Innovative education: the role of sensors and AI in classrooms

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Abstract: What are the most important skills required to become a good engineer nowadays? There are many answers oriented differently but lifetime experiance analysises of the most successfull engineers indicate that the key is to seek permanently and understand how complex systems work, considering all interacting components of it. It can be carried out efficiently only if somebody thinks critically and has the ability to approach and solve advanced technologies related challenges. The most important part of this concept realization is related to education, because the engineering field is constantly evolving, so continuous learning and staying updated with the latest trends and technologies is crucial. Integrating sensors and advanced Artificial Intelligence (AI) in educational institutes is possible in more than one form. Smart classrooms are equipped with diverse sensors and AI that improves the physical environment of classrooms and monitors the physiological and behavioral data collected from both students and teachers. It also enhances the engagement of students and provides personalized learning experiences. Besides smart classrooms, sensors can be used as educational tools, especially in STEM (Science, Technology, Engineering and Mathematics) fields. This paper demonstrates that integrating ultrasonic sensors in teaching methods help visualize elements of physics and math, promote creative thinking and motivate to pursue a carrier in engineering.

1. Introduction

Sensors are devices that detect and respond to changes in their environment locally and remotely. They convert physical parameters, such as light, temperature, sound and motion, to electrical signals that can be measured and analyzed. Sensors serve as „natural" sensory organs of machines, letting them perceive and react to their environment if they are connected to control loops. Consequently the sensors are essential to modern technology. Therefore it is vital to know their characteristics, their different applications, usability, performance and to be able to exploit their usage in maximum extent. This knowledge can be aquired from a very young age, considering there are sensors all around in our world. It is inevitable to use them in daily life, they have become part of several fields of industry too. Sensors are used regularly everywhere from the medical field to the vehicle and space related industry.

Advanced sensors are typically applied alongside Artificial Intelligence and are called „Smart sensors". In recent years AI has dynamically developed, enabling new technologies to be widespread. The AI makes possible for computer systems to perform tasks that normally require human intelligence. These include learning, reasoning, self-improvement, language understanding and solving problems[1]. They can apply rules to use aquired information, draw conclusions based on rules, learn from experience and regulate themselves based on feedback. Possibilities are nearly limitless. Smart sensor systems lead by Artificial Intelligence alleviate workload off workers, making it possible to work to their maximum potencial and enhance their results.

2. Smart Classroom

In the past few years smart sensor technologies have became means of education transformation. Sensor technology has become a basic part of applicating advanced technologies, such as AI, the Internet of Things (IoT), information technology and handling big data in the classroom. Smart Classrooms are a model of contemporary educational settings, defined by the use of digital equipment, information and communication technologies (ICT) and interactive learning systems. Smart classrooms form a bridge between students and teachers, to help teachers work more efficiently and to make the environment more conductive to learning and teaching. The goal of smart classrooms is to enhance educational outcome and to make the learning experience as pleasant as possible. The application of sensor systems focuses on all aspects of education. The system incorporates multiple sensors for data collection, including, but not limited to, cameras, temperature, light and air quality sensors and noise level meters[2]. These sensors collect environmental and biological data, and uses it to elevate the learning experience.

2.1. How does it work?

Smart sensor technologies are utilized to collect real-time data from the classroom and its participants. Then processors handle the collected data and make instructions for the actuators. The actuators provide responses in a form of indicator light or sound signal. Figuration 1 shows the process that is under implementation in the new building of University of Debrecen, Faculty of Engineering.

