Review

Not peer-reviewed version

A Comprehensive Review of Sensor Technologies and Signal Processing Solutions for Low-Power IoT Systems with Mini Computing Devices

Alexandros Gazis * , Ioannis Papadongonas , Athanasios Andriopoulos , Constantinos Zioudas , Theodoros Vavouras

Posted Date: 16 January 2025

doi: 10.20944/preprints202411.1090.v2

Keywords: Mini Computing Devices; Signal Processing; Low-Power Systems; Educational Technology; IoT (Internet of Things); Sensors; Measurement Solutions; Affordable Instrumentation; Big Data; Smart Sensors

Article

A Comprehensive Review of Sensor Technologies and Signal Processing Solutions for Low-Power IoT Systems with Mini Computing Devices

Alexandros Gazis [1,*], Ioannis Papadongonas [2], Athanasios Andriopoulos [3], Constantinos Zioudas [4] and Theodoros Vavouras [5,6]

[1] Department of Electrical and Computer Engineering, School of Engineering, Democritus University of Thrace, 67100 Xanthi, Greece
[2] Department of Electrical Engineering and Information Technology, School of Computation, Information and Technology, 80333, Munich, Germany
[3] Department Of Business Administration, School Of Administrative, Economics And Social Sciences, University of West Attica, 12243 Athens, Greece
[4] Department Of Social Sciences, School of Social Sciences, Hellenic Open University, 26331 Patra, Greece
[5] Department Of Humanities, School of Humanities, Hellenic Open University, 26335 Patra, Greece
[6] Department of Theoretical and Applied Linguistics, School of Italian Language and Literature, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
* Correspondence: agazis@ee.duth.gr

Abstract: This paper provides a comprehensive overview of sensors commonly used in low-cost, low-power systems, focusing on key concepts such as IoT, Big Data, and smart sensor technologies. It outlines the evolving roles of sensors, emphasizing their characteristics, technological advancements, and the transition toward "smart sensors" with integrated processing capabilities. The article also explores the growing importance of mini computing devices in educational environments. These devices provide cost-effective and energy-efficient solutions for system monitoring, prototype validation, and real-world application development. By interfacing with wireless sensor networks and IoT systems, mini-computers enable students and researchers to design, test, and deploy sensor-based systems with minimal resource requirements. Furthermore, the paper examines the most widely used sensors, detailing their properties and modes of operation to help readers understand how sensor systems function. The aim of this study is to provide an overview of the most suitable sensors for various applications by explaining their uses and operations in simple terms. This clarity will assist researchers in selecting the appropriate sensors for educational and research purposes or understanding why specific sensors were chosen, along with their capabilities and possible limitations. Ultimately, this research seeks to equip future engineers with the knowledge and tools needed to integrate cutting-edge sensor networks, IoT, and Big Data technologies into scalable, real-world solutions.

Keywords: mini computing devices; signal processing; low-power systems; IoT (Internet of Things); sensors; measurement solutions; big data; smart sensors; educational technology; affordable instrumentation

---

Citation:

1. . Introduction

In recent years, the extensive use of IoT and Big Data has been incorporated into the education of young scientists, [1]. The first term is derived from the ever-increasing number of devices that are connected to a large interconnected network of computing devices, [2]. The second derives from the data that are increasing in our everyday lives and applications making them so "big" that there needs

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 January 2025 doi:10.20944/preprints202411.1090.v2

to be a specific term to categorize, them [3]. The term big is used in terms of volume, velocity, and variety (the 3 Vs), [4], which is closely tight to their processing which is performed using deep learning techniques or Artificial Intelligence.

One of the most basic ways of understanding and finding all this information is the so-called intelligent sensors (smart sensors), [5]. As such, the future of these technology domains are interconnected with the main issue being that the processing power of testing new and existing methods on these areas is becoming exponential. For example, the new trend of chatbot machines using AIS such as Generative adversarial networks, (GAN) which is one of the hottest trends and widely used applications of AI has been heavily criticized for the processing of both training the data used and the time and electricity it requires to answer even the simplest of questions, [6]. As such, there needs to be a computing device that will be able to be used in schools and research facilities as a rapid prototype solution or as a training tool for the students to be educated and learn about these new technologies [7–9]. These devices, if focused in all of the areas mentioned above must be both low power and low cost so either students/young scientists, [10], or hobby enthusiasts on a budget, [11], can and will be able to use them at school or research facilities will be able to easily buy/replace them and maintain them at the lowest cost possible, [12–14]. To find this threshold between pricing and computing capabilities, several solutions are being discovered annually, [15,16]. Some examples include new minicomputers that can connect to external computing devices and support even big and resource-intensive applications like computer vision, [17,18]. The main issue and what this article will study and present are not microcontrollers i.e. devices that receive a signal and base some code/process provide a single output but smarter devices that also incorporate some sort of feedback and memory for the programmers/electrical engineers, [19].

As such, regardless of the needs or an application, the first step for a researchers on a budget to get accustomed to these technologies is to have small in size and low in cost devices that will be able to support these applications (not necessarily at a scale), [20–22]. This article aims to showcase the existing mini-computing devices in the industry regarding how to program small to medium-sized applications and suggest low-cost and low-power solutions mainly focusing on educational purposes applications. Specifically, the outline of this article is that we first briefly review what a sensor is, its properties, and its characteristics. Then, we showcase why we use them and what are the most known categories of them, then we expand on the existing solutions where mini computing devices can be used to connect, use and host these sensors and provide more detailed comparison tables of computing devices that incorporate all the necessary skills for development. In this paper, the pricing of sensors or mini computing devices is not included as it is highly dependable on the area but, it is noted that the range of these devices and their respective capabilities are similar in terms of processing power.

2. Problem Formulation

2.1. Defining Sensory Devices

A sensor is generally defined as a device that is used to measure or detect a physical quantity and produces a measurable output. The first use of sensors was when they appeared alongside living beings and specifically in our everyday instruments and tools. Specifically, the human eyes and ears are typical examples where the initially one may consider what sensing is. As such, one can define sensing via the previous example where, the former detects part of the spectrum of electromagnetic radiation and the latter detects sound, i.e. pressure waves. Over time, man has noticed the lack of measuring instruments for solving everyday practical problems, such as measuring length, weight, or volume, [23,24]. Then as time progressed, these observations and various practical reasons in our everyday lives created the need to measure more accurately than just sensing these physical quantities.

2.2. Defining Sensory Devices Generations and Advancements

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 January 2025 doi:10.20944/preprints202411.1090.v2

Since the beginning of sensor development, the term "smart sensor" has appeared for a variety of devices. This term refers to devices that fully or partially integrate an information processing unit. It is worth pointing out that this embeddedness is necessary either in the form of a data processing system, or in the form of memory feedback, an automatic calibration or compensation process, or even noise cancellation, otherwise the sensor will not be considered 'smart' or 'intelligent', [25–27].

The first generation of 'intelligent' sensors are devices that are usually connected to electronic signal processing and amplification circuitry, [26,28]. The second generation consists of sensors that are remotely located from their installation site and are connected to a section of analog electronic circuitry to adjust and modulate their desired operation, [29,30]. The third generation contains a powerful sensor component usually connected with a signal determination module and is composed of integrated circuits and/or passive components existing in the same implementation part (module). The conversion of the analog to digital signal (A/D conversion) in the converter and the microprocessor are external elements of the sensor composition and structure, [31–33]. Fourth-generation smart sensors are a product of regulation circuits combined with an identical monolithic or hybrid integrated circuit. More specifically, in this phase, the transducer and digital processing circuits communicate with discrete elements and are, as in the previous generation, external elements of the sensor composition and signal conditioning circuits. The generated output is bidirectionally interfaced to the microprocessor which provides the possibility of automatic control of the operation, [34–36].

