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IoT–Integrated Optical Thickness Sensor with LED Light Source

Badania nad zintegrowanym z IoT czujnikiem optycznym grubości z wykorzystaniem źródła światła LED do monitorowania jakości produktu

***Abstract**. This research investigates the development of a cost–effective IoT–integrated optical thickness sensor utilizing an LED light source for product quality monitoring. The primary objective is to assess the feasibility of employing a simple optical device to measure the thickness and color of transparent flat surfaces. The methodology involves an RGB LED source that emits light toward the transparent plastic sheet, with the transmitted light being collected by a photodetector and sent to a NODEMCU through an operational amplifier. The LED–emitted rays are partially reflected by the material layer, while the remainder of the light is either absorbed or transmitted depending on the material properties. The optical sensor is connected to the Blynk application to enable IoT capabilities, allowing for the collection of 200 data points per measurement. Experimental results demonstrated that the sensor achieved a maximum sensitivity of 1.44 V/mm and a linearity of 95.49% when measuring a transparent green plastic sheet with a green LED light source. This work underscores the potential of integrating optical sensing technology with IoT solutions to enhance quality control processes in various industries.*

***Streszczenie.** Niniejsze badania badają rozwój ekonomicznego zintegrowanego z IoT optycznego czujnika grubości wykorzystującego źródło światła LED do monitorowania jakości produktu. Głównym celem jest ocena wykonalności zastosowania prostego urządzenia optycznego do pomiaru grubości i koloru przezroczystych płaskich powierzchni. Metodologia obejmuje źródło LED RGB, które emituje światło w kierunku przezroczystej folii plastikowej, a światło przechodzące jest zbierane przez fotodetektor i przesyłane do NODEMCU za pośrednictwem wzmacniacza operacyjnego. Promienie emitowane przez diodę LED są częściowo odbijane przez warstwę materiału, podczas gdy reszta światła jest pochłaniana lub przekazywana w zależności od właściwości materiału. Czujnik optyczny jest podłączony do aplikacji Blynk, aby umożliwić funkcje IoT, umożliwiając zbieranie 200 punktów danych na pomiar. Wyniki eksperymentalne wykazały, że czujnik osiągnął maksymalną czułość 1,44 V/mm i liniowość 95,49% podczas pomiaru przezroczystej zielonej folii plastikowej za pomocą zielonego źródła światła. W pracy podkreślono potencjał integracji technologii czujników optycznych z rozwiązaniami IoT w celu usprawnienia procesów kontroli jakości w różnych gałęziach przemysłu.*

Keywords: Optical sensor, LED, IoT
Słowa kluczowe: czujnik optyczny, LED, IoT

Introduction

Smart infrastructure is closer to reach than ever. The Internet of Things (IoT) interconnects numerous numbers of data acquisition and processing tools, such as actuators and sensors, enabling the construction of smart cities and factories based on efficient and reliable infrastructure [1, 2]. This infrastructure integrates production lines, quality control systems, and safety tools with distributed sensors and communication networks [3], while omnipresent telecommunication networks smoothly and efficiently support heterogeneous transmission technologies [4]. Achieving reliable and efficient quality control requires the development and integration of sensors with information and telecommunication technologies (ICT). Machine–to–machine protocols, combined with the Internet of Things, blur the boundaries between the manufacturing and telecommunication sectors [5]. Intelligent and cost–effective data acquisition and processing bridge the gap between these two sectors [6].

Fiber optic and photonic technologies play a significant role in telecommunication networks. Within the IoT framework, they operate as sensors at the device layer and as transmission media at the network layer [7]. Contemporary transport infrastructure is built on optical telecommunication systems, which provide valuable, ubiquitous support to the transport networks in IoT systems [8].

Photonics sensors are well–suited for quality control IoT applications. Manufacturing quality and process control do not impose strict constraints on energy consumption and network reach, unlike traffic control and navigation applications [9]. Photonics sensors can be widely deployed in both discrete and distributed systems [9, 10]. Additionally, they can operate in harsh and hazardous environments [11], and photonics sensors are immune to electromagnetic interference [12]. Therefore, photonics sensors can be deployed in hospitals, factories as well as both on–shore and underwater oil and gas facilities [13–15].