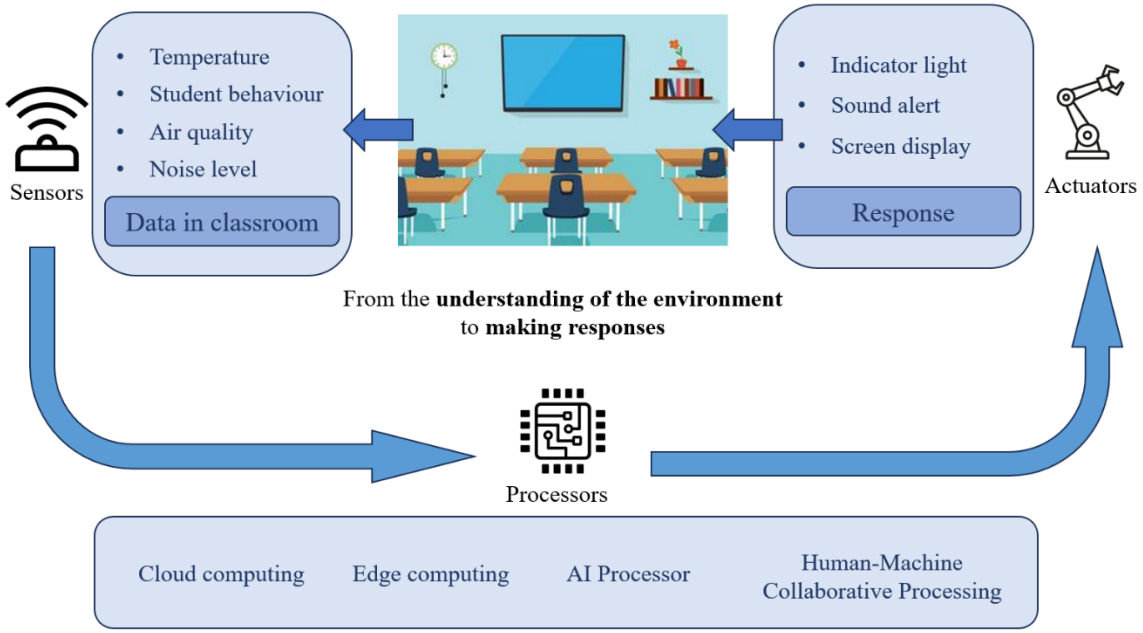

Figure 1: The system of a smart classroom

2.2. Types of sensors used in Smart Classroom

The role of smart sensors in classrooms are multifaceted. They can be employed to monitor the conditions of the environment to create an atmosphere that is most suitable for learning and teaching. Additionally, they can function as an assistant to the teachers, alleviating the burden of classroom management for educators by assisting in recording attendence and giving them feedback on students state of attention. The sensors incorporated in smart classrooms can be categorized in two groups based on the monitored properties and the information they can provide.

2.2.1. Environmental sensors. These sensor systems examine the conditions of the classroom. The deployment of environmental sensors is able to help to regulate and control the indoor environment of the classroom, in order to create a comfortable sphere neccessary for efficient learning. These sensor

systems are typically equipped with microcontrollers to command actuators and data displays, making invisible signals processsable for humans. In educational settings usually Weather Management System (WMS) is used, which is a Raspberry Pi-based sensor system, that can collect numerous weather data, including temperature and humidity. The duty of environmental sensors is to control three main categories: the condition of the air, lighting and noise, many of them under development of students.

Condition of air refers to temperature, humidity and pollution in the air (CO_2, CO and dust particles). This may include smart window opening and closing, operating fans, controlling ventillation and air conditioning to keep the condition of air in the optimal domain. See details in table 1.

In terms of lighting the main focus is on natural light and classroom activities. Adjusting the lighting according to these has been proved to enhance student alertness, therefore inspiring better performance[2]. It is also reducing eye strain, making the experience more healthy. Furthermore it can provide a more energy preserving method, utilizing as much natural sunlight as possible, without disturbing classroom activities (reflecting on screens), it can achieve an energy saving effect.

Another important feature is noise control. Unneccessary noise can be damaging not only to the efficiency of the learning process, it can also induce sensory overload, causing stress to students. High volume has been proven to be harmful to both the well-being and productivity of the students. In order to create a quiet and comfortable environment, noise controlling sensors give a visual signal (indicator light) to notify the students and the teacher when the noise level exceeds the given threshold.

Table 1. Common environmental sensors in smart classrooms.

Sensor type	Monitoring Purpose
Thermal sensor	Classroom temperature
Carbon dioxide sensor	Monitoring carbon dioxide levels in the air
Photosensitive sensor	Monitoring light levels
Acoustic sensor	Detecting noise levels

2.2.2. Biometric sensors. These sensors gather information on physiological and behaviorial properties, giving insight into cognitive processes and emotional responses. Biometric sensors examine physical indicators of the emotional state of a person, including movement, eye gaze, expressions and body temperature [2]. These sensor systems provide data on the engagement, attendance and stress levels of the students as table 2 indicates. Analyzing these can help improve the educational material, realizing which parts make the students lose focus can indicate what has to be changed.

Proceeding from stress levels, engagement and abscences of a person, an individual study plan can be given, enhancing their progress. Biometric sensors help educators managing the classroom, recording attendance and alerting of deviation of the students' attention. Attendance can be recorded based on facial recognition or fingerprints, preventing false attendancies. These sensor systems can assist students who have leraning difficulties or disabilities. Providing personalized learning methods and plans improves their academic results.

Biometric sensors enable accessibility support for students with disabilities. This system can assist individuals with hearing or speech impairments in the classroom, by hand movement and gesture recognition, enabling them to engage in conversations with people who might not know sign language. These technologies are often static, making it difficult to use them in dynamic interactions. There is room for improvement and future researches to make this technology more suitable for real-time fields, like a classroom.

Table 2. Biometric sensors in a smart classroom

Sensor type	Monitoring Purpose
Facial recognition system	Identification and emotional state analysis
Eye-tracking device	Focus and engagement analysis
Heart rate monitor	Stress levels and engagement
Fingerprint sensor	Identification

2.3. Shortcomings of sensors in classrooms

Although a classroom equipped with advanced technology has various benefits, it faces numerous shortcomings as well. While environmental sensors are usually not that noticable, they can be installed in corners or different points of the classroom that are not visible, biometric sensors have to be in the proximity of the participants. This makes the experience itself less assuring. Often times the presence of foreign objects are enough to alter behaviors. This is called the „Hawthorne effect"[3], people act differently when they know they are being observed. Some biometric sensor require to be worn or have to make contact with the people. This might inspire better performance in some cases. On the other hand being constantly observed might cause stress and even paranoia. Also wearing heart rate monitors and eye-tracking devices for longer periods of time, makes the environment uncomfortable. This needs further development in how to aquire these informations without distracting the students.

3. Ultrasonic sensors in STEM

There are other ways of utilizing sensors in education besides smart classrooms. Actively using sensors in the teaching process also has its benefits. It has been proven that hands-on education is more effective than theoretical education only. Students tend to memorize processes better when they see and experience them. Using sensors in simplified measures help visualize concepts of Physics and Math. Sensors can be effective tools of education, especially in STEM fields. STEM stands for Science, Technology, Engineering and Mathematics. It is an educational approach that emphasizes the importance of these four disciplines and the correlation between them. Its main goal is to equip students with useful skills, such as problem-solving, critical thinking and analytical skills[4]. These skills are essential in this modern era of machines and advanced technologies. It is a well known fact that younger children are more receptive regarding new technologies and innovative ways of education. Young children have the natural ability to think innovatively, without the restrictions of traditions and outdated paradigms. The educational system has to encourage thinking and the desire to create. By incorporating engineering learning within the regular classroom curriculum the understanding of complicated processes is made more achieveable. It is vital to make the tasks easily understandable and manageable for the majority of students. On the other hand they have to be thought provoking to motivate further ideas and appliances.

3.1. Why ultrasonic sensors?

Ultrasonic sensors are one of the most common sensors. They are used across several fields, from medical appliances to driver assistant systems in vehicles. They are highly available and their operation is not complicated, making it suitable for educational purposes. Ultrasonic sensors can be used in a wide range of tasks: detecting objects, measuring distance, velocity and fluid levels. The working principle of ultrasonic sensors is similar to animals' echolocation observed in bats or whales. A transducer emits an impulse-like sound wave at a frequency between 20 kHz and 200 kHz, making it inaudible for the human ear. Objects in the path of the wave reflect the sign [5]. The sensor detects the reflected wave and calculates the distance based on wave speed in the medium, such as air or water, and multiplied by the time elapsed between emitting and detecting the reflected wave.

$$d = \frac{c \cdot t}{2} \quad (1)$$

Ultrasonic sensors can detect objects regardless of shape, size or color (even transparent), moving targets as well as immobile ones. They can be used for a variety of detections and object tracking. They are capable of sensing different types of textures: solid, liquid, granular or powdered particles[6]. The velocity of sound in air is approximately 340 m/s, this can be affected by temperature, pressure and humidity. Ultrasonic sensors are the most punctual on low-speed and short ranges. They work on frequencies beyond the human audible range, therefore making it safe for people to work regularly in the proximity. These sensors can be used together with other sensors, creating detection systems. These factors make the ultrasonic sensors advantageous in educational purposes. Also ultrasonics are highly available and affordable.

Ultrasonic sensors can serve as easily understandable presentation tools or means of more complex experiments. Ultrasonic sensors could be the ideal first step for students who would like to pursue a carrier in engineering. It enables students to experiment with different ways of installing, connecting them with other sensors. It helps teachers explain the concept of sound waves and gives examples on how they can be used. Ultrasonic sensors can be used in interactive learning activities, such as creating games where students must navigate a maze or complete tasks based on sensor input.

3.2. Measuring with ultrasonic sensor

Ultrasonic sensors can be applied in various education manners, can be used individually or in an array of different sensors. The method shown below is one of the simple solutions used in our department on a daily basis. Here an sensor is connected to an Arduino UNO microcontroller board.

3.2.1. HC-SR04 ultrasonic sensor. This sensor is one of the most popular ultrasonic sensors, used in many applications where measuring distance or sensing objects is required. The module has two projects which forms the ultrasonic transmitter and the receiver as figure 2 shows. The transmitter spreads the sound waves at a particular direction and starts a timer as characterised in table 3 and table 4. The waves are reflected by any object in their path. Once the reflected wave is sensed by the receiver of the sensor the timer stops. The distance between the sensor and the detected object is calculated by equation (1), using time and the velocity of the waves in the transmitting medium.

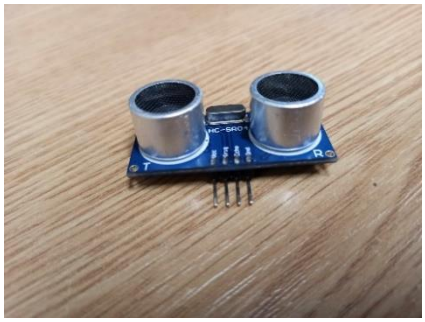

Figure 2. HC-SR04 sensor.

Table 3. Properties of HC-SR04

Range	2 cm – 400 cm
Accuracy	0.3 cm
Frequency	40 kHz
Power supply	5 V
Current consumption	15 mA

Table 4. Pin configuration of the HC-SR04 modul.

Pin name	Description
Vcc	The Vcc pin powers the sensor, typically with 5V
Trigger	Input pin. Initializes measurement by sending US wave.
Echo	Output pin. Sends a signal for a period of time equal to the time taken for the US wave to return.
Ground	This pin is connected tot he ground of the system.

3.2.2. Arduino UNO. Arduino UNO is a microcontroller board that has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button [7]. It is a user-friendly easily operable board shown in figure 3. It can be used connected to a computer with a USB cable or powered by an AC-to-DC adapter or battery.

Figure 3. Arduino UNO board [7]

3.2.3. Measurement. The ultrasonic sensor module HC-SR04 has to be connected to the Arduino UNO microcontroller board as figure 4 indicates. The system is powered by a computer, that is connected to the board with a USB cable. The code that operatest he system is written on the computer, in the Arduino Software Integrated Development Environment (IDE), than it is uploaded tot he microcontroller board. The transmitter of the ultrasonic sensor converts electronic signals into ultrasonic waves and emits them at the frequency of approximately 40 kHz, the waves upon contacting an object get reflected. The reflected ultrasonic waves are sensed by the receiver of the sensor that converts them to electronic signals[8]. The taken measures are displayed on the screen of the computer, in a way that is readable for the user.The measurements were carried out by first author.

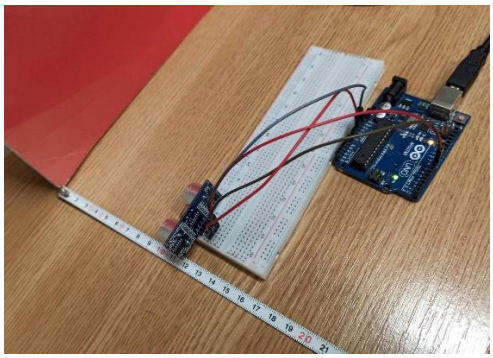

Figure 4. Measuring in a classroom

3.2.4. Expectations and results. As seen above the measuring procedure is not complicated. Students can experiment with different objects, shapes, colours and different distances. Various examples can be tested, how the punctuality differs if there are distractions in the medium as table 5 points out. How does the range of the sensor change in rain or in case of soundproof materials? All these questions might arise in a classroom and can be answered by trial. This experience might motivate thinking, curiosity and creative processes. The desire to know more and create are the basic fundaments of engineering. Inspiring a new generation of engineers is essential for the future of industry and further developments.

Table 5. Results of the measurement

Distance	**Measured distance**		
8 cm	8.12 cm	8.08 cm	8.14 cm
10 cm	10.44 cm	10.34 cm	10.35 cm
12 cm	12.05 cm	12.07 cm	12.08 cm

4. Discussion and further work

The integration of sensor technology and Artificial Intelligence in smart classrooms is constantly innovating the current education methods. Both the smart classrooms and STEM education is neccessary in a reformed educational system. It should be an intention to improve engineering education even further. Using sensors both actively as educational tools and as classroom monitoring devices is the future of education.

STEM education has to be the new standard. Implementing basic engineering excercises in the regular classroom curriculum improves essential skills in children. This should be explored further, new options and methods. The taken measurements have to be extended, in presence of various disturbing factors and diverse arrangements. Establishing engineering mindset and inspiring thinking is inevitable even at an early age. Learning through experiences is highly effective and more benefitial than acquiring only theoretical knowledge. The simple measuring procedure of the ultrasonic sensor is a great way to make students familiar with sensors and to help them understand more complex systems. Making the learning process easier for the future is an important goal.

5. Conclusion

The paper draws attention on smart classroom system performancies and challenges, its potencial for modern engineering aducation, wchich is an elaborate technological phenomenon to be managed. The idea to lighten the burden of workload of humans, by advanced technology is the base of all inventions. Integrating sensors serves this purpose. Using ultrasonic sensor we demonstrated that enhancing the learning environment and optimalizing the experience of educational settings improves productivity, reserves health and students show better academic results. Teaching future engineers is the fundamentals of engineering inspires thought-provoking experiments and motivates the future generations of engineers. Making the environmet comfortable and convenient to learning processes and implementing methods that help understanding complex concepts through uncomplicated procedures is an accessible and achieveable target.

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