Advancement of Community Weather Information Network through the Use of Low-cost Automatic Weather Station

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Abstract

The emergence of open-source electronics platforms in recent years such as Arduino microcontroller boards and mini-size measurement sensors as well as the advance of wireless communication technology provide favourable opportunities for the development of low-cost automatic weather stations. Riding on the above technological trends, the Hong Kong Observatory (HKO) develops and promotes the use of Arduino-based automatic weather stations (AB-AWS) with a view to further enhancing the existing Community Weather Information Network (Co-WIN) providing real-time community weather information to meet the needs of the Big-Data era.

The AB-AWS is of modular design with simple architecture. It has the advantages of high portability and high operational flexibility. Different sensors can be connected to the AB-AWS to provide measurements of air temperature, rainfall, relative humidity and air pressure, etc. Other sensors for measuring air quality say PM_{10}, NO_x, SO_x, CO, CO_2, etc. as well as gamma radiation can also be installed. 3D printing technology is used to fabricate the necessary components such as temperature radiation shield in carrying out the installation works.

This paper summaries the experience of HKO in developing its next generation of Co-WIN, viz. Co-WIN 2.0, through the implementation of AB-AWS. One of the objectives of Co-WIN 2.0 is to deploy a large number of AB-AWS to the field so that more weather data can be collected through this crowdsourcing mechanism for various applications. Training workshops were organized for local schools and organizations to train teachers and students how to fabricate an AB-AWS via a Do-It-Yourself (DIY) approach. The challenges and difficulties during the implementation are also discussed.

1. Introduction

With the advancement in miniaturization of electronic devices and the popularity of Internet-of-things (IoT) in recent years, small smart devices with network connectivity can be more easily developed to facilitate collection and exchange of data on a real-time basis. For weather observations, the emergence of open-source software and hardware platforms, such as Arduino microcontroller boards and mini-size measurement sensors as well as wireless communication modules provide favourable opportunities for the development of low-cost automatic weather stations (AWS) with reasonable accuracy. Riding on the above technological trends, the Hong Kong Observatory (HKO), in recent years, develops and promotes the use of low-cost Arduino-based automatic weather stations (AB-AWS) with a view to further enhancing the existing Community Weather Information Network (Co-WIN) to provide real-time community weather information to meet the needs of the Big-Data era. The HKO also takes the opportunity to expand the network through the development of low power, miniature AWS which can be installed more easily in parks and along the streets, as well as being portable for carrying out field surveys to gather useful weather data for the public.

2. Community Weather Information Network (Co-WIN)

The Community Weather Information Network (Co-WIN) was first launched in 2007 (Lee et al., 2012; Tam & Ong, 2012). It is now a joint collaboration project between HKO, the Hong Kong Polytechnic University (PolyU) and the Chinese University of Hong Kong (CUHK). Co-WIN encourages schools and community groups to install and operate AWS at their own premises, with professional advice and assistance from HKO, PolyU and CUHK. The prime objective of Co-WIN is that members of the community can learn more about weather and climate change through their participation in making weather observations and analysing the collected data. The data gathered via Co-WIN are shared with the public in real-time on its website (http://cowin.cse.cuhk.edu.hk/) (Figure1), which serves as a supplement to the official data provided by the HKO for enhancing the spatial coverage of weather data in Hong Kong.

The existing Co-WIN AWS are off-the-shelf products with a tailor-made software developed jointly by HKO and PolyU to ensure data synchronization, integrity of AWS system settings and standardizing the AWS data format before transmission. Weather elements measured include air temperature, relative humidity, wind direction and speed, air pressure and rainfall amount, while some members also install additional sensors for measuring solar radiation and ultraviolet radiation. As of the end of September 2017, Co-WIN has recruited 160 members, most of which are primary and secondary schools, while the remaining include elderly centre, the Scout Association of Hong Kong, and other organizations.

3. The Next Generation of Co-WIN - Co-WIN 2.0

3.1 The Need for Implementing Co-WIN 2.0

The existing Co-WIN AWS are essentially proprietary systems and the data gathered via the sensors are encrypted and can only be displayed on a dedicated software running on a PC. Though it can output files with known data format, little can be done to further improve or expand the existing AWS. Moreover, the prices of the hardware components are not particularly low when compared with the emerging smart devices nowadays. Hence, the overall implementation and maintenance cost of an existing Co-WIN AWS is not low which hinders its sustainability and expandability.