Recently, photonics sensors have garnered increased attention due to their sensitivity, stability, and reliability [16]. However, the development of photonics sensors can become a costly endeavor. Optical equipment, such as laser light sources, modulators, and lock–in amplifiers, contributes to the high costs associated with photonics sensors. The complexity of these sensors requires professional handling, rendering them often inaccessible to small industries [17]. Furthermore, IoT integration is essential for photonics sensors in quality control applications. Thus, future developments in photonics sensors should take these considerations into account.

Films below a specified thickness may physically fail by bursting, splitting, or leaking. These films can become less effective at preventing the migration of oxygen and contaminants, leading to product spoilage. Measuring and manufacturing within tight tolerances can significantly reduce raw material waste, thereby improving productivity and reducing costs. To manufacture plastic raw materials in different colors, pigments and toners are used to match these colors. Colorimeters are necessary to maintain the consistency of the color in plastic products, a process that photonics sensors can facilitate [18].

Photonics sensors have been developed to detect the thickness of samples. Chromatic confocal systems based on inclined illumination achieve an axial measurement accuracy at the micron level, as demonstrated in tests measuring glass slide thickness [19]. A fiber–optic confocal probe with an integrated camera achieved a lateral resolution of 1.2 µm for a 2.5–mm radius ball lens, allowing it to measure the central thickness of small ball lenses and other optical tools [20]. A laser confocal sensor designed for surface topography measured surface roughness within the range of 0.2–7.0 µm, with a relative accuracy of 5% [21]. Lens–fiber interference (LFI) systems have been used to monitor the thickness of transparent sheets with known refractive indices [22]. A fiber optic displacement sensor detected the thickness of transparent plates in the range of 1.0 –2.5 mm; its peak output varied linearly with sample thickness [23]. These sensors demonstrated promising performance; however, they often require costly equipment and careful, professional handling. Additionally, the large equipment needed for these sensors occupies significant space. Therefore, photonics sensors should aim to be more compact and cost–effective to achieve wider adoption for quality control [24].

This paper presents a simple and cost–effective photonics device for product quality monitoring. The IoT–integrated sensor measures the thickness of transparent surfaces, incorporating an LED light source and photodetector circuits for measuring both thickness and color of these transparent flat surfaces. The photonics sensor has been integrated with an IoT platform, and the results of the experimental analysis are presented in this paper.

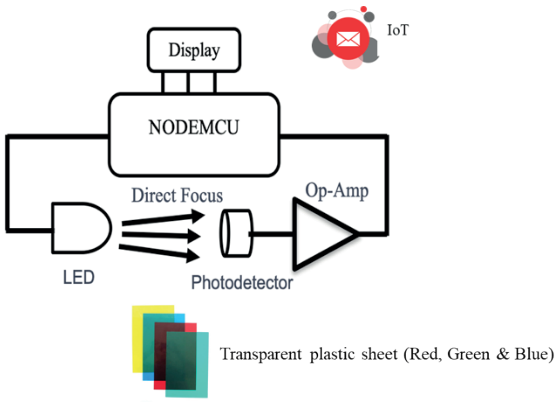


Fig. 1. Sensing Mechanism for thickness measurements

Methodology

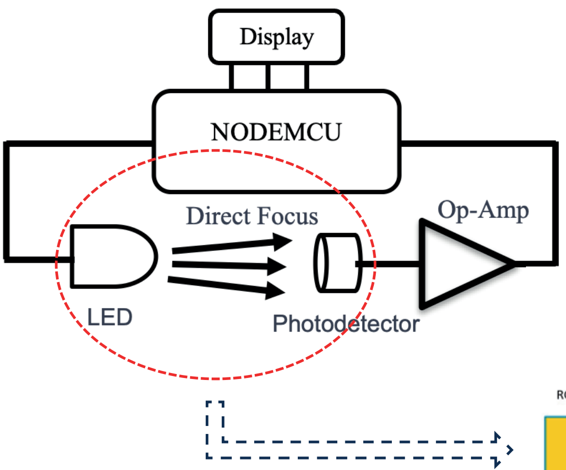
The proposed sensor's sensing mechanism is shown in Figure 1. The RGB LED source emits light towards the tested material/transparent sheet. The transmitted light is collected by the photodetector (SFH 203 P OSRAM) and sent to a NODEMCU through an op–amp (LT1884 manufactured by Analog Devices Inc.). The LED–emitted rays are partially reflected by the transparent plastic sheets, while the rest of the light is absorbed or transmitted depending on the materials' properties.

