# GEODESY

**UDC 528.526.6+528.022.62**

Yaroslav LOPATIN[1*], Wilhelm HEGER[2]

[1] Department of Higher Geodesy and Astronomy, Lviv Polytechnic National University, 12, S. Bandery Str., Lviv, 79013, Ukraine, *tel +38(066)3897993, e-mail: y.lopatin95@gmail.com, https://orcid.org/0000-0003-2194-4214

[2] Faculty of Landscape Sciences and Geomatics of Neubrandenburg University of Applied Sciences, 2, Brodaer Str., Neubrandenburg, 17033, Germany

https://doi.org/10.23939/istcgcap2021.93.005

# AUTOMATION OF THE MEASUREMENT PROCEDURE IN THE MECHANICAL NORTH-SEEKING GYROSCOPE

The aim of the work is to develop an automated measuring system in a mechanical gyrocompass with the help of specially developed hardware and software in order to facilitate the operation of the device and minimize observer errors. The developed complex provides automation only for the time method, as for the method of the turning point it is necessary to constantly contact the motion screw of the total station. The project is based on an integrated system, the hardware part of which contains a single-board computer, camera, and lens. The main software is a developed motion recognition algorithm with the help of image processing. This algorithm was created using the Python programming language and the open-source computer vision library OpenCV. With the help of the hardware, a video image of the gyroscope's reference scale is obtained, and with the help of the software, the moving light indicator and its position relative to the scale are identified in this image. The result of the study is a functioning automatic measurement system, which determines the value of the azimuth of the direction with the same accuracy as manual measurements. The system is controlled remotely via a computer and wi-fi network. To test the system, a series of automatic and manual measurements were performed simultaneously at the same point for the same direction. Based on the results obtained, it can be stated that the accuracy of the system is within the limits specified by the manufacturer of the device for manual measurements. The application of computer vision technology, namely the tracking of a moving object in the image for gyroscopic measurements can give a significant impetus to the development of automation systems for a wide range of measuring instruments, which in turn can improve the accuracy of measurement results. The developed system can be used together with the Gyromax AK-2M gyrocompass of GeoMessTechnik for carrying out automated measurements, training of new operators. With the help of the developed model, it is possible to avoid gross errors of the observer, to facilitate the measurement process which will not demand the constant presence of the operator near the device. In some dangerous conditions, this is a significant advantage.

*Key words:* automation, gyroscope, computer vision, motion detection, image processing.

## Introduction

The main goal of measurement automation is to avoid human interference in this process, thereby excluding possible errors of the observer, accidental shocks and blows, incorrect reading of indicators. The idea of developing automatic systems for already existing mechanical gyrocompasses arose in the early 2000s when powerful software and programming tools began to appear. In [Wetherelt & Hunt, 2002] the development of the "electronic eye" for the Wild GAK1 gyrocompass is covered. This system consists of a sensor for converting light into voltage, which transmits information to the signal conditioning and communication unit. With the movement of the gyro light indicator, the sensors convert the received light information into voltage and transmit the position of the gyroscope tape on the scale to the computer. The disadvantage of this system is the wired data transmission via COM cable to the external computer.

In the previous work of the author [Heger, et al., 2019] there was an attempt to use a linear camera as a motion sensor, which converted the intensity of light into a voltage signal but was connected to a single-board computer, which allowed to transmit data wirelessly. However, the size and format of the linear sensor did not allow the implementation of this idea in the working system.

Unfortunately, more research on this topic is not publicly available. Or they are so little known that they are not published in periodicals. But research and development of automated gyroscopic systems is actively carried out using Micro-Electro-Mechanical Systems (MEMS) [Johnson, et al., 2010], Fiber-Optic Gyros (FOG) [Sun, et al., 2010] and Ring Laser Gyros (RLG) [Juang & Radhamanan, 2009]. In [Barbour & Schmidt, 2001] authors covered all technologies, that were trending in the early 2000s. There are also quite non-standard developments that are based on completely different principles of gyroscope operation, for example, Maglev gyro [Zhen, et al., 2013], Coriolis Vibrating Gyro (CVG) [Parent, et al., 2007].

Returning to traditional suspended gyro compasses, there have been models with automatic azimuth measurement on the market for a long time. The most famous are the Gyro X II gyrocompass from SOKKIA and the GYROMAT devices from the DMT company, which have shown themselves in practice as one of the best in the world [Heister & Liebl, 2016]. At the same time, they remain the most expensive devices not available to most businesses and customers. This is precisely the interest in the automation of already existing mechanical gyrocompasses. It aims to reduce the cost and increase the reliability of the device.

## Aim

The purpose of this work is to develop an automatic measuring system that will carry out azimuth measurements with minimal operator participation, which in turn will facilitate the use of the gyrocompass and also avoid gross observer errors.

## Methodology

The idea of automation is based on the delegation of the registration process of the gyroscope's light index position on a measuring scale to the single-board computer to which a video camera is connected (Fig. 1). For the usual azimuth measurement with a mechanical gyrocompass, the operator needs to independently observe the movement of the light index on the scale and record its extreme positions, as well as the timestamp when the index passes through the zero-point of the scale. With the help of video broadcasting and computer vision algorithms, an application that will notice the movement of a light index on an image and determine the coordinates of its position can be developed. Wireless communication and measurement control from a distance can be established with a single-board computer.

