Laser-Based Volume Measurement System for Optimizing the 3D Printing Process

Krzysztof Zbroja, Mariusz Giergiel
AGH University of Krakow, Poland

Marcin Ostrowski
Centrum Badań i Rozwoju Technologii dla Przemysłu SA

Abstract: This article presents the development of a volume measurement system for calibrating material flow in the print head of a 3D printer operating with FDM technology, with usage of pellet material. To ensure high printing precision, it was necessary to design a measurement system capable of calibrating material flow by determining the volume of the deposited material path. A laser triangulation method – an optical, non-contact distance measurement technique – was employed for this purpose. In this approach, diffused laser light, focused through a lens, is projected onto a CCD or CMOS sensor. The position of the laser beam on the sensor allows for the precise calculation of the distance to the object. Given the high cost of commercial laser profilometers and the closed architecture of low-cost systems offered by existing 3D printer manufacturers, a custom measurement solution was developed. The system architecture is based on low-cost an widely accessible materials. A dedicated image processing algorithm was developed to analyze the deformation of the laser line and convert the profile data into volumetric measurements. The system interfaces with the printer's control unit. Experimental validation was conducted using a reference object – a machined plate with a insertion of known dimensions. The results confirmed high measurement accuracy, with errors in the range of tenths of a cubic millimeter, which is considered sufficient for the intended application.

Keywordse: laser triangulation, laser measurement, extrusion, pellet, 3D printing, FDM, profile sensor

1. Introduction

Fused Deposition Modeling (FDM) is one of the most popular 3D printing technologies. It involves forming a part from a path of molten polymer fed by a printing head. Most solutions use the material in the form of filament – a strand of thermoplastic material with precisely defined diameter. The main disadvantage of this solution is the high material cost.

The ADDM sp. z o. o. company is developing a printing head allowing to 3D print elements using standard granulate widely used in polymer processing industry. This solution will significantly reduce the costs of manufacturing 3D printed parts. The solution differs from other heads available on the market using granules in terms of high precision of material dosing and the unique mechanism of retraction. This mechanism allows to use mentioned granulate head in the way that normal filament heads are used.

As the head developed, the need for an external flow calibration system has been noticed. The principle of its operation was to measure the volume of a single material path and compare

Autor korespondujący:
Krzysztof Zbroja, kzbroja@agh.edu.pl

Artykuł recenzowany
nadesłany 15.02.2026 r., przyjęty do druku 20.07.2026 r.

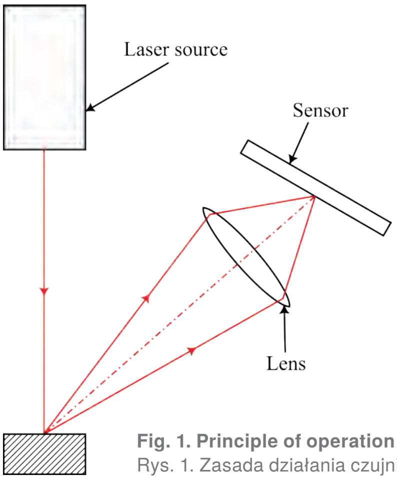

Fig. 1. Principle of operation of the triangulation sensor
Rys. 1. Zasada działania czujnika triangulacyjnego

it with the set value. The measurement is performed before printing of exact element, on a single trial path of material. Based on the measurement data, the extrusion parameters can be corrected. An important demand for measurement is to be done with a non-contact method. According to big dimensions of pellet printing head, size limits for measurement systems were not as strict as in case of normal filaments printers.

It was decided to choose the laser triangulation method for measuring dimensions of printed path. Triangulation is a non-contact, optical method of measuring the distance from a point on a surface. The principle of operation is shown in Fig. 1. A laser beam emitted from the light source is projected onto measured object and is scattered on it. Scattered light is focused using a lens and hits the sensor (usually a CCD or CMOS matrix). Based on the position of the light beam on the sensor, the distance between the object and the sensor is determined [1]. The laser triangulation method is used in both point sensors (distance sensors) and linear sensors (profile sensors).

