THE REVERSE VALIDATION OF TRAJECTORIES FOR ROBOT

Vadim Lyalin
M.T. Kalashnikov Izhevsk State University, Faculty of Computer Science, Russia, Udmurt Republic, Studencheskaya 42, Izhevsk 426069, Russia, iwt@istu.ru

Alexander Lozhkin
M.T. Kalashnikov Izhevsk State University, Faculty of Computer Science, Russia, Udmurt Republic, Studencheskaya 42, Izhevsk 426069, Russia, iwt@istu.ru

Vanessa Prajová
Slovak University of Technology, Faculty of Materials Science and Technology, Institute of Industrial Engineering and Management J. Bottu 25, 917 24 Trnava, Slovak Republic, vanessa.prajova@stuba.sk

Pavol Božek
Slovak University of Technology, Faculty of Materials Science and Technology, Institute of Applied Informatics, Automation and Mechatronics, J. Bottu 25, 917 24 Trnava, Slovak Republic, pavol.bozek@stuba.sk

Keywords: reverse validation, inertial navigation system, robot, operation

Abstract: The paper comments the new possibilities of utilizing the inertial navigation system in a manufacturing technique. It deals with new principles of robots and inertial navigation systems based robotized production systems operating reliability. The inertial navigation is self-supporting navigation technique utilizing for measuring accelerometers and gyroscopes. By them it is possible to watch a position and orientation of an object relative to a known starting point. Currently, for the 3D inertial navigation execution the inertial navigation system (INS) is used and you can encounter it on the board of army or civil airplanes where it is the primary source of navigation information. INS includes one navigation computer at minimum and a platform or module comprising accelerometers and gyroscopes. The reason to use INS for navigation is its autonomy and impossibility of purposeful interrupting its operation from the outside.

1 Introduction

The inertial navigation is self-supporting navigation technique utilizing for measuring accelerometers and gyroscopes. By them it is possible to watch a position and orientation of an object relative to a known starting point. A basic element of each inertial navigate system (INS) is inertial measure unit, that consists usually of three gyroscopes for angle speed measurement and three accelerometers for linear speeding-up measurement [1], [2] . By processing of the signals from this equipment it is possible to watch the position and orientation.

Inertial navigation is known by its application especially in aircraft industry, tactical and strategic missiles, space ships, submarines and ships navigation. The small, light and price accessible navigation systems with a chance to be applied also in other areas are produced on the present thanks to the MEMS (Micro-Electro-Mechanical Systems) technologies expansion.

A continual economic force of cost minimization and technological processes streamlining require innovations and improving. The new methods require detailed analysis of the issue and searching for new solutions. Among effects that require practical attention there belong also manufacturing technique inertial navigation systems applications, which can be applied for machines stability control, vibration progress observation in mechanical technologies, robots and robotized production systems operative, production system clashing cases preventing et cetera.

Continuous assessment of the controlled and navigated robot using the sensors for motion detection, i.e. gyroscopes and accelerometers can be ensured by inertial navigation. Via the navigation computer and data obtained from the motion detectors the position, orientation as well as the direction can be constantly determined without using external information sources. The current position of the object is assessed on the basis of knowing the initial position and subsequent continual measurement of acceleration and direction of the motion in the reference system. The inertial navigation principle is based on Newton´s laws expressing the motion change at using the external forces as well as the acceleration which is proportional to the orientation and size of the external force [3], [4].

2 Inertial navigation system analysis and description

Currently, for the 3D inertial navigation execution the inertial navigation system (INS) is used and you can encounter it on the board of army or civil airplanes where it is the primary source of navigation information. INS includes one navigation computer at minimum and a platform or module comprising accelerometers and gyroscopes. The reason to use INS for navigation is its autonomy and impossibility of purposeful interrupting its operation from the outside. The sensors of acceleration (accelerometers) as well as the sensors of angular velocity (gyroscopes) are firmly attached to the platform connected the navigated means.

The basic element INS is represented by IMU, Inertial Measurement Unit. Sensors whose outcome is influenced only by object motion on which the IMU is located are considered as primary sensors of IMU. These primary sensors in the inertial navigation are used for n are represented by angular velocity/speed sensors whose output signals after integration are used for the determination of orientation in space and the accelerometers whose output signals after precise compensating the gravitation acceleration and Coriolis force can be integrated into the velocity and position. Platform-free systems have the sensors located into the 3D coordinate system so that each axis of the navigated object corresponds to the accelerometer´s sensitivity axis as well as to the angular velocity sensor. Such an inertial measurement unit has six degrees of freedom, i.e. it allows the measurement of transaction and rotation movements in three-orthogonal axes. The inertial sensors accuracy is of key significance in the autonomous navigation [5].

For industrial robots the orientation, or precise determination of the programmed point in space is the necessary condition for their moving without collision or accident which is essential not only of a robotic device but of the running process as well. Currently, when for increasing the reliability of robotized workplaces operation in the production technology comes into consideration the main orientation is on integrating the inertial navigation systems into the control process and operation control of robotic as well as other peripheral means of production systems [6], [7] .

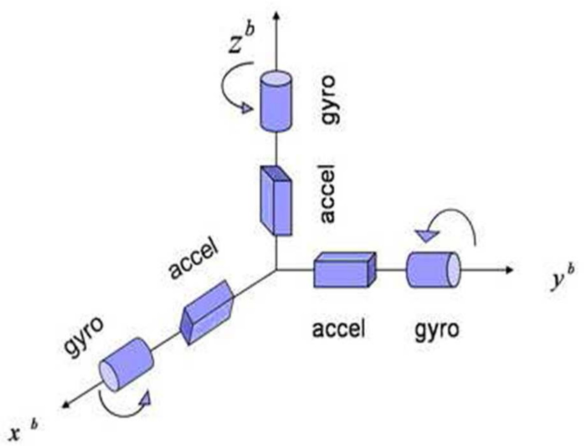

Figure 1 Basic principle of INS activity

A new and not researched control method of robots´ trajectory as well as of other means and components in production so far is represented by utilizing inertial navigation systems on the basis of hybrid MEMS (micro-electro-mechanic-systems) sensors which appeared not long ago. The research in INS is running in several branches of industry related to aviation, rockets, ships, however, nobody has researched these systems implemented in the field of control neither control of industrial robots in real time.

Inertial navigation system consists of a measurement unit comprising gyroscopes rotating around three axes X, Y, Z, then three accelerometers operating in these axes X, Y, Z (see Figure 1) and a navigation computer assessing data obtained from measurement devices/instruments.

The basis is represented by the system of autonomous robot´s trajectory control aimed at the prevention of collisions. In the new concept, the control of the current position is dealt with by the autonomous system of accelerometers and gyroscopes in three axes [8]. Another progressive method, not frequently used so far, is the utilization of INS in the system of robot´s trajectory control. If the robot´s position is not calibrated on a regular basis, the deviation will continuously increase and big differences between the real robot´s position and programmed position can grow which is unacceptable for practice.

The navigation autonomy, i.e. independence on external sources of navigation information was the main reason for INS implementation. In contrast to all other navigation systems the inertial navigation is completely self-sufficient and independent on external environment, i.e. the system can resist external influences such as magnetic faults, electronic disturbances and signal deformation.

If we implement INS as an independent control into the robot´s control system, the programmed position will be constantly compared to its real position in the working environment. Thus, the robot´s position will be continuously checked and calibrated via the navigation computer [9], [10], [11]. The deviation does not grow and there are no differences between the real and programmed positions of the robot.

3 Position of the Robot

In determining the position of a robot as well as its management is the ability to use the device, which works in the inertial coordinate system and can determine the position of the arm of the robot in its workspace. In this case, the robot arm is equipped with a detection device (an inertial navigation system), which detects the speed, acceleration and rotation of the arm of the robot in the coordinate system. Using this system, it is possible to determine the position of a robot in space very well where the other methods for the detection of the position cannot be used. The position can be obtained subsequently adjusted according to the requirements and the robot arm is then able to watch any route to reach the desired position.

Location data obtained from the inertial measuring device are sent to the management computer, which compares it with the required values and those are subsequently adjusted, so the required position can be reached by the robot arm. The data from the management computer are sent to the robot using a robot control system. The process of sending and checking data is called reverse validation [12].

Inertial measurement unit measures the kinematic values - angular velocity and linear acceleration. The earth can be considered an inertial system if we neglect spin, then taking into account a kinematic theory is true: if we know the initial position of the object as well as its initial speed at the object at the time while we measure R, together with the acceleration using accelerometer placed on the shoulder of the robot, so we can determine the speed of the object at the time.

Due to the use of mathematical operations integration occurs over time position error. The size of this error depends on the type of inertial measuring system or on the quality of the accelerometer in the system. One of the options to remove the positioning error is resetting the zero point of inertial measurement system at regular intervals.

In determining the position of a robot using a gyroscope, inertial measurement unit using the angular velocity ω measured around the axes x, y, z in Cartesian coordinate system. From the measured angular velocity using mathematical adjustments we calculate the angular rotation φ. This represents a motor rotation respectively rotation of each arm of the robot. So thanks to the output data of the gyro we can determine the position of the robot arm in space [13], [14]. The output of the gyro can be analogue or digital. Processing outputs is using the management computer to calculate the necessary change in order to move the robot arm to desired position in space. This type of controlling position is called a reverse validation.

When measuring the rotation of gyroscope an error occurred when integrated, which increases over time. This is also possible as in accelerometer removed by resetting the zero inertial measurement system. A fundamental difference between the accelerometer and gyroscope is that error of integration in accelerometer is greater than in gyroscope due to a double integration [15].

4 Application of inertial navigation system

Figure 2 shows robot 1 controlled by the central computer 2. In the place of robot 1 which is prior defined the autonomous system INS 3 is located and is connected to the navigation computer 4 which is connected via the series peripheral interface SPI 5 to the central computer 2. This way it is possible to continuously control the trajectory as well as the position of the observed point in the working environment of the robot 1.

If the initial position of robot 1 is defined, the initial position of INS 3 attached to the robot 1 is defined as well. The motion and current position of robot 1 controlled by the central computer 2 in the working environment is continuously checked and compared to the data of the autonomous INS system 3 about the position by the navigation computer 4 via the series peripheral interface 5.

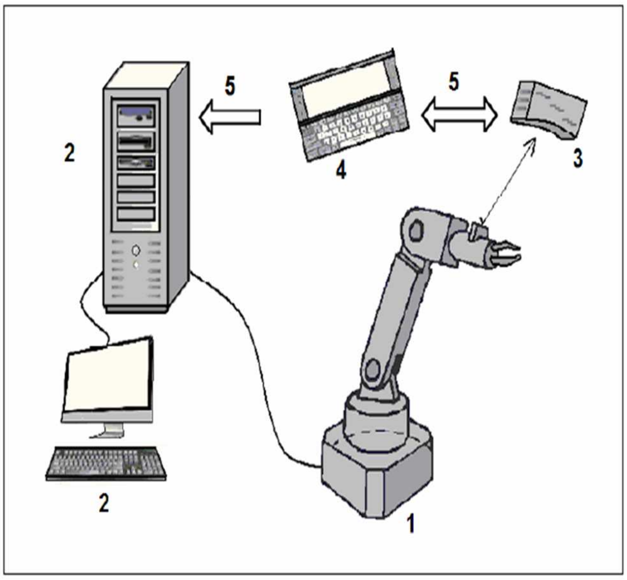

Figure 2 Implementation of the robot´s autonomous trajectory control
1 – robot, 2 – central computer, 3 – inertial navigation system, 4 – navigation computer, 5 – series interface

The navigation computer 4 validates the immediate position of robot 1 and by means of the series SPI peripheral interface 5 it communicates with the central computer 2 making thus the position of robot 1 more precise. This way the robot´s position is constantly assessed and specified by autonomous INS. We speak about Reverse Validation [16], [17] .

Once the autonomous INS system is applied in the system, no position sensors are necessary. During the repetitive motions robot 1 records the position deflections to the programmed position exponentially growing with the operation time. To minimize the measurement deflections, it is necessary to carry out the continuous calibration of the robot´s position by the system of autonomous control of the robot´s trajectory. When we deploy the autonomous INS system into the control system of robot 1, the calibration is not needed since the autonomous INS system constantly communicates with the navigation computer 4 via the series SPI peripheral interface 5. The central computer 2 assesses the data from the navigation computer 4 and compares them to the data form the control program. Then by the evaluation of the differences in data, it immediately declines the deflection to minimum in real time.

5 Conclusion

For industrial robots the orientation, or precise determination of the programmed point in space is the necessary condition for their moving without collision or accident which is essential not only of a robotic device but of the running process as well. Currently, when for increasing the reliability of robotized workplaces operation in the production technology comes into consideration the main orientation is on integrating the inertial navigation systems into the control process and operation control of robotic as well as other peripheral means of production systems [18].