Finally, in fifth-generation sensors, the converter of the analog to digital signal is located in a similar monolithic or hybrid integrated circuit where the signal conditioner is placed. It is worth mentioning that, depending on the design, a number of these sensors can have as an output a digital signal with the possibility of simultaneous and continuous communication with the microcontroller and the corresponding modern computer system. To achieve this function during their communication, a host system via a communication bus or wired network is used, [37,38]. The main advantages of this generation is the existence of multiple signals from different sensors, the automatic detection of the level of properties such as temperature, humidity, and other environmental factors that can disturb a measurement, the automatic correction of the main errors that occur during the operation of the predetermined life span of the components and, in general, the integration of large-scale integrated systems (VLSI), [39].

2.3. Defining Sensory Devices Properties

For choosing the appropriate instrument for a specific application, it is important to know the characteristics of a sensor device. This is reflected by its performance and behavior during measurements. Some of the most important aspects to take under consideration for technical instruments and consist of the following characteristics and properties:

1. *Accuracy*: measuring how close is the measurement of the sensory device to the actual value of the property that is being measured. As such, high accuracy is translated to minimal error and reliable and accurate results for varying conditions, [40].
2. *Tolerance*: measures and defines the acceptable range of deviation from a specified value of the values and conditions the sensor can withstand without failing or producing incorrect readings, [41].
3. *Linearity*: refers to the degree to which the sensor's output is directly proportional to the input across its entire range. As such, high linearity provides consistent and predictable measurements whereas it may introduce errors and noise to the final data interpretation, [42,43].
4. *Distinctness*: refers to a sensor's ability to differentiate the values between small changes in the measured parameter. As such, sensors with high distinctness can detect fine variations in the input signal.
5. *Repeatability*: refers to the ability of a sensor to provide the same measurement results under the same conditions over multiple trials thus ensuring reliability and consistent performance, [44].

6. *Sensitivity*: refers to the sensor's ability to detect small changes in an input parameter. As such, a sensor with high sensitivity provides minimal variations thus ensuring long-term minoring of crucial environmental and operational changes and conditions, [45].

2.4. Most Known and Widely Used Types of Sensors

This section offers a comprehensive overview of various sensor types commonly used in measurement and control applications. We will explore sensors designed to measure temperature, optics, electrical resistivity, thermistors, pressure, rubber, capacitance, level, humidity, speed, distance, and force/weight. These sensors are vital across numerous industries, including manufacturing, automation, environmental monitoring, and scientific research.

2.4.1. Sensors for Measuring Temperature

Temperature is defined as the physical quantity that determines the equilibrium of a system in terms of its thermal characteristics. The basic discovery for measuring this quantity was the thermometer, which nowadays consists mainly of electronic components and is divided into two categories:

1. *Contact thermometers*: they can produce the desired reading by coming into contact with the system whose temperature is being measured, i.e. by measuring their temperature. In this category, the accuracy of the measurement depends to a large extent on the extent to which thermal equilibrium has been established between the thermometer and the system, [46]
2. *Remote thermometers*: they can give the desired indication of the thermal radiation of the system and indirectly calculate the temperature, since physical contact between the thermometer and the system to be measured is not considered necessary, [47].

The type of sensor to be used to obtain the required measurement depends on several factors, such as the range of variation of the temperature to be measured, the required accuracy, and the fidelity of the environment in which the sensor is placed. Mechanical or other stresses are often a problem and accordingly, the difficulty or ease of measurement is strongly related to the temperature value, the medium in which we want to determine the temperature, and the overall topology of the problem, [48,49]. Some common examples of contact sensors are fiber optic sensors, [50,51], resistors (platinum/nickel), [52–54], thermistors, [55,56], thermocouples, [57,58], cryogenic sensors, [59,60], and integrated thermometers, [61,62].

2.4.2. Sensors for Optics

Fiber optic sensors involve devices that are connected to various parameters using thin optical fibers as the only means of stimulating and reading the sensing element, [63,64]. These fibers are the same as those used in telecommunication devices, [64,65]. For example, when measuring the temperature in the windings of a high-voltage power transformer, the voltage can reach high values of up to 500[kV], so the use of sensors communicating with metallic conductors is impossible for safety reasons, making this type of sensor necessary. Optical fibers have various characteristics, the variation of which can be exploited by the engineer to produce the necessary sensory instruments required for a problem, [66–68]. Such characteristics are micro-bindings, [69], interferometric phenomena, [70,71], changes in refractive index, [72] polarization changes, [73,74], wavelength variations, [75,76], the diffractive barriers, [77], occurrence of the Sagnac effect (detection of rotational motion), [78,79].

2.4.3. Sensors for Electrical Resistivity

The measurement of electrical resistance can lead, under the right conditions, to a fairly accurate calculation and determination of temperature. It should be pointed out here that, according to the literature, resistors and thermometers can be made from a wide range of materials, but the required function between electrical resistivity and temperature is not the same for all classes of materials,

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 January 2025 doi:10.20944/preprints202411.1090.v2

[80,81]. This is the reason why for the measurement of temperature, nickel, platinum, and copper are mostly used.

Platinum Resistance Thermometers (PRT) are widely used as contact sensors as most of their variants can be used for temperature measurements with an accuracy of a few [mK]. The same sensor can be used in different temperature ranges without any hysteresis effects. Its characteristics remain very stable even after many cycles of use and are characterized by low cost and high accuracy. For their activation and operation, it is necessary to have an external excitation, which can be either current or voltage, to find the required quantity by finding their electrical resistance after a predetermined calibration procedure, [82,83].

In modern times, thin-film sensors have been established, these are electronic devices from which the wire sensors are composed of a helical very thin platinum wire placed inside the interior of a ceramic tube. In this way, protection and support of the device is achieved and the overall cost of construction and maintenance of a system is reduced, [84,85]. In particular, wire sensors are in the majority of cases particularly costly compared to thin film sensors due to the purity of the metal.

To ensure the correct operation of the above devices and to avoid wear due to high thermal stresses and other environmental factors that contribute both to the destruction of the equipment and to a reduction in the accuracy of the measurement, the three-wire technique is often used, [86,87]. In particular, the operating principle is the following: suppose three conductors, of which conductors A and B are of identical length and their resistances are at opposite ends of the bridge (cross-connection).

2.4.4. Thermistor Sensors

One of the breakthroughs in terms of smart sensors has been thermistors. More specifically, they are made of semiconducting materials, usually metal oxides, [88]. The specific conductivity of a semiconductor is given by the relation:

$$\sigma = e^* (n^*pe + p^*ph)$$

where e is the charge of the electron,

n, p are the concentrations of electron and hole carriers

pe, ph are the electron and hole mobilities

At this point it is emphasized that the temperature coefficient of thermistors is generally negative and despite the existence of thermistors with a positive temperature coefficient its use cases are not widespread, [89]. The variation of the temperature coefficient has a large variation which may even reach an order of magnitude of one percent per ^{o}C. This fact allows them to detect very small temperature changes that could not be detected by a platinum resistor or thermocouple.

Based on thermistors and the need to further analyze the data they generate, integrated temperature sensors on semiconductors such as microprocessors were created, [90,91]. Their characteristics are the linearity of the output signal, their small size, low cost, extremely high order of accuracy, and limited operating range (from -40 to +120 ^{0}C) as long as they are satisfactorily calibrated.

