Increasing the Position Tracking Accuracy of an Autonomous Mobile Minirobot, an Essential Condition for the Remote Command and Control of the Motions

S. Petrache*, N. Alexandrescu*
D. Băcescu*

** Dept. of Mechanical Engineering and Mechatronics, POLITEHNICA University of Bucharest, 060042 Bucharest, Romania (Tel: 021-402.92.15; e-mail: silviupsf@yahoo.com)*

Abstract: In the paper there are presented the results of an applicative research whose object was to increase the position tracking accuracy of a crawler mobile minirobot. Both the minirobot's position tracking in the operating space and the commands of the electric micromotors for driving the active wheels causing the motion, are made via remote control by two main components of a complex automated command system, an optoelectronic installation for position tracking a luminous mark on the minirobot, respectively a control system of a virtual minirobot – a counterpart of the real one in a virtual space. The communication architecture and the used technologies, created the possibility to control the minirobot without using physical connections both locally, and remotely via the Internet. The improvement of the minirobot's position tracking performance proved its efficiency through the correctness of the de command decisions for the trajectories, and also through the correctness of their execution.

Keywords: autonomous mobile minirobot, position tracking equipment, optoelectronic sensor,

1. INTRODUCTION

The remote tracking system for the positions of an autonomous mobile minirobot represents the main structure of an automated command, control and monitoring system of the minirobots' motion. Mainly, the whole system operates on the basis of remote- data transmission, by means of the Ethernet, for the commands of equipment, determined by an operator or by a pre-set sequence. Generically speaking, the transmission of the commands to the remote equipment is called teleoperation, regardless whether the commands' decision belongs to a human operator or to de automated control system.

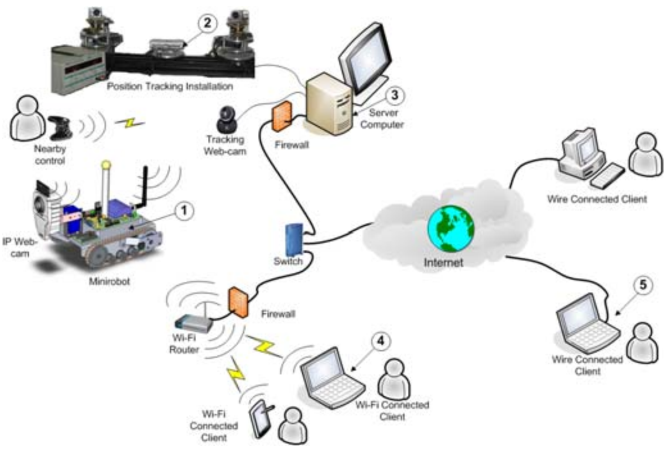


Fig. 1. The general command control and monitoring architecture of the minirobot in a pre-determined space

The configuration of the system corresponding to the principle in which the whole command, control and monitoring architecture of the minirobot was conceived and structured, in a pre-determined space, is presented in figure 1. One can see both the controlled minirobot Petrache et al. (2010) - (1) together with position tracking equipment - (2) which allows both the determination of its coordinates in a known space, and the rest of the equipments used for the whole architecture: (3) - server computer, (4) - Wi-Fi connected client, (5) - wire connected client.

In order to find the minirobot space coordinates relative to a known coordinates system, there was chosen an equipment which uses the triangulation method Bucşan et al. (1998), Băcescu (2002). This variant was selected since it is not the necessary to mount a sensor system on the minirobot in order to achieve the same purpose. By choosing this solution it is avoided both the physical and the software loading of the minirobot, because both the electronics and the calculation algorithm are transferred to the installation, which will do the measurements and the calculations in order to determine the coordinates. Moreover, compared with the variant of a GPS module attached to the minirobot, this solution is more precise, if one especially takes into account the relative accuracy to a known system, but also less expensive because of its components' costs.

2. THE PRESENTATION OF DE THE MINIROBOT POSITION TRACKING INSTALLATION

Triangulation can be used in order to calculate the coordinates and the distance from a segment bounded by two reference points, to a mobile point. For the used installation in the command system which is the object of the paper, the two reference points are represented by two optoelectronic receiver-devices in continuous rotation, whose distance between each other, called stereoscopic base, is known. In order to determine the two necessary angles so as to be able to apply the triangulation principle, the mobile represented in this case by a minirobot, has a source of light, as a position tracking marker especially attached for this purpose. The emitted light beam is received by the optoelectronic device on different intensity during its motion. The angle of the device at which the received light intensity was maximum, is considered to be the searched afferent angle. Thus, there are determined the two necessary angles in order to apply the triangulation principle.

In figure 2, there are presented the geometrical elements on which the optoelectronic installation operates.

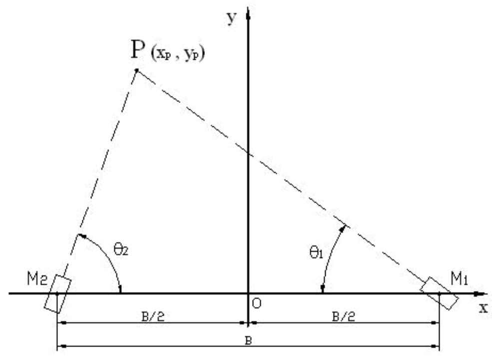


Fig. 2. The principle scheme of the installation for determining the coordinates by means of triangulation.

The stereoscopic base, being constructively known, by means of the B value, there results the following:

$$\begin{cases} y_P = \dfrac{B\sin(\theta_1)\sin(\theta_2)}{\sin(\theta_1+\theta_2)} \\ x_P = 0.5B - \dfrac{y_P}{\mathrm{tg}\,\theta_1} \end{cases} \tag{1}$$

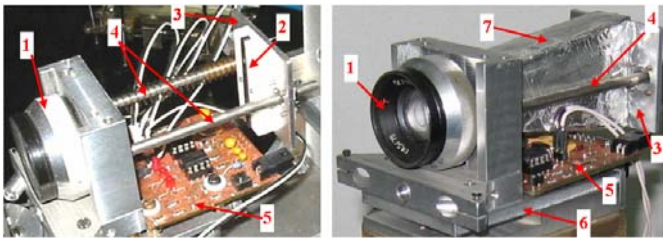
For the created application as a functional model, there was used a variant of an installation for determining the coordinates based on the triangulation principle, previously made by a team of opticians Băcescu et al. (2002), Băcescu et al. (2003), Băcescu et al. (2005), and which was improved in order to be easily integrated in the conceived command and control structure. Due to these improvements the installation became more flexible, easier to use, thus also facilitating the possibility to be integrated in other different software applications, and, most important, it became more precise, as well, for the minirobot position tracking.

An important aspect of the installation in figure 3 is represented by the supporting and driving module of an optoelectronic device. – figure 4 The conception took into account the fact that there are necessary two such independent functioning modules, placed on one single supporting element (a track), to which one can attach an optoelectronic device, which uses for its functioning optic phenomena (photoreceptor), and which can be easily changeable with other possible different types of transducers based on other principles such as radio waves or ultrasounds emission and reception.

Fig. 3. View of the position tracking installation determining the minirobot's coordinates

Fig. 4. Module including the rotating transducer platform and the attached optoelectronic device

Thus, on each single module - figure 4, there is placed an optoelectronic device using a photoreceptor element - figure 5. The module uses an incremental rotation transducer in order to determine the current angles. Each rotation transducer is attached to a rotating platform driven by a controlled servomotor. Essentially, the platform makes a rotational movement around the central axis which the incremental transducer measures. The rotation made by using the electric servomotor can be clockwise or counter-clockwise. The installation uses an electronic command interface for electric motors conceived for commanding by means of the computer's parallel port.



a) b)

Fig. 5. Optoelectronic device

The optoelectronic device's role is to receive the beam, coming from the tracked source of light, to initially process the afferent analogical signal and to provide the result to an analogical input from the acquisition board in order to make a complex digital processing. In order to do that the device is made up of the following elements which are presented in figure 5: (1) the objective which focuses the light beam on the photoreceptor element, (2) a photodiode type photosensitive bar placed on the board (3) held by two bars (4) whose role is to support, to guide but also to set the focal distance between the ocular and the photoreceptor element by means of a spring and a nut placed on the screwed end of one of the bars. The space between the ocular and the photoreceptor element was covered with a flexible sheath coated with tinfoil (7) so that the received beam should be less affected by the parasite ambient light surrounding the installation. In this way there diminishes the risk of detecting other sources of light which can be found outside the interest field visualised by the installation. In the lower part one can also see the electronic module (5) whose role is to receive and analogically process the signal coming from the photodiode in order to further provide it to the acquisition board. All the components are placed on the element (6) whose role is to both support and to fix the whole device to the module platform to which it is attached.

The information received by the two modules placed on a known stereoscopic base, provided by the rotation transducers correlated with the signals of the photoreceptor element of the afferent device, allow the determination of the necessary angles for the distance calculation up to the luminous point of the moving mobile. The mathematical support is represented by the triangulation method which allows the determination of the spatial position, in any moment of the mobile, whose luminous source is tracked. The source is materialized by an electric bulb/ a luminous point, placed on the moving mobile, which is permanently position tracked by the installation.

3. RESEARCHES AND EXPERIMENTAL RESULTS

The experimental researches had as purpose the determination of the effects of several building modifications in improving the functionality performance of the installation.

3.1. Determining the installation's accuracy for the minirobot's space position tracking

Since position tracking means to know, at a given moment, the coordinates of the luminous point, placed on the minirobot which moves in the operating space, the purpose of a first set of experiments is to determine the accuracy with which this installation determine these coordinates – figure 3.

In order to determine the accuracy, the minirobot was placed in a P point, selected arbitrarily, whose coordinates were determined on one hand by means of the installation, and on the other hand by means of instruments of measurement.

By means of instruments of measurement the actual coordinates of the minirobot are as follows: Yp=1479mm and Xp=90mm and the distance OP=1481.74mm. By using the installation whose stereoscopic base was of B=1000mm, and the acquisition board configured for analogue input of 6000 samples/second and a x4 type decoding for the transducer which provides 3600 impulses/rotation allowing an acquisition resolution of de 360/(3600x4) = 0.025 degrees of the two "B" base adjacent angles, there were obtained the values according to which there resulted the variation graphs of the two Xp (figure 6), Yp (figure 7) values.

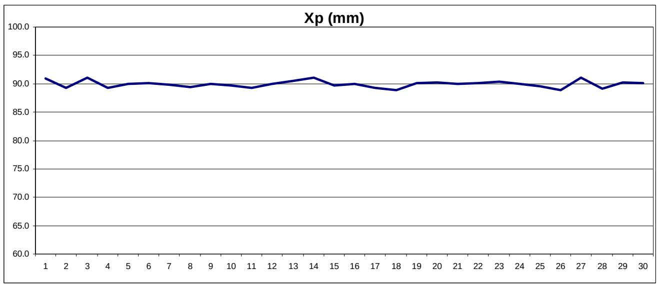


Fig. 6. The variation graph for the Xp coordinate

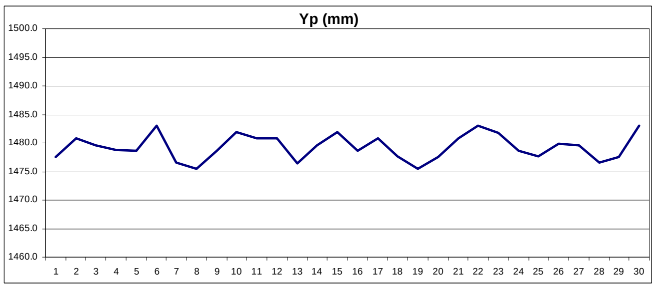


Fig. 7. The variation graph for the Yp coordinate

By analysing the obtained results we found the following errors:

- for the Xp coordinate, to the 90mm measured coordinate, the variation was between -1.20÷1.06mm,
- for the Yp coordinate, to the 1479mm measured coordinate, the variation was between -3.56÷3.95mm

By taking into account these differences, which are actually position tracking errors there were analyzed and there were searched solutions for determining the measurement accuracy of the installation.

3.2. The Resolution Influence of the Angle Acquisition on the Measurement Accuracy

Since the rotation transducer provides 3600 pulses/rotation, used in the x4 mode, it can yield a maximum resolution of 13800 impulses/rotation which means 360/13800=0.025 sexagesimal degrees. This value represents the minimum angular increment for the angle's measurement. Thus one can consider that the angle's maximum acquisition error, determined by the transducer's accuracy, is in-between the value of ±0.025 degrees, varying its sign according to the direction of the rotation in which the acquisition was made.

By taking account this error, there were made the variation graphs of the maximum errors which can result for different values of the B stereoscopic base - figure 8 for the situation in which the luminous source is situated on the direction of the center of the stereoscopic base (Xp = 0), and the Yp coordinate has values of 500, 1000 and 1500mm. The calculations are made according to the relations in 2 in which Yp is the correct value and Yperr is the value obtained with a maximum positive acquisition error of +0.025 degrees for both θ_1 and θ_2 angles, respectively.

$$\left.\begin{aligned} y_P &= \frac{B\sin(\theta_1)\sin(\theta_2)}{\sin(\theta_1+\theta_2)} \\ y_{Perr} &= \frac{B\sin(\theta_1+0.025)\sin(\theta_2+0.025)}{\sin((\theta_1+0.025)+(\theta_2+0.025))} \end{aligned}\right\} \Rightarrow err = y_P - y_{Perr} \qquad (2)$$

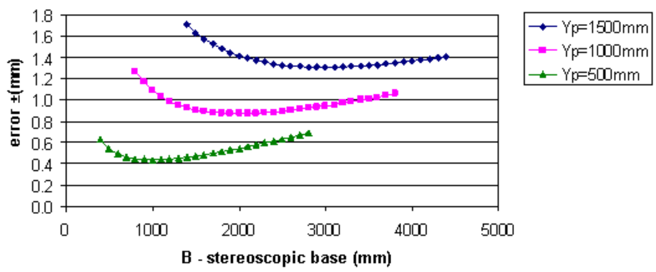


Fig. 8. The variation of the maximum errors for an acquisition resolution of 0.025 sexagesimal degrees

For comparison, there were made the obtained graphs for the situation in which the angular rotation transducer would have been used in the x1 mode, for which the maximum resolution would become of 3600 impulses/rotation, which will be transposed in 360/3600=0.1 sexagesimal degrees - figure 9 , which is a much more reduced resolution than the previous one.

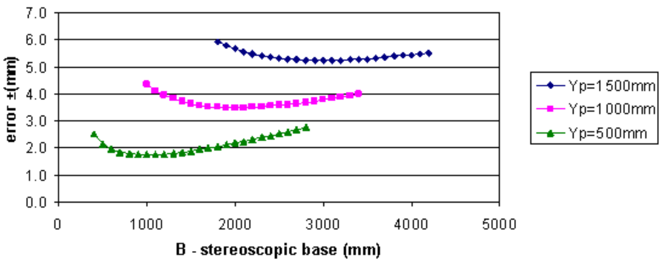


Fig.9. The variation of the maximum error for an acquisition resolution of 0.1 sexagesimal degrees

By analyzing the two resulted graphs, more aspects can be mentioned: the error decreases, approximately in inverse proportion, together with the increasing of the angles' accuracy of measurement and in direct proportion with the decreasing of the distance to the stereoscopic base. Moreover one determines a very important aspect: that the **minimum values of the errors** by maintaining the Yp constant, **are obtained for the situation in which the B stereoscopic base is approximately double compared to the measured Yp value**. Thus, there results it is optimal that the stereoscopic base should get modified adaptively for permanently known values, according to the measured distances. The double value of the B stereoscopic base compared to the Yp, when the errors are minimum, lead to the conclusion that the θ_1 si θ_2 optimal angles are around the value of 45°. This value must be maintained for any Yp value and by modifying the B base accordingly, by adapting it to the Yp.

This very important conclusion is being materialized by using an electrical micromotor, whose rotation is permanently known, and which moves on equal values but on opposed directions the two optoelectronic modules of the installation. **In this way there results an increased position tracking accuracy, a fact which represents a significant improvement of the functional performance of this installation.**

3.3. The influence of the stereoscopic base position on the accuracy of measurement

In this context there was also studied the influence of the horizontal direction coordinate on the measurement errors, caused by the inaccuracy of the angles measurement. Together with the relations in (2), which determined the error on the Y axis, one also uses the relations in (3) corresponding to the error on the X axis. For the graph in figure 10 these two sets of relations were used by considering the following: the B stereoscopic base equal with 1000mm, the constant Yp coordinate, having a value of 1500mm, and the angle's acquisition error as being equal with the minimum which can be obtained by means of the used rotation transducer, namely 0.025 sexagesimal degrees.

$$\left.\begin{aligned} x_P &= 0.5B - \frac{y_P}{tg\,\theta_1} \\ x_{Perr} &= 0.5B - \frac{y_{Perr}}{tg\,(\theta_1 + 0.025)} \end{aligned}\right\} \Rightarrow err = x_P - x_{Perr} \qquad (3)$$

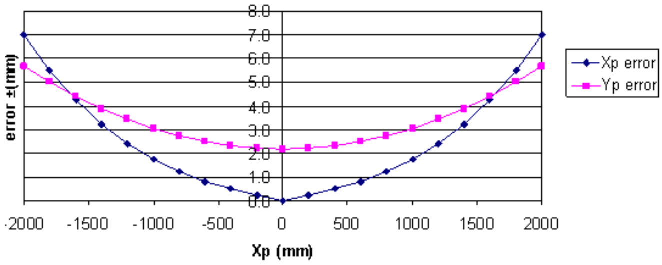


Fig. 10. The variation of the maximum errors on the two directions according to the Xp value

One can see that the value of the Xp coordinate has an influence not only on the errors on the X axis but also on those on the Y axis.

By taking into account the previous finding and comments, referring to the influence of the value of the stereoscopic base on the error, in figure 11 there are presented comparatively the graphs for the obtained errors by the variation of the Xp coordinate for the case of three stereoscopic bases of values of: 1000, 4000 respectively 8000mm, the conditions referring to the Yp coordinate and to the angle's accuracy and measurement being the same.

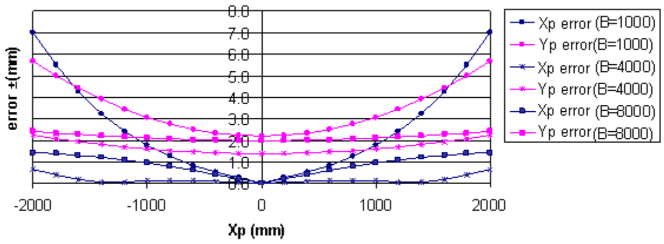


Fig. 11. The variation of the maximum errors on the two directions according to the Xp value, having the Yp=1500mm, in the case of three different stereoscopic bases

In this case, as well, it is found that the stereoscopic base influences the obtained errors both on the X direction and on the Y direction. The minimum values of the maximum errors are found for the medium value (=4000mm) of the stereoscopic base which leads in this case, too, to the previously obtained conclusion according to which the stereoscopic base contributes to the obtaining of minimum errors only if it is adaptive and correlated with the value of the to-be-measured coordinates.

By taking into account another new considered aspect – that the errors increase as only the Xp increases, one can conclude that the maintaining of the luminous source on a perpendicular direction on the centre of the stereoscopic base represents another means for increasing accuracy, which can be materialized through an electrically driven mechanism which causes the rotation of the stereoscopic base.

3.4. The influence of the sampling rate on the accuracy of measurement.

In order to obtain the angle's acquisition there was taken into consideration the minimum value of the acquisition signal from the optoelectronic module. In figure 12 there are presented two situations which can occur when correlating the minimum measured angle and the sampling rate.

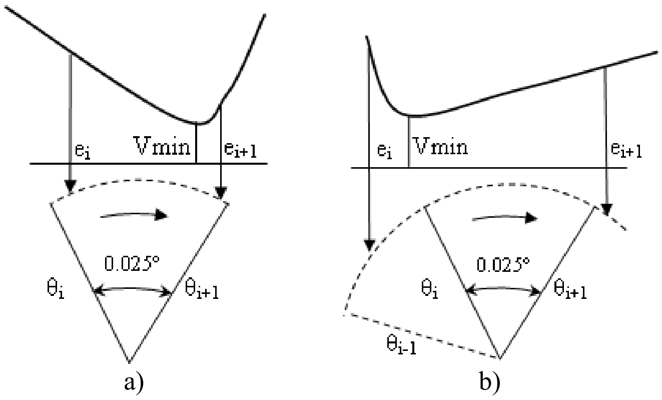


Fig. 12. The correlation between the minimum measured angle and the sampling of the signal received from the optoreceptor device

In the a) case the sampling rate is more increased than the number of impulses/rotation used for the angle's measurement. This fact implies that at least one sample will be acquired between two successive impulses of measurement of the θ_i-θ_{i+1} angle, which in the case of using the transducer's maximum resolution has the value of 0.025 sexagesimal degrees. In the example in figure 12 a) there was considered the situation in which 2 consecutive samples are acquired in such an interval. One can see that the angle's acquisition will be determined by the e_{i+1} sample. One can see that, although the acquisition is a bit delayed, the result of the angle's acquisition will still remain θ_i, being the same even if it was acquired at the occurrence of the Vmin value. Thus, the angle's acquisition error is considered to be determined by the inaccuracy of the rotation transducer.

In the b) case the sampling rate is more reduced than the number of impulses/rotation used for the angle's measurement. In this situation, between two consecutive samples e_i-e_{i+1}, the indicated value of the angle can be modified at least once. In the example in the figure there was considered a situation in which between 2 consecutive samples the angle modifies its value twice θ_i, θ_{i+1} . The angle's acquisition corresponding to the e_{i+1} sample will lead to a result which is affected by an angular error which is larger than the minimum measurement step of the rotation transducer. Thus, the angle's acquisition error will depend on the sampling rate of the acquisition signal. One can conclude that the values succeeding at a slower pace also determine the angle's acquisition. The angle's measurement intervals cannot be modified, but the samples de succession intervals can be decreased by the rotation speed – sampling rate combination. Thus, so that the angle's measurement errors should only be the ones resulted from the rotation transducer's inaccuracy, one must have the following:

$$\frac{\text{rotation speed}}{\text{sampling rate}} < 0.025° \qquad (4)$$

Since the scanning interval is of approximately one second for 120º, there will result a sampling rate of:

$$\text{sampling rate} > \frac{120}{0.025} = 4800 \text{ samples/sec} \qquad (5)$$

This condition, which also contributes to the increasing of the position tracking accuracy, can be applied by correlating it with the rotation speed of the optoelectronic modules.

4. CONCLUSIONS

According to the experimental researches which were done, there were identified and are being materialized new constructive and functional solutions due to which the performance of the optoelectronic installation for the minirobot's position tracking is improving, which means a main importance increase of the accuracy - parameter principle in the field of the mechatronic systems.

Both possibilities regarding to the adaptive modification of the stereoscopic base and its real time rotation, actually of the transducer's reference trihedron to a fixed trihedron linked to the work space, which represent the results of the research, are being put to use.

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