one or more sensors, which in turn collects one or more sensor metrics. To give an example, the environmental sensor board features one sensor, measuring several sensor metrics e.g., atmospheric pressure, temperature, and relative humidity. Currently, four different sensor boards have been developed: a) an environmental sensor, b) a microphone sensor, c) a button sensor, and d) a power module. The environmental sensor board accurately measures parameters regarding the environment: i) temperature, ii) air pressure, iii) indoor air quality (IAQ) index and iv) relative (air) humidity. The IAQ index is determined based on both the current measured and
previous sensor values. It indicates or quantifies the quality of the air available in the surrounding. The microphone sensor board measures the audio level of the surroundings using a microphone by collecting a 20 ms audio recording. The button sensor board hosts four buttons with four accompanying LEDs. When a button is pressed, all buttons will briefly light up. The motherboard and sensor boards can be powered through the power module board. It integrates a battery with an ambient light energy harvester. Next to this, it also hosts a light sensor, measuring the light level of the surroundings. If for any reason the battery gets drained, there is still a possibility to charge the battery using the micro-USB port.

C. Dashboard

Students can log in on the dashboard1 with their unique session name. The displayed sensor data can be selected from different periods, i.e., day, week, month, year, all. The dashboard includes a graph for each type of sensor metric. Each motherboard has a distinct coloring, to conveniently see the sensor values originating from the same motherboard.

III. MODULAR AND LOW-POWER DESIGN

The boards are designed taking good practice [8] in mind to keep the energy consumption low. All IWAST documentation and source code files (hardware and firmware) are open-source and available online2. The power consumption of the separate sensor boards is summarized in Table I and presented in more detail in Fig. 4. A thorough overview of the system is presented in Fig. 3. Fig. 5 shows some demo measurements from the sensors.

A. Motherboard

To lower the technical skills required to build a wireless sensing device, we have designed the motherboard in a modular and versatile way. The motherboard consists of a central ATSAMD21G18 microcontroller paired with an RN2483a radio for data transmission. Sensor boards can be plugged into each of the six sides of the IWAST motherboard. To standardize the communication between motherboard and sensor board, an I2C bus interface is used, implemented with one custom command set across all sensor boards.3 By decoupling the motherboard from the sensor-specific communication, we provide a future-oriented interface, allowing a possible extension. To that end, each sensor board features a microcontroller, which handles on-board sensor configuration, readings, and communication with the motherboard. As such, it acts as a bridge between the I2C communication with the motherboard and any sensor-specific interface, e.g., analog, SPI, etc.

To define the desired behavior for a specific set, i.e., a motherboard with its connected sensors, the motherboard can be connected via USB to a PC and configured using a custom configurator tool. The motherboard starts with notifying the configurator of its connected sensors. The behavior for each sensor can be configured separately. For example, using the configurator, we can decide that a first sensor should be read every 5 minutes, while a second sensor will only notify the motherboard if its readings are above a certain threshold. All these settings, along with communication-specific settings, e.g., security keys, are stored in the motherboard’s non-volatile memory.

When a motherboard is powered (or on reset), it will wait for 30 seconds for a USB connection. After that, it will configure its connected sensors according to the configuration stored in its non-volatile memory. After that, it enters a low-power state.

During low-power operation (sleep), the motherboard will periodically wake up and poll sensors for readings based on the configured poll interval and go back to sleep. Whenever a sensor board has data ready, either because a configured threshold is exceeded or because it has been polled earlier, it notifies the motherboard using its dedicated interrupt line. This interrupt will wake up the motherboard, after which it reads the sensor’s readings and relays them to the radio for transmission. Then it’s nap time again.

Footnotes:
1 dramco.be/projects/iwast/platform
2 github.com/dramco-iwast
3 The sensor command set is described in dramco-iwast.github.io/docs.
4 LoRaWAN transmission of (typical) accumulated 36 byte data packet using Spreading Factor 11
Fig. 4: Current consumption of the IWAST system with all sensors connected: a LoRaWAN transmission by the motherboard, an air quality measurement, a sound level measurement, and a threshold-based light/battery level measurement. Note the different x-axis scale between measurements.

![Current consumption graph](image)

(a) Temperature output from the air quality module

(b) Sound level output from the sound module

Fig. 5: Data output example of the IWAST system: temperature measurements over the course of several days and sound level monitoring in a school environment shows clear periods of activity. Extracted from dramco.be/projects/iwast/platform/ of the set "Bart the Genius".

| Sensor Module      | Active       | Inactive | Sleep |
|--------------------|--------------|----------|-------|
| Motherboard        | Current      | Time (ms)|       |
| Environmental      | 25400        | 7000     | 55    |
| Microphone         | 4000         | 500      | 25    |
| Button             | 7300         | 2000     | 0.330 |
| Power/Light        | 4000         | 28       | 3.2   |

TABLE I: Power consumption of the sensor modules and motherboard in μA at 3.3 V.

B. Environmental Sensor

The air quality sensor board is equipped with a Bosh BME680 sensor, accompanied by an ST STM32L072KZ microcontroller. This controller is running the Bosch Software Environmental Cluster (BSEC) supported firmware, running a proprietary algorithm to obtain a calibrated IAQ value. In essence, this output is an index that can have values between 0 and 500 with a resolution of 1 to indicate or quantify the quality of the air available in the surrounding.