A new and not researched control method of robots´ trajectory as well as of other means and components in production so far is represented by utilizing inertial navigation systems on the basis of hybrid MEMS sensors which appeared not long ago. The research in INS is running in several branches of industry related to aviation, rockets, ships, however, nobody has researched these systems implemented in the field of control neither control of industrial robots in real time.

The system of autonomous control of the robot´s trajectory can be used for the determination of the precise robot´s position in its working environment.

Acknowledgment

Supported by Minobrnauki of Russian Federation, Grant GZ/TVG 14(01.10).

The contribution is sponsored by VEGA MŠ SR No 1/0367/15 prepared project „Research and development of a new autonomous system for checking a trajectory of a robot“ and by KEGA MŠ SR No 006STU-4/2015 prepared project „University textbook "The means of automated production" by interactive multimedia format for STU Bratislava and Kosice“.

References

[1] BISHOP, H. R.: *The Mechatronics Handbook*, CRC Press, 2006.

[2] BOŽEK, P., PIVARČIOVÁ, E., KORSHUNOV, A.: *Reverse validation in the robots control*, Applied Mechanics and Materials 2015.

[3] FRANKOVSKÝ, P., HRONCOVÁ, D., DELYOVÁ, I., VIRGALA I.: *Modeling of Dynamic Systems in Simulation Environment MATLABSimulink – SimMechanics*, American Journal of Mechanical Engineering, vol. 1, no. 7 2013, p. 282–288, 2013.

[4] BOŽEK, P., POKORNÝ, Peter.: *Analysis and evaluation of differences dimensional products of production system,* Applied Mechanics and Materials. 2014.

[5] MOLNÁR, V., FEDORKO, G., MICHALIK P.: *Computer integrated system for static tests of pipe conveyer belts*. 4th Balkan Mining Congress, Slovenia, 2011.

[6] BOŽEK, P., KORSHUNOV, A., KOLLÁR, P.: *Technological system for weight measurements in a logistic warehouse*. Applied Mechanics and Materials, 2015.

[7] WEBER, W.: *Industrieroboter*, HANSER, 2009.

[8] LOZHKIN, A., ABRAMOV, I., BOŽEK, P., NIKITIN, Y.: *The issue of calculating elliptic trajectories*, Manufacturing technology, 2014.

[9] QASEM, H., GORGIS, O., REINDL, L.: *Design and calibration of an inertial sensor system for precise vehicle navigation*, in Positioning, Navigation and Communication, 5th Workshop on, vol., no., pp.229-231, 27-27, [Online] Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4510379&isnumber=4510344 [Mar 2008], 2008.

[10] CHYNORADSKÝ, L.: *Control the robot using inertial navigation system*, pp. 52-56, 2015. (Original in Slovak)

[11] PIRNÍK, R., HRUBOŠ, M., NEMEC, D., MRAVEC, T.: *Control the wheel chassis based on data from inertial sensors*, 2015.

[12] MIMOUNI, A., AZZOUZ, E., GHEMRI, B.: *Lightninginduced overvoltages on overhead lines: Modelling and experimental validation,* Journal of Electrical Engineering. Vol. 62, No. 3, 2007.

[13] LOZHKIN, A., DYUKINA, N.: *Structurization of analytical geometry on the base of symmetries*, LAP, Saarbruken. 2012.

[14] GOGA, V., BOŽEK, P.: *Application of INS to mechatronic systems control and regulation using virtual dynamic models*, Piscataway: IEEE, 2013.

[15] BENSER, E.T.: *Trends in inertial sensors and applications*, in Inertial Sensors and Systems (ISISS), IEEE International Symposium on , vol., no., pp.1-4, [Online] Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7102358&isnumber=7102353 [Mar 2015], 2015.

[16] LOZHKIN, A.,G.: *Method formalization of semantic relations in language of machine-building drawings*, Designing and manufacturing of metal-plastical structure, IMI-UdSU,. Izhevsk, 1990.

[17] LOZHKIN, A.,G.: Applied planemetry with singular transformations. IE UrO RAS, Ekaterinburg, 2009.

[18] LYALIN, V., E.:*Intelligent information-measuring technology and control systems for the interpretation of geophysical researches of wells*, RIO UrO RAS, Ekaterinburg, 2013.

Review process

Single-blind peer reviewed process by two reviewers.