Figure 2 shows the sensor's connection to the Blynk application to achieve IoT capabilities through network connectivity. The sensor's optical unit consists of the optical source, the tested material, and the photodetector in an open–space setup. The Blynk app is a simple IoT connectivity tool and serves as an application builder for IoT prototyping, deployment, and management.

A red LED light source is set up, and a transparent red plastic sheet is placed between the LED and the photodetector. The transparent red plastic sheets range from one to four sheets. Each transparent plastic sheet has a thickness of 0.3 mm. The photodetector will collect the light that passes through the transparent red plastic layers and send it to the IoT platform to be recorded 200 times. The experiment is repeated with green and blue transparent plastic sheets using the red LED light source. Once the experiments with the red LED light source for all three colors of transparent plastic are completed, the experiments are repeated with green and blue LED light sources. Next, all the collected data is analyzed, and the performance of this sensor is determined.

Results and discussion:

Figure 3 shows the sensor performance with different thicknesses for transparent red PVC. The thickness range was 0.33–1.8 mm. The red sensitivity was –0.33 V/mm com-



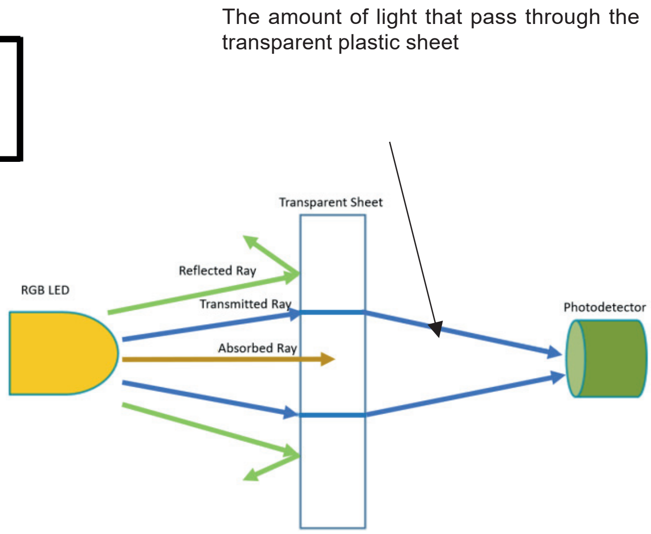


Fig. 2: Optical sensor connection to the Blynk application

pared to 0.03 for the green and blue. The green and blue showed similar results. Table 1 shows that the sensor's linearity for the red was >99%. The standard deviation was 0.183 V. The sensor showed a resolution of 0.261 mm.

Figure 4 presents the sensor performance with different thicknesses for transparent green PVC. The thickness range was 0.3–1.8 mm. The green sensitivity was –1.44 V/mm compared to –0.27 for the red and –1.02 for the blue. Table 2 shows that the sensor's linearity for the red was 95.5%. The standard deviation was 0.828 V. The sensor showed a resolution of 0.063 for the green sheet.

Figure 5 presents the sensor performance with different thicknesses for transparent blue PVC. The thickness range was 03–1.8 mm. The blue sensitivity was –1.12 V/mm compared to –0.11 for the red and –1.35 for the blue. Table 3 shows that the sensor's linearity for the red was 98%, and the standard deviation was 0.636 V. The sensor showed a resolution of 0.143 for the blue.

Figure 6 compares the sensitivity between thickness and the transparent sheet colour. The green sheet with a green source had a sensitivity of –1.44 V/mm. The blue sheet was –1.35, and the red was –0.03 for the sheet thickness testing. The blue source with the blue sheet testing had a –1.12 V/mm sensitivity compared to –1.02 V/mm for the green sheet and –0.03 V/mm for the red sheet. The red source had a –0.33 V/mm for the red sheet testing and a –0.27 V/mm and –0.11 V/mm for the green and blue sheets, respectively. The green light source has the best consistency for sensitivity.

Figure 7 shows the linearity of the sensing performance. The red source with red sheets reached 99.83%. The green with green sheets was 95.49%. The blue with blue sheets was 97.99%. The green light source has the best consistency linearity. The sensor design shows a promising linear response.

Figure 8 shows the resolution of the sensor. The resolution indicates the slightest thickness variation the sensor can detect. The sensor designed here showed a resolution of 0.261 mm for the red sheet, 0.063 mm for the green sheet, and 0.143 mm for the blue sheet. The green light source has the best consistency and resolution.

Conclusion:

This study successfully demonstrates the feasibility of a cost–effective, IoT–integrated optical thickness sensor using an RGB LED light source for product quality monitoring.