To minimize power consumption, it always runs in a low power state, in which a measurement will only be taken every 5 minutes (Ultra Low Power (ULP) cycle). When needed, the motherboard can request extra measurements in between this 5-minute ULP cycle. Further intelligence is implemented in the firmware to minimize the number of measurements, thus also minimizing power consumption. For example, when the motherboard manually requests a measurement close to an ULP cycle, this value is used instead of starting an extra measurement. When no measurement is going on, the sensor is put to sleep, consuming 1 μA. The on-board controller remains active, however: consuming 1.06 mA, which could be further reduced by letting the on-board controller sleep between the BSEC cycles. When sensing, the majority of the consumed power can be attributed to the inherent workings of the gas sensor. This involves two steps:

1) Heating the gas sensor hot plate to a target temperature (typically between 200 °C and 400 °C) and maintaining this temperature for a certain duration of time. This consumes 14 mA for a duration of 1.71 s.

2) Measuring the resistance of the gas-sensitive layer, yielding a consumption of 1.57 mA for a duration of 1.85 s.

C. Microphone Sensor

The used Vesper VM1010 microelectromechanical systems (MEMS) microphone features extremely low active mode current, and includes an efficient sleep mode function. The
A single cell lithium polymer (LiPo) battery with a capacity integrated light sensor. storage, a small solar panel for energy harvesting, and an module. This sensor module includes a battery for energy The IW AST system is energy provisioned by the power measurements from the sound and environmental sensor. last period. These measures may be correlated to the objective last period or indicating the air quality experienced during the restaurant meal, indicating how noisy the class was during the sound level, assuming a class to be noisier and less attentive [11]). Furthermore, pupils also plan to investigate the relation between classroom air quality with sound level, assuming a class to be noisier and less attentive when air quality is worse. Again, these measurements may be supplemented with subjective data on noise levels/pollution measured with interrupt-based IoT sensing compare to the sound level measured with a sound level meter?”, and ‘Which class visiting a classroom is the noisiest (and thus likely the least attentive [11])?’. Furthermore, pupils also plan to investigate the relation between classroom air quality with sound level, assuming a class to be noisier and less attentive when air quality is worse. Again, these measurements may be supplemented with subjective data on noise levels/pollution collected via the button sensor.

D. Button Sensor
The button-sensor works completely interrupt-based and is always in sleep. Sleep current is below 1 µA. On a button press, the device becomes active for 1.7 s with an average current consumption of 7.3 mA. The button sensor may be used to collect subjective data from pupils, e.g., scoring the restaurant meal, indicating how noisy the class was during the last period or indicating the air quality experienced during the last period. These measures may be correlated to the objective measurements from the sound and environmental sensor.

E. Power Module
The IWAST system is energy provisioned by the power module. This sensor module includes a battery for energy storage, a small solar panel for energy harvesting, and an integrated light sensor. A single cell lithium polymer (LiPo) battery with a capacity of 500 mAh battery is included in the power module. This battery can be charged by USB and trickle charged through solar energy harvesting. To make the power module energy efficient, the onboard ADC and voltage divider for measuring the battery voltage is only enabled sporadically. A Panasonic AM-5412 amorphous solar panel enables solar energy harvesting. Combined with a nano power boost charger and buck converter chip (Texas Instruments BQ25570), we are able to efficiently extract microwatts to milliwatts of power generated from the photovoltaic cells.

The power module is equipped with a high accuracy and low power ambient light sensor: the Vishay VEML7700 (consuming only 6.6 µW). Unfortunately, this sensor does not feature any built-in threshold detection, so a sporadic polling technique is implemented: briefly waking up the system every 16 s, checking the last value of the light sensor and comparing it against the threshold value.

IV. IWAST IN THE WILD

A. Ventilation requirements during Covid-19
The IWAST system was used to evaluate the air quality in classrooms [9], especially during the Covid pandemic. Not only was regular ventilation imposed by the government, also there exists a relationship between the air quality and the Covid-19 deaths [10]. Therefore, measuring the IAQ index is imperative for public health. These measurements may be supplemented with subjective data collected via the button sensor.

B. Noise Levels in the Classroom, Restaurant, and Playground
Pupils used the IWAST system to measure sound levels in their classroom and playground, with research questions such as ‘What is the difference in sound level between the front and the back of the classroom?’, ‘How does the sound level measured with interrupt-based IoT sensing compare to the sound level measured with a sound level meter?’; and ‘Which class visiting a classroom is the noisiest (and thus likely the least attentive [11])?’. Furthermore, pupils also plan to investigate the relation between classroom air quality with sound level, assuming a class to be noisier and less attentive when air quality is worse. Again, these measurements may be supplemented with subjective data on noise levels/pollution collected via the button sensor.

V. CONCLUSIONS AND FUTURE WORK
This paper describes the design of a modular remote sensing platform for STE(A)M applications, called IoT With a Soft Touch. This IoT platform is developed to i) stimulate students to do STE(A)M by lowering the technicality and ii) targeting ‘softer’ applications (e.g., environmental and health care). The system comprises a motherboard and some sensor boards. Next to an elaboration of the IWAST system, we explain how we addressed the challenges related to the design of a modular and low-power platform. The modularity and flexibility of the system are obtained by using hexagon-shaped boards, allowing to connect a sensor to all faces of the motherboard. Moreover, the use of dedicated microcontrollers on the sensor boards decouples the inner-workings of the sensors from
the motherboard, making it easily extendable. The platform employs strategies such as sleep-modes and interrupt-based communication to extend the battery lifetime as much as possible. Based on the evaluation and the needs of the schools, we pursue to further extend the set of different sensor boards. In addition, the concepts to improve the energy efficiency of these systems will be made more clear towards the pupils. For instance, we will include a power report to illustrate the effect on the energy consumption based on the configured parameters.

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