There are many ready-made triangulation profile sensors available on the market [A1, A2]. However, their high cost makes their integration with the printing head economically impossible. Leading 3D printer manufacturers integrate similar solutions into their systems [A3]. However, these solutions are closed systems that cannot be connected to third-party hardware. For these reasons, it was necessary to develop dedicated solution for the volume measurement.

The second chapter presents a literature review on the use of machine vision in 3D printing. The third chapter describes the components used to build the system. The fourth chapter describes construction of the device. The fifth chapter presents the image processing algorithms used in the sensor. The sixth chapter describes their software implementation. The seventh presents results of system tests. The last chapter presents conclusion.

2. Literature Review (State of the Art)

Vision systems are widely used for process monitoring and quality control in 3D printing. Wyrobek et al. [2] utilized a commercial laser profile sensor to measure the geometry of printed tracks and the relative positions of these tracks.

Straub [3] developed a multi-camera system for monitoring the progress of the 3D printing process. The system enables the automatic detection of filament feed interruptions and premature process termination.

Nuchitprasitchai et al. [4] presented two methods for real--time monitoring of the 3D printing process. The first method is based on a single camera. The image captured by the camera is compared with an image generated from the 3D model of the printed object. The second method uses two cameras and involves reconstructing a three-dimensional model from stereo images. The reconstructed model is then compared with the original CAD model.

Kopsacheilis et al. [5] presented a 3D printing monitoring system based on a depth camera. After every predefined number of printed layers, the printing process was interrupted and a point cloud was acquired using the camera. The captured point cloud was then compared with a reference point cloud generated from the 3D model.

Montalti et al. [6] presented a method for post-process quality control of parts manufactured by 3D printing using a 3D scanner.

Fahmy et al. [7] developed a vision system for evaluating the quality of 3D printing using cereal-based materials. The system consisted of two cameras that enabled measurements of the printed material tracks from both the top and side views.

Delli and Chang [8] presented a print monitoring system based on a single RGB camera and machine-learning algorithms. The camera was positioned above the build platform. Images were captured during pauses in the printing process after a predefined number of layers had been completed.

Faes et al. [9] used a laser triangulation method to measure the height of a printed track. Their experimental setup consisted of a digital microscope and a laser line projector. This approach is similar to the method presented in this paper. However, the image-processing algorithms used to determine the height of individual measurement points differ. Furthermore, the authors did not provide information regarding features such as compensation for variations in build platform height or calibration procedures for the measurement system.

Although numerous vision-based monitoring systems for additive manufacturing have been proposed, most of them focus on defect detection, dimensional verification, or process monitoring. Only a limited number of studies have addressed the direct measurement of the volume of deposited material tracks using low-cost laser triangulation systems integrated with FDM printers. Therefore, this work proposes a dedicated volumetric measurement system based on laser triangulation and custom image-processing algorithms for material flow calibration in pellet-fed FDM printing systems.

3. Selection of System Components

The research task began with the selection of appropriate components for the construction of the scanner. The selection was based on criteria such as component availability, documentation availability and a developed community, ease of integration with the printer control system, and affordable price. The availability of documentation and the possibility of community support were important to ensure that work on solving possible hardware and software problems did not dominate the research work itself. Price was important because the entire system could not significantly increase the price of the printhead.

The Raspberry Pi 4B single-board computer (SBC) was used as the computing platform. It is a minicomputer equipped with a 64-bit Quad-core Cortex-A72 (ARM v8) processor clocked at 1.5 GHz [A4]. The one used in the project has 4 GB of RAM. An important feature is the availability of GPIO pins, which enable triggering individual actions using binary signals from external devices. This enabled the system to synchronize with the 3D printer controller board. Another important feature is the availability of a CSI connector for connecting a camera. Due to the popularity of the solution, there are many compatible cameras available on the market. They are usually small in size, which was important in the described application. The SBC is running Raspberry Pi OS based on Debian 11 (bullseye).