Table 1: Sensing performance summary for red transparent PVC sheet.

Sensor Performance	Red	Green	Blue
Sensitivity (V/mm)	-0.33	-0.03	-0.03
Linearity (%)	99.83%	85.67%	65.73%
Standard Deviation (V)	0.183	0.017	0.024
Resolution	-0.261	0.000	-2.835

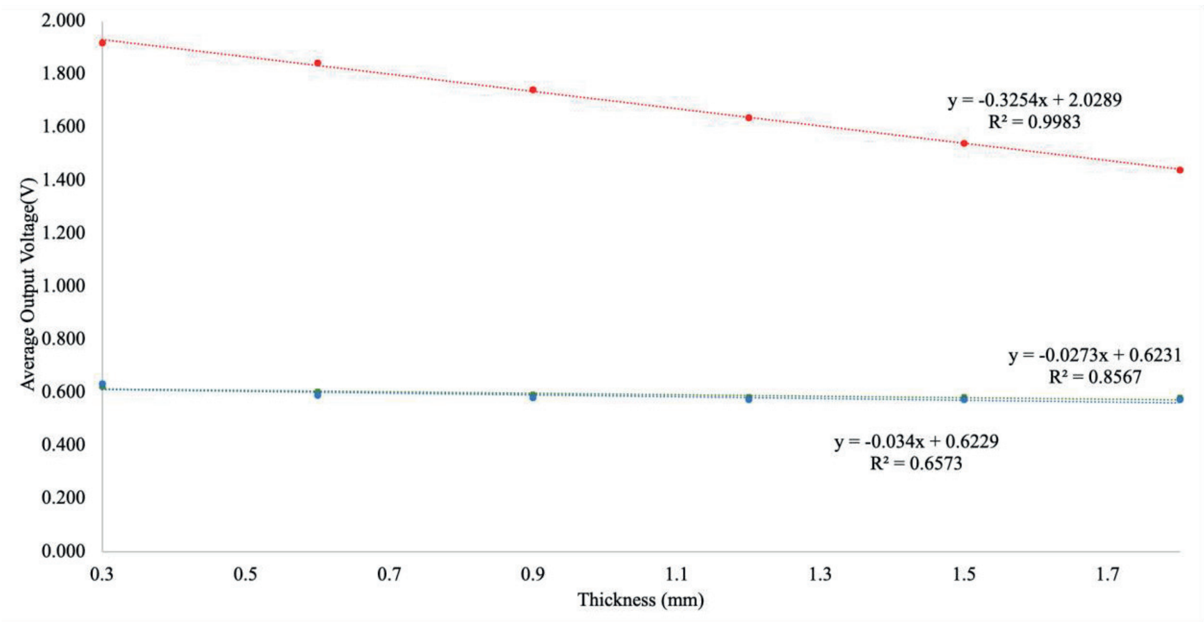


Fig. 3: Sensing performance for red transparent PVC sheet with RGB LED light Source

Table 2: Sensing performance summary for green transparent PVC sheet.

Sensor Performance	Red	Green	Blue
Sensitivity (V/mm)	-0.27	-1.44	-1.02
Linearity (%)	67.86%	95.49%	87.55%
Standard Deviation (V)	0.183	0.828	0.610
Resolution	-0.021	-0.063	-0.071

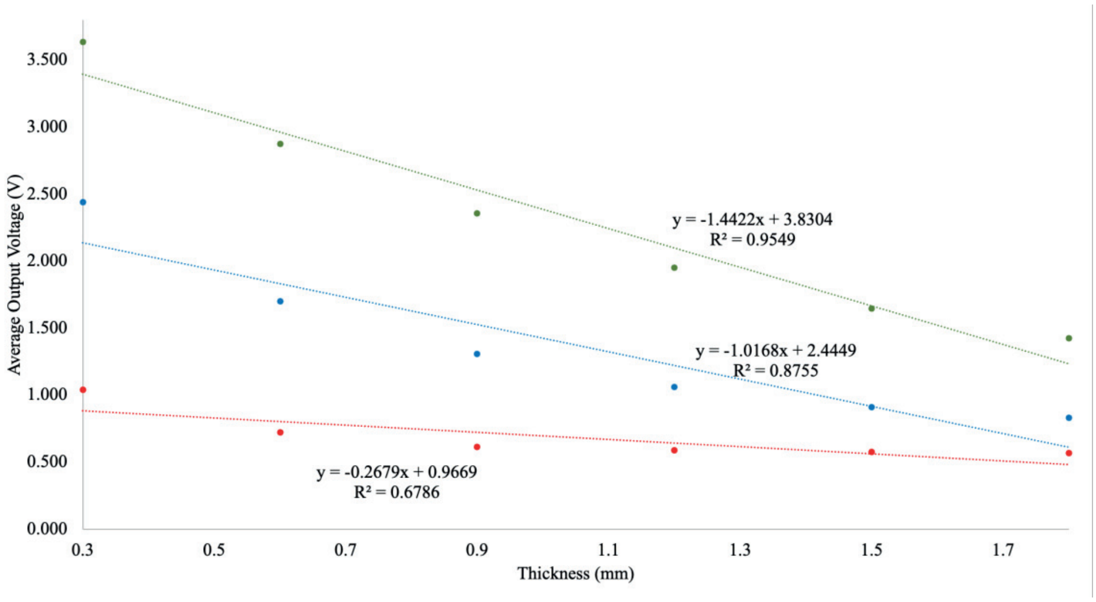


Fig. 4: Sensing performance for green transparent PVC sheet with RGB Light Source

Table 3: Sensing performance summary for blue transparent PVC sheet.

Sensor Performance	Red	Green	Blue
Sensitivity (V/mm)	-0.11	-1.35	-1.12
Linearity (%)	64.53%	92.62%	97.99%
Standard Deviation (V)	0.075	0.788	0.636
Resolution	-0.762	-0.141	-0.143

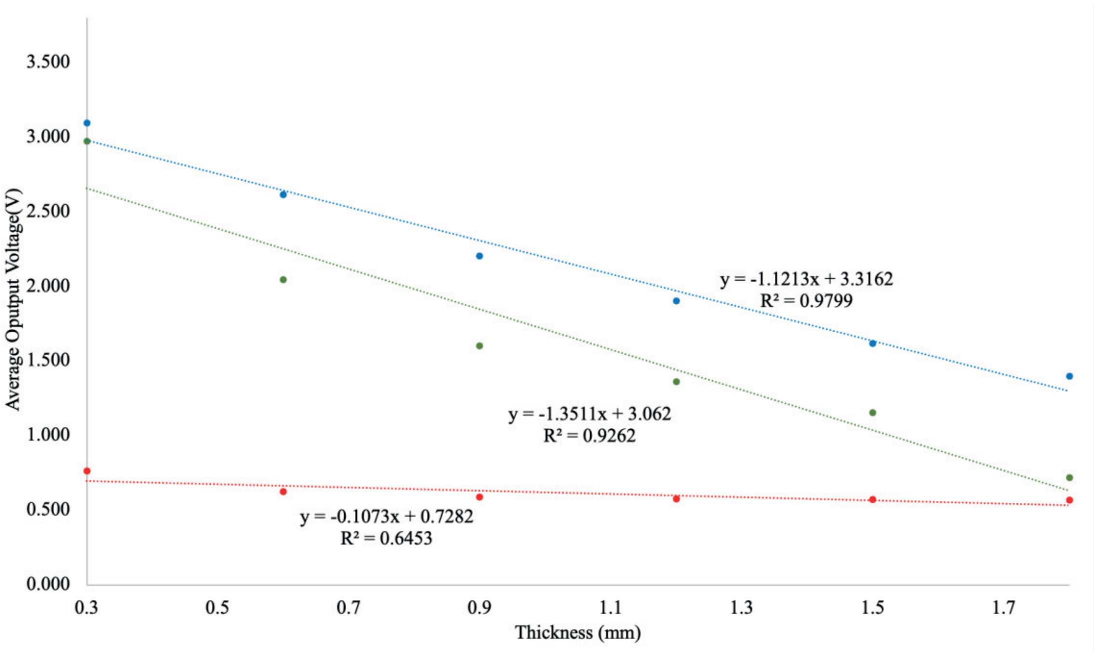


Fig. 5: Sensing performance for blue transparent PVC sheet with RGB Light Source

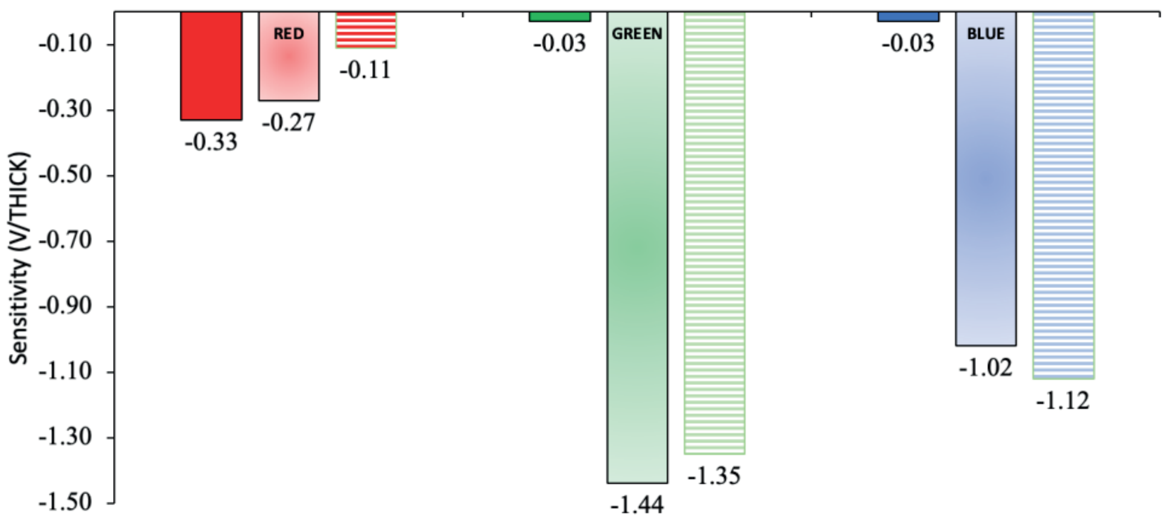


Fig. 6: Sensitivity comparison for the three transparent PVC sheets

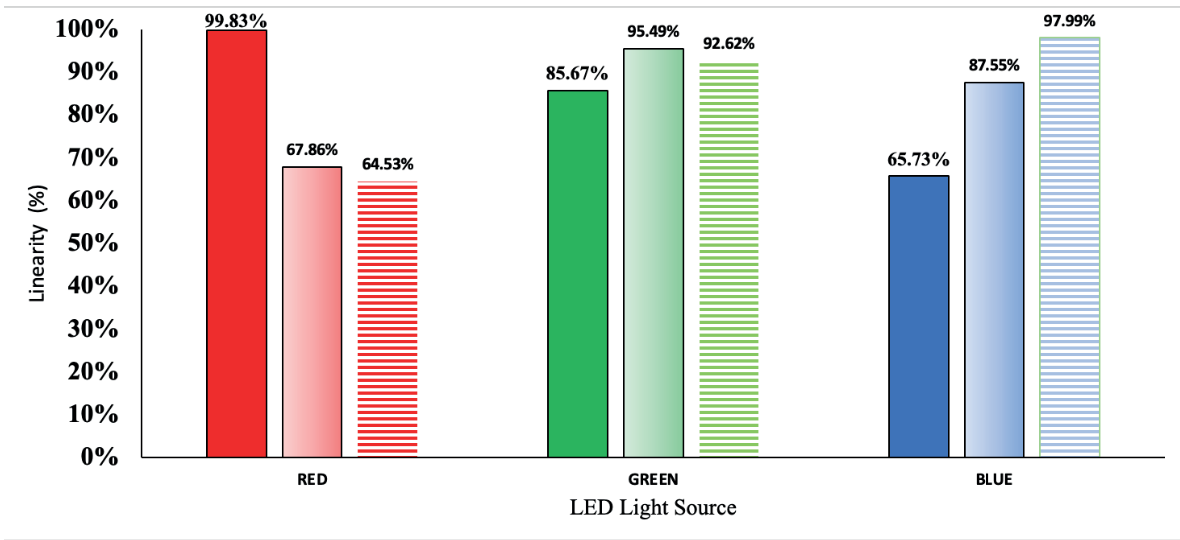


Fig. 7: Linearity comparison for the three transparent PVC sheets

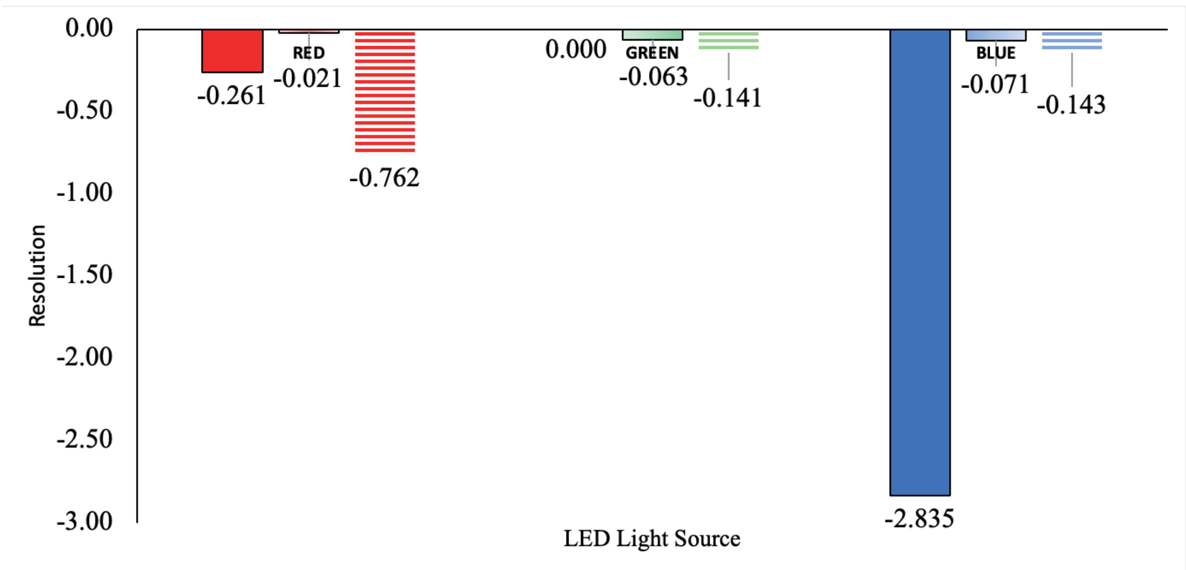


Fig. 8: Resolution comparison for the three transparent PVC sheets

The sensor output showed that the thicker transparent sheets had lower average output voltages. The integration of the sensor with IoT capabilities via the Blynk application further emphasizes the utility of real–time data collection and monitoring in quality control processes. This research paves the way for the adoption of low–cost optical sensing solutions in various industries, offering a promising avenue for improving product consistency and efficiency in manufacturing environments.

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REFERENCES:

[1] R. V. Kolhe, P. William, P. M. Yawalkar, D. N. Paithankar, and A. R. Pabale, "Smart city implementation based on Internet of Things integrated with optimization technology, " Measurement: Sensors, vol. 27, p. 100789, 2023.
[2] M. Ryalat, H. ElMoaqet, and M. AlFaouri, "Design of a smart factory based on cyber–physical systems and Internet of Things towards Industry 4.0," Applied Sciences, vol. 13, no. 4, p. 2156, 2023.
[3] M. S. Al–Kahtani, F. Khan, and W. Taekeun, "Application of internet of things and sensors in healthcare, " Sensors, vol. 22, no. 15, p. 5738, 2022.
[4] T. Park, N. Abuzainab, and W. Saad, "Learning how to communicate in the Internet of Things: Finite resources and heterogeneity, " IEEE Access, vol. 4, pp. 7063–7073, 2016.
[5] M. S. Raza, T. Zongsheng, and M. M. A. Muslam, "A review of human–to–machine and machine–to–machine approaches for internet of things, " in 2020 International Conference on Communications, Signal Processing, and their Applications (ICCSPA), 2021: IEEE, pp. 1–5.
[6] A. Morchid, R. El Alami, A. A. Raezah, and Y. Sabbar, "Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges, " Ain Shams Engineering Journal, p. 102509, 2023.
[7] P. P. Ray, "A survey on Internet of Things architectures, " Journal of King Saud University–Computer and Information Sciences, vol. 30, no. 3, pp. 291–319, 2018.
[8] A. S. Naik, S. K. Reddy, and G. R. Mandela, "A systematic review on implementation of Internet–of–Things–based system in underground mines to monitor environmental parameters, " Journal of The Institution of Engineers (India): Series D, pp. 1–17, 2023.
[9] M. Soori, B. Arezoo, and R. Dastres, "Internet of things for smart factories in industry 4.0, a review, " Internet of Things and Cyber–Physical Systems, 2023.
[10] N. Khan, W. D. Solvang, and H. Yu, "Industrial Internet of Things (IIoT) and Other Industry 4.0 Technologies in Spare Parts Warehousing in the Oil and Gas Industry: A Systematic Literature Review, " Logistics, vol. 8, no. 1, p. 16, 2024.
[11] A. M. i. Maidi, N. Shamsuddin, W.–R. Wong, S. Kaijage, and F. Begum, "Characteristics of ultrasensitive hexagonal–cored photonic crystal fiber for hazardous chemical sensing, " in Photonics, 2022, vol. 9, no. 1: MDPI, p. 38.
[12] T. He, W. Wang, B.–G. He, and J. Chen, "Review on optical fiber sensors for hazardous–gas monitoring in mines and tunnels, " IEEE Transactions on Instrumentation and Measurement, 2023.
[13] N. R. Amalia, A. M. Hatta, S. Koentjoro, A. M. Nasution, and I. Puspita, "Fiber Sensor for Simultaneous Measurement of Heart and Breath Rate on SmartBed, " in 2020 IEEE 8th International Conference on Photonics (ICP), 2020: IEEE, pp. 68–69.
[14] P. Kumar, G.–L. Shih, C.–K. Yao, S. T. Hayle, Y. C. Manie, and P.–C. Peng, "Intelligent Vibration Monitoring System for Smart Industry Utilizing Optical Fiber Sensor Combined with Machine Learning, " Electronics, vol. 12, no. 20, p. 4302, 2023.
[15] Y.–Y. Wang, F.–X. Zhang, Q.–C. Zhao, and C.–R. Che, "Real–time monitoring of pressure and temperature of oil well using a carbon–coated and bellow–packaged optical fiber sensor, " Optical Fiber Technology, vol. 67, p. 102703, 2021.
[16] J. Wang, Y. Han, Z. Cao, X. Xu, J. Zhang, and F. Xiao, "Applications of optical fiber sensor in pavement Engineering: A review, " Construction and Building Materials, vol. 400, p. 132713, 2023.
[17] H. Nazemi, A. Joseph, J. Park, and A. Emadi, "Advanced Micro– and Nano–Gas Sensor Technology: A Review, " Sensors, vol. 19, no. 6, p. 1285, 2019. [Online]. Available: https://www.mdpi.com/1424–8220/19/6/1285.
[18] S. Aleksic, "A survey on optical technologies for IoT, smart industry, and smart infrastructures, " Journal of Sensor and Actuator networks, vol. 8, no. 3, p. 47, 2019.
[19] B. Sutapun, A. Somboonkaew, R. Amarit, and S. Chanhorm, "Development and Beam–Shape Analysis of an Integrated Fiber–Optic Confocal Probe for High–Precision Central Thickness Measurement of Small–Radius Lenses, " Sensors, vol. 15, no. 4, pp. 8512–8526, 2015. [Online]. Available: https://www.mdpi.com/1424–8220/15/4/8512.
[20] Q. Yu et al., "Thickness Measurement for Glass Slides Based on Chromatic Confocal Microscopy with Inclined Illumination, " Photonics, vol. 8, no. 5, p. 170, 2021. [Online]. Available: https://www.mdpi.com/2304–6732/8/5/170.
[21] S. Fu, F. Cheng, T. Tjahjowidodo, Y. Zhou, and D. Butler, "A Non–Contact Measuring System for In–Situ Surface Characterization Based on Laser Confocal Microscopy, " Sensors, vol. 18, no. 8, p. 2657, 2018. [Online]. Available: https://www.mdpi.com/1424–8220/18/8/2657.
[22] W. A. Ramadan, M. A. Shams El–Din, H. H. Wahba, A. S. El–Tawargy, and A. A. Hamza, "Lens–fibre interference proposed to monitor a transparent sheet's thickness variations, " Applied Physics B, vol. 117, no. 4, pp. 1073–1080, 2014/12/01 2014, doi: 10.1007/s00340–014–5928–5.
[23] D. Sastikumar, G. Gobi, and B. Renganathan, "Determination of the thickness of a transparent plate using a reflective fiber optic displacement sensor, " Optics & Laser Technology, vol. 42, no. 6, pp. 911–917, 2010/09/01/2010, doi: https://doi.org/10.1016/j.optlastec.2010.01.008.
[24] Rymarczyk, T., Szumowski, J., Adamkiewicz, P., Tchórzewski, P., & Sikora, J. (2017). Electrical capacitance tomography and optical detection in quality control system. Prz. Elektrotechniczny, 93, 211–214.