

# Study of communication between driver sbRIO9632 and Raspberry Pi 3

**B Nalepa, A Gwiazda and W Banas**

Silesia University of Technology, Faculty Mechanical Engineering,  
Institute of Engineering Processes Automation and Integrated Manufacturing Systems,  
Konarskiego 18A, 44 – 100 Gliwice, Poland

E-mail: bartlomiej.nalepa@polsl.pl

**Abstract.** The purpose of this article is to analyse communication between Raspberry Pi 3 and a mobile robot Starter Kit 2.0 equipped with sbRIO9632 driver. Sending data between devices was carried out by the TCP / IP protocol. The first chapter discusses the issues related to the duration of algorithms that recognize objects in images. Subsequently, the measurement system is presented along with the description of the TCP / IP protocol. Next, the method of testing the connection between Raspberry Pi 3 and the mobile robot was determined. The TCP / IP protocol was chosen as a way of data exchange and the server and communication client were established. Two time measurements were used to diagnose the TCP / IP connection. The first timer was measured from the time the image was taken from the camera by digital image processing, sending data to the server response. The second timer measured the communication time (sending the packet - response). Time measurements were made in two situations: communication was via a network cable and using a router (wireless communication). The last chapter of this article was the analysis of results and conclusions.

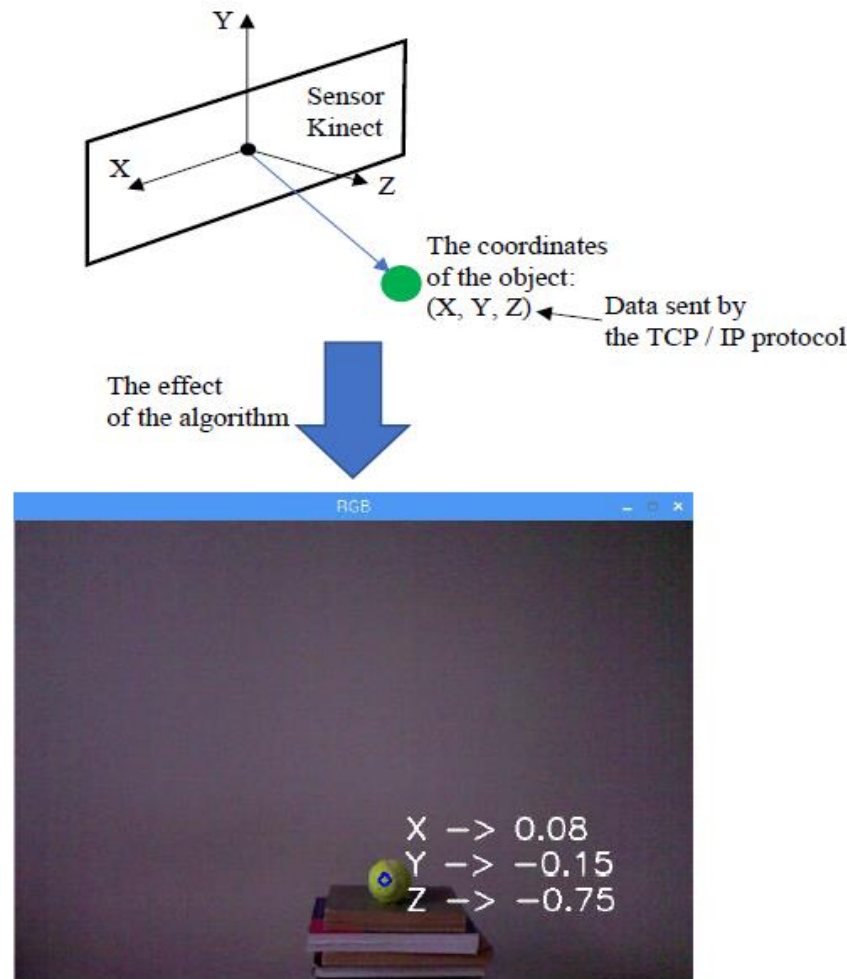
## 1. Introduction

In robotics, the duration of the algorithm's operation to recognize the object and its effectiveness are the most important for a programmer. This article presents measurement of digestion time: algorithm and sending data by the examined network protocol. The first one consists of the MS Kinect sensor, Raspberry Pi 3 and performs algorithms related to image processing. The second system is the Starter Kit 2.0 mobile robot containing the sbRIO9632 driver that performs the manipulation traffic.

The hardware analysis shows that the two devices presented will have to communicate in order to exchange data. Sending and receiving data packets can take place as follows: communication via serial port (UART → MAX232 → RS232 → computer), TCP / IP protocol, MODBUS / TCP. The first method will not be analysed because the data exchange is much slower than the internet protocol. The next two methods are very similar in functionality. There are libraries for the TCP / IP protocol in the robot control software, so this article only examines this method of communication. After making a choice about how to exchange data, it should be examined which variables can affect the result of the experiment. The duration of the program depends primarily on the number of algorithms that must be performed. Therefore, the question should be asked: Will the RGB image processing require much more time than the same operations on the image in shades of gray? The next parameter was the time of sending data by the TCP / IP protocol. Also in this case, you can ask questions: Send only the position of the object in XYZ coordinates (obtained using image thresholding, central



moments determination or Viola - Jones algorithm [1]), send the entire RGB image or in shades of gray using more computing power the receiving unit? What time will be needed to send one string (position) or matrix (RGB image)?



**Figure 1.** Object recognition and tracking using the Viola-Jones method (Python program).

Figure 1 shows the effect of the Viola - Jones algorithm [1] for object recognition and tracking. As a result of the method presented, you can receive the coordinates of the object. Another way to determine the position of the object sought is to set the image and then to determine the central moments. The last mentioned method was used in the written program as a way to create a string variable that was sent by the TCP / IP protocol to the target device.

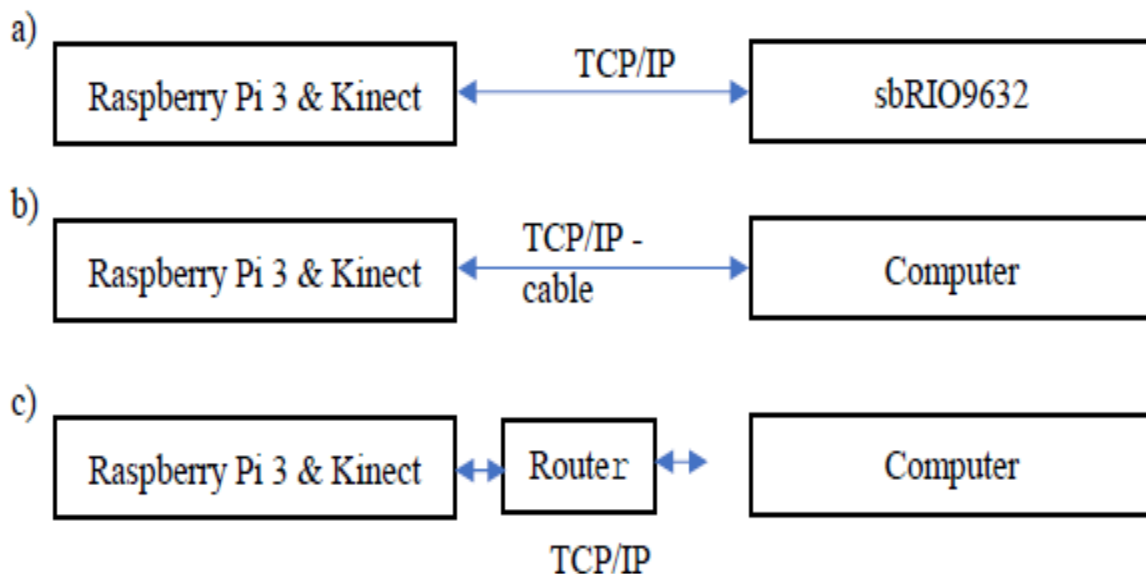
The conducted research on the time of the program operation and communication will allow for the possible correction of the algorithm controlling the mobile robot while tracking the object or building the map of the environment.

TCP/IP can be used to:

- data acquisition from a PLC that manages the sensor systems [2],
- sending data between a virtual controller and a simulation [3],
- reading the results of measurements of dynamic parameters for industrial robots [4],
- data acquisition from the PLC controller that controls the machine [5].

## 2. Measuring system - TCP / IP protocol

In this article, a system consisting of the mobile robot Starter Kit 2.0 (sbRIO9632 driver) and Raspberry Pi 3 together with a Kinect sensor is considered. The research will concern the connection of the two mentioned controllers with an Internet cable enabling data transmission via the TCP / IP protocol. In a device that will operate in the vicinity of Raspberry Pi 3 is connected to the robot controller (figure 2a). To collect the sbRIO9632 measurement data, the computer was replaced. Two types of connection were considered: using an internet cable (figure 2b) and a wireless router (figure 2c).

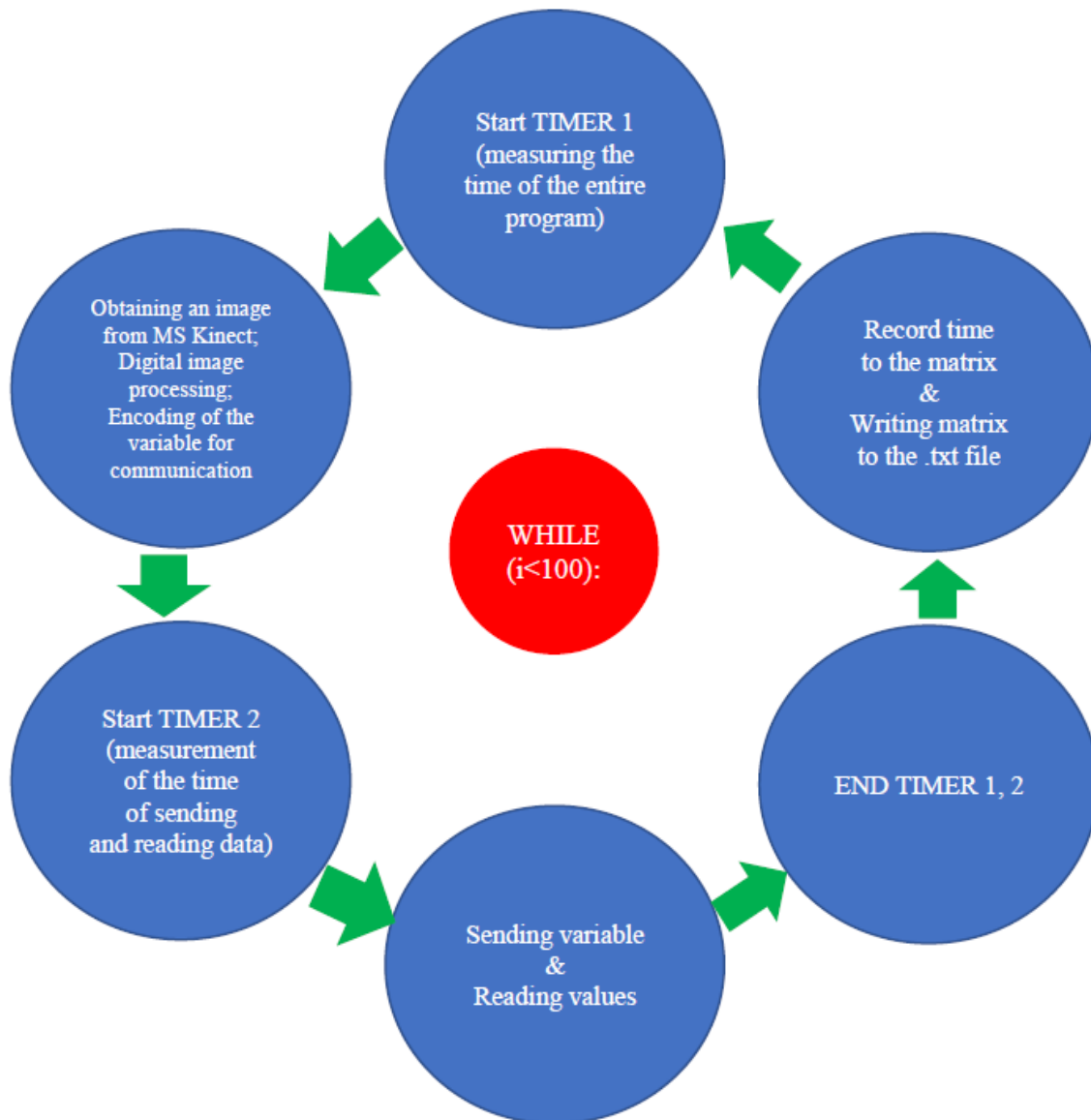


**Figure 2.** Communication using the TCP / IP protocol: computer - server, Raspberry Pi 3 – client.

The programs in both controllers were written in Python using the socket library, setting the server's IP address (sbRIO9632 / Computer) to 192.158.1.101 and the communication port at 5005. Figure 3 shows the scheme of the program [6, 7, 8].

The program code uses the following libraries: socket [7], OpenCV [9], NumPy [10], libfreenect [11], time [12]. The main element of the application is the WHILE loop, which is performed a hundred times. The first line of the code in the loop writes to the variable the start time of the given cycle. Then the signal from the Kinect sensor is read and saved in the RGB image format and the image in shades of gray. Subsequently, algorithms related to digital image processing are performed: changing the HSV colour palette, thresholding the image after predefined colour limits and calculating central moments. The use of these methods allows you to track the object along with the determination of its coordinates. The final stage before sending the variable is to combine the coordinate values into one string variable. Next, the initiating communication commands are entered, specifying the necessary data exchange parameters. Before transmission starts, the parameter is assigned the current time to the variable. The next step is to encode the variable into bytes and send it to the server. The server's response to sending the value causes the current time measurement to be taken and subtracted from those made previously. Received times are saved to the matrix. After executing a hundred repetitions of loops, the program saves tables to text format files

The server assigned to the computer is attached before the clients start activity. The management unit is waiting for signals from customers. When the connection is established, a data packet is sent from the slave. It is followed by decoding and generating a response.



**Figure 3.** The scheme of the program.

The result of the algorithm is to generate a file containing 100 time measurements for a single program cycle and for communication between two devices. The results obtained will allow their analysis along with determining the significance of the impact of changing any of the parameters.

### 3. Analysis of test results

The parameters presented in table 1 were used for the tests. The results of the experiments were program cycle times and data sending. The results were analysed using two-level plans. Two parameters were adopted on two levels of variation. Experiments were carried out for each variable configuration. Then, on the basis of the mathematical apparatus described in [13 – 17], mathematical models of objects were determined.

**Table 1.** States of defined variables (Gray - image in shades of gray, compare [13 – 17]).

The name of the variable	Symbol	Level of volatility (-)	Level of volatility (+)
Image (O)	$x_1$	Gray $\rightarrow$ 640x480	RGB $\rightarrow$ 640x480x3
Element sent (E)	$x_2$	Number $\rightarrow$ 15	Image $\rightarrow$ 640x480

Variable coding and decoding are presented using unit change ( $u_i$ ) and midvalue of variable ( $m_i$ ) [13 – 17]:

$$u_1 = \frac{O_{max} - O_{min}}{2} \quad (1)$$

$$u_1 = \frac{921600 - 307200}{2} = 307200$$

$$m_1 = \frac{O_{max} + O_{min}}{2} \quad (2)$$

$$m_1 = \frac{921600 + 307200}{2} = 614400$$

$$x_1 = \frac{x_1 - m_1}{u_1} = \frac{O - 614400}{307200} \quad (3)$$

$$u_2 = \frac{E_{max} - E_{min}}{2} \quad (4)$$

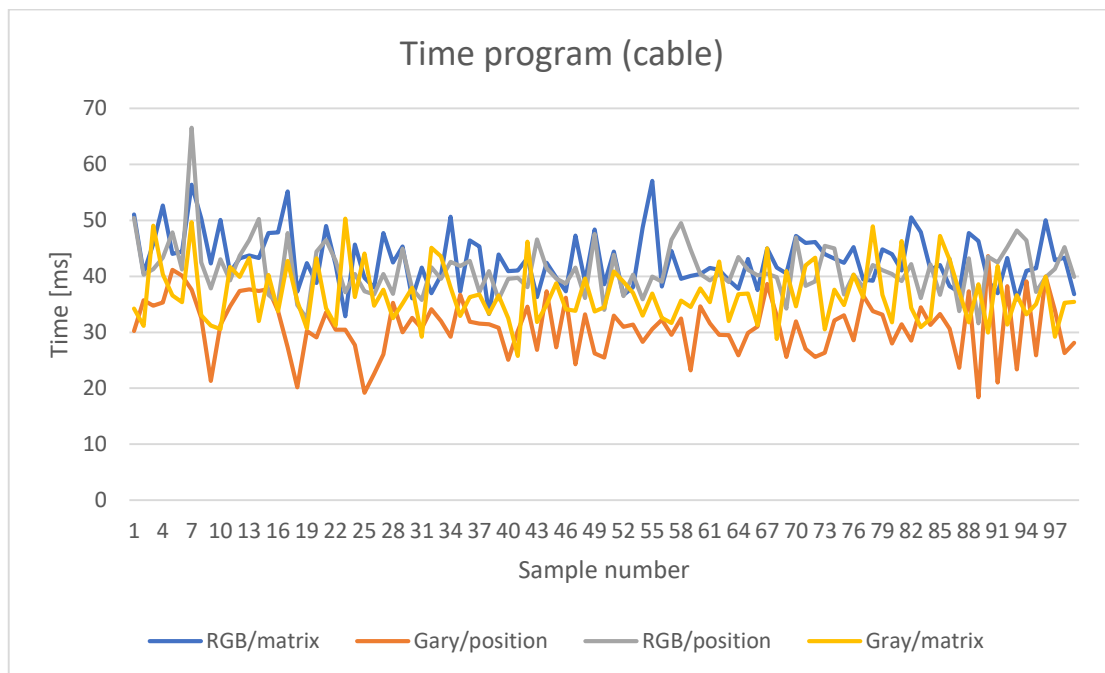
$$u_2 = \frac{307200 - 15}{2} = 153592,5$$

$$m_2 = \frac{E_{max} + E_{min}}{2} \quad (5)$$

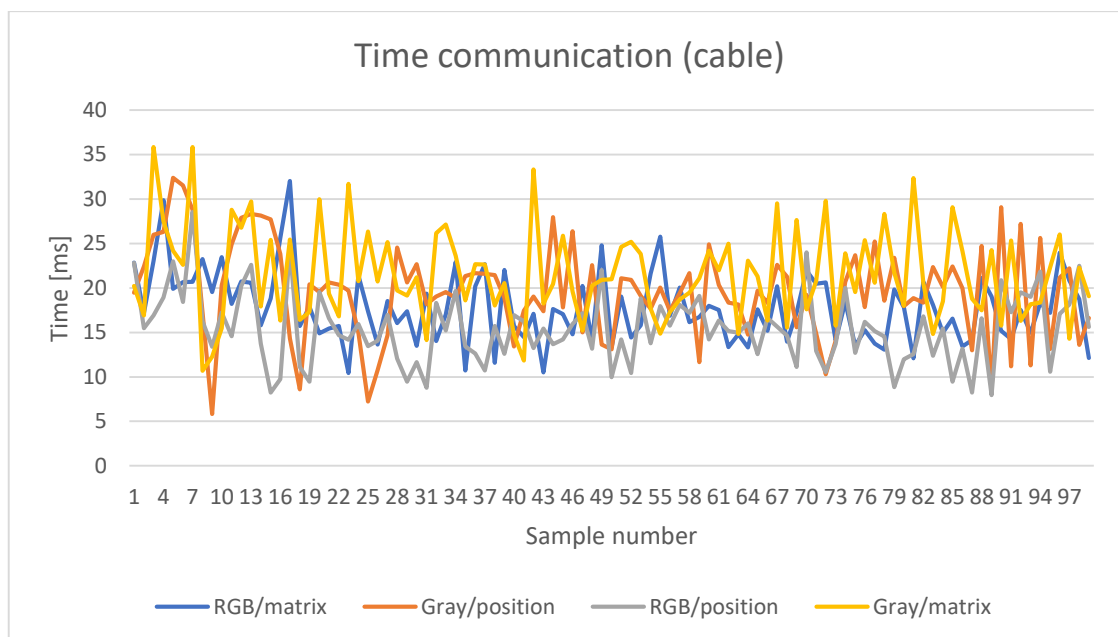
$$m_2 = \frac{307200 + 15}{2} = 153607,5$$

$$x_2 = \frac{x_2 - m_2}{u_2} = \frac{E - 153607,5}{153592,5} \quad (6)$$

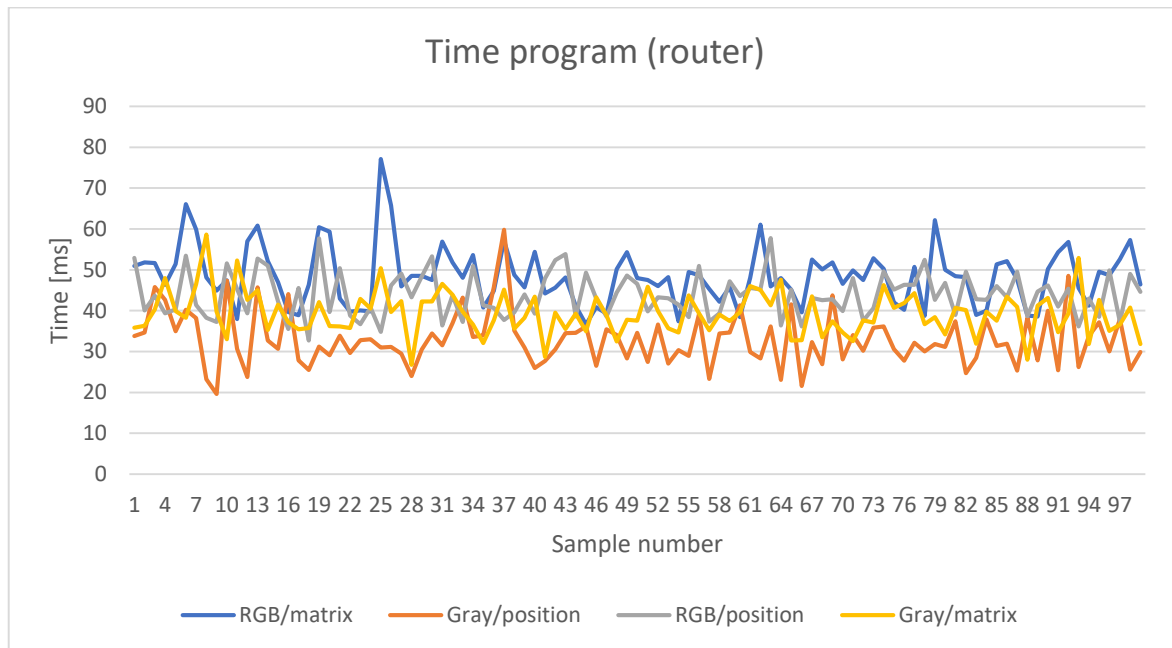
Figures 4, 5, 6, 7 show graphs of program operation times and the duration of communication between devices for connecting with an internet cable or wirelessly (router).



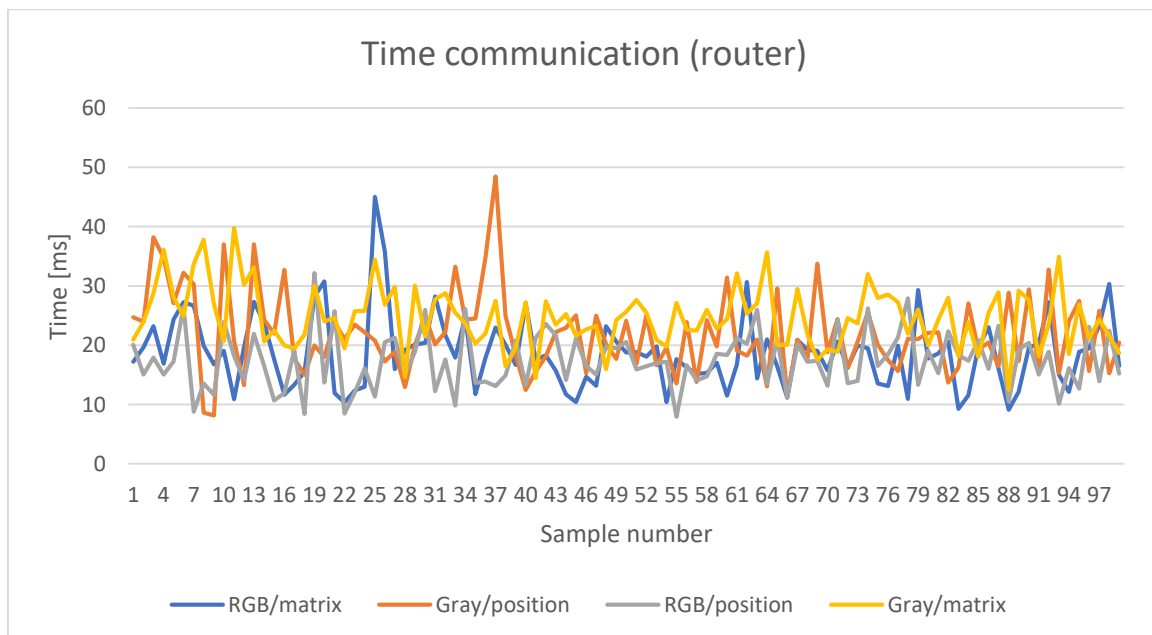
**Figure 4.** Program operation time – internet cable.



**Figure 5.** Communication time – internet cable.



**Figure 6.** Program run time – router.



**Figure 7.** Communication time – router.

Table 2 shows the plan of the experiment for a two-level satellites plan, where:

- $\bar{y}_{tpc}$  – average time of program operation - internet cable,
- $\bar{y}_{tcc}$  – average communication time - internet cable,
- $\bar{y}_{tpr}$  – average program operation time - router,
- $\bar{y}_{trc}$  – average communication time - router.

**Table 2.** Static two-level plan [13 – 17].

Experience number	$x_0$	$x_1$	$x_2$	$x_{12}$	$\bar{y}_{tpc}$	$\bar{y}_{tcc}$	$\bar{y}_{tpr}$	$\bar{y}_{tcc}$
1	+	+	+	+	43.2318	17.8087	49.0551	19.2336
2	+	+	-	-	41.7152	16.0544	44.1335	17.9611
3	+	-	+	-	36.7627	21.4453	39.2077	24.7019
4	+	-	-	+	31.2379	20.1288	32.1836	20.8447

Creating a mathematical model based on the regression equation [13 – 17]:

a) A mathematical model of a system that measures the average program run time - an internet cable:

Character coded:

$$t_{pc} = 38,24 + 4,24x_1 + 1,76x_2 - x_1x_2 \quad (7)$$

Decoded character:

$$t_{pc} = 38,24 + 4,24 \left( \frac{O - 614400}{307200} \right) + 1,76 \left( \frac{E - 153607,5}{153592,5} \right) - \left( \frac{O - 614400}{307200} \right) \left( \frac{E - 153607,5}{153592,5} \right) \quad (8)$$

Test of significance of regression equation coefficients on the basis of t- Student statistic on the significance level  $\alpha = 0,1$ :

- $b_0$  – important coefficient,
- $b_1$  – important coefficient,
- $b_2$  – important coefficient,
- $b_{12}$  – important coefficient.

b) Mathematical model of the system measuring the average communication time - the internet cable:

Character coded

$$t_{kc} = 18,86 - 1,92x_1 + 0,77x_2 + 0,11x_1x_2 \quad (9)$$

Decoded character:

$$t_{kc} = 18,86 - 1,92 \left( \frac{O - 614400}{307200} \right) + 0,77 \left( \frac{E - 153607,5}{153592,5} \right) + 0,11 \left( \frac{O - 614400}{307200} \right) \left( \frac{E - 153607,5}{153592,5} \right) \quad (10)$$

Test of significance of regression equation coefficients on the basis of t- Student statistic on the significance level  $\alpha = 0,1$ :

- $b_0$  – important coefficient,
- $b_1$  – important coefficient,
- $b_2$  – important coefficient,
- $b_{12}$  – coefficient is not important.

c) Mathematical model of the system measuring the average program run time - router:

Character coded

$$t_{pr} = 20,69 - 2,09x_1 + 1,28x_2 - 0,65x_1x_2 \quad (11)$$

Decoded character:



$$t_{pr} = 20,69 - 2,09 \left( \frac{O - 614400}{307200} \right) + 1,28 \left( \frac{E - 153607,5}{153592,5} \right) - 0,65 \left( \frac{O - 614400}{307200} \right) \left( \frac{E - 153607,5}{153592,5} \right) \quad (12)$$

Test of significance of regression equation coefficients on the basis of t- Student statistic on the significance level  $\alpha = 0,1$ :

- $b_0$  – important coefficient,
- $b_1$  – important coefficient,
- $b_2$  – important coefficient,
- $b_{12}$  – important coefficient.

d) Mathematical model of the system measuring the average communication time - router:

Character coded:

$$t_{kr} = 41,15 + 5,45x_1 + 2,99x_2 - 0,53x_1x_2 \quad (13)$$

Decoded character:

$$t_{kr} = 20,69 - 2,09 \left( \frac{O - 614400}{307200} \right) + 1,28 \left( \frac{E - 153607,5}{153592,5} \right) - 0,65 \left( \frac{O - 614400}{307200} \right) \left( \frac{E - 153607,5}{153592,5} \right) \quad (14)$$

Test of significance of regression equation coefficients on the basis of t- Student statistic on the significance level  $\alpha = 0,1$ :

- $b_0$  – important coefficient,
- $b_1$  – important coefficient,
- $b_2$  – important coefficient,
- $b_{12}$  – important coefficient.

The first stage of summarizing the results obtained is the analysis of table 2. In the case of program operation time in two types of connection, the times when communicating with the router were longer than those performed by the Internet cable. The maximum difference was 6ms.

The communication times between devices were longer when connected to the router. The maximum difference was 3ms.

The next step is to analyse the obtained mathematical models. Four mathematical models were defined, where the significance of the impact of individual parameters was examined. Only in one case the product of parameters was irrelevant - the internet cable communication time.

#### 4. Conclusion

Eight thousand samples were tested. The duration of the program and the communication process were measured. On the basis of two-level plans, 4 mathematical models for both times were determined for two types of connections. The results obtained indicate that always a longer communication time and program operation was recorded when using the router. Differences between the results are not significant and should not affect the tracking of objects by a mobile robot. However, measurements were taken when the router was within two meters of the computer. The times of sending data will also depend on the type of router and probably on the length of the internet cable. The conducted research allowed to determine the duration of: the digital image processing algorithm and the data packet sent by the TCP/IP protocol.

The next stages of research will be the creation of a point cloud using Raspberry Pi 3 and the Kinect sensor. Then send the 3D image to the computer where the data received will be verified.

## 5. References

- [1] Viola P and Jones M 2001 *Comp. Vis. Patt. Recog.* (DOI: 10.1109/CVPR.2001.990517)
- [2] Ćwikła G and Foit K 2017 Problems of integration of a manufacturing systems with the business area of a company on the example of the Integrated Manufacturing Systems Laboratory. *MATEC Web of Conferences* **94** UNSP 06004
- [3] Herbuś K and Ociepka P 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **227** (DOI: 10.1088/1757-899X/227/1/012056)
- [4] Banaś W Ćwikła G Foit K Gwiazda A Monica Z and Sękala A 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **227** (DOI: 10.1088/1757- 899X/227/1/012012)
- [5] Banaś W, Gwiazda A, Monica Z, Sękala A and Foit K 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **145** (DOI: 10.1088/1757- 899X/145/5/052016)
- [6] Fall KR and Stevens W R 2012 *TCP/IP Illustrated, Volume 1: The Protocols* (Michigan: Addison – Wesley Professional Computing Series)
- [7] Description of the library socket, <https://docs.python.org/2/library/socket.html> (access 09.03.2018)
- [8] Donahoo M J and Calvert K L 2001 *TCP/IP Sockets in C: Practical Guide for Programmers* (USA: Morgan Kaufmann Publishers)
- [9] Description of the library OpenCV, [https://docs.opencv.org/3.1.0/d6/d00/tutorial\\_py\\_root.html](https://docs.opencv.org/3.1.0/d6/d00/tutorial_py_root.html) (access 09.03.2018)
- [10] Description of the library NumPy, <https://docs.scipy.org/doc/numpy-dev/reference/> (access 09.03.2018)
- [11] Description of the library libfreenect, <https://github.com/OpenKinect/libfreenect> (access 09.03.2018)
- [12] Description of the library time, <https://docs.python.org/2/library/time.html> (access 09.03.2018)
- [13] Pavelic V and Saxena U 1969 Basics of Statistical Experiment – Design *Chemical Engineering* **6**
- [14] Smirnov V Yu and Kuznetsova A V 2017 *Pattern Recognition and Image Analysis* **27**(2) 175 (DOI: 10.1134/S1054661817020109)
- [15] Oehlert G W 2010 *A First Course in Design and Analysis of Experiments* (University of Minnesota)
- [16] Montgomery D C 2013 *Design and Analysis of Experiments* (Arizona: WILEY)
- [17] Seltman AJ 2015 *Experimental Design and Analysis*, [www.stat.cmu.edu/~hseltman/309/Book/Book.pdf](http://www.stat.cmu.edu/~hseltman/309/Book/Book.pdf) (access 24.03.2018)