The Raspberry Pi HQ M12 Camera was chosen for image acquisition. This is a device dedicated to cooperation with Raspberry Pi SBCs. The 12.3 Mpx resolution allows for adequate measurement resolution, even with a delimited ROI. The camera is compatible with M12 format lenses, making the whole setup more compact than when using the model with CS-mount lenses. The camera was equipped with an Arducam M2306ZM13 lens with a focal length of 8 mm and a viewing angle of 50°.

The LD-G650A03 miniature laser line projector was used as a light source. It is based on a laser diode that emits red light (650 nm). The module is equipped with a knob that enables adjustment of the distance at which the laser line is focused. The 3–5 V supply voltage allows power to be supplied from the voltage output on the Raspberry Pi pins.

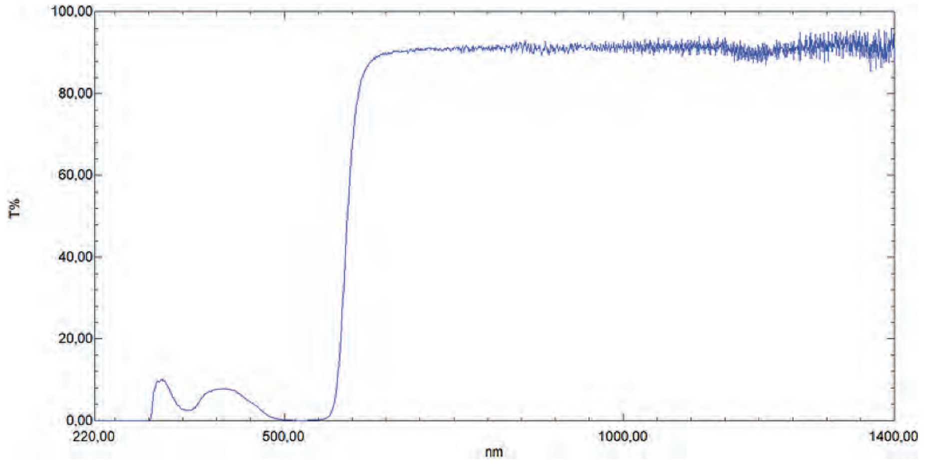

Fig. 2. Characteristic of the filter used in the system
Rys. 2. Charakterystyka filtra użytego w systemie

In order to limit the influence of external lighting on the system measurement, it was necessary to use an optical filter that only transmits light with a wavelength close to the laser wavelength. Due to the prices of professional filters with a narrow bandwidth, it was decided to use a gel filter dedicated to photography. A red filter was selected, the characteristic of which, tested on a Schimadzu UV-2600i spectrometer, is shown in Fig. 2.

4. Device Construction

As part of the research, a prototype of the device was made. The prototype body was made as a 3D printed element. It has mounting holes that allow the components to be mounted in such a way that the plane of the camera matrix is tilted by 45° relative to the plane of the laser. Since the camera is located a short distance from the measured object, it was necessary to slightly move the lens away from the sensor. This resulted in a reduction in the minimum focusing distance. This effect was achieved by screwing the lens only part way down the thread. The lens position was secured by installing additional M12x0.5 lock nuts.

A gel filter was mounted on the lens. The filter was fixed using a 3D printed plastic ring. The ring was press-fitted onto the end of the lens. The filter, in the form of a round piece of stiff foil, is attached between the ring and the lens.

Since the computing unit was placed in the machine's control cabinet, it was located at a certain distance from the measuring system. Standard ribbon cables used to connect cameras to CSI connectors are several centimeters long. In order to increase this distance, adapters were used, equipped with a CSI socket on one side and an HDMI socket on the other. They allow you to increase the distance between the SBC and the camera using an standard HDMI cable.

