MACHINES FOR INSPECTION OF PIPES

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Keywords: mechatronics, machine, locomotion, pipes, wheeled
Abstract: Machines for inspection of pipes are locomoted inside pipe via used various types of locomotion. This arcticle deals with wheeled in-pipe locomotion. Developed in-pipe machines are described. Pipe is as constrained space and it is complicated to design the machine for this purpose. Problems that are necessary to solve can be divided into several groups, small dimension and scalling effect of actuators, power supply and cables, impurities inside pipes etc.

1 Introduction

In-pipe micromachines are able to move in the pipe to inspect or to repair the pipe or other special tasks. Pipe is as confined space i.e. this is constraint for micromachine dimensions, degrees of freedom etc. There are a lot of interdisciplinary problems in design and realisation of in-pipe micromachine. It is difficult to choose suitable actuators, sensors, and power supply etc.

In term of biological analogy, it is possible to divide ways of locomotion into two main groups [1-15]:

- artificial locomotion,
- biological inspired locomotion.

In term of physical principle, we can divide both these groups into several basic locomotion ways. It is important to say that it is not final and changeless dividing [1-15].

Wheeled locomotion principle: Wheels are standard synthetic components, which are very often used for locomotion purposes. However inner pipe wall is not perfect. There are a lot of obstacles, which have various characters. When inner pipe wall is dirty, wheels tend to slipping.

Crawled locomotion principle: Tracks is also unfinished rotating element. It is most adaptable to surface then wheels but it is not so often used as wheels.

Legged locomotion principle: Legs are components, which have inspiration in biology (e.g. spider, cockroach etc.). Many biological organisms reach high speed, which locomote via legs. These organisms overcome difficult obstacles and there are fascinating for designers.

Inchworm-like principle: The inchworm strategy comes from biological example. The inchworm is capable of manoeuvring in extremely small spaces, it can do so in arbitrary orientations to gravity and can withstand substantial external forces attempting to diverge it from its intended course. It can do these things because its mobility system is governed by a simple rule: "Never let go of what you're holding until you're holding something else!“.

Inertial stepping locomotion principle: The principle based on fact that a part of device (inertial mass) oscillates with suitable frequency. Backward tendency of motion is damped.

Worm-like locomotion principle: The locomotion uses anisotropic properties of friction between device and pipe wall. Forward friction force is less then backward friction force. It causes that device locomotes in forward direction.

Travelling wave locomotion principle: Device has articulated body and generates travelling wave from head to tail [1-15].

In-pipe inspection is considered as objective method for crack detection and in some cases it is only one possible way of pipe inspection. There are very known facts about accident in nuclear power plant, which has very bad impact to people and environment. These damages caused with pipe crack are higher than value of the pipe system. These facts were the initial impulse for in-pipe inspection developing. Some pipe systems are placed in environment, which is dangerous for people, so this is area right for in-pipe micromachine. In-pipe inspection is always cheaper than eliminating of accident results. It is very difficult to develop universal inspection in-pipe micromachine. In the most cases is possible to determine concrete conditions, in which the micromachine will locomotes. Following this condition, the way of locomotion and sensing system are selected. Situation is more complicated if inner pipe diameter decreased [1- 15].

2 Wheeled modular machine for constant inner pipe diameter

At first a compact machine MATALU for in-pipe locomotion has been developed for pipe with inner diameter from 34 to 36 mm (Figure 1). This concept has low traction force and problem with crossing of T – joint.

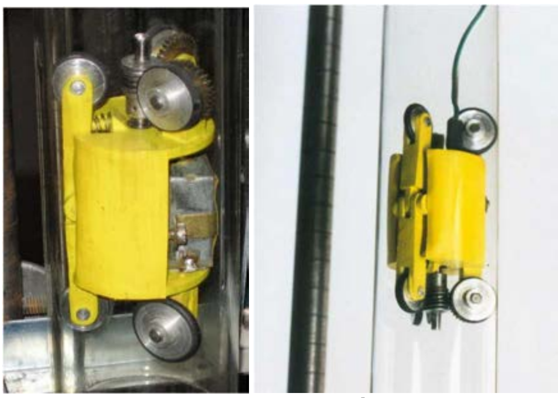

Figure 1 Compact in-pipe machine MATALU

Next developed wheeled machine FENAUS has been arranged as modular mechatronic system for pipe inspection of inner diameter from range 34-36 mm. (Figure 2) [16, 17].