On the other hand, the emerging open-source Arduino microcontroller boards, commonly used worldwide for educational purposes, and mini-size measurement sensors as well as wireless communication modules provide favourable opportunities for the development of low-cost and low power automatic weather stations (AWS) with reasonable accuracy. Furthermore, the modular design of the Arduino-based electronics platform makes it easy for training Co-WIN members to pick up the technology and hardware maintenance via a Do-It-Yourself (DIY) approach, the strategy of which also ties in with the worldwide education policy under the theme STEM in enhancing students' competitiveness in science and technology development.

3.2 Basic Requirements and Components of Co-WIN 2.0 AWS

In developing a new generation AWS for implementing Co-WIN 2.0, the following basic requirements have been drawn out:

(1) It should be built on an open-source electronics platform;
(2) It should be modular in design with easy-to-use hardware and software;
(3) The hardware platform, including weather measurement sensors, should be readily available from various sources on the market;
(4) The hardware components should be customizable and expandable by users; and
(5) There is no need for an operating system (so as to minimize power consumption).

One of the prime concerns in implementing the new generation AWS is cost effective. The hardware modules should be easy to integrate and program. The popular Arduino microcontroller boards are therefore the best choice to be the core for the AWS, and the Arduino UNO, which is the most widely used variant of the Arduino microcontroller series, has thus been chosen for development of a prototype of the new generation Co-WIN AWS. Even low in cost, the Arduino UNO has 14 digital input/output ports and 6 analogue input ports coupled with a small size factor which are sufficient for the development of the new Co-WIN 2.0 AWS (Figure 2).

Program development for the Arduino UNO can be easily done through the open-source software named Arduino Integrated Development Environment (IDE) which is freely available with Windows, MAC and Linux versions (Figure 3 shows a sample display of the Arduino IDE). The IDE can be used with all the variants of the Arduino family of microcontrollers and many other Arduino compatible microcontroller boards are also available on the market.

Based on the above considerations, an Arduino-based AWS (AB-AWS) has been developed. Figure 4 shows the schematic diagram of a basic AB-AWS which uses the Arduino UNO microcontroller as the core of the AWS. Each component of the AB-AWS is an independent module or modular in design, having a communication interface through which the Arduino UNO can receive measurement results from sensors and output data for display, storage or transmission purposes. For most of the hardware components, a library of interface programs is freely available from suppliers to facilitate users to integrate the hardware with the Arduino UNO. Typically, the various hardware modules would require a power of 5V or 3.3V from the Arduino or from a separate external power supply. Interfacing these hardware modules with Arduino UNO can be done using either one wire master-slave digital communication protocol or more complicated intra-board communication method such as the I^2C multi-master multi-slave communication protocol.

3.3 Selection of Sensors

The selection of the type or model of sensors would be application dependent. Besides, the cost of the sensor, its robustness as well as the sensor accuracy to meet the specific measurement requirement should also need to be considered. Readily available sensors and their related interface modules on the market can keep the production costs of the AB-AWS to a minimum as well as ensuring its sustainability.

Sensor modules that are self-contained with built-in hardware interface and power regulation are essentially chosen (Figure 5). Typically, each sensor module would require the power input from the Arduino and interface through digital, analog, or serial communication protocols. Vendor provided software libraries or from a generic open-source library would allow easier integration.

4. Implementation of the Co-WIN 2.0 AWS

4.1 Prototype of Co-WIN 2.0 AWS

A prototype of Co-WIN 2.0 AWS has been developed for installation at Co-WIN member sites or at the field. At present, AB-AWS designed for permanent installation essentially consists of sensors for measuring the basic weather elements such as temperature, relative humidity, air pressure and rainfall amount. Figure 6 shows a typical AB-AWS installed in the field. The following sensor modules together with their claimed measurement parameters are shown below:

(1) Temperature and Relative Humidity sensor (Model: DHT22)
Temperature measurement range and accuracy: -40°C to 125°C, ±0.5°C
Relative Humidity measurement range and accuracy: 0% to 100%, ±5%

(2) Pressure sensor (Model: BMP280):
Pressure measurement range: 300hPa to 1100hPa, ±1 hPa

For rainfall measurement, a specially designed circuit has been built which can accept off-the-shelf tipping bucket raingauges, if required.

