# Method for Determining Coordinates of a Solid Body with Six Degrees of Freedom

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***Abstract* – A method for determining of the coordinates of moving solid body with six degrees of freedom is described. The method could be applied in examining of behavior of moving solid body, in exception of ship model in maneuvering pool.**

***Keywords* – models, method for determining, trajectory, measuring.**

## I. INTRODUCTION

A lot of optical technologies that can provide information about the movement of a body have been developed. These technologies have common mathematics frame concerning the optic of Fourier and the theory of signal processing. Historically these technologies have been developed separately from each other, because of the reason that they do not have common elements that are tie-pieces.

The above mentioned optical methods have a wide application in different areas – in production processes, in determining of contours of surfaces, in non destructive testing, in solving dynamic problems (analysis of vibrational parts), analysis of random forms etc.

The following method for determining the coordinates of moving body with six degrees of freedom is the subject of our research in finding suitable method for exploring the behavior of ship models.

## II. ESSENCE OF THE METHOD

The purpose of the described method is determining of the moving of ship radio-controlled model in maneuvering pool with the following dimensions 40x40m.

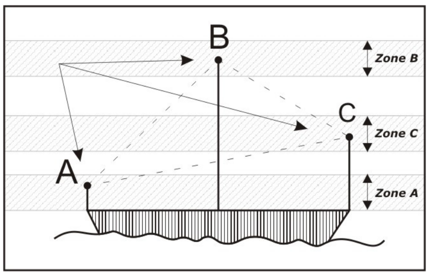


Fig. 1. Distribution of the light sources[1]

On two contiguous corners of the maneuvering pool are mounted cameras which trace the movement of three bright spot light sources (small electrical bulbs or light emitting diodes) attached to the model, see Fig. 2. The light sources that are used in the method are mounted on different heights, so that allows them to be presented in different areas on the camera screen in vertical direction. The transposition of the light sources on different levels, as shown on Fig. 1, allows exploration of the six degrees of freedom of a solid body. Each of the cameras is connected with tracking device, which automatically directs the optical axis of the camera to the object that is traced through the process of its movement.

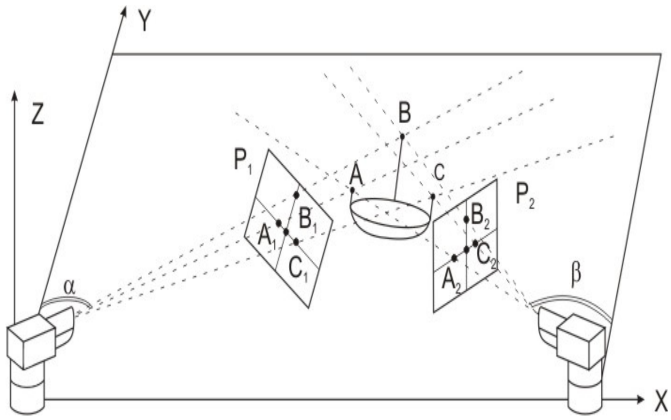


Fig. 2. Scheme of measuring system

Both of the cameras use pan-tilt mounts, as a part of a servo system containing direct current reversive engine, with rotary optical encoder between the camera and the platform.

At the time of working this method out, the revolving Moiré gauge is used for determining of the angle of rotation of the camera. It produces a number of electrical pulses when the camera is rotated in horizontal plain. These pulses in form of binary information are passed to a computer in order to make a database. Except this information the information passed to the computer contains data about the position of the three dot spot light sources in the field of vision of each of the cameras. Their position in vertical direction is given by counting the television lines considered from falling edge of vertical blanking pulse, Fig. 4 and Fig. 5. The horizontal position of the object in the field of vision of the camera is given by digitizing of the lines and taking into consideration the position of the light sources towards the falling edge of vertical blanking pulse.

The binary information packs incoming from both of the cameras, are stored into the computer memory with the purpose for further processing.

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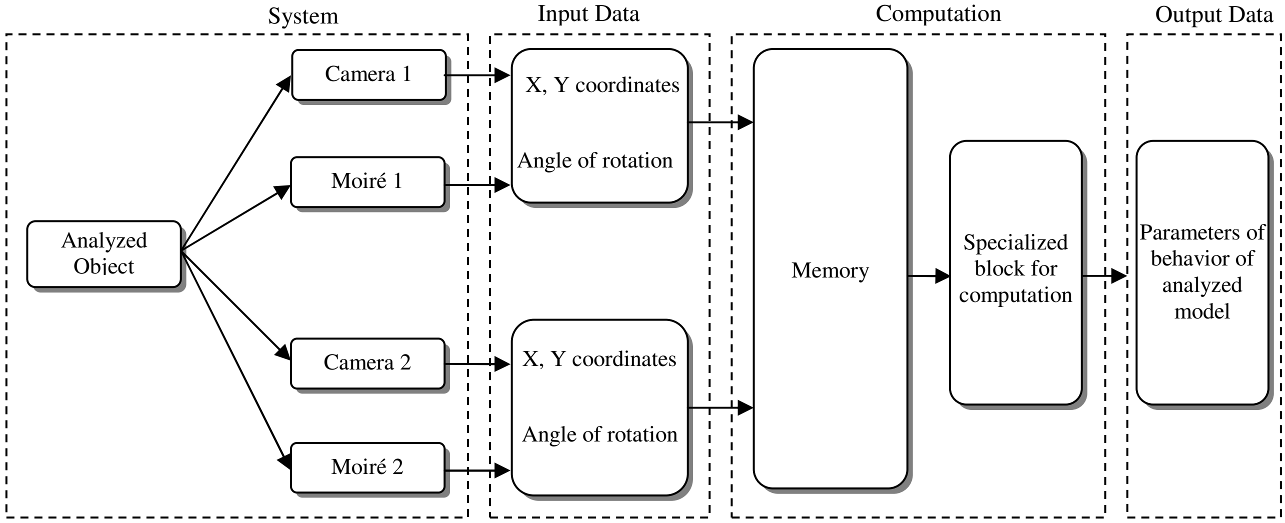


Fig. 3. Basic scheme of the method

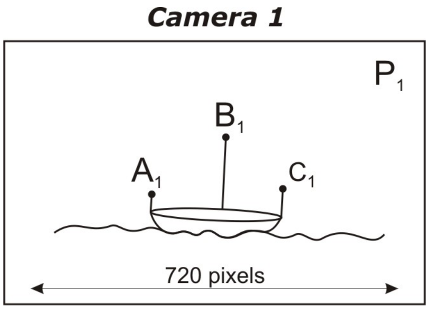


Fig. 4. Picture taken from camera 1

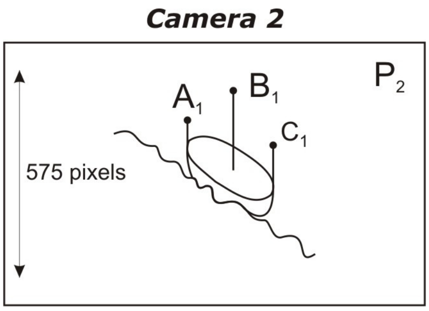


Fig. 5. Picture taken from camera 2

The main idea of the given method lies on a basic principle – if we know the coordinates of three points of a solid body, which means that we have an accurate definition of its exact position and orientation.

The position of the ship model is calculated using the two angles of rotation $\alpha$ and $\beta$. The orientation of the model is given by the coordinates of the three dot spot light sources upon the television screen.

On Fig. 3 is visualized the basic stages of the method. The System group provides the data needed for the input of computation stage, where are gathered all of the input data. The specialized block for computation makes all of the needed analysis and computation, all of the smooth filtering and interpolation works.

## III. Determining of the Key Parameters

*1. Determining of the angle of rotation of the Moiré gauges.*

The angles of rotation $\alpha$ and $\beta$ are determined by the rotation of the Moiré gauges shown on Fig. 6.

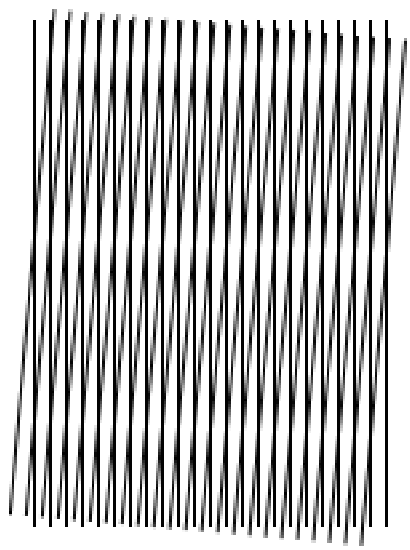

Fig. 6. Gratings of Moiré gauge

Moiré gauge consists of two identical gratings having the following parameters: $l$ – constant of the gratings; $\gamma$ – raster period angle between gratings. When the two gratings are absolutely parallel they no fringe is observed, only dark and light fields can be seen. When there is a small angle between the gratings there is a moiré pattern. The distance $T$ between them is given by the following formula:

$$T = \frac{l}{2\sin\frac{\gamma}{2}} \tag{1}$$

The grating lines displacement on the width $l$ cause perpendicular transposition of the moiré pattern at the distance $T$. For small angles $\gamma$ = *1'* the transposition is given by the following equation:

$$T = \frac{l}{\gamma} \tag{2}$$

This principle is used in the pulse measurement of angle rotation.

In this method there are two cameras mounted on two neighboring corners of the pool. The optical axes of these two cameras using an automatic tracking system are always focu–sed on the tracing the object. The readings from both cameras are always time synchronized with each other by time code for obtaining correct data from them at the same time.

In this way the location of the object is determined by two angles of rotation. The two cameras have initial synchro–nization and run from 0˚ to 90˚ with pitch of 1'.

*2. Determining the position of the object in the field of vision of the cameras.*

The X and Y coordinates of the analyzed object are determined by using the formed raster image from the both cameras Fig. 7. Each camera is characterized by its parameters of resolution. In this case is used the standard with 625 lines (575 active).

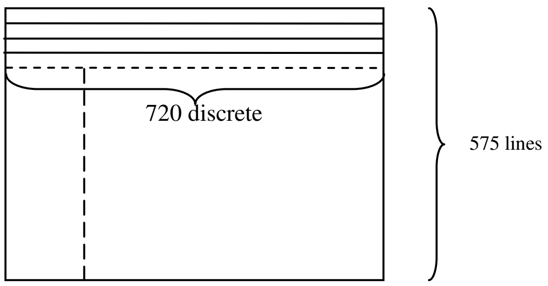


Fig. 7. Scheme of TV image

The Y coordinate is determined by the number of the line on which is situated the object (0 -575). The X coordinate is determined by the number of the discrete of the corresponding line on which is situated the object (0 - 720).

## IV. Accuracy of the Method

The accuracy of the method exclusively depends on accuracy of Moiré gauges that have been used. To determine accuracy the length of the chord of maximal distance between the camera and the model is computed. With dimensions 40x40 m of the maneuver pool and rotation angle of 1' the length of the chord with maximal distance is 0,016 m, which satisfies the requirements of the practice Fig. 8.

The choice of the camera lens must be conformable to the requirement of the measured accuracy of X and Y coordinates. The camera optics is chosen so that it can comply with following conditions:

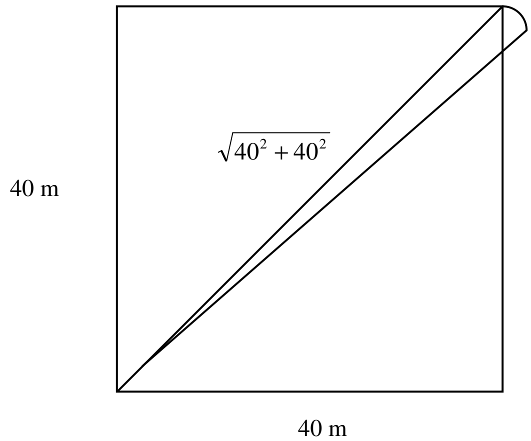


Fig. 8. Maximal distance scheme

- the model to be in range when it is too close;
- not to be so wide-angle, because from its side this will decrease the accuracy of measurement of the coordinates of the light sources.

The Moiré gauges should meet the technical requirements of at least 22 000 pulses/round. That will ensure the accuracy of the measurements as it is necessary 21 600 pulses/round.

## V. Necessary Amount of Memory and Speed Performance

For the method is important to specify necessary amount of memory according to previously defined accuracy of measuring. In this case the position of the object in the maneuver pool is considered to be determined with accuracy of 0,016 m. The average speed of the model is considered 12km/h. The amount of memory is calculated for the following data components:

- Angle of rotation of the camera. The measurements of the rotation angle are with accuracy of 1'. The camera motion angle is 90˚ and that defines 5400 possible readings, witch on its side defines using of 13 bit binary number;
- X co-ordinate of the object. The co-ordinate has a value in rage 0 - 720, which necessitates using of 10 bit binary number;
- Y co-ordinate of the object. The co-ordinate has a value in rage 0 – 575, which necessitates using of 10 bit binary number.

The presence of three light sources, witch are defining the position of the object, necessitates for each one of them two readings for X and Y coordinates. The computations that have been made are pointing that for one obtained reading from each camera are necessary:

- 13 bits for rotation angle of the camera and 3 x 20 = 60 bits for X and Y coordinates of the three light sources;
- total of 73 bits for one surveying camera and 146 bits for two.

The necessitated requirements for accuracy of measurements up to 0,016 m at 12km/h average speed require data transfer speed of 17.82 Kbytes/s. For one minute object tracking is required the following amount of memory: amount of memory for 1 min = 60 x 17.82 Kbytes/s = 1069.2 Kbytes = 1.04 Mbytes.

## VI. CONCLUSION

1. A method for determining of the position of moving object in continuous moments in time is described.

2. An assessment of necessary data transfer speed with an eye on obtaining necessary accuracy is accomplished.

3. So obtained values of the parameters empower for calculation and determining of the trajectory of movement, instant and average speed, and acceleration of analyzed object.

4. The necessary amount of memory for storing data obtained during analysis is defined.

5. Through database values and appropriate software the complete object's behavior could be visualized during the process of analysis.

## REFERENCES

[1] Craig, J.J., Introduction to Robotics – Mechanics and control, Addison, Wesley Publishing Company, 1991.

[2] Ján Bartl, Roman Fíra, Miroslav Hain, Inspection of surface by the moirè method, Measurement Science Review, vol. 1, number 1, 2001.

[3] Kafri O., Glatt I., The physics of moirè metrology, New York, Toronto, John Wiley & Sons.

[4] http://www.bshc.bg