Figure 2 Modular in-pipe machine FENAUS

Machine consists of energy module, connecting module, end module, control module and drive module. Composition of machine can be arranged in accordance with application. Minimum configuration contains driving module and end module (Figure 3). Nevertheless, it is possible to make configuration with two drive modules and three energy modules analogous to train.

Figure 3 Modular in-pipe machine FENAUS in short version

Every module is connected to other via using the spring joint, which enables very good manoeuvring to cross also elbow and T – joints (Figure 4).

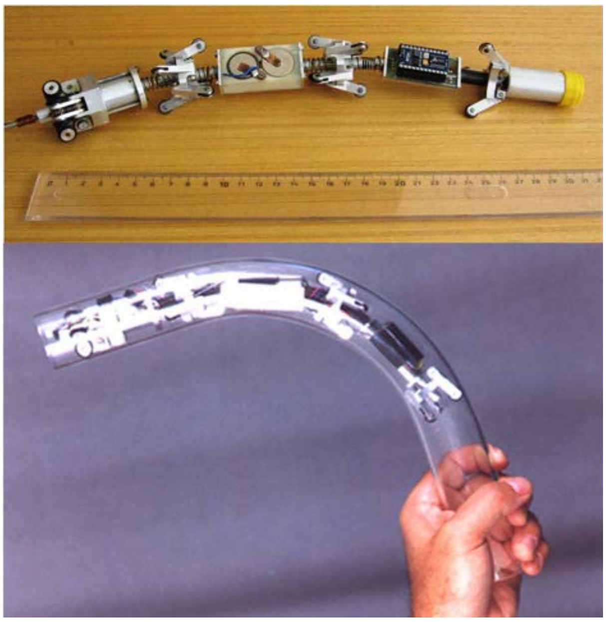

Figure 4 Modular in-pipe machine FENAUS in elbow

Drive module (Figure 5) consist of DC brush motor with 2 stage cylindrical-worm gearing. Torque is distributed to wheels through the worm gear that are connected on the every shaft of traction wheels. Traction wheels are in three pairs around the driving module body. Normal force between the wheels and inner pipe wall are generated via using the helical springs.

Energy module (Figure 6) are made from plastic and includes NiMH accumulators and Lithium monocells for supplying energy to DC motor, sensors and

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microcontroller. This module is used in case if wireless working of in-pipe machine is required.

Control module (Figure 7) includes the microcontroller Basic Stamp 2SX and other electronics for DC motor controlling and data capturing from sensors.

Figure 5 Drive module of machine FENAUS

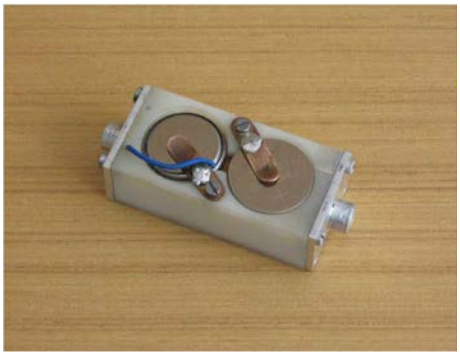

Figure 6 Energy module of machine FENAUS

Figure 7 Control module of machine FENAUS

Connecting module (Figure 8) is designed for improving of overall machine stability. Also this module connects other modules without wheels.

End module (Figure 9) is dedicated for carrying of the sensors of pipe crack and sensor for navigation and camera for tele-operator using.

Overall length of the machine is 280 mm nut it depends on selected configuration. Minimum bend radius of elbow is 135 mm. Maximum velocity is 30 mm/s with one drive module, one control module, one end module, one energy module and two connecting modules.