Although weather data gathered by the AB-AWS can be stored locally using a SD card module connected to the Arduino UNO, real-time data transmission, in particular via wireless means, is also necessary in order to share the data on the Co-WIN website for public consumption. For wireless data transmission, Arduino compatible modem modules exist with a variety of connectivity, such as GSM/GPRS, 4G, and bluetooth but these modules inherently need higher power requirements and they are also more difficult to program. On the other hand, Radio frequency (RF) transceiver (transmitter and receiver) units can be considered where power is scarce at the measurement site. RF connectivity from the AB-AWS measurement site to a nearby base station that has internet connectivity would provide a good alternative to the high-powered modem module at the site, but it requires the establishment of a base station which is usually installed indoors or at a sheltered place. At present, the prototype Co-WIN 2.0 AWS has been developed using a pair of RF transmitter and receiver units. Figure 7 shows the wireless communication modules that are available for use in transmitting data gathered by the Arduino UNO.

4.2 Use of 3D printing technology

During the initial stage in developing a prototype for the Co-WIN 2.0 AWS, off-the-shelf accessories have been used for housing and making electrical connections for the AB-AWS. Some accessories of the AB-AWS, in particular the radiation shield, are difficult to be sourced given the special geometry of the parts required and their suitability when used outdoors. With the increasing popularity of 3D printing technology in schools and tertiary institutes, use of 3D designs for prototyping parts and enclosures for the AB-AWS has been explored. Prototypes for the radiation shield have been successfully developed, printed and tested for their suitability. However, the materials commonly used in the 3D printing process, in particular the polylactic acid (PLA) thermoplastics are bio-degradable due to their origin from renewable sources such as corn starch. Nevertheless, short term tests have shown that they can resist UV and direct sunlight quite well before any noticeable degradation. Since coloured PLA materials would see colour fading quickly, white PLA is generally selected in subsequent 3D models and products for the AB-AWS. Figure 8 shows typical models developed for the AB-AWS using 3D printing.

4.3 Promotion of Co-WIN 2.0 AWS Through Training Workshops

To tie in with the world-wide education policy under the theme STEM in enhancing students' competitiveness in science and technology development, a 'Train-the-trainer' and 'Do-It-Yourself' (DIY) approach have been used to introduce Co-WIN members to familiarize themselves with the AB-AWS. Training workshops have been organized for local schools and organizations to train teachers and secondary school students on the Arduino UNO architecture and the basic concept of building an AWS. Each workshop covered topics from basic sensor principles, interfacing techniques, programming as well as sensor siting and measurement limitations. Calibration of the sensors, including in-situ comparison with calibrated units, was also described. Since the modular design of the Arduino-based electronics platform makes it easy for the participants to pick up the technology, feedbacks from teachers and students via hands-on experience with building an AB-AWS were positive and encouraging (Figure 9).

5. Discussion

Although an Arduino UNO proves to be a very useful platform in quickly building up an AWS, there are still limitations in the microcontroller board which would affect the design and implementation of the AWS. Firstly, with only 32kB of actual programmable memory, the Arduino UNO can only be employed for simple setup to handle a limited number of sensors. Secondly, Arduino UNO has a limited number of input/output ports which in turn limits the number of sensors that can be used. One solution is through the use of the I^2C communication protocol which, using a master-slave approach, can then support a large number of I^2C devices at the same time (Figure 10). Thirdly, although Arduino UNO can power external modules through its on-board regulators, it can only supply up to 500 mA current in total. Further power requirements would need external power supply. Fourthly, the Arduino has limited serial input/output ports which poses some issues when using GPS modules for location finding, serial data connectivity, and storing data onto SD cards or flash drives. Lastly, the Arduino UNO also does not have a real time clock (RTC) which is important to identify data to certain time and place when the unit is deployed for mobile use in conjunction with a GPS module. Notwithstanding the above, some or many of these problems can be overcome through the use of external modules such as the GPS and RTC, or using Arduino-like modules that have more onboard memories, multiple serial UART or software controlled ports that mimic a USART port, GPS, RTC.