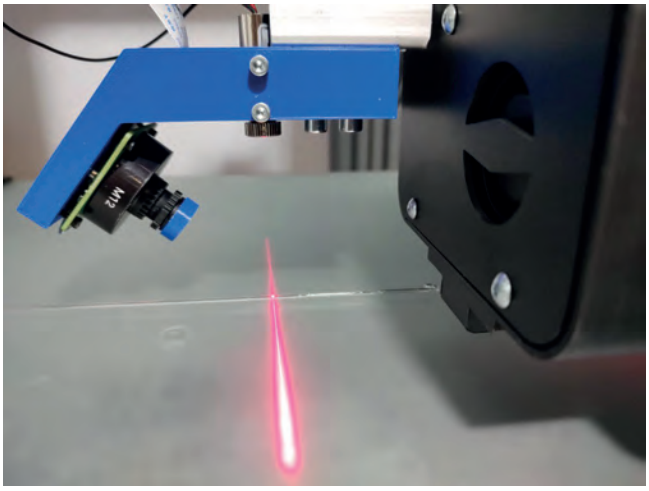

Fig. 3. An early version of the developed system - all components are visible
Rys. 3. Wczesna wersja systemu – wszystkie elementy są widoczne

The system was mounted next to the print head so that the laser beam was in a direction perpendicular to the X axis of the moving table. The early version of the system, without covers is shown in Fig. 3.

5. Algorithms

As part of the project, an algorithm was created to determine the shape of a single profile based on the recorded deformation of the laser line. Knowledge of profile's shape and distance between profiles allows to calculate elementary volume of each profile. Distance between measured profiles is fixed in 3D printer control unit, which provides trigger signal for every camera frame. Volume of measured object is calculated as a sum of elementary volumes of profiles.

Profile calculation algorithm:

1. Image acquisition
2. Limiting the ROI of the image to the area containing the analyzed object
3. Conversion between BGR and monochromatic image
4. Undistorting
5. Creating an empty matrix with dimensions identical to the dimensions of the image
6. For every column:
   - 6.1. Assigning 0 as the temporary maximum value in a column
   - 6.2. For each pixel in the column, if its value is greater than the temporary maximum value, the pixel value is assigned to the temporary maximum value.
   - 6.3. The average profile height in a given column is set to 0.
   - 6.4. For each pixel in a column, if its value is greater than or equal to the temporary maximum value minus 1, the pixel position is included in the average profile height.
   - 6.5. Average height is calculated based on the considered pixel positions.
   - 6.6. Height in pixels is converted to height in mm.
   - 6.7. The average ground height calculated in the previous algorithm call is subtracted from the current value to compensate for ground unevenness. For the first algorithm call, the average ground height is 0.
   - 6.8. If the profile height does not exceed the threshold value, the height is assumed to be 0. This allows for noise elimination.

6.9. The elementary volume is calculated based on the height. The millimeter-to-pixel conversion rates for length and width are known.
6.10. The average ground height is calculated as the average height of the points that do not exceed the threshold value.
7. The profile volume is added to the volume of the measured object.

In addition, more algorithms were used to calibrate the device.

Camera calibration was utilized to compensate for image distortions resulting from camera manufacturing inaccuracies. An algorithm from OpenCV library documentation [A5] was chosen. A 6 × 4 square chessboard was used as the calibration pattern. One square size was 3 mm × 3 mm. Such a small size of the chessboard was necessary because the system is designed to measure objects located a short distance from the camera. Calibration was performed based on 25 images.