To implement this project, it was decided to use a single-board computer Raspberry Pi 4 and a camera from the same manufacturer – Raspberry Pi High-Quality Camera with 12,3 megapixels and Tamron 16mm lens. Due to its low-cost and fairly high-quality image, this camera is widely used in scientific research in various fields [Cuciuc, 2018; Dinesh & Bhaskar, 2020; Albert & Surducan, 2017].

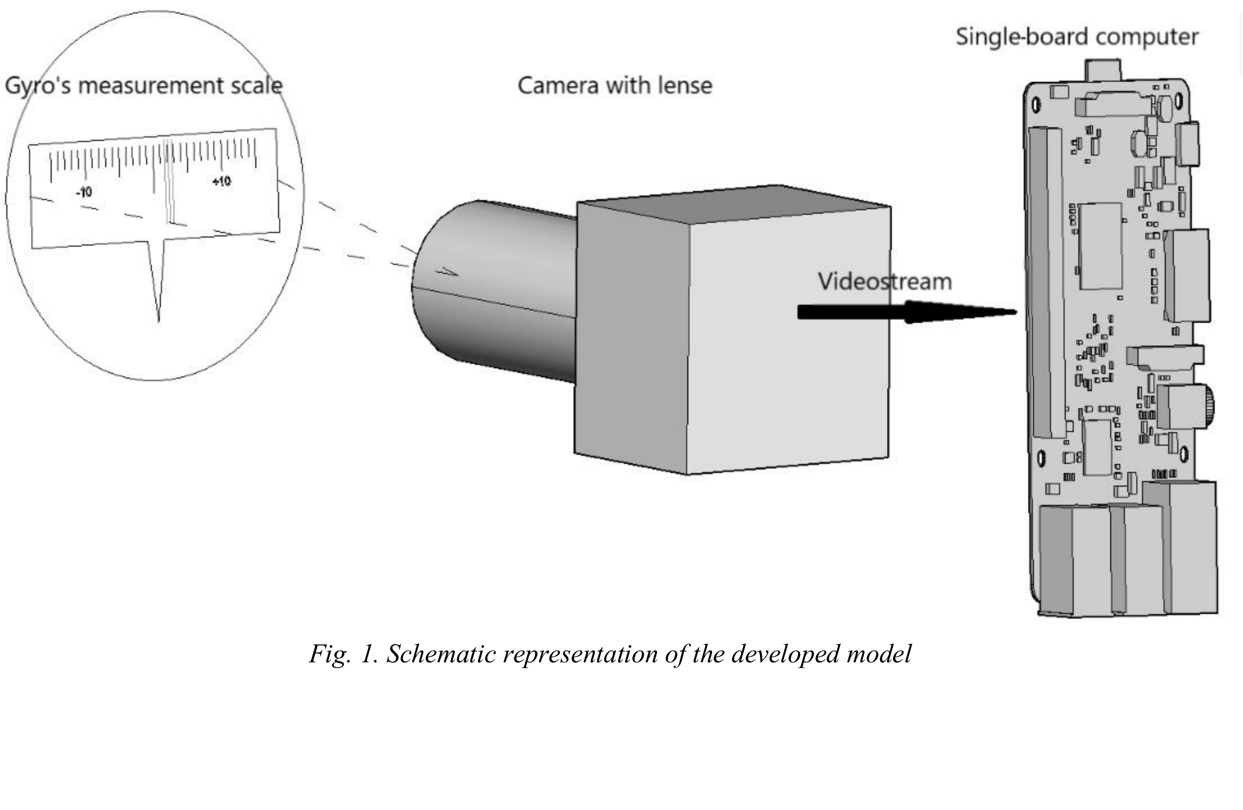
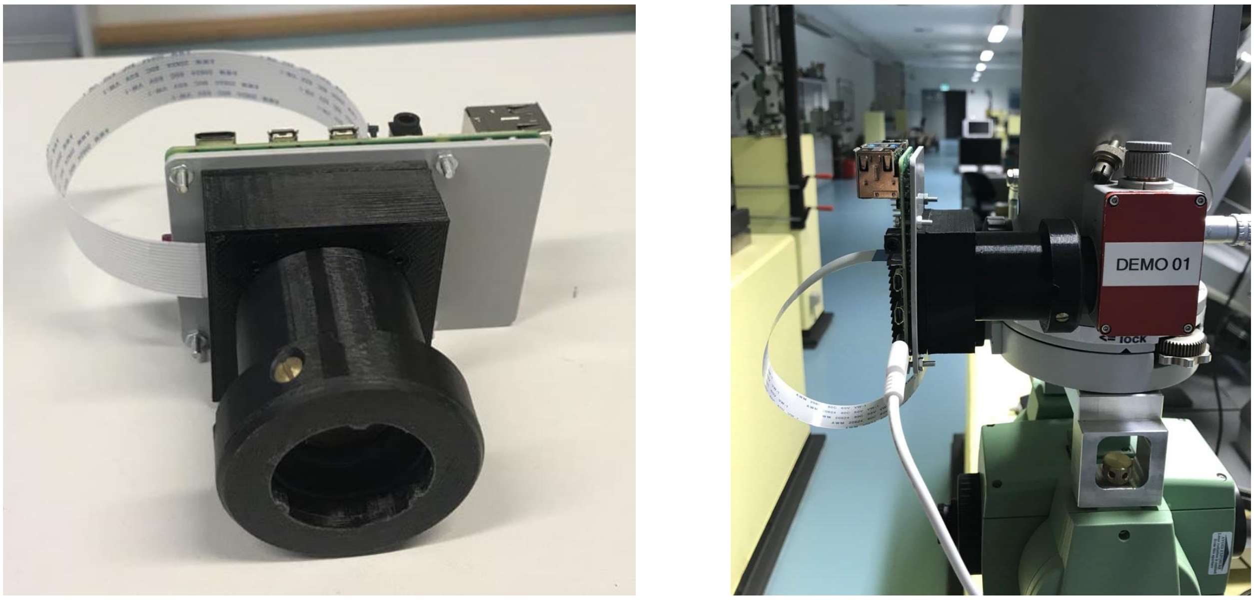