Smart sensors are usually defined as remote sensors that produce their readings without being in physical contact with the system, usually by detecting the thermal radiation emitted by all available bodies with a temperature above absolute zero. As a result, in the majority of applications, this thermal radiation is detected in the infrared region of the electromagnetic spectrum, [92,93]. Their advantages are manifold as the temperatures recorded are very high and in many cases exceed the physical limits of the contact sensor materials. In addition, the difficult step of finding and designing the optimum location for sensor installation is omitted. Also, wear and tear on the sensor is significantly reduced as it does not require the kind of stress that contact sensors are subjected to and also covers cases where wired contact would be impossible.

2.4.5. Sensors for Measuring Pressure

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 January 2025 doi:10.20944/preprints202411.1090.v2

This category includes sensors that exist to measure the force exerted on a surface, which has the direct consequence that its unit of measurement is N·m², [94]. The pressure to be measured may be the product of liquids or gases and consists of an energy detection mechanism (Newton) and their conversion into electrical signals. The main types of these sensors are: elastic pressure sensors, [95], piezoelectric pressure sensors, [96], and capacitive pressure sensors, [97].

2.4.6. Rubber Pressure Sensors

As their name indicates, this category includes sensors whose one or more parts can be subjected to temporary changes (deformation, bending) of their dimensions, [98]. These sensors are usually found in Bourdon tube pressure measurements where the operation is based on a calibrated needle placed on a surface, [99]. In the event of pressure, it moves and the tube to which it is connected deviates from its initial point and this force is measured. Due to the displacement of the needle, the above procedure is often used for distance measurement using displacement sensors. Displacement refers to the change in position of the object by some distance or angle where if it schematically depicts a straight line, it is defined as linear. Similarly, if the reference point is rotation about a given axis of rotation it is defined as angular, [100].

2.4.7. Capacitive Pressure Sensors

In this category of sensors, the diaphragm is placed between two armature elements in each of which a capacitor is formed. The two existing capacitors are then connected to a bridge which is in equilibrium for zero pressure. The occurrence of an electrical signal disturbs the equilibrium and therefore changes the capacitance which contributes to the calculation of the necessary elements. The main negative aspect of these devices is that they are prone to errors in the presence of oscillations or temperature extremes. The basic structure of the measurement bridge and their structure lies in their operation which is determined by the circuitry of the capacitors and the signal to be applied to them respectively, [101–103].

2.4.8. Level Pressure Sensors

Level sensors are defined as sensors whose main purpose is to control a process and are commonly found in industrial applications. In particular, they are intended to determine the maximum and minimum level in a specific and well-defined area of action for the triggering of an actuator. If no moving parts are required in the structures concerned, they can also be converted into point-level sensors, for example, to measure capacitance or for the manufacture of lasers, infrared beams, or photocells, [104,105].

2.4.9. Sensors for Measuring Humidity

The parameter of humidity is one of the most important variables in the design and study of many elements. In particular, humidity and temperature are the main factors to be taken into account to eliminate or even find and counteract corrosion of sensors and measurements. As far as measurement is concerned, it consists of air molecules and chemical reactions that are highly variable in the respective external environment [106,107].

2.4.10. Sensors for Measuring Speed

In several applications, especially in terms of controlling a machine or its correct operation, it is necessary to monitor data on the flow of a process. The maintenance of airflow, for example, either for proper ventilation or to prevent overheating of a generator and heating and ventilation systems in general, is based entirely on sensors for measuring the speed of air and, in some applications, of liquids. Velocity in these measurements is defined as the distance traveled per unit of time and is expressed in meters per second, [108–110].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 January 2025 doi:10.20944/preprints202411.1090.v2

2.4.11. Sensors for Measuring Distance

In this category, there are different implementations to achieve the same measurement depending on the objective, available budget, and desired accuracy. The first one is the sonar-type sensors where the detection and the return of values are done using a parabolic curve in space, which covers a distance proportional to the power of the sensor. This method is preferred when it is necessary to cover a large distance between the sensor and the wall, [111,112]. Due to the mode of its operation, the measurements usually generate a lot of noise. The second is for range sensors where, the sensor is placed at a fixed point (usually pressed) based on a fixed radius, which passes through a certain space. This beam, in the majority of cases, is light amplification by forced emission of radiation (laser) or infrared rays (infrared), [113].

2.4.12. Force-Weight Sensors

The function of weight sensors is that of the so-called S-type load cell. Essentially, it is a transducer that converts a load, in this case, a force, applied (i.e. weight) into an electrical signal, [114,115]. Installing such sensors is particularly difficult and special attention must be paid to sensitivity, accuracy, and calibration. The operation of S-type sensors is based on the principle of the Wheatstone Bridge. In particular, the principle of operation of the bridge is to apply a potential difference to one pair of ends and measure the voltage difference. In the equilibrium state of the bridge, when no load is applied, this voltage difference is approximately equal to zero, [116].

2.4.13. Concise Outline of Sensor Types

The most useful and extensively used sensor types are presented in Table 1 below:

Table 1. A detailed analysis of the most known and used low-cost and low-power sensor devices.

Sensor Type	Reference Number
Temperature Sensors	[23,46,47]
Contact Thermometers	[46,47]
Remote Thermometers	[48,65]
Optic Sensors	[50,51]
Electrical Resistivity Sensors	[53,[54]
Thermistor Sensors	[88,91]
Pressure Sensors	[94,95]
Humidity Sensors	[106,107]
Speed Sensors	[49,108]
Distance Sensors	[111,[112]
Force -Weight Sensors	[114,116]

3. Comparison of Mini computing solutions

After considering many well-known industry options such as Onion Omega2+, [117], ASUS Tinker Board, [118], and Le Potato, [119], Raspberry Pis were chosen to suggest for their balance of storage, speed, processor capabilities, community support, and cost-effectiveness, [120]. Moreover, Omega2+ devices are less expensive and can be suggested to be used in several case studies but lack processing power, whereas an interesting solution is the Tinker Board which lacked extensive community support for sensors and documentation. Similarly, from the mini computing devices studied, Le Potato, despite superior CPU and GPU performance, also suffered from limited community support. Given that our model of study is focused on educational purposes thus it is not resource-intensive, Raspberry Pis, a solution that is not overly engineered is in most cases suggested and preferred. All mini-computers mentioned support SD and Wi-Fi, ensuring connectivity and the ability to store local measurements cost-effectively on an SD card and transmit data remotely. A comparative analysis of these devices is provided in Table 2.

Table 2. A comparison analysis of the most known and used low-cost and low-power computing devices in the industry.

Device	CPU Model	CPU Technology	RAM	Speed	Power	Operating Systems	Recommended Programming Languages
Raspberry Pi 4 Model B	Quad-core 1.5GHz Arm Cortex-A72	ARMv8-A	1-8GB LPDDR 4	1.5 GHz	5V 3A	Raspberry Pi OS, Ubuntu	Python, C, C++, Java, Scratch
Raspberry Pi 3 Model B	Quad Core 1.2GHz Broadcom BCM2837	ARMv8-A (32-bit)	1GB LPDDR 2	1.2 GHz	5V 2.5A	Raspberry Pi OS, Ubuntu	Python, C, C++, Java, Scratch
Onion Omega2+	580 MHz MIPS	MIPS 24KEc	128MB DDR2	580 MHz	3.3V 0.18A	OpenWrt, Debian	Python, JavaScript, C++
ASUS Tinker Board S	Quad-core 1.8 GHz RK3288-CG.W	ARM Cortex-A17	2GB LPDDR 3	1.8 GHz	5V 1.6A	TinkerOS, Armbian	Python, C, C++, Java
Nvidia Jetson Nano	Quad-core ARM Cortex-A57	ARMv8-A	4GB LPDDR 4	921 MHz	5V 2A	Ubuntu-based JetPack OS: Linux4Tegra, Jetson Linux, Ambian	Python, C, C++, CUDA

4. Conclusions

The current century is often characterized as the "information century," but to harness the vast amounts of information available, it is essential to understand, process, and apply data effectively to relevant problems. This article began by outlining the aim of providing young scientists, researchers, and technical hobbyists with detailed information on how to use sensory devices. We analytically defined what a sensor is, its unique characteristics, and the evolution of sensors, from simple measurement devices to smart sensors. We also elaborated on various types of sensors, emphasizing their unique capabilities and features.

The technical novelty of this article lies in presenting several core components and providing a concise literature review on a vast amount of different sensory devices and mini-computers used to develop early rapid prototypes. These prototypes can serve as a method to validate the ground truth of complex and expensive computing devices and in our case to be used as a low-power and low-cost devices to serve educational purposes. We predict that the capabilities of these devices will continue to increase while their costs remain manageable, given their performance potential.

This article offers readers the ability to define different types of sensors, and by studying Table 1, they can better understand the initial steps of creating a top-down approach for their intended systems. As a result, future scientists can use this article as a reference for selecting sensors and identifying the most suitable types of sensors and mini-computers for their systems. While Raspberry Pi is often considered the go-to solution in many cases, it is evident from the data and the tables of this manuscript that other options should also be considered based on the specific applications of each project. Lastly, as for future use cases and studies, it should be really interesting to provide a more detailed comparison between these low-cost and low-power devices and other even lower-cost devices such as Chrome Books or ChromeOS flex using devices, [121].

Author contributions: Conceptualization, Gazis Alexandros and Vavouras Theodoros; methodology, Andriopoulos Athanasios and Zioudas Constantinos; software, Papadongonas Ioannis; validation, Gazis Alexandros, Andriopoulos Athanasios, and Zioudas Constantinos; formal analysis, Gazis Alexandros; investigation, Gazis Alexandros and Vavouras Theodoros; resources, Vavouras Theodoros; data curation, Gazis Alexandros and Andriopoulos Athanasios writing—original draft preparation, Gazis Alexandros, Papadongonas Ioannis, Vavouras Theodoros; writing—review and editing, Vavouras Theodoros, Gazis Alexandros, Zioudas Constantinos; supervision, Gazis Alexandros and Vavouras Theodoros; project administration, Gazis Alexandros and Vavouras Theodoros. All authors have read and agreed to the published version of the manuscript.

Funding: The APC was funded by Academia Engineering journal editors as part of a special issue/call for papers.

Institutional review board statement: Not applicable.

Informed consent statement: Not applicable.

Sample availability: The author(s) declare that no physical samples were used in this study.

Conflict of interest: The author(s) declare no conflict of interest.

References

1. Taherkordi, A., Eliassen, F., & Horn, G. (**2017**, April). From IoT big data to IoT big services. In *Proceedings of the symposium on applied computing* (pp. 485-491). https://doi.org/10.1145/3019612.3019700
2. Gazis, A. (**2021**). What is it? The Internet of Things explained. *Academia Letters*, 2. https://www.doi.org/10.20935/AL1003
3. Gazis, A., & Gazi, T. (**2021**). Big data applications in industry fields. *ITNOW*, 63(2), 50-51. https://doi.org/10.1093/itnow/bwab056
4. Pramanik, S., & Bandyopadhyay, S. K. (**2023**). Analysis of big data. In *Encyclopedia of data science and machine learning* (pp. 97-115). IGI Global. www.doi.org/10.4018/978-1-7998-9220-5.ch006
5. Rodriguez-Garcia, P., Li, Y., Lopez-Lopez, D., & Juan, A. A. (**2023**). Strategic decision making in smart home ecosystems: A review on the use of artificial intelligence and Internet of things. *Internet of Things*, 22, 100772. https://doi.org/10.1016/j.iot.2023.100772
6. Gui, J., Sun, Z., Wen, Y., Tao, D., & Ye, J. (**2021**). A review on generative adversarial networks: Algorithms, theory, and applications. *IEEE transactions on knowledge and data engineering*, 35(4), 3313-3332. https://doi.org/10.1109/TKDE.2021.3130191
7. Pal, J., Patra, R., Nedevschi, S., Plauche, M., & Pawar, U. S. (**2009**). The case of the occasionally cheap computer: Low-cost devices and classrooms in the developing regions. *Information Technologies & International Development*, 5(1), pp-49. https://itidjournal.org/index.php/itid/article/view/325.html
8. Parapi, J. M. O., Maesaroh, L. I., Basuki, B., & Masykuri, E. S. (**2020**). Virtual education: A brief overview of its role in the current educational system. *Scripta: English Department Journal*, 7(1), 8-11. https://doi.org/10.37729/scripta.v7i1.632
9. Kim, S. W., & Lee, Y. (**2016**). Development of a software education curriculum for secondary schools. *Journal of The Korea Society of Computer and Information*, 21(8), 127-141. http://dx.doi.org/10.9708/jksci.2016.21.8.127
10. Kong, S. C. (**2016**). A framework of curriculum design for computational thinking development in K-12 education. *Journal of Computers in Education*, 3, 377-394. https://doi.org/10.1007/s40692-016-0076-z
11. Ali, M., Vlaskamp, J. H. A., Eddin, N. N., Falconer, B., & Oram, C. (**2013**, September). Technical development and socioeconomic implications of the Raspberry Pi as a learning tool in developing countries. In 2013 5th *Computer Science and Electronic Engineering Conference (CEEC)* (pp. 103-108). IEEE. http://dx.doi.org/10.1109/CEEC.2013.6659454
12. Kurkovsky, S., & Williams, C. (**2017**, June). Raspberry Pi as a platform for the Internet of Things projects: Experiences and lessons. In Proceedings of the 2017 *ACM Conference on Innovation and Technology in Computer Science Education* (pp. 64-69). https://doi.org/10.1145/3059009.3059028

13. Alex David, S., Ravikumar, S., & Rizwana Parveen, A. (**2018**). Raspberry Pi in computer science and engineering education. In *Intelligent Embedded Systems: Select Proceedings of ICNETS2*, Volume II (pp. 11-16). Springer Singapore. http://dx.doi.org/10.1007/978-981-10-8575-8_2
14. Alharbi, F. (**2024**). Integrating the internet of things in electrical engineering education. International Journal of Electrical Engineering & Education, 61(2), 258-275. https://doi.org/10.1177/0020720920903422
15. Ng, D. T. K., Su, J., Leung, J. K. L., & Chu, S. K. W. (**2023**). Artificial intelligence (AI) literacy education in secondary schools: a review. *Interactive Learning Environments*, 1-21. https://doi.org/10.1080/10494820.2023.2255228
16. Margulieux, L. E., Shapiro, B. R., & Calandra, B. D. (**2024**). *Recommendations for Computer Science Education in Colleges of Education*. Authorea Preprints. https://doi.org/10.22541/au.171052957.79200843/v1
17. McGettrick, A., Theys, M. D., Soldan, D. L., & Srimani, P. K. (**2003**). Computer engineering curriculum in the new millennium. *IEEE Transactions on Education*, 46(4), 456-462. https://doi.org/10.1109/TE.2003.818755
18. Zhao, W. (**2015**, March). Enriching engineering curricula with a course on cutting-edge computer technologies. In 2015 *IEEE Integrated STEM Education Conference* (pp. 44-48). IEEE. http://dx.doi.org/10.1109/ISECon.2015.7119943
19. Irigoyen, E., Larzabal, E., & Priego, R. (**2013**). Low-cost platforms used in Control Education: An educational case study. *IFAC Proceedings Volumes*, 46(17), 256-261. https://doi.org/10.3182/20130828-3-UK-2039.00058
20. Afreen, R. (**2014**). Bring your device (BYOD) in higher education: Opportunities and challenges. *International Journal of Emerging Trends & Technology in Computer Science*, 3(1), 233-236. https://www.researchgate.net/publication/324216221_Bring_Your_Own_Device_BYOD_in_higher_education_Opportunities_and_challenges
21. McCrady-Spitzer, S. K., Manohar, C. U., Koepp, G. A., & Levine, J. A. (**2015**). Low-cost and scalable classroom equipment to promote physical activity and improve education. *Journal of Physical Activity and Health*, 12(9), 1259-1263. http://dx.doi.org/10.1123/jpah.2014-0159
22. Buń, P. K., Wichniarek, R., Górski, F., Grajewski, D., Zawadzki, P., & Hamrol, A. **(2016).** Possibilities and determinants of using low-cost devices in virtual education applications. *EURASIA Journal of Mathematics, Science and Technology Education*, 13(2), 381-394. http://dx.doi.org/10.12973/eurasia.2017.00622a
23. Gazis, A. (**2023**). The advancement of microsensors in the age of IoT and Industry 4.0. *Advances in Analytic Science*, 1, 122. https://doi.org/10.54517/aas.v5i1.2671
24. Kiran Kolluri, S. S., & Ananiah Durai, S. (**2024**). Wearable micro-electro-mechanical systems pressure sensors in health care: Advancements and trends—A review. *IET Wireless Sensor Systems*. https://doi.org/10.1049/wss2.12084
25. Yamasaki, H. (**1996**). What are intelligent sensors? In Handbook of sensors and actuators (Vol. 3, pp. 1-17). *Elsevier Science BV*. eBook ISBN: 9780080523903. https://shop.elsevier.com/books/intelligent-sensors/yamasaki/978-0-444-89515-8
26. Zeisel, D. (**2003**). Development of future sensor generations: commercial vs. technological aspects. *In Molecular Electronics: Bio-sensors and Bio-computers* (pp. 417-425). Dordrecht: Springer Netherlands. http://dx.doi.org/10.1007/978-94-010-0141-0_20
27. Niu, H., Yin, F., Kim, E. S., Wang, W., Yoon, D. Y., Wang, C., ... & Kim, N. Y. (**2023**). Advances in flexible sensors for intelligent perception systems enhanced by artificial intelligence. *InfoMat*, 5(5), e12412. https://doi.org/10.1002/inf2.12412
28. Glisic, B. (**2022**). Concise historical overview of strain sensors used in the monitoring of civil structures: The first one hundred years. *Sensors*, 22(6), 2397. https://doi.org/10.3390/s22062397
29. Levis, P., Gay, D., Handziski, V., Hauer, J. H., Greenstein, B., Turon, M., ... & Wolisz, A. (**2005**). T2: A second-generation os for embedded sensor networks. *Technical Report TKN-05-007*, Telecommunication Networks Group, Technische Universitat Berlin. https://www.academia.edu/2784288/T2_A_second_generation_os_for_embedded_sensor_networks
30. Gervais-Ducouret, S. (**2011**, February). Next smart sensors generation. In 2011 *IEEE Sensors Applications Symposium* (pp. 193-196). IEEE. https://doi.org/10.1109/SAS.2011.5739775

31. Reago, D. A., Horn, S. B., Campbell Jr, J., & Vollmerhausen, R. H. (**1999**, July). Third-generation imaging sensor system concepts. In *Infrared Imaging Systems: Design, Analysis, Modeling, and Testing X* (Vol. 3701, pp. 108-117). SPIE. https://doi.org/10.1117/12.352991
32. Bonnaud, O. (**2020**). The technological challenges of microelectronics for the next generations of connected sensors. *Int. J. Plasma Environ. Sci. Technol*, 14(1), 1-8. https://www.researchgate.net/publication/340599904_The_technological_challenges_of_microelectronics_for_the_next_generations_of_connected_sensors
33. Sony, S., Laventure, S., & Sadhu, A. (**2019**). A literature review of next-generation smart sensing technology in structural health monitoring. *Structural Control and Health Monitoring*, 26(3), e2321. https://onlinelibrary.wiley.com/doi/10.1002/stc.2321
34. Mukhopadhyay, S. C., Jayasundera, K. P., & Fuchs, A. (Eds.). (**2012**). Advancement in sensing technology: New *developments and practical applications* (Vol. 1). Springer Science & Business Media. https://doi.org/10.1007/978-3-642-32180-1
35. Kalsoom, T., Ramzan, N., Ahmed, S., & Ur-Rehman, M. (**2020**). Advances in sensor technologies in the era of smart factory and industry 4.0. *Sensors*, 20(23), 6783. https://doi.org/10.3390/s20236783
36. Ullo, S. L., & Sinha, G. R. (**2021**). Advances in IoT and smart sensors for remote sensing and agriculture applications. *Remote Sensing*, 13(13), 2585. https://doi.org/10.3390/rs13132585
37. Chaudhary, V., Kaushik, A., Furukawa, H., & Khosla, A. (**2022**). Towards 5th generation AI and IoT-driven sustainable intelligent sensors based on 2d mxenes and borophene. *ECS Sensors Plus*, 1(1), 013601. https://www.doi.org/10.1149/2754-2726/ac5ac6
38. Deroco, P. B., Wachholz Junior, D., & Kubota, L. T. (**2023**). Paper-based wearable electrochemical sensors: a new generation of analytical devices. *Electroanalysis*, 35(1), e202200177. https://doi.org/10.1002/elan.202200177
39. Chakravarthi, V. S. (**2020**). A practical approach to VLSI system on chip (SoC) design. *Springer International Publishing*. https://www.springerprofessional.de/a-practical-approach-to-vlsi-system-on-chip-soc-design/17208494
40. Zappi, P., Lombriser, C., Stiefmeier, T., Farella, E., Roggen, D., Benini, L., & Tröster, G. (**2008**). Activity recognition from on-body sensors: accuracy-power trade-off by dynamic sensor selection. In *Wireless Sensor Networks: 5th European Conference*, EWSN 2008, Bologna, Italy, January 30-February 1, 2008. Proceedings (pp. 17-33). Springer Berlin Heidelberg. http://dx.doi.org/10.1007/978-3-540-77690-1_2
41. Chouikhi, S., El Korbi, I., Ghamri-Doudane, Y., & Saidane, L. A. (**2015**). A survey on fault tolerance in small and large scale wireless sensor networks. *Computer Communications*, 69, 22-37. http://dx.doi.org/10.1016/j.comcom.2015.05.007
42. Wang, F., & Theuwissen, A. (**2017**). Linearity analysis of a CMOS image sensor. *Electronic imaging*, 29, 84-90. https://doi.org/10.2352/issn.2470-1173.2017.11.imse-191
43. Ji, B., Zhou, Q., Lei, M., Ding, S., Song, Q., Gao, Y., ... & Zhou, B. (**2021**). Gradient architecture-enabled capacitive tactile sensor with high sensitivity and ultrabroad linearity range. *Small*, 17(43), 2103312. https://doi.org/10.1002/smll.202103312
44. Keegan, K. G., Kramer, J., Yonezawa, Y., Maki, H., Pai, P. F., Dent, E. V., ... & Reed, S. K. (**2011**). Assessment of repeatability of a wireless, inertial sensor–based lameness evaluation system for horses. *American journal of veterinary research*, 72(9), 1156-1163. https://doi.org/10.2460/ajvr.72.9.1156
45. Vig, J. R., & Walls, F. L. (**2000**, June). A review of sensor sensitivity and stability. In Proceedings of the 2000 *IEEE/EIA International Frequency Control Symposium and Exhibition* (Cat. No. 00CH37052) (pp. 30-33). IEEE. https://doi.org/10.1109/FREQ.2000.887325
46. Mnati, M. J., Chisab, R. F., Al-Rawi, A. M., Ali, A. H., & Van den Bossche, A. (**2021**). An open-source non-contact thermometer using low-cost electronic components. *HardwareX*, 9, e00183. http://dx.doi.org/10.1016/j.ohx.2021.e00183
47. Zhao, Y., & Bergmann, J. H. (**2023**). Non-contact infrared thermometers and thermal scanners for human body temperature monitoring: a systematic review. *Sensors*, 23(17), 7439. https://doi.org/10.3390/s23177439

48. Li, S., Liu, G., Li, R., Li, Q., Zhao, Y., Huang, M., ... & Su, Y. (**2021**). Contact-resistance-free stretchable strain sensors with high repeatability and linearity. *ACS nano*, 16(1), 541-553. http://dx.doi.org/10.1021/acsnano.1c07645
49. Javaid, M., Haleem, A., Rab, S., Singh, R. P., & Suman, R. (**2021**). Sensors for daily life: A review. *Sensors International*, 2, 100121. https://doi.org/10.1016/j.sintl.2021.100121
50. Udd, E., & Spillman Jr, W. B. (Eds.). (**2024**). Fiber optic sensors: an introduction for engineers and scientists. *John Wiley & Sons*. http://dx.doi.org/10.1002/9781118014103
51. Venketeswaran, A., Lalam, N., Wuenschell, J., Ohodnicki Jr, P. R., Badar, M., Chen, K. P., ... & Buric, M. (**2022**). Recent advances in machine learning for fiber optic sensor applications. *Advanced Intelligent Systems*, 4(1), 2100067. https://doi.org/10.1002/aisy.202100067
52. Kilinc, N., Sanduvac, S., & Erkovan, M. (**2022**). Platinum-nickel alloy thin films for low-concentration hydrogen sensor application. *Journal of Alloys and Compounds*, 892, 162237. http://dx.doi.org/10.1016/j.jallcom.2021.162237
53. Claggett, T. J., Worrall, R. W., Clayton, W. A., & Lipták, B. G. (**2022**). Resistance Temperature Detectors (RTDs). *In Temperature Measurement* (pp. 75-84). CRC Press. eBook ISBN9781003063919. https://www.routledge.com/Temperature-Measurement/Liptak/p/book/9780801983856
54. Kilinc, N., & Erkovan, M. (**2023**). Nanostructured Platinum and Platinum Alloy-Based Resistive Hydrogen Sensors: A Review. *Engineering Proceedings*, 48(1), 18. https://doi.org/10.3390/CSAC2023-14912
55. Reverter, F. (**2021**). A tutorial on thermal sensors in the 200th anniversary of the Seebeck effect. *IEEE Sensors Journal*, 21(20), 22122-22132. http://dx.doi.org/10.1109/JSEN.2021.3105546
56. Liu, R., He, L., Cao, M., Sun, Z., Zhu, R., & Li, Y. (**2021**). Flexible temperature sensors. *Frontiers in Chemistry*, 9, 539678. https://www.doi.org/10.3389/fchem.2021.539678
57. Elangovan, K. (**2024**, September). Enhanced Dual-Slope-Based Digitizer for 4-Wire Connected Resistive Sensors. In *2024 IEEE Region 10 Symposium (TENSYMP)* (pp. 1-4). IEEE. https://doi.org/10.1109/TENSYMP61132.2024.10752304
58. Webster, E. (**2021**). A critical review of the common thermocouple reference functions. *Metrologia*, 58(2), 025004. http://dx.doi.org/10.1088/1681-7575/abdd9a
59. Yeager, C. J., & Courts, S. S. (**2001**). A review of cryogenic thermometry and common temperature sensors. *IEEE Sensors Journal*, 1(4), 352-360. http://dx.doi.org/10.1109/7361.983476
60. Huang, X., Davies, M., Moseley, D. A., Gonzales, J. T., Weijers, H. W., & Badcock, R. A. (**2022**). Sensitive fiber optic sensor for rapid hot-spot detection at cryogenic temperatures. *IEEE Sensors Journal*, 22(12), 11775-11782. https://doi.org/10.1109/JSEN.2022.3174894
61. Giansanti, D., & Maccioni, G. (**2007**). Development and testing of a wearable Integrated Thermometer sensor for skin contact thermography. *Medical engineering & physics*, 29(5), 556-565. http://dx.doi.org/10.1016/j.medengphy.2006.07.006
62. Yoon, H. W., Khromchenko, V., & Eppeldauer, G. P. (**2019**). Improvements in the design of thermal-infrared radiation thermometers and sensors. *Optics Express*, 27(10), 14246-14259. http://dx.doi.org/10.1117/12.2519506
63. Fairuz Omar, A. (**2013**). Fiber Optic Sensors: An Introduction for Engineers and Scientists. *Sensor Review*, *33*(2). https://doi.org/10.1108/sr.2013.08733baa.010
64. Karapanagiotis, C., & Krebber, K. (**2023**). Machine learning approaches in Brillouin distributed fiber optic sensors. *Sensors*, *23*(13), 6187. https://doi.org/10.3390/s23136187
65. Huang, M. F., Salemi, M., Chen, Y., Zhao, J., Xia, T. J., Wellbrock, G. A., ... & Aono, Y. (**2019**). First field trial of distributed fiber optical sensing and high-speed communication over an operational telecom network. *Journal of Lightwave Technology*, 38(1), 75-81. http://dx.doi.org/10.1109/JLT.2019.2935422
66. Alwis, L., Sun, T., & Grattan, K. T. V. (**2016**). Developments in optical fiber sensors for industrial applications. *Optics & Laser Technology*, 78, 62-66. https://doi.org/10.1016/j.optlastec.2015.09.004
67. Del Villar, I., & Matias, I. R. (Eds.). (**2020**). Optical Fibre Sensors: Fundamentals for Development of Optimized Devices. *John Wiley & Sons*. ISBN: 978-1-119-53479-2. https://ieeexplore.ieee.org/book/9261257
68. Allsop, T., & Neal, R. (**2021**). A review: Application and implementation of optic fiber sensors for gas detection. *Sensors*, 21(20), 6755. https://doi.org/10.3390/s21206755

69. Kuswanto, H., Abimanyu, I., & Dwandaru, W. S. B. (**2022**). Increasing the Sensitivity of Polymer Optical Fiber Sensing Element in Detecting Humidity: Combination of Macro and Micro Bendings. *Trends in Sciences*, 19(7), 3200-3200. https://doi.org/10.48048/tis.2022.3200
70. Miliou, A. (**2021**, July). In-fiber interferometric-based sensors: Overview and recent advances. In *Photonics* (Vol. 8, No. 7, p. 265). MDPI. https://doi.org/10.3390/photonics8070265
71. Zhu, C., Zheng, H., Ma, L., Yao, Z., Liu, B., Huang, J., & Rao, Y. (**2023**). Advances in fiber-optic extrinsic Fabry–Perot interferometric physical and mechanical sensors: A review. *IEEE Sensors Journal*, 23(7), 6406-6426. http://dx.doi.org/10.1109/JSEN.2023.3244820
72. Khan, R., Gul, B., Khan, S., Nisar, H., & Ahmad, I. (**2021**). Refractive index of biological tissues: Review, measurement techniques, and applications. *Photodiagnosis and Photodynamic Therapy*, 33, 102192. http://dx.doi.org/10.1016/j.pdpdt.2021.102192
73. Caucheteur, C., Guo, T., & Albert, J. (**2016**). Polarization-assisted fiber Bragg grating sensors: Tutorial and review. *Journal of Lightwave Technology*, 35(16), 3311-3322. https://doi.org/10.1109/jlt.2016.2585738
74. Sasagawa, K., Okada, R., Haruta, M., Takehara, H., Tashiro, H., & Ohta, J. (**2022**). Polarization image sensor for highly sensitive polarization modulation imaging based on stacked polarizers. *IEEE Transactions on Electron Devices*, 69(6), 2924-2931. https://doi.org/10.1109/TED.2022.3140288
75. Ning, Y. N., Meldrum, A., Shi, W. J., Meggitt, B. T., Palmer, A. W., Grattan, K. T. V., & Li, L. (**1998**). Bragg grating sensing instrument using a tunable Fabry-Perot filter to detect wavelength variations. *Measurement Science and Technology*, 9(4), 599. www.doi.org/10.1088/0957-0233/9/4/007
76. Sang, W., Huang, S., Chen, J., Dai, X., Liu, H., Zeng, Y., ... & Shao, Y. (**2023**). Wavelength sequential selection technique for high-throughput multi-channel phase interrogation surface plasmon resonance imaging sensing. *Talanta*, 258, 124405. http://dx.doi.org/10.1016/j.talanta.2023.124405
77. Fengjie, X., Zongfu, J., Xiaojun, X., & Yifeng, G. (**2007**). High-diffractive-efficiency defocus grating for wavefront curvature sensing. *JOSA A*, 24(11), 3444-3448. https://doi.org/10.1364/JOSAA.24.003444
78. Mohammadi, M., Seifouri, M., & Olyaee, S. (**2024**). The rotation sensing based on the Sagnac effect in silicon-integrated optical gyroscope with noise considerations. *Optical and Quantum Electronics*, 56(6), 1-22. http://dx.doi.org/10.1007/s11082-024-06895-6
79. Choi, W. S., Shim, K. M., Chong, K. H., An, J. E., Kim, C. J., & Park, B. Y. (**2023**). Sagnac effect compensations and locked states in a ring laser gyroscope. *Sensors*, 23(3), 1718. https://doi.org/10.3390/s23031718
80. Sophocleous, M. (**2017**). Electrical resistivity sensing methods and implications. *Electrical Resistivity and Conductivity*, 10, 67748. https://www.intechopen.com/chapters/54410
81. Piro, N. S., Mohammed, A. S., & Hamad, S. M. (**2023**). Electrical resistivity measurement, piezoresistivity behavior and compressive strength of concrete: a comprehensive review. *Materials Today Communications*, 106573. https://doi.org/10.1016/j.mtcomm.2023.106573
82. Pant, U., Meena, H., Gupta, G., Bapna, K., & Shivagan, D. D. (**2022**). Evaluation of self-heating effect in platinum resistance thermometers. *Measurement*, 203, 111994. https://doi.org/10.1016/j.measurement.2022.111994
83. Kako, S. (**2023**). A Comparative Study about Accuracy Levels of Resistance Temperature Detectors RTDs Composed of Platinum, Copper, and Nickel. A*l-Nahrain Journal for Engineering Sciences*, 26(3), 216-225. http://dx.doi.org/10.29194/NJES.26030216
84. Rusby, R., & Pearce, J. (**2024,** October). Full-range interpolations for long-stem standard platinum resistance thermometers down to the triple point of argon. In *AIP Conference Proceedings* (Vol. 3230, No. 1). AIP Publishing. https://doi.org/10.1063/5.0234578
85. Qu, W., & Wlodarski, W. (**2000**). A thin-film sensing element for ozone, humidity and temperature. *Sensors and Actuators B: Chemical*, 64(1-3), 42-48. https://doi.org/10.1016/S0925-4005(99)00481-5
86. Elangovan, K., Antony, A., & Sreekantan, A. C. (**2021**). Simplified digitizing interface architectures for three-wire connected resistive sensors: Design and comprehensive evaluation. *IEEE Transactions on Instrumentation and Measurement*, 71, 1-9. http://dx.doi.org/10.1109/TIM.2021.3136176
87. Reverter, F. (**2022**). A microcontroller-based interface circuit for three-wire connected resistive sensors. *IEEE Transactions on Instrumentation and Measurement*, *71*, 1-4. https://doi.org/10.1109/TIM.2022.3219492

88. Bodic, M. Z., Aleksic, S. O., Rajs, V. M., Damnjanovic, M. S., & Kisic, M. G. (**2023**). Thermally Coupled Thick Film Thermistors: Main Properties and Applications. *IEEE Sensors Journal*. https://doi.org/10.3390/s24113547
89. Wang, H. (**2023**). Experimental Research on the Stability of Negative Temperature Coefficient Thermistors. *IEEE Instrumentation & Measurement Magazine*, 26(8), 42-47. https://doi.org/10.1109/MIM.2023.10292623
90. Chatterjee, N., Bhattacharyya, B., Dey, D., & Munshi, S. (**2019**). A combination of an astable multivibrator and microcontroller for thermistor-based temperature measurement over the internet. *IEEE Sensors Journal*, 19(9), 3252-3259. http://dx.doi.org/10.1109/JSEN.2019.2896251
91. Liu, Z., Huo, P., Yan, Y., Shi, C., Kong, F., Cao, S., ... & Yao, J. (**2024**). Design of a Negative Temperature Coefficient Temperature Measurement System Based on a Resistance Ratio Model. *Sensors*, 24(9), 2780. https://doi.org/10.1016/j.enconman.2017.02.022
92. Corsi, C. (**2007**). Smart sensors. *Infrared physics & technology*, 49(3), 192-197. https://doi.org/10.1016/j.infrared.2006.06.002
93. Wei, H., Gu, J., Ren, F., Zhang, L., Xu, G., Wang, B., ... & Li, Y. (**2021**). Smart materials for dynamic thermal radiation regulation. *Small*, 17(35), 2100446. https://doi.org/10.1002/smll.202100446
94. Yuan, H., Zhang, Q., Zhou, T., Wu, W., Li, H., Yin, Z., ... & Jiao, T. (**2024**). Progress and challenges in flexible capacitive pressure sensors: Microstructure designs and applications. *Chemical Engineering Journal*, 149926. https://doi.org/10.1016/j.cej.2024.149926
95. Lu, Y., Qu, X., Zhao, W., Ren, Y., Si, W., Wang, W., ... & Dong, X. (**2020**). Highly stretchable, elastic, and sensitive MXene-based hydrogel for flexible strain and pressure sensors. *Research*. https://doi.org/10.34133/2020/2038560
96. Zhi, C., Shi, S., Si, Y., Fei, B., Huang, H., & Hu, J. (**2023**). Recent progress of wearable piezoelectric pressure sensors based on nanofibers, yarns, and their fabrics via electrospinning. *Advanced Materials Technologies*, 8(5), 2201161. https://doi.org/10.1002/admt.202201161
97. Mishra, R. B., El-Atab, N., Hussain, A. M., & Hussain, M. M. (**2021**). Recent progress on flexible capacitive pressure sensors: From design and materials to applications. *Advanced materials technologies*, 6(4), 2001023. https://doi.org/10.1002/admt.202001023
98. Wang, Y., Xi, K., Mei, D., Liang, G., & Chen, Z. (**2016**). A flexible tactile sensor array based on pressure conductive rubber for contact force measurement and slip detection. *Journal of Robotics and Mechatronics*, 28(3), 378-385. https://doi.org/10.1016/j.sna.2019.07.036
99. Mondal, B., Roy, J. K., Mondal, N., & Sarkar, R. (**2016**, November). An approach to design a Bourdon tube pressure transmitter for remote measurement. In 2016 *10th International Conference on Sensing Technology (ICST)* (pp. 1-6). IEEE. https://doi.org/10.1109/ICSensT.2016.7796254
100. Szelitzky, E., Kuklyte, J., Mândru, D., & O'Connor, N. E. (**2014**). Low-cost angular displacement sensors for biomechanical applications review. *Journal of Biomedical Engineering and Technology*, 2(2), 21-28. https://www.sciepub.com/portal/downloads?doi=10.12691/jbet-2-2-3&filename=jbet-2-2-3.pdf
101. Dong, C., Bai, Y., Zou, J., Cheng, J., An, Y., Zhang, Z., ... & Li, N. (**2024**). Flexible capacitive pressure sensor: Material, structure, fabrication and application. *Nondestructive Testing and Evaluation*, 1-42. https://doi.org/10.1080/10589759.2024.2327639
102. Ha, K. H., Huh, H., Li, Z., & Lu, N. (**2022**). Soft capacitive pressure sensors: trends, challenges, and perspectives. *ACS nano*, 16(3), 3442-3448. https://doi.org/10.1021/acsnano.2c00308
103. Zhou, Q., Liu, X., Luo, S., Jiang, X., Yang, D., & Yuan, W. (**2023**). Design and numerical simulation of capacitive pressure sensor based on silicon carbide. *IEEE Sensors Journal*. https://doi.org/10.1109/JSEN.2023.3329367
104. Vorathin, E., Hafizi, Z. M., Ismail, N., & Loman, M. (**2020**). Review of high-sensitivity fiber-optic pressure sensors for low-pressure sensing. *Optics & Laser Technology*, 121, 105841. https://doi.org/10.1016/j.optlastec.2019.105841
105. Lai, C. W., Lo, Y. L., Yur, J. P., & Chuang, C. H. (**2011**). Application of fiber Bragg grating level sensor and Fabry-Perot pressure sensor to simultaneous measurement of liquid level and specific gravity. *IEEE Sensors Journal*, 12(4), 827-831. https://doi.org/10.1016/j.measurement.2011.10.026

106. Farahani, H., Wagiran, R., & Hamidon, M. N. (**2014**). Humidity sensors principle, mechanism, and fabrication technologies: a comprehensive review. *Sensors*, 14(5), 7881-7939. https://doi.org/10.3390/s140507881
107. Sajid, M., Khattak, Z. J., Rahman, K., Hassan, G., & Choi, K. H. (**2022**). Progress and future of relative humidity sensors: a review from a materials perspective. *Bulletin of Materials Science*, 45(4), 238. https://doi.org/10.1007/s12034-022-02799-x
108. El-Sheimy, N., & Youssef, A. (**2020**). Inertial sensors technologies for navigation applications: State of the art and future trends. *Satellite Navigation*, 1(1), 2. https://doi.org/10.1186/s43020-019-0001-5
109. Abduljawwad, M., Khaleel, M., Ogedengbe, T. S., & Abraheem, S. (**2023**). Sensors for daily utilization. *Int. J. Electr. Eng. and Sustain.*, 106-119. https://ijees.org/index.php/ijees/article/view/53
110. Balestrieri, E., Daponte, P., De Vito, L., & Lamonaca, F. (**2021**). Sensors and measurements for unmanned systems: An overview. *Sensors*, 21(4), 1518. https://doi.org/10.3390/s21041518
111. Zhmud, V. A., Kondratiev, N. O., Kuznetsov, K. A., Trubin, V. G., & Dimitrov, L. V. (**2018**, May). Application of ultrasonic sensor for measuring distances in robotics. *In Journal of Physics: Conference Series* (Vol. 1015, No. 3, p. 032189). IOP Publishing. https://www.doi.org/10.1088/1742-6596/1015/3/032189
112. Ye, Y., Zhang, C., He, C., Wang, X., Huang, J., & Deng, J. (**2020**). A review on applications of capacitive displacement sensing for capacitive proximity sensor. *Ieee Access*, 8, 45325-45342. https://doi.org/10.1109/ACCESS.2020.2977716
113. Gazis, A., & Katsiri, E. (**2020**). A wireless sensor network for underground passages: Remote sensing and wildlife monitoring. *Engineering reports*, 2(6), e12170. https://doi.org/10.1002/eng2.12170
114. Russel, A., Karda, J., Jain, P., Kale, S., & Khaire, P. (**2016**). Simulation and Experimental Study for Selection of Gauge Area Cross-Section of 'S'Type Load Cell. https://www.academia.edu/89142605/Simulation_and_Experimental_Study_for_Selection_of_Gauge_Area_Cross_Section_of_S_Type_Load_Cell
115. Hastawan, A. F., Haryono, S., Utomo, A. B., Hangga, A., Setiyawan, A., Septiana, R., ... & Triantino, S. B. (**2021**, March). Comparison of testing load cell sensor data sampling method based on the variation of time delay. In *IOP Conference Series: Earth and Environmental Science* (Vol. 700, No. 1, p. 012018). IOP Publishing. http://dx.doi.org/10.1088/1755-1315/700/1/012018
116. Zhang, L., Zhu, J., Li, Y., & Jin, Y. (**2021**, October). Automation Level of Measurement and Development of Load Cells. In 2021 3rd *International Conference on Artificial Intelligence and Advanced Manufacture* (pp. 387-391). https://doi.org/10.1145/3495018.3495085
117. Upadhyay, D.; Sampalli, S.; Plourde, B. (**2020**). Vulnerabilities' Assessment and Mitigation Strategies for the Small Linux Server, Onion Omega2. *Electronics* Jun 10;9(6):967. https://doi.org/10.3390/electronics9060967
118. Clark, L. (**2019**) What is the ASUS Tinker Board? *In Practical Tinker Board: Getting Started and Building Projects with the ASUS Single-Board Computer*:3–11. https://doi.org/10.1007/978-1-4842-3826-4_1
119. Kratz, S.; Monroy-Hernández, A.; Vaish, R. (**2022**). What's Cooking? Olfactory Sensing Using Off-the-Shelf Components. In Adjunct Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology; Oct 29; pp. 1–3. https://doi.org/10.1145/3526114.3558687
120. Mekala, R.; Sathya, M. (**2023**) Raspberry Pi-based Smart Energy Meter Using Internet of Things with Artificial Intelligence. *Eng. World*. 5. E-ISSN: 2692-5079. https://doi.org/10.37394/232025.2023.5.23
121. Tamayo, J. D., Reyes, A. M., Andrada, E. J., Amores, S. M., & Garcia, J. O. (**2024**). Deployment and Evaluation of ChromeOS. *International Journal of Multidisciplinary*: *Applied Business and Education Research*, 5(7), 2474-2479. https://doi.org/10.11594/ijmaber.05.07.09