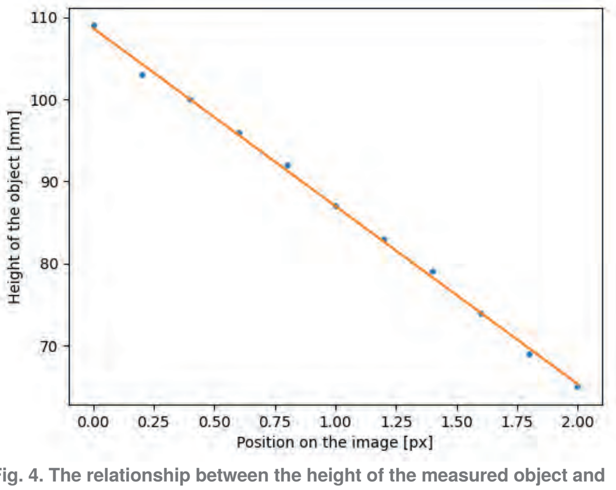

Fig. 4. The relationship between the height of the measured object and the position of the line in the analyzed area of the camera sensor
Rys. 4. Zależność wysokości mierzonego obiektu od położenia linii w analizowanym obszarze czujnika kamery

The next issue was to determine the relationship between the position in the image (given in pixels) and the height of a given profile point (in millimeters). Initially, it was planned to determine the dependencies using polynomial interpolation. This was to take into account possible nonlinearities resulting from perspective. However, the measurements carried out showed that on the scale of the developed system, the effects resulting from perspective do not have a significant impact and the determined dependence can be approximated as linear (Fig. 4). According to that, only coefficients of straight line were calculated.

Coefficients are calculated in the following way:
1. The image is acquired when there is no object in the measurement space (the system measures an empty table).
2. A profile is determined from the image in the same way as in the main algorithm.
3. The average position of the profile points in the Y axis (in pixels) is taken as corresponding to a height of 0 mm y_{0mm}.
4. The image is acquired when a 2 mm high element is placed on the table.
5. A profile is determined from the image in the same way as in the main algorithm.
6. The average of the 10 highest values of the profile position in the Y axis (in pixels) is taken as corresponding to a height of 2 mm y_{2mm}.
7. A straight line is determined passing through the points $(0, y_{0mm})$ and $(2, y_{2mm})$.

The last parameter determined during system calibration is the millimeters per pixel conversion coefficient in the axis parallel to the laser beam. It is determined by placing an object 2 mm high and 5 mm wide in the system's field of view. A profile is determined based on the image. Then the points on the profile corresponding to the appropriate height are counted. By dividing the 5 mm length by the number of pixels, the millimeters per pixel conversion rate is determined.

For the system to work properly, it is necessary to perform the following operations in the following order:
1. Internal calibration of camera
2. Straight line coefficients calculation
3. Millimeters per pixel conversion coefficient calcualtion

6. Implementation

The developed algorithms were implemented in C++ on the Raspberry Pi 4B platform. The program utilized the following libraries:
- OpenCV – image processing library,
- raspicam – library for communication with CSI camera,
- pigpio – library that allows to control GPIO,
- httplib – library for http communication.

The program provides two operation modes: automatic mode and configuration mode.

Automatic mode is used for measurements in cooperation with the printer controller board. In this mode, the program is controlled by binary signals on the GPIO inputs. It allows to coordinate program flow with printer movements. Three digital inputs are used for control: start of measurement, triggering of a single profile and end of measurement. Program's state machine consist of three states:
1. Standby state – the volume of the measured object is reset to zero. The program waits for a high state on the pin responsible for starting the measurement. If it appears, the program goes to state 2.
2. Measurement state:
   2.1. If a high state appears on the pin responsible for measuring a single profile, the profile measurement algorithm is executed. The volume of the measured object is increased by the measured profile elementary volume.
   2.2. If a high state appears on the pin responsible for ending the measurement, the program goes to state 3.
3. Measurement completion status – results are sent to the printer driver via HTTP protocol. Program goes to state 1.

The configuration mode allows to set system parameters using the algorithms used in the previous chapter. Additionally, it allows to preview both the recorded image and the generated profile. An example image and a profile based on it are shown in Fig. 5.