6. Future work and Conclusion

Further work is required for implementing a wind sensor and a raingauge module for measuring more weather elements. Issues such as cost, readiness, accuracy, etc of different sensors should have to be tackled. Besides, equipment housing should be further improved to safeguard from severe weather. The use of better sensors, such as miniature PT100 platinum resistance thermometer, would also be explored.

Despite some limiting factors of the Arduino, its small footprint in size and lack of an OS allows it to be useful in developing small devices or incorporating novel designs. Integration into smaller packages, especially with IoT applications, and coupling with a modular approach, AB-AWS can be used to produce an AWS that can approach the usability and reliability of an ordinary AWS.

With the experience gained through the implementation of the AB-AWS, the HKO is developing new prototypes of miniature and low power smart weather sensors for urban weather monitoring (Figure 11). This also ties in with the growing emphasis on smart city development where urban weather and environmental information can be made readily available for public consumption.

7. Acknowledgements

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8. References

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Figure 1 Map showing the temperature data of Co-WIN AWSs in Hong Kong. Inserted figure on the lower right shows an existing Co-WIN AWS installed on the rooftop of a local school.

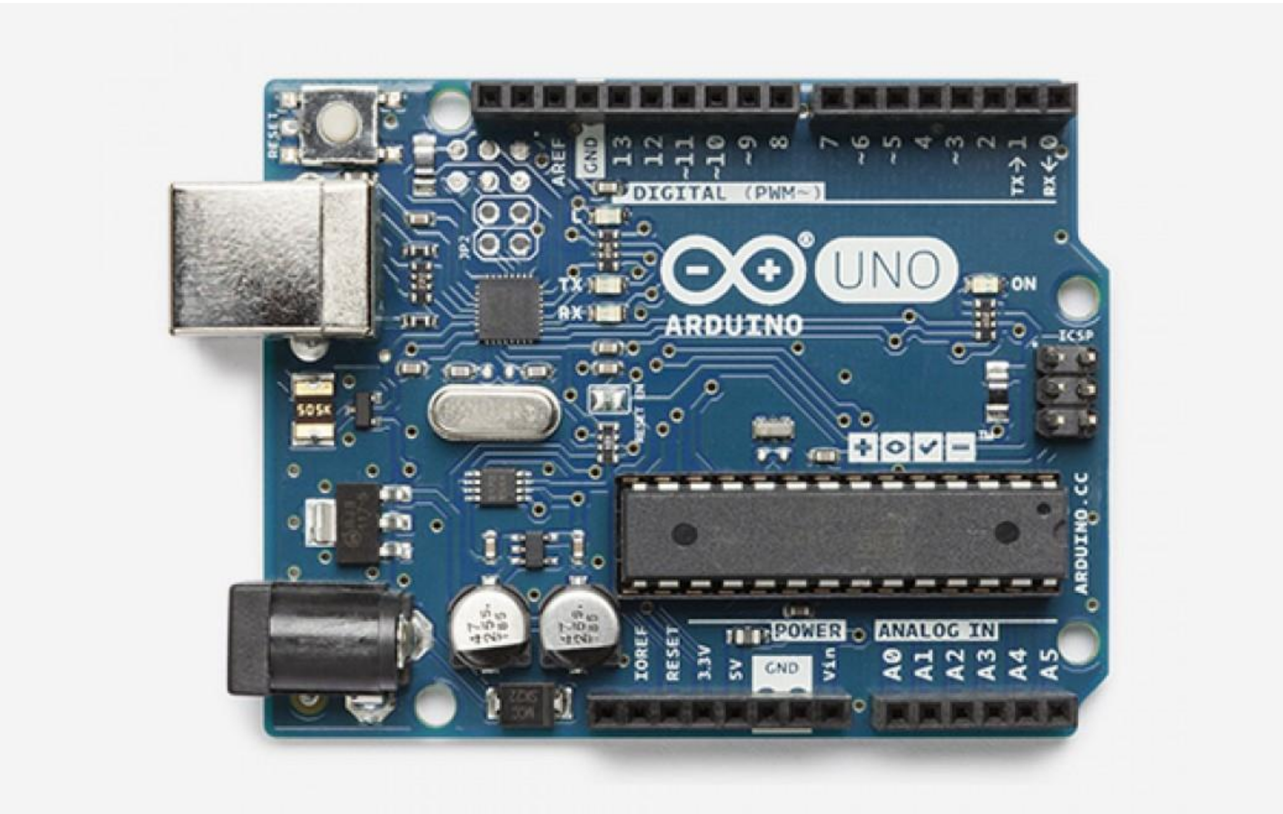

Figure 2 The Arduino UNO microcontroller board used as the core of the new Co-WIN 2.0 AWS

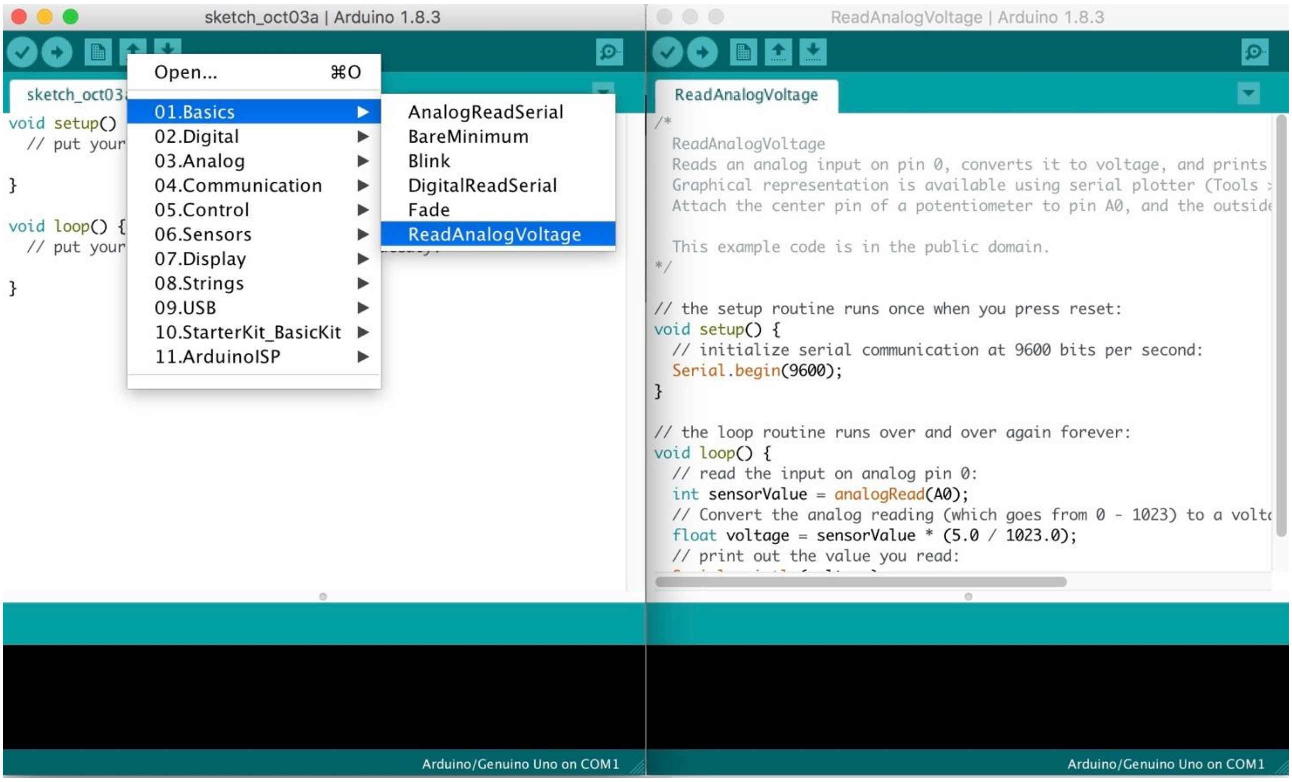

Figure 3 Sample display of the Arduino IDE. Library programs are readily available for interfacing the hardware modules to the Arduino UNO microcontroller board (see sample codes on the right)

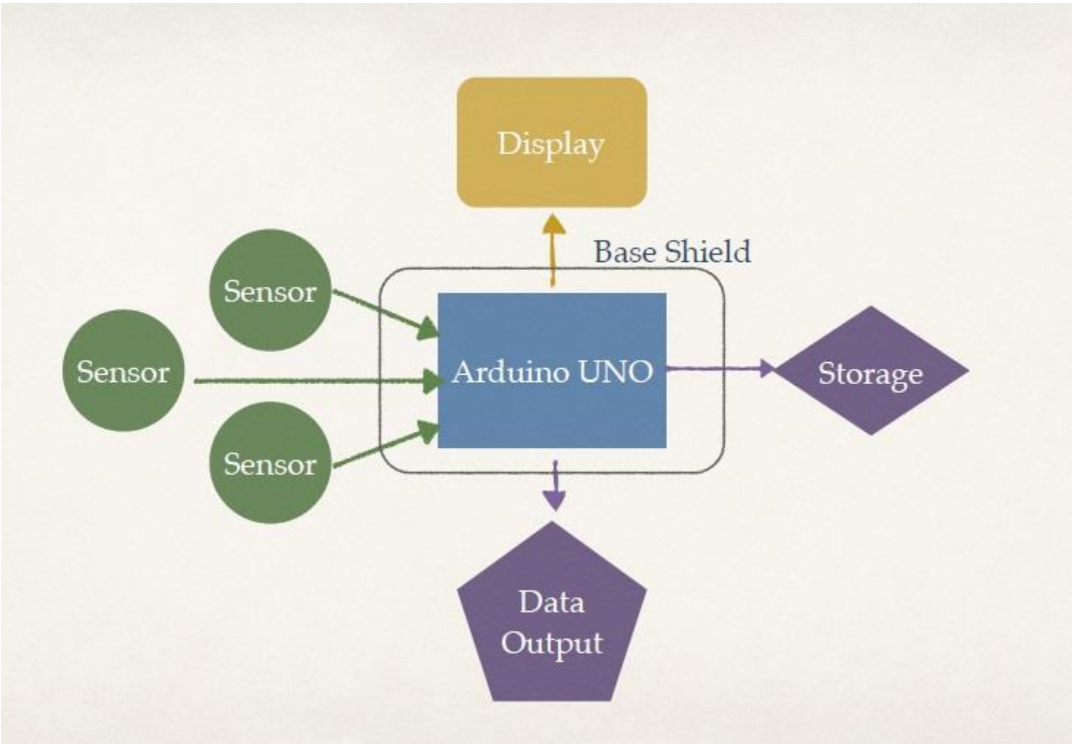

Figure 4 Schematic diagram of a basic AB-AWS

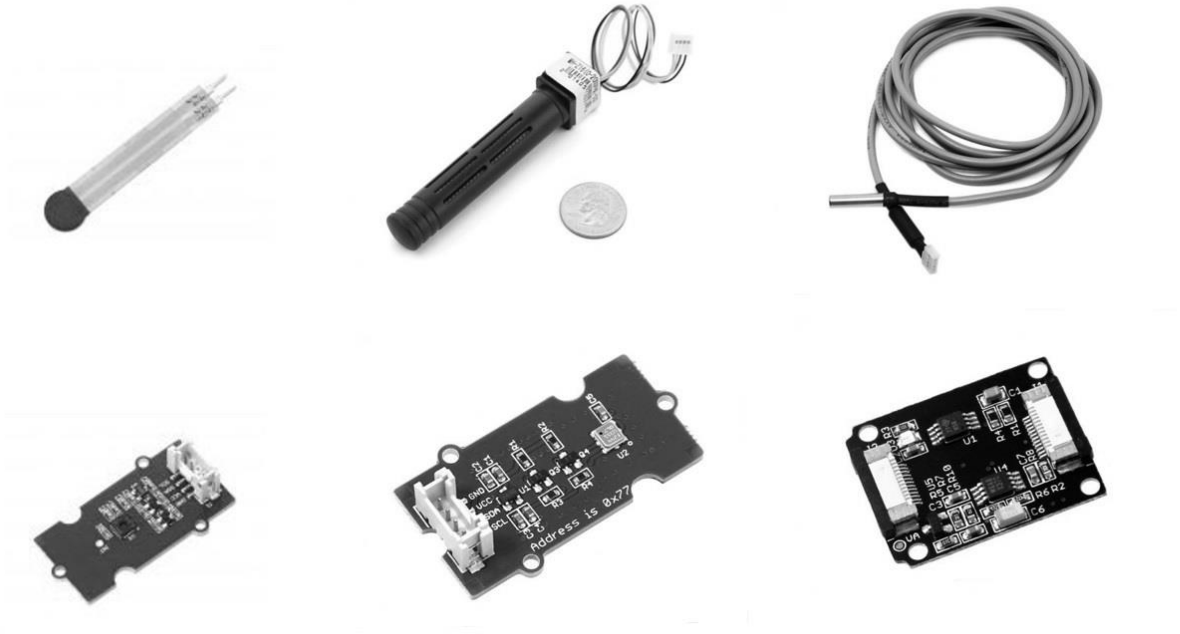

Figure 5 Examples of stand-alone sensors and sensor modules available on the market that are compatible with Arduino microcontroller boards.

Figure 6 The prototype of a new generation Co-WIN 2.0 AWS installed in the field. Power is provided using batteries charged by a solar panel.

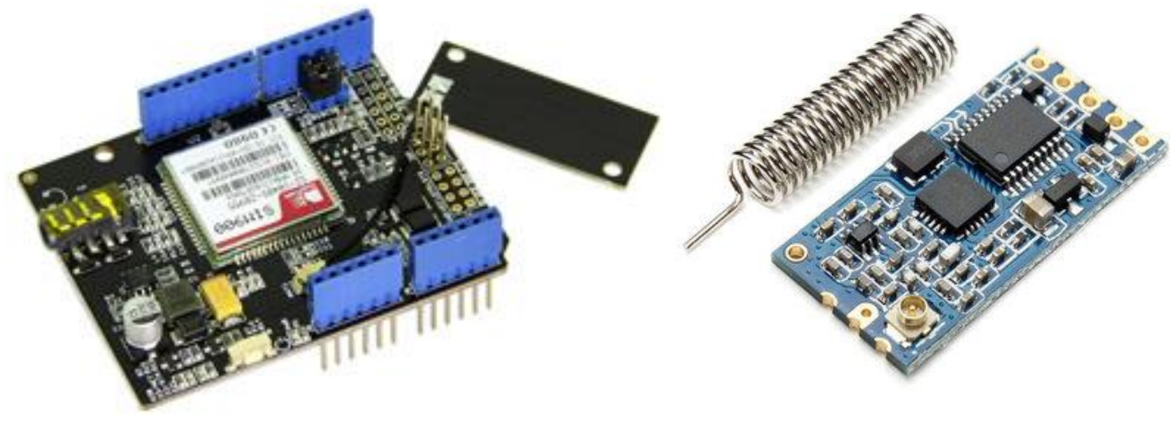

Figure 7 Left - Arduino compatible GPRS modem shield. Right – a 433 MHz RF Transceiver used in the Co-WIN 2.0 AWS.

Figure 8 Accessories of a radiation shield and a small raingauge designed for the AB-AWS using 3D printing (upper photos: computer images; lower photos: 3D printed products)

Figure 9 Teachers and students participating actively in the workshop on building an AB-AWS.

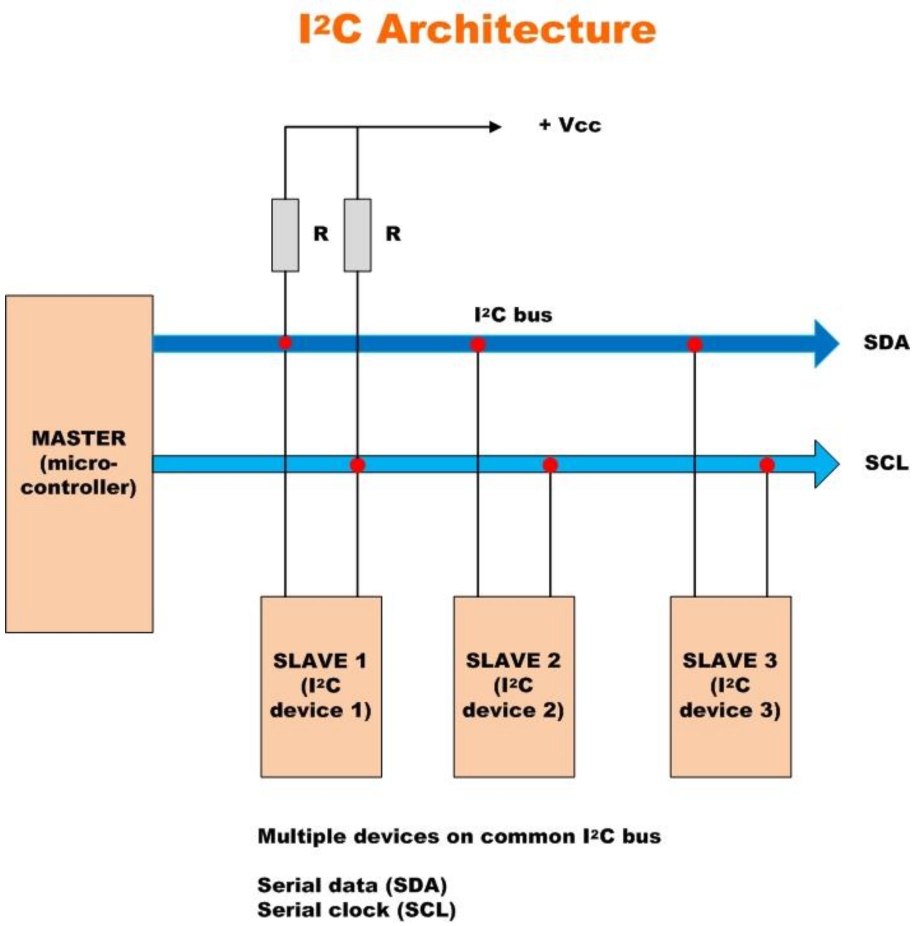

Figure 10 The I^2C multi-master, multi-slave communication architecture

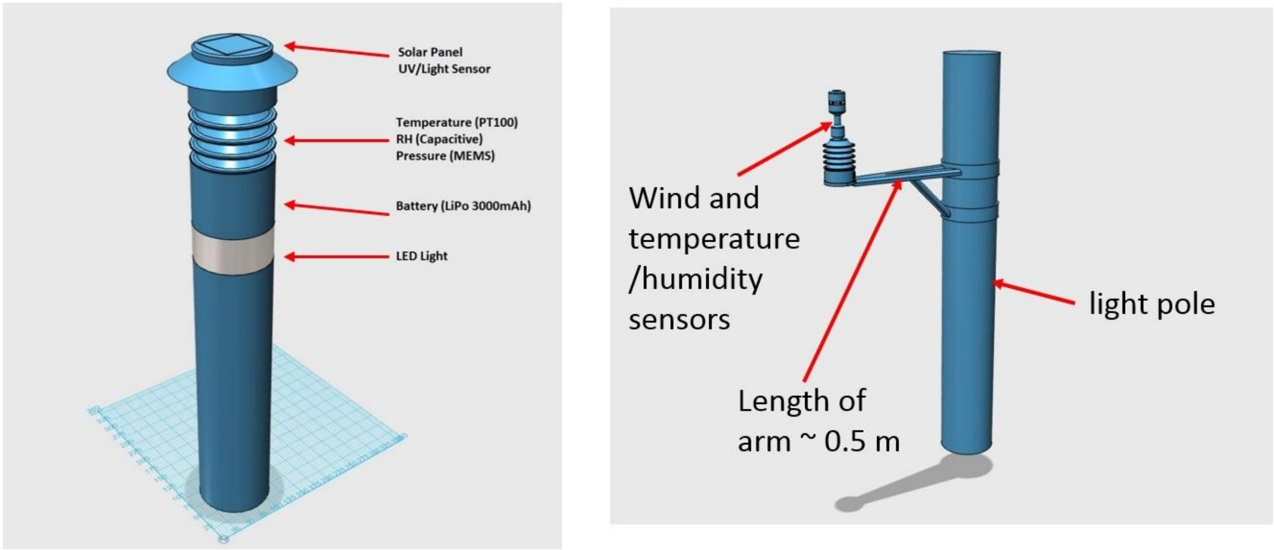

Figure 11 New prototypes of miniature and low power smart weather sensors for urban weather monitoring