*Fig. 1. Schematic representation of the developed model*

In order to place the measuring scale of the gyrocompass exactly in the center of the camera lens, a special housing was developed on the 3D printer, with the help of which the camera is connected to the mount of the gyrocompass (see Fig. 2). The housing has two holes through which the focus and aperture can be adjusted. The horizontal position of the module can be adjusted using the image displayed on the computer screen, where the data is transmitted wirelessly. Since the eyepiece of the gyrocompass is currently unavailable for observations, the gyro motor can be released in the same way, by controlling the movement of the light index on the computer screen.




*a* *b*

*Fig. 2. Camera module inside the plastic housing: a – disassembled; b – connected to the gyro*

For further operations with the image and the ability to track motion on it, the computer vision library OpenCV [Gollapudi, 2019] for the Python programming language was used. This is a powerful tool for working with images, in particular for movement tracking and all kinds of image transformations.

In order to get the position of the light index relative to the scale, first, it is necessary to tie the measurement scale to the image coordinate system. Since with each connection of the camera module to the gyro bayonet, the position of the camera slightly shifts in relation to the measuring scale, it was decided to take the leftmost index on the scale (-15) as the origin. All scale indices can be identified as separate objects in the image using the threshold function which changes the intensity value of each individual pixel by either 0 or 255, depending on whether the original intensity value was greater or less than a given threshold. In other words, it’s called binary image (Fig. 3), that consists only of two colors. With the help of such a transformation, it is easier to detect separate objects on the image. The distance between the leftmost index (-15) and the rightmost (+15) in pixels is approximately 600 pixels (Fig. 4). The distance between adjacent indices is 19 to 21 pixels. This slight inaccuracy is due to the different thickness of the black lines on the scale, as well as the resolution of the camera. The gyroscope tape indicator itself is 3 pixels wide. Therefore, the middle row of pixels can be taken as its center. In the case of ordinary observations of the gyro scale with the help of the eyes, the space between two adjacent indices can be conditionally divided into 10 parts. With the help of the camera, the same segment can be divided into 20 parts. This means that the position of the gyro index can be determined up to 0.05 scale units.

The basis of the motion recognition algorithm is the comparison of the reference image of the gyro scale, where the light indicator is absent at all, and all subsequent frames of the video broadcast of the scale, on which the light indicator is present. By finding the absolute difference between two datasets (i.e. images), it is possible to determine where they differ. And they differ only in the presence of a light indicator. Now the position of the light indicator in the picture can be determined. The black frame in (Fig. 5) that surrounds the light index is the result of the algorithm, and the black dot in the middle shows the position of the gyroscope tape index.

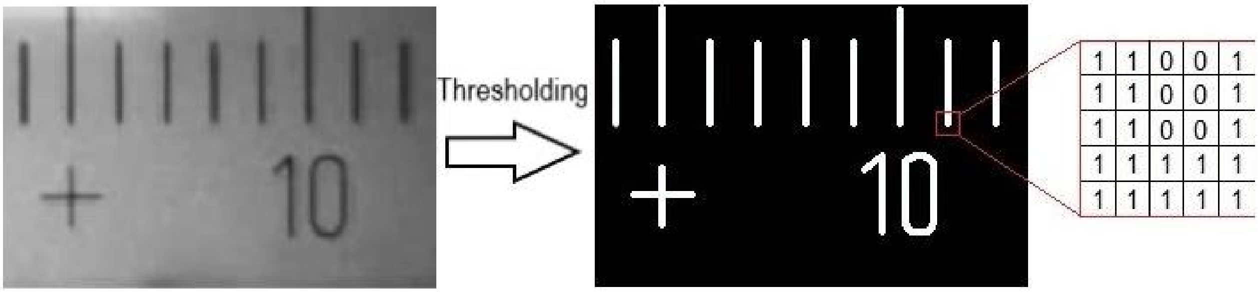



*Fig. 3. Transformation of the input image into the binary*

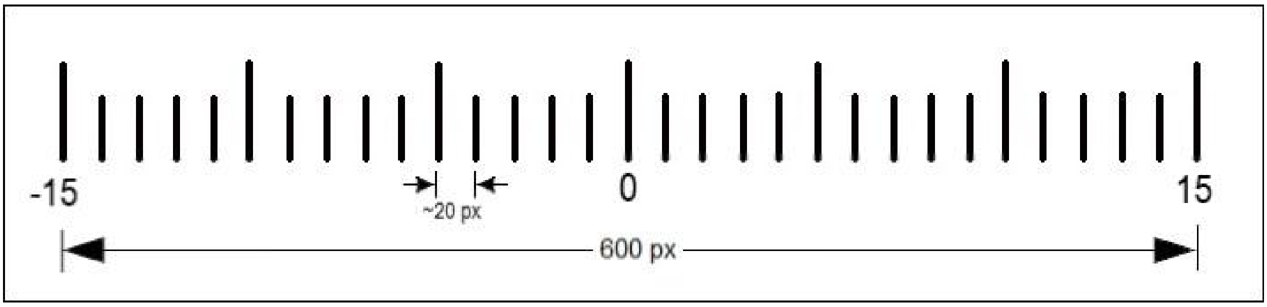



*Fig. 4. Schematic representation of the measurement scale on the video image*

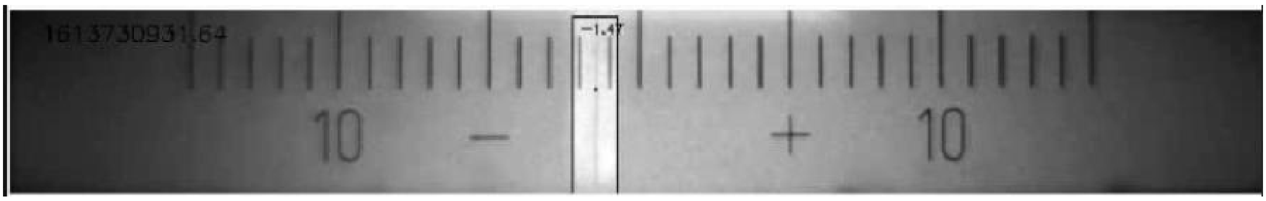



*Fig. 5. Movement detection algorithm on the display*

Now it is possible to follow the movement of the gyroscope tape index in digital form and record its extreme positions on the scale, as well as timestamps of passing through the zero point. The measurement procedure is the same as for conventional gyro measurements. But it should be noted that due to additional oscillations of the gyrocompass tape, the measurement data is somewhat noisy, which can affect the value of the turning points and the exact time of crossing the zero point. Therefore, the Savitsky-Golay filter was applied to filter the data and smooth the measured sine wave.

## Results

To check the accuracy and reliability of the developed system, several series of measurements were carried out automatically and mechanically. In parallel with the automatic recording of the movement data of the gyroscope tape indicator, a manual measurement was carried out by observing the movement of the gyroscope tape indicator on the computer screen, which broadcast the camera image. All of them were carried out on the same pillar for the same target. The data for manual and automated measurements are given in tables 1 and 2. Analyzing the data obtained, it can be noted that the difference in standard deviation between manual and automatic methods is 2 mgon, which in degree equivalent is approximately six arcseconds. The difference in the mean value of azimuth is 3 mgon, which in degree equivalent is about 10 arcseconds. The manufacturer of the AK-2M gyrocompass claims an azimuth accuracy of 6 mgon or 20 arcseconds.

*Table 1*

**Series of manual measurements**

| No | z | N´1 | dt1 | dt2 | a1 | a2 | dN1 | dN2 | Azi(raw) | Azi(corr.) | V | diff of $dN_{1/2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | gon | gon | s | s | gon | gon | gon | gon | gon | gon | gon | gon |
| 1 | 79.387 | 181.550 | -0.08 | 2.15 | 3.98 | 3.90 | 0.000 | 0.006 | 297.834 | 297.843 | -0.003 | **-0.006** |
| 2 | 79.387 | 181.549 | -0.71 | 1.32 | 3.00 | 3.00 | -0.002 | 0.003 | 297.837 | 297.843 | -0.003 | **-0.004** |
| 3 | 79.388 | 181.552 | 1.10 | 0.55 | 3.53 | 3.50 | 0.003 | 0.001 | 297.834 | 297.843 | -0.003 | **0.001** |
| 4 | 79.388 | 181.554 | -3.03 | -2.14 | 2.30 | 2.40 | -0.005 | -0.004 | 297.839 | 297.841 | -0.001 | **-0.001** |
| 5 | 79.388 | 181.554 | 0.43 | -1.36 | 3.80 | 3.80 | 0.001 | -0.004 | 297.836 | 297.845 | -0.005 | **0.005** |
| 6 | 79.388 | 181.554 | 0.55 | -2.10 | 2.03 | 2.03 | 0.001 | -0.003 | 297.835 | 297.841 | -0.001 | **0.004** |
| 7 | 79.388 | 181.554 | 1.29 | 3.74 | 3.15 | 3.15 | 0.003 | 0.009 | 297.828 | 297.837 | 0.003 | **-0.006** |
| 8 | 79.387 | 181.552 | 4.14 | 7.91 | 2.10 | 2.10 | 0.006 | 0.012 | 297.826 | 297.835 | 0.005 | **-0.006** |
| 9 | 79.388 | 181.554 | 0.05 | 3.60 | 2.00 | 2.00 | 0.000 | 0.005 | 297.832 | 297.843 | -0.003 | **-0.005** |
| 10 | 79.388 | 181.553 | -4.02 | 3.58 | 2.18 | 2.10 | -0.006 | 0.006 | 297.836 | 297.841 | -0.001 | **-0.012** |
| 11 | 79.388 | 181.554 | 7.65 | 8.52 | 1.78 | 1.73 | 0.010 | 0.011 | 297.824 | 297.833 | 0.007 | **-0.001** |
| 12 | 79.387 | 181.552 | 4.71 | 7.32 | 1.55 | 1.50 | 0.005 | 0.008 | 297.829 | 297.840 | 0.000 | **-0.003** |
| 13 | 79.388 | 181.552 | 4.20 | 3.39 | 2.65 | 2.65 | 0.008 | 0.007 | 297.828 | 297.837 | 0.003 | **0.002** |
| 14 | 79.388 | 181.552 | 5.47 | 1.69 | 3.15 | 3.10 | 0.013 | 0.004 | 297.827 | 297.837 | 0.003 | **0.009** |
| | | | | | | | | | **mean** | **297.840** | **gon** | |
| | | | | | | | | | **sdev** | **0.003** | **gon** | |

*Table 2*

**Series of automated measurements**

| No | z | N´1 | dt1 | dt2 | a1 | a2 | dN1 | dN2 | Azi(raw) | Azi(corr.) | V | diff of $dN_{1/2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | gon | gon | s | s | gon | gon | gon | gon | gon | gon | gon | gon |
| 1 | 79.387 | 181.550 | -1.95 | 0.42 | 3.99 | 3.87 | -0.006 | 0.001 | 297.840 | 297.848 | -0.005 | **-0.007** |
| 2 | 79.387 | 181.549 | -1.16 | 0.75 | 3.01 | 3.01 | -0.003 | 0.002 | 297.838 | 297.844 | -0.001 | **-0.004** |
| 3 | 79.388 | 181.552 | 0.18 | -0.60 | 3.55 | 3.54 | 0.000 | -0.002 | 297.837 | 297.846 | -0.003 | **0.002** |
| 4 | 79.388 | 181.554 | -6.82 | -3.50 | 2.40 | 2.45 | -0.012 | -0.006 | 297.843 | 297.845 | -0.002 | **-0.006** |
| 5 | 79.388 | 181.554 | -1.29 | -2.18 | 3.78 | 3.78 | -0.004 | -0.006 | 297.839 | 297.849 | -0.006 | **0.002** |
| 6 | 79.388 | 181.554 | -5.55 | -7.39 | 2.07 | 2.07 | -0.008 | -0.011 | 297.844 | 297.848 | -0.005 | **0.003** |
| 7 | 79.388 | 181.554 | -1.07 | -0.17 | 3.16 | 3.09 | -0.002 | 0.000 | 297.835 | 297.843 | 0.000 | **-0.002** |
| 8 | 79.387 | 181.552 | 3.71 | 4.79 | 2.12 | 2.09 | 0.006 | 0.007 | 297.829 | 297.837 | 0.006 | **-0.002** |
| 9 | 79.388 | 181.554 | -3.01 | 0.12 | 2.02 | 2.00 | -0.004 | 0.000 | 297.837 | 297.846 | -0.003 | **-0.005** |
| 10 | 79.388 | 181.553 | -4.56 | -2.48 | 2.18 | 2.11 | -0.007 | -0.004 | 297.841 | 297.846 | -0.003 | **-0.003** |
| 11 | 79.388 | 181.554 | 6.41 | 6.35 | 1.75 | 1.69 | 0.008 | 0.008 | 297.826 | 297.834 | 0.009 | **0.000** |
| 12 | 79.387 | 181.552 | 5.21 | 5.34 | 1.56 | 1.48 | 0.006 | 0.006 | 297.830 | 297.838 | 0.005 | **0.000** |
| 13 | 79.388 | 181.552 | 2.77 | 1.65 | 2.65 | 2.64 | 0.005 | 0.003 | 297.831 | 297.840 | 0.003 | **0.002** |
| 14 | 79.388 | 181.552 | 4.65 | 1.06 | 3.20 | 3.10 | 0.011 | 0.002 | 297.829 | 297.838 | 0.005 | **0.009** |
| | | | | | | | | | **mean** | **297.843** | **gon** | |
| | | | | | | | | | **sdev** | **0.005** | **gon** | |

Analyzing the difference in azimuth values between manual and automatic measurements in Fig. 4, it can be seen that the value of the azimuths determined by the automatic method is almost always greater than the value of the azimuth obtained by the manual method. To understand the reason for such a constant deviation in one direction, it is necessary to analyze the values of dt1 and dt2, which are the difference between the time of the right and left half-swing of the gyro tape (Fig. 5 and 6). They affect the final azimuth value the most. It can be seen from the graphs that the time differences dt1 and dt2 are almost always larger for manual measurements. This may mean that the position of the gyro light index, at which the time stamp is recorded, does not coincide with the zero-point of the scale due to the strong vibrations of the gyro tape.

However, the result obtained is within the acceptable accuracy. This nuance leaves room for improving the measuring algorithm and, possibly, improving the accuracy of determining the azimuth.

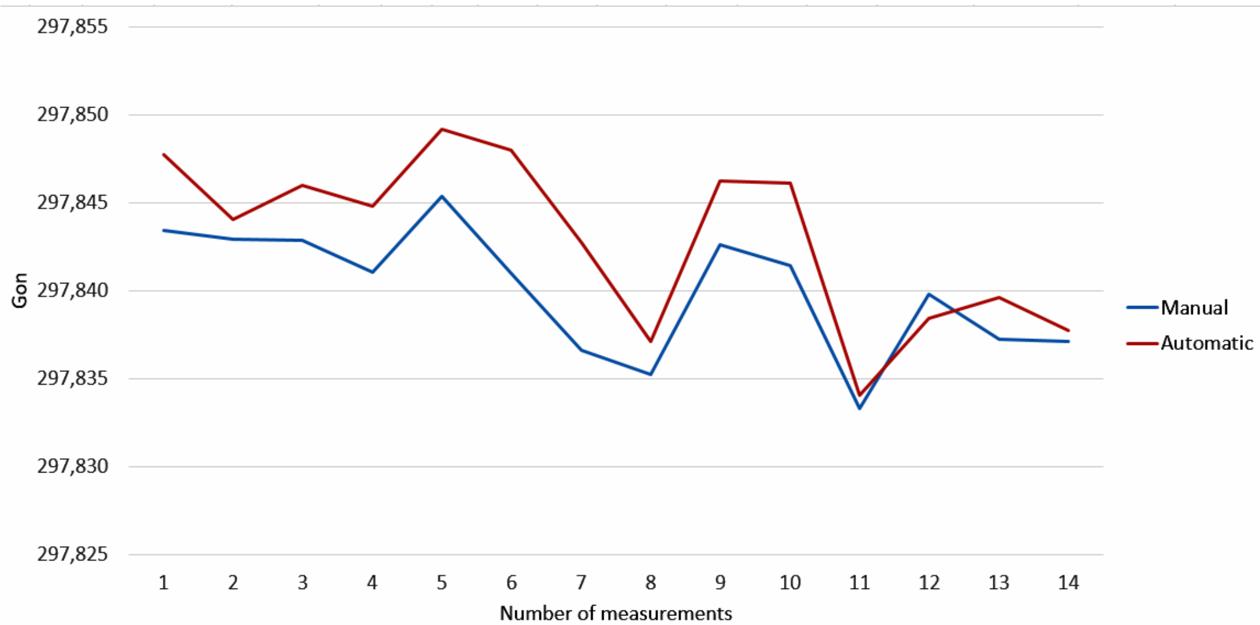



*Fig. 6. Comparison of the Azimuth values between manual and automated measurements (gon)*

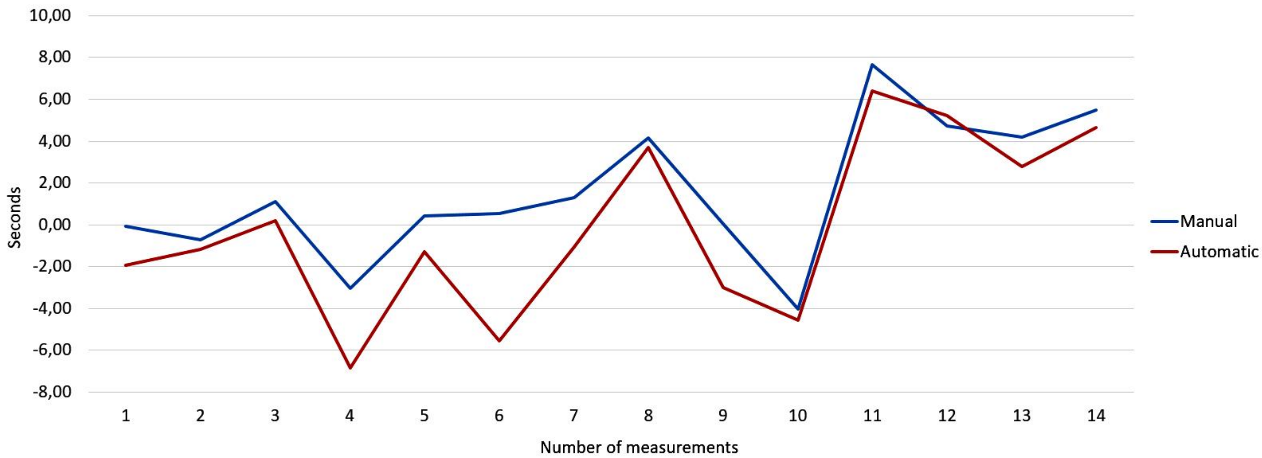



*Fig. 7. Comparison of the dt1 values between manual and automated measurements*

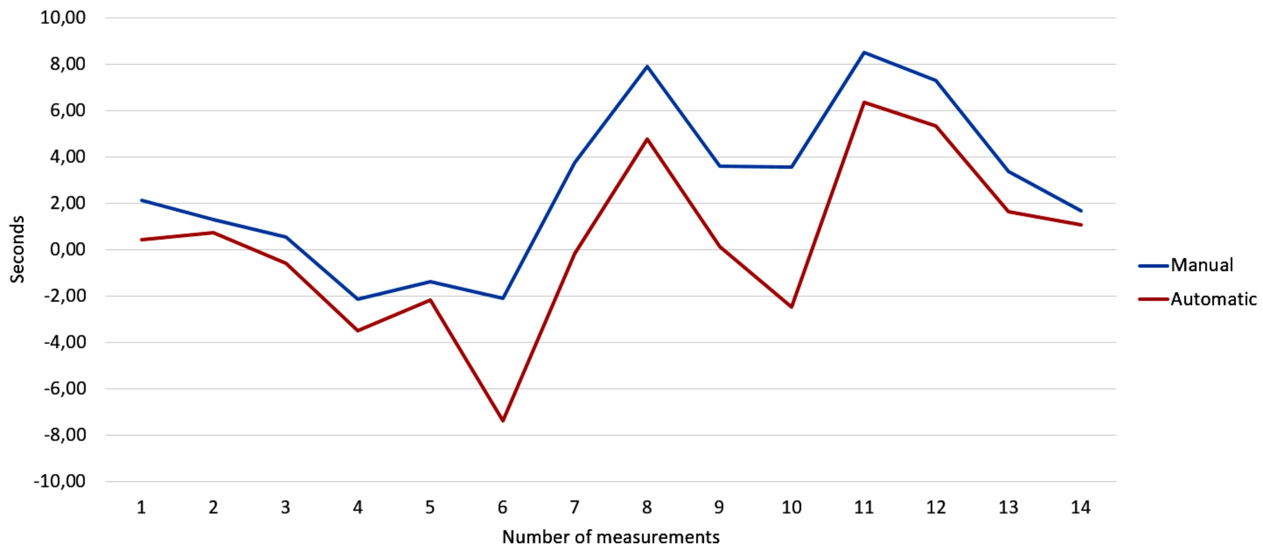



*Fig. 8. Comparison of the dt2 values difference between manual and automated measurements*

**Scientific novelty and practical significance**

The process of the azimuth determination in the gyroscope was improved. This was implemented using the developed detachable measurement automation module with the involvement of the image processing technology. This opens up opportunities for improving the existing old models of gyrocompasses, as well as for the further development of monitoring gyroscopic systems.

As for the practical value, the developed automatic measurement modules can be equipped with the existing models of the AK-2M gyroscope, which will improve their attractiveness and facilitate their operation.

**Conclusions**

Using a Raspberry Pi 4 single-board computer, a Raspberry Pi HQ camera and a Tamron 16mm lens, a measurement automation module was created for the Gyromax AK-2M mechanical gyrocompass. The developed automation system is capable of autonomously determining the value of the azimuth direction without operator intervention. Using computer vision algorithms and hardware for image recording and processing, a tracking system was created that follows the movement of the gyroscope tape index along the scale and records all its positions.

The results of test measurements showed that the azimuth values obtained automatically differ from the azimuth values obtained mechanically by 3 mgon (approx. 10 arcseconds). And the standard deviation of a series of automated measurements (5 mgon) is within the declared accuracy of the device.

Further steps to improve the technology may consist in calibrating the algorithm for determining the position of a moving object in the image, testing different filters to remove noise. Using a camera with a higher resolution will allow to determine the position of the indicator light on the scale more accurately, which in turn will increase the precision of measurements. The good idea will be to investigate the possibility of remote controlling the robotic total station using a single-board computer, which will automatically correct the position of the horizontal circle in accordance with the position of the gyro tape indicator. This would make it possible to automate the Turning Point Method, which requires constant adjustment of the horizontal position of the total station.

REFERENCES

Albert, S., & Surducan, V. (2017, December). Raspberry Pi camera with intervalometer used as crescograph. In *AIP Conference Proceedings* (Vol. 1917, No. 1, p. 030009). AIP Publishing LLC.

Barbour, N., & Schmidt, G. (2001). Inertial sensor technology trends. *IEEE Sensors Journal*, *1*(4), 332–339. doi:10.1109/7361.983473

Cuciuc, M. (2018). Suitability of the Raspberry Pi camera for cosmic ray detection and measurement. 2018 *IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC).*

Dinesh, M., & Bhaskar, K. B. (2020). Smart Highway Accident Alert Using Raspberry Pi Camera. *Journal of Digital Integrated Circuits in Electrical Devices*. Volume-5, Issue-1 (January-April, 2020)

Gollapudi, S. (2019). OpenCV with Python. *Learn Computer Vision Using OpenCV*, 31–50. doi:10.1007/978-1-4842-4261-2_2

Heger, W., Trevoho, I., & Lopatin, Y. (2019). Investigations to digitizing of the gyro oscillation swing by a line camera. *Modern achievements of geodetic science and industry.* (2), 45–53. (in Ukrainian).

Heister, H., & Liebl, W. (2016). Measurement Uncertainty of Gyro-measurements in the Construction Works of the Gotthard Base Tunnel. The surveyors in the longest tunnel of the world. Special Edition English. Ingenieur-Geometer Schweiz (IGS).

Johnson, B. R., Cabuz, E., French, H. B., & Supino, R. (2010). Development of a MEMS gyroscope for northfinding applications. *IEEE/ION Position, Location and Navigation Symposium*. doi:10.1109/plans.2010.5507133

Juang, J., & Radharamanan, R. (2009). Evaluation of Ring Laser and Fiber Optic Gyroscope Technology. *Proceedings of the American Society for Engineering Education*, Middle Atlantic Section ASEE Mid-Atlantic Fall 2009 Conference; King of Prussia, PA, USA. 23–24 October 2009

Parent, A., Le Traon, O., Masson, S., & Le Foulgoc, B. (2007). A Coriolis Vibrating Gyro Made of a Strong Piezoelectric Material. *2007 IEEE Sensors*. doi:10.1109/icsens.2007.4388541

Sun, H., Zhang, F., & Li, H. (2010, August). Design and implementation of fiber optic gyro north-seeker. In *2010 IEEE International Conference on Mechatronics and Automation* (p. 1058–1062). IEEE.

Wetherelt, A., & Hunt, P. (2004). Azimuth Determinations Using an Adapted Wild GAK1. *Survey Review* 37(294):592-603, October 2004

Zhen, S., Zhiqiang, Y., & Zhe, Z. (2013). Study on Automatic North-Seeking Key Technologies of Maglev Gyroscope. *The Open Mechanical Engineering Journal*, 2013, 7, 83–89.

Ярослав ЛОПАТІН[1*], Вільгельм ГЕГЕР[2]

[1] Кафедра вищої геодезії та астрономії, Національний університет “Львівська політехніка”, вул. С. Бандери, 12, Львів, 79013, Україна, *тел. +38(066)3897993, e-пошта: y.lopatin95@gmail.com

[2] Факультет ландшафтних наук та геоматики, Вища школа Нойбранденбурга, 2, Бродаер штр., Нойбранденбург, 17033, Німеччина

## АВТОМАТИЗАЦІЯ ВИМІРЮВАНЬ У МЕХАНІЧНОМУ ГІРОКОМПАСІ

Мета роботи полягає у розробці автоматизованої вимірювальної системи в механічному гірокомпасі за допомогою спеціально розробленого апаратного та програмного забезпечення для того, щоб полегшити експлуатацію приладу та мінімізувати похибки спостерігача. Розроблений комплекс передбачає автоматизацію лише для часового методу, оскільки для методу поворотної точки необхідно постійно контактувати з навідним гвинтом тахеометра. В основі проєкту – інтегрована система, апаратна частина якої містить одноплатний комп’ютер, камеру та об’єктив, а в основі програмного забезпечення – розроблений алгоритм розпізнавання руху із застосуванням технологій обробки зображення. Цей алгоритм створений за допомогою мови програмування Python та Computer Vision бібліотеки з відкритим початковим кодом OpenCV. За допомогою апаратної частини отримується відеозображення відлікової шкали гіроскопа, а за допомогою програмного забезпечення на цьому зображенні ідентифікується рухомий світловий індикатор та його позиція відносно шкали. Результатом дослідження є функціонуюча автоматична система вимірювання, яка визначає значення азимута напрямку з такою ж точністю, що й мануальні вимірювання. Система керується дистанційно за допомогою комп’ютера через wi-fi мережу. Для перевірки системи проведено серію автоматичних та мануальних вимірювань, які виконувались одночасно в одному й тому самому пункті для одного й того самого напрямку. На основі отриманих результатів можна стверджувати, що точність системи є в межах, зазначених виробником приладу для мануальних вимірювань. Застосування технології комп’ютерного зору, а саме відстеження рухомого об’єкта на зображенні для гіроскопічних вимірювань може дати відчутний поштовх для питання розробки систем автоматизації вимірювань для широкого спектра вимірювальних приладів, що своєю чергою може призвести до покращення точності результатів вимірювання. Розроблена система може застосовуватись разом з гірокомпасом Gyromax AK-2M фірми GeoMessTechnik для проведення автоматизованих вимірювань, навчання нових операторів. За допомогою розробленої моделі можна уникнути грубих похибок спостерігача, полегшити процес вимірювання, який не вимагатиме постійної присутності оператора біля приладу. В деяких небезпечних умовах це є суттєвою перевагою.

*Ключові слова:* автоматизація, гіроскоп, computer vision, відстеження руху, обробка зображення.

Received 23.04.2021