7. System Testing

In order to test the correct operation of the system, it was necessary to use an object with known geometry. For this purpose, a milled plate was used, which had a projection 5 mm wide and 2 mm high. Thirty measurements were made at different locations along the length of the projection, each over a distance of 10 mm. The theoretical volume for each measurement was therefore 100 mm³. The measurement results are presented in Table 1.

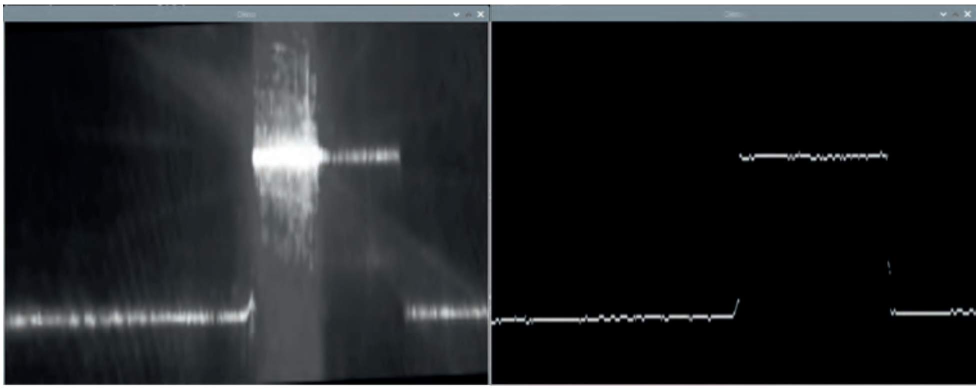

Fig. 5. Left: camera image; right: profile generated from the image
Rys. 5. Po lewej: obraz pozyskany z kamery; po prawej: profil wygenerowany na podstawie obrazu

The maximum relative error of the results was 0.696 %. The standard deviation was 0.3096. This accuracy was considered sufficient from the point of view of the application of the system.

8. Conclusions

The developed system is capable of measuring the volume of a single path from a 3D printer head using pellet. This proves the possibility of using low-cost, widely available components to develop a measurement system that replaces much more expensive ready-made universal solutions in a given area. Calculation of costs is shown in Table 2. For the comparison cost of ready-made profile sensors exceeds 15,000 PLN net [A7].

Further work should focus on modifying the system's optics so that a larger part of the camera sensor can be used. This will improve the resolution of the system. To achieve this goal, it is necessary to change the optics to one with higher magnification.

Table 1. Measurements of the volume
Tabela 1. Wyniki pomiarów objętości

Measurement number	Measured volume [mm³]	Measurement number	Measured volume [mm³]
1	99.6338	16	100.313
2	99.9824	17	100.183
3	100.388	18	100.24
4	100.315	19	99.9765
5	100.2	20	99.9787
6	100.259	21	100.392
7	99.485	22	100.326
8	99.403	23	100.193
9	99.9781	24	100.283
10	100.409	25	99.9328
11	100.309	26	99.4135
12	100.247	27	99.9854
13	99.3036	28	100.406
14	99.9834	29	100.335
15	100.397	30	100.253

Table 2. System's cost calculation [A6]
Tabela 2. Kalkulacja kosztów system [A6]

Item	Name	Cost [PLN net]
Single Board Computer	Raspberry Pi 4B 4 GB RAM	405.69
Camera	Raspberry Pi HQ M12 Camera	178.66
CSI Extender	KAmodCSIextender	36.5
Line laser diode	LD-G650A03 - Line	9.06
Sum		629.91

One problem is the shallow depth of field. It does not pose any difficulties when analyzing thin tracks – the system therefore meets current needs. In a later stage of development, it will be beneficial to change the mechanical structure of the camera itself. The lens should be at an angle of less than 90° to the sensor, as is usually done in triangulation sensors [1]. This will allow you to increase the measurement range.

Acknowledgements

The research was conducted as part of the FEMP.01.02-IP.01-0347/23-00 project "Development of a system for automatic calibration and control of operating parameters of a printhead processing polymer material in the form of granulate using FDM 3D printing technology", implemented by ADDM sp. z o.o. in cooperation with CBRTP SA.

The FEMP.01.02-IP.01-0347/23-00 project, worth PLN 368,016.00, was obtained through the Małopolska Entrepreneurship Center (IP.OI.FEMP) under the European Regional Development Fund in the Program: European Funds for Małopolska 2021–2027, Priority: European Funds for Research and Development and Entrepreneurship, Measure: Innovation Vouchers for SMEs, with financial support in the amount of PLN 254,320.00.

Bibliography

1. Donges A., Noll R., *Laser Triangulation*, [In:] „Laser Measurement Technology", Springer Series in Optical Sciences, Vol. 188, 2015, DOI: 10.1007/978-3-662-43634-9_10.
2. Wyrobek K., Stryczek R., *Laserowy pomiar geometrii ścieżki druku 3D*, „Pomiary Automatyka Robotyka", R. 29, Nr 4, 2025, 49–56, DOI: 10.14313/PAR_258/49.
3. Straub J., *Initial Work on the Characterization of Additive Manufacturing (3D Printing) Using Software Image Analysis*, "Machines", Vol. 3, No. 2, 2015, 55–71. DOI: 10.3390/machines3020055.
4. Nuchitprasitchai S., Roggemann M., Pearce J., *Factors effecting real-time optical monitoring of fused filament 3D printing*, "Progress in Additive Manufacturing", Vol. 2, 2017, 133–149, DOI: 10.1007/s40964-017-0027-x.
5. Kopsacheilis C., Charalampous P., Kostavelis I., Tzovaras D., *In Situ Visual Quality Control in 3D Printing*, [In:] Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020), Vol. 3, 2020, 317–324, DOI: 10.5220/0009329803170324.
6. Montalti A., Ferretti P., Santi G.M., *A Cost-Effective Approach for Quality Control in Material Extrusion 3d Printing Via 3d Scanning*, 2024, DOI: 10.2139/ssrn.4825393.
7. Fahmy A., Becker T., Jekle M., *3D printing and additive manufacturing of cereal-based materials: Quality analysis of starch-based systems using a camera-based morphological approach*, "Innovative Food Science & Emerging Technologies", Vol. 63, 2020, DOI: 10.1016/j.ifset.2020.102384.
8. Ugandhar D., Chang Shing., *Automated Process Monitoring in 3D Printing Using Supervised Machine Learning*, "Procedia Manufacturing", Vol. 26, 2018, 865–870, DOI: 10.1016/j.promfg.2018.07.111.
9. Faes M., Vogeler F., Coppens K., Valkenaers H., Abbeloos W., Goedemé T., Ferraris E., *Process Monitoring of Extrusion Based 3D Printing via Laser Scanning*, International Conference on Polymers and Moulds Innovations – PMI2014, 2014, DOI: 10.13140/2.1.5175.0081.

Other sources

A1. Keyence, Skaner laserowy 2D/3D, [www.keyence.eu/plpl/products/measure/laser-2d/lj-x8000].
A2. Wenglor, *2D/3D Profile Sensors*, [www.wenglor.com/en/weCat3D-2D3D-Profile-Sensors/s/2D-3D-Profilsensoren+weCat3D].
A3. Bambu Lab Wiki, *Bambu Lab Micro Lidar*, [https://wiki.bambulab.com/en/x1/manual/micro-lidar-model].
A4. *Raspberry Pi computer hardware*, [www.raspberrypi.com/documentation/computers/raspberry-pi.html].
A5. *Camera calibration With OpenCV*, [https://docs.opencv.org/4.x/d4/d94/tutorial_camera_calibration.html].
A6. KAMAMI, [www.kamami.pl].
A7. LEUZE, *Pomiar profilu*, [www.leuze.com/pl-pl/produkty/czujniki-pomiarowe/czujniki-do-mierzenia-konturow/pomiar-profilu]

Laserowy system pomiaru objętości dla optymalizacji procesu druku 3D

Streszczenie: W artykule przedstawiono system pomiaru objętości do kalibracji przepływu materiału w głowicy drukarki 3D pracującej w technologii FDM z wykorzystaniem granulatu. Aby zapewnić wysoką precyzję druku, konieczne było zaprojektowanie systemu pomiarowego zdolnego do kalibracji przepływu materiału przez określenie objętości ścieżki osadzonego materiału. W tym celu zastosowano metodę triangulacji laserowej – optyczną, bezkontaktową technikę pomiaru odległości. Rozproszone światło lasera, skupione za pomocą soczewki, jest rzutowane na matrycę CCD lub CMOS. Położenie wiązki laserowej na matrycy pozwala na precyzyjne obliczenie odległości do obiektu. Biorąc pod uwagę wysoki koszt komercyjnych profilometrów laserowych i zamkniętą architekturę tanich systemów oferowanych przez producentów drukarek 3D, opracowano niestandardowe rozwiązanie pomiarowe. Architektura systemu oparta jest na tanich i powszechnie dostępnych materiałach. Opracowano dedykowany algorytm przetwarzania obrazu służący do analizy odkształceń linii laserowej i konwersji danych profilowych na pomiary objętościowe. System współpracuje z jednostką sterującą drukarki. Walidację eksperymentalną przeprowadzono z użyciem obiektu odniesienia – obrobionej płyty z elementem o znanych wymiarach. Wyniki potwierdziły wysoką dokładność pomiaru, z błędami rzędu kilku dziesiątych części milimetra sześciennego, co jest wartością wystarczającą dla zamierzonego zastosowania.

Słowa kluczowe: triangulacja laserowa, pomiar laserowy, ekstruzja, druk 3D, granulat, FDM, czujnik profilu

Krzysztof Zbroja, MSc Eng.
kzbroja@agh.edu.pl
ORCID: 0000-0003-1358-3922

He is a doctoral student at the AGH University of Krakow, Faculty of Mechanical Engineering and Robotics, Department of Robotics and Mechatronics. His doctoral thesis topic is "Multi-criteria quality control system in the prefabrication industry". He completed master's engineering studies in Industrial Automation and Robotics at the same faculty. From 2021 to 2025 was employed as an automation engineer in CBRTP S.A. Now he is working as automation engineer in Tech2Energy Sp. z o.o. He has experience in developing systems for industrial and process automation and automatic quality control, including programming PLC and HMI systems, robots and computer vision algorithms.

Prof. Mariusz Giergiel, DSc PhD Eng.
giergiel@agh.edu.pl
ORCID: 0000-0002-4212-1113

Professor at AGH University of Krakow, Faculty of Mechanical Engineering and Robotics, Department of Robotics and Mechatronics. Member of local and international scientific societies, author of over 200 scientific publications. His research interests include: modeling and analysis of system dynamics, issues related to the modeling, design, construction, and control of mobile robots, inspection robots, particularly those designed to operate in harsh conditions and environments, sensory systems and the use of SLAM techniques in the navigation and control of mobile robots.

Marcin Ostrowski, MSc Eng.
marcin.ostrowski@cbrtp.pl
ORCID: 0009-0002-3041-5023

Marcin Ostrowski is a graduate of Wrocław University of Science and Technology, specializing in Electronics and Telecommunications with a focus on Electronic and Computer-Based Automation Systems. He has been professionally active in the field of industrial automation since 2004. Since 2023, he has worked as an automation engineer at CBRTP S.A. in Kraków, where he participates in the implementation of research and development projects. His professional interests include industrial automation, control systems, and the automation of manufacturing processes.