Figure 8 Connecting module of machine FENAUS

Figure 9 End module of machine FENAUS

Another problem, which is necessary to solve, is slipping of wheels on inner pipe wall. There is a possibility to do wheels with controlled compressive force in order to minimise slipping. This idea could bring to FENAUS intelligence and improve the overall performance and energy saving which is very necessary in autonomous FENAUS [16, 17].

3 Wheeled machine with adjustable wheels

Traditional conceptions of wheeled in-pipe machines tend to wheels slipping or self-blocking. Next designed in-pipe mechanism CEREVKA has adjustable wheels. It means that wheels are able to adapt to inner diameter inside pipe in range from 100 to 200 mm. Only mechatronic conception design allows solving of this problem. One of the possible ways of the wheeled in-pipe machines is placement of the traction and stabilization wheels to the arms regularly placed around the machine body (Figure 10) [18-21].

The basic part (Figure 11) is the machine body (1), which is connected with guiding rod (2). Carrier (3) is moving on guiding rod (2). Wheel holder (4, 5, 9) are connected to the machine body (1) and carrier (3) via plane joints. Wheel holder (4) holds driven wheel (6) and wheel holder (9) holds stabilization wheel (7). Stabilization wheel provides the better stabilization of machine locomotion inside pipe. Connecting part (8) is placed between these wheels (6, 7). Parts (3, 4, 8, 9) compose the parallelogram mechanism. This mechanism can be as source of the problems in described situation of locomotion inside the pipe. For this reason carrier (3) has to be divided (Figure 12) into the part (3) and part (10). These parts will be connected via spring (11). This configuration allows assuring of connection of the every wheel with inner pipe wall. This divided carrier with spring allows the passive compensation of the pipe deviations. Active adapting to change of inner pipe diameter is able to realize via change of the carrier position (3) from the machine body (1). This position change is can be obtained through the position servomechanism in combination with screw mechanism [18-21].

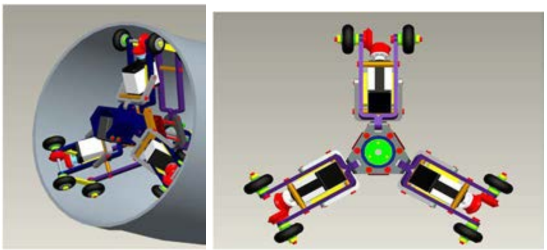

Figure 10 Wheeled machine with adjustable wheels CEREVKA

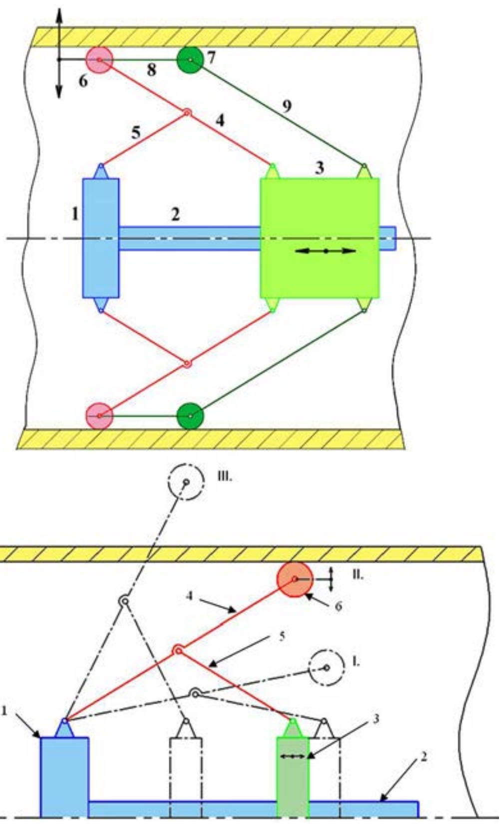

Figure 11 Machine arm arrangement of wheeled machine with adjustable wheels CEREVKA

Every driven wheel (6) is driven via independent actuator (16) (Figure 13). The placement of this actuator (16) has been proposed nearest to the driven wheel (Figure 13). Actuator is placed between the wheel holders (4, 5) because of elimination of the parts collision in process of adaptation to changed inner diameter of the pipe.

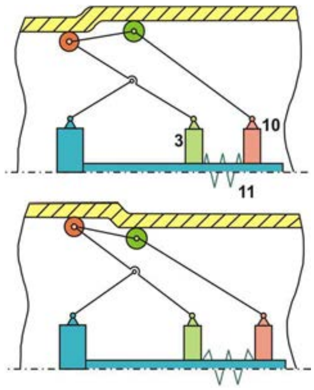

Figure 12 Adaptation to the change of the inner pipe surface geometry of wheeled machine with adjustable wheels CEREVKA

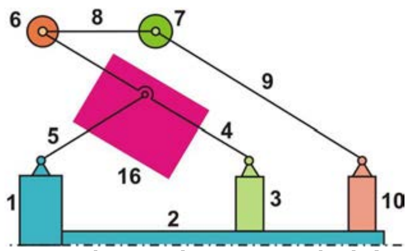

Figure 13 Servomechanism placement on wheeled machine with adjustable wheels CEREVKA

Every arm (Figure 13) is consisting of pair of parts (4, 5, 8 and 9). Final design is shown on (Figure 14).

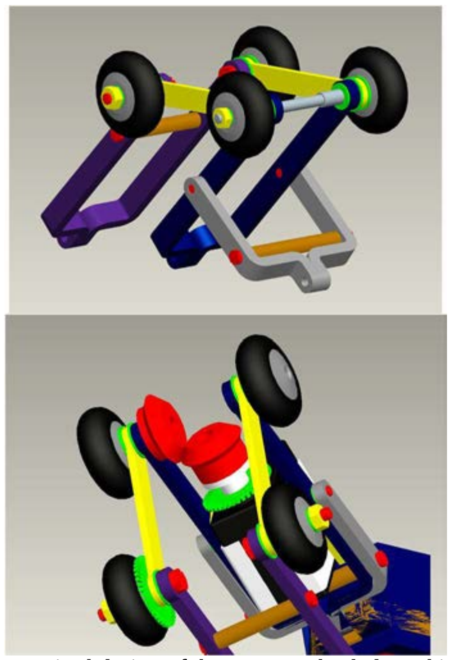

Figure 14 Final design of the arm on wheeled machine with adjustable wheels CEREVKA

Opening and closing of the arms is provided via displacement of the part (3a) (Figure 15). Displacement of the part (3a) could be secured through the screw mechanism placed in axis of the machine. Screw rod (2a) is at the both ends fixed in bearings. Screw rod (2a) is connected with part (3a) through thread (it is female screw). So, part (3a) and screw rod (2a) compose the screw mechanism. Rotating of the screw rod (2a) causes the displacement of the part (3a) and it means that arms of the machine will open or close.

Part (3b) has no thread (there is only simple hole) because of possibility to adaptation to change of inner pipe diameter near the driven wheels (6) and near the stabilization wheels (7).

Guiding of the parts (3a) and (3b) is provided through three guiding rods (circular cross-section) (2b).

Guiding rods (2b) is fixed in machine body (1) and end part (2c) (fig. 11). End part (2c) is able to move through the part (10). This proposition causes shortening of the overall machine length. Part (10) is used for pressing of the stabilization wheels (7) to the inner pipe wall. This is the reason that part (10) is not fixed to the part (3a). Part (10) is able to move on six guiding rods (17). The pressing of the stabilization wheels is provided through the springs (11).

Wheel holders are connected to the part (1), (3b) and (10) through the joint pins [18-21].

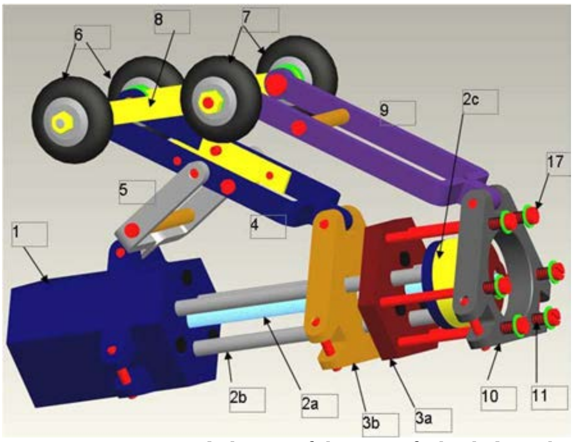

Figure 15 Opening and closing of the arm of wheeled machine with adjustable wheels CEREVKA

Part (3b) can free-run on guiding rods (2b). The spring (12) is placed between part (3a) and (3b) (Figure 16). This spring is deformation part used for normal force measurement between driven wheels and inner pipe wall. The change of the normal force is caused via change of the inner pipe diameter and it will make spring deformation. Consequently, it is necessary to measure spring deformation through the distance sensor.

Spring deformation is measured through the hall sensor (13) (placed on part 3a) and permanent magnet (14) (placed on part 3b). The microcomputer will evaluate the change of distance between the part (3a) and (3b). After that, microcomputer can affect to actuator for opening and closing of the arms. This is a way how to control normal force between the driven wheels and inner pipe wall [2, 3].

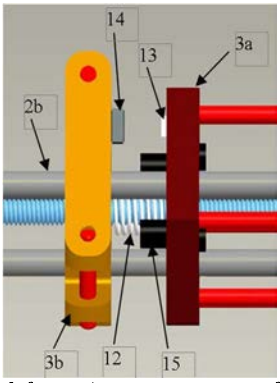

Figure 16 Spring deformation measurement of wheeled machine with adjustable wheels CEREVKA

Actuator has to rotate with screw rod (2a) in suitable direction for controlling of the arm opening and closing. This is a way how to react to the changed conditions inside the pipe. Final design of the adaptable in-pipe machine is shown on (Figure 17).

- Overall machine weight: 0,628 kg

Basic dimensions:

- Opening of the arms (range of the inner pipe diameters):

Min.:98 mm; Max.: 204mm

- Length (for 100 mm pipe): 186 mm
- Length (for 200 mm pipe): 134mm
- Maximum locomotion speed in horizontal pipe 0,082m/s.

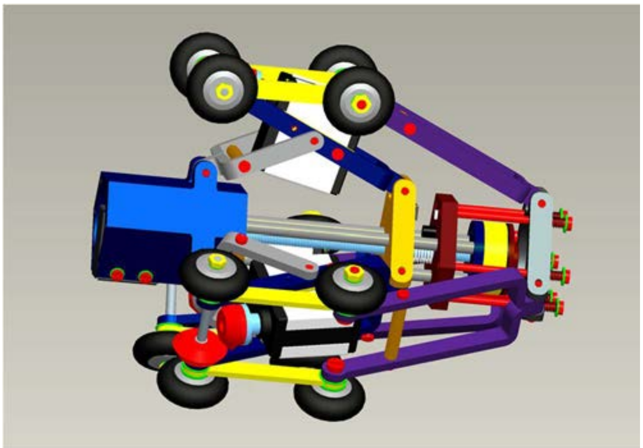
Figure 17 Final design of wheeled machine with adjustable wheels CEREVKA

The overall in-pipe machine will consist of several these modules (Figure 18) arranged one after another. These modules will connect through the suitable controlled joints. This articulated structure looks like snake will be able to locomote inside curved pipes like elbow, reduction of diameter, double branch joint etc [18-21].

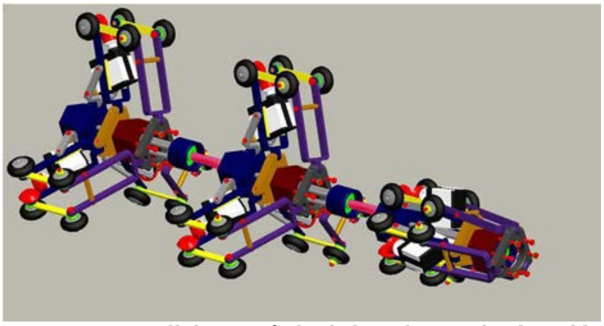

Figure 18 Overall design of wheeled machine with adjustable wheels CEREVKA

4 Conclusion

This mechatronic concept is one of the possible solutions for elimination of above mentioned weakness. It provides to obtain better designed in-pipe machine performance and other properties than in-pipe machine used before. The controlling of the value of the normal force also causes the improving of the energy balance and decreasing of loses [18-23].

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DIAGNOSTICS OF MECHATRONIC SYSTEMS

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Keywords: diagnostics, mechatronic systems, model, fuzzy logic, neural networks
Abstract: The features of diagnostics of mechatronic systems are reviewed. A logical-linguistic model of diagnosis and prediction of residual life of mechatronic systems has been developed. The proposed model is a complex consisting of a description of the initial linguistic variables diagnostic parameters and technical conditions, the laws of the physical processes of degradation in mechanical, electrical, electromechanical, electronic devices, changes in patterns of diagnostic parameters in the event of defects in view of the functioning and modes of mechatronic systems. Identified patterns are presented in the rule base of fuzzy inference to determine the technical condition and calculation of residual life and intervals of diagnosing MS. Experimental studies have confirmed the adequacy of the logical-linguistic model of mechatronic systems. A direction of further research will be improvement of the model accuracy for chosen mechatronic object.

1 Introduction

Modern mechatronic systems (MS) are becoming more intelligent. MS should define its technical condition and to predict the residual life of the work. The diagnosis techniques are still being explored by many researcher, some of them as in [1] - [10]. Currently, promising directions of development of methods of diagnosis are the methods of artificial intelligence based on fuzzy logic and neural networks. Fuzzy logic can significantly simplify the description of the object model of diagnosis and are easier for hardware implementation [11] - [13]. Neural networks are used to identify objects, recognition and forecasting of MS [14] - [19]. Advantages of the classifier built based on neural networks, to traditional valuation methods lies in the following factors: the independence of the noise, self-learning, and the possibility of parallel processing. An important step in any method of diagnosis is to build a mathematical model, giving adequate information on the functioning of MS.

2 Logic-linguistic model of diagnosing mechatronic systems

Analysis of the known systems of diagnosis showed that there is no common approach to the construction of systems of diagnosing MS on artificial intelligence. As a rule, building a system of diagnosing MS is based on a mathematical model of the object of diagnosis. These models are very complicated, even for simple components such as bearings. Due to the diversity of mathematical models of functional elements, modules MS problem is pairing disparate mathematical models together. Furthermore, in this model, there is no mechanism of defects and failures, and without concern for their impact on the function of the target MS. The model object of diagnosis should be suitable for the various functional elements of the physical nature and take into account the emergence of these random defects.

For diagnosing mechatronic objects considered logical-linguistic model. This model is based on the description of input linguistic variables and technical conditions, the degradation of the physical processes in the mechanical, electrical, electromechanical, electronic units, regularities between defects and diagnostic parameters, knowledge of the functioning of MS algorithms for self-learning and knowledge.

Logic-linguistic model of diagnosis MS and calculation intervals diagnosis based on fuzzy logic is represented by a system of equations:

$$\begin{cases} x(t) = F(x(t_0),t), \\ D(t) = G(x(t_i),t), \\ Z(t) = H(x(t),D(t),t), \\ R(t) = W(x(t),D(t),Z(t),t), \\ \Delta t = V(x(t),D(t),R(t),t), \end{cases} \quad (1)$$

where $x(t) = F(x(t_0), t) -$ equation of diagnostic parameters;
x(t) – vector of diagnostic parameters;
$x(t_0), t$ – a set of diagnostic parameter measurements;
$D(t) = G(x(t_i), t)$ – equation to calculate the trend vector of diagnostic parameters;
t – utilized lifetime;
$Z(t) = H(x(t), D(t), t)$ – equation to evaluate the technical condition;
$R(t) = W(x(t), D(t), Z(t), t)$ – equation residual life assessment at the point in time t;
$\Delta t = V(x(t), D(t), R(t), t)$ – equation for calculating intervals diagnose.

A feature of MS as hierarchical structures is that the technical condition of the MS is determined by the condition of the elements in the worst condition and residual life is determined by the minimum residual life of the elements. Model diagnosing and forecasting facilities process equipment is implemented in the software product package MatLab Fuzzy Logic Toolbox. Fuzzy inference system technical condition assessment is realized on the basis of knowledge of fuzzy Mamdani type with three input variables *x, D, t*. As the membership functions of the linguistic variable term M can be selected trapezoidal function. In terms of membership functions as L, H linguistic variable chosen z, s functions.

Mamdani fuzzy inference is selected, the t-norm is maximum. Defuzzification carried out by the method of the centre of gravity, as it provides good accuracy and speed setting fuzzy knowledge base. The configurable parameters are used as the weights of rules, the coordinates of the maxima of the term of membership functions M linguistic variable.

3 Algorithms and software for diagnostics

A review of existing algorithms and software diagnosis shows no universal algorithms for diagnosing MS.

Neural networks are a promising mathematical tool for the creation of automatic diagnosing mechatronic objects. Neural networks have the following advantages: fast learning algorithms, the ability to work in the presence of significant noise, the ability to work with various information, the ability to simultaneously to solve several problems (parallelism of information processing), and reliable operation.

Statistical methods for recognizing the MS condition used in cases where the mathematical model of the physical processes is unknown or impossible to obtain. For example, when the physical processes described reliably enough known equations of mathematical physics, or the dimension of the model exceeds the capacity of existing computers. At the same time, statistical pattern recognition techniques require a substantial amount of state a priori data, i.e. Data obtained through experiments. Therefore, costly experiments, statistical methods can be detected, the small acceptable.

Diagnosing system faults using deterministic methods of recognition effectively in the presence of a mathematical model of its functioning. These models are, in most cases can be analysed only by numerical methods, which restricts their use in real-time troubleshooting and management of the technical system. Almost all real processes of functioning of technical systems have nonlinear behaviour. In these cases, experts are commonly used, that is there is human intervention in the process of diagnosis and management of the technical system. If deterministic knowledge available or mathematical modelling costly estimated time, or does not provide the required accuracy, there may be used other methods. These methods are modelling the knowledge of the operator by means of heuristic knowledge and inference strategies, such as is done in expert systems based on fuzzy logic to the implementation of hardware-based or software-algorithmic emulation of neural networks.

An important property of neural networks is that they study the dynamics of the system during a workout consisting of several training cycles, with the training data coming either from the previous cycle, consisting of a real signal. After each cycle, the neural network learns more and more about the dynamics of the object. One of the most important features of neural networks is their ability to study the dynamic behaviour of nonlinear systems automatically, if the neural network architecture comprises at least three layers. Perhaps the use of neural networks is in the problems of predicting residual service life of MS.

Algorithm of diagnosing establishes the composition and the procedure for diagnosing MS.

Generally, the following types of diagnosis:

- elementwise, consisting in diagnosing each element separately;

- modular, consisting in diagnosing individual mechatronic modules, each of which in turn consists of a number of elements;

- group comprising diagnosing a group of elements that are interrelated, but do not form a mechatronic module.

To construct a rational algorithm diagnosis is necessary:

- MS introduce a system recognized as a separate functional elements and relationships between them;

- determine a list of all possible faults and give a formal description of the system;

- create a mathematical description of the fault system.

Drawing algorithms diagnosis much simpler, if the task list of the defects indicated construction site where possible types of defects. Often, you want to find a place where a defect and determine its cause.

Algorithm of diagnosis often involves the following sequence. First, measure the main characteristics of the MS and determine whether it works in a given mode or has excessive deviation. Further, a cause of these deviations and with the help of special tests detects a fault.

Thus, in the first stage is carried out functional diagnostics, and then - a test to find a defect diagnosis.

When diagnosing electrical and electronic elements necessary to determine the fault to the independent element (resistor, diode, transistor, etc.). In this case, to assess the performance of the system will need to test with great resolution.

Since MS are modular in their diagnosis is sometimes sufficient diagnostics module. Rectify faults in this case is achieved by replacing the faulty module serviceable.

In monitoring performance (serviceability) diagnostic system must objectively determine the defective or faulty item or unit. Verifying the operation is to determine how the module is at the current time, and whether the parameters of his work good technical condition.

It is currently, as a mathematical apparatus for diagnosing using methods of artificial intelligence, such as expert systems, artificial neural networks, fuzzy logic techniques and genetic algorithms.

Neural networks are non-linear model without knowledge of its structure and give results in a short period of time.

As the inputs of neural networks are the current, voltage, power, temperature, vibration, and the accuracy of spatial positions and rigidity, movement, power settings, time intervals.

The main problem encountered when using a neural network, a selection of the best features and the input parameters of the neural network, making it compact and classification of defects - accurate.

The mechanism of withdrawal of the expert system inference classifies states of the object using a database containing the history of the state of the equipment, which would describe the trends characteristic types of faults. Knowledge of trends in diagnostic parameter of any type of fault - a crucial moment, since it allows the expert system to conclude that the acceptance or disregard of a fault on the basis of a threshold value.

The key decision in the diagnosis of this condition is the choice of an efficient system of classification. They can be divided into two main groups: a model based on the knowledge and data.

Requires diagnostic tool with the ability to dynamically acquire knowledge is not demanding to the presence of examples of faults for the correct diagnosis and applicable to various typologies of equipment, at least one series of the machines.

Often, it seems difficult to collect data that reflect the whole "region error", while easier to define "area of the working values." Modern approaches are built on neural networks are trained on data taken from a properly functioning installation, and are able to detect a fault on the basis of data that lie outside the area defined during training.

Neural networks make it possible to effectively identify the cause and type of damage to mechatronic systems, working with noisy data, eliminating the need for intermediate electronic interference filters or filter by mathematical methods as well as to adapt to a particular instance.

Intelligent diagnostic system constructed as self-learning, self-tuning system with flexible decision-making procedures, as a system, based on knowledge and creates new knowledge in the operation.

The tasks of the intellectual system of diagnosing includes: assessment of technical conditions; data envelopment analysis, etc. Class intelligent diagnostic systems meet the following five principles:

- presence of interaction between the system of diagnosing the real outside world using information communication channels. Intelligent diagnostic system is obtained from his knowledge and influences it. Implementation of this principle allows organizing communication channel for knowledge extraction and organization of purposeful behaviour;
- fundamental openness of the system in order to enhance intelligence and improve their own behaviour (openness of the system is ensured by the self-tuning, self-organization and self-education). The system of knowledge of intellectual diagnostic system consists of two parts: your knowledge and proven knowledge. This principle allows organizing the completion and acquisition of knowledge;
- existence of mechanisms of functioning of the forecast changes in the environment and their own behaviour in a dynamically changing system of the outside world. In accordance with this principle, the intellectual system of diagnosing not fully intelligent, if it does not have the ability to predict changes in the outside world and of their own behaviour;
- existence of a system of building structure corresponding to the principle of IPDI (Increase of Precision with Decrease of Intelligence): the higher the control accuracy, the smaller the intelligence system. It is a way of building complex intelligent systems diagnostics when inaccurate knowledge of the model of the object or control his behaviour can be compensated by increasing the intelligence generated by the system;
- preservation operation at break ties or loss of control actions of the higher levels of the hierarchy.

For example, the intellectual system of diagnosing of CNC based on information system analysis of the technological equipment for the forming quality parameters using artificial neural networks, which are the basis of knowledge of the system and optimize the control action (cutting mode parameters) using a genetic algorithm.

4 Conclusions

A logical-linguistic model of diagnosis and prediction of residual life of MS has been developed. The proposed model is a complex consisting of a description of the initial linguistic variables diagnostic parameters and technical conditions, the laws of the physical processes of degradation in mechanical, electrical, electromechanical, electronic devices, changes in patterns of diagnostic parameters in the event of defects in view of the functioning and modes of MS. Identified patterns are presented in the rule base of fuzzy inference to determine the technical condition and calculation of residual life and intervals of diagnosing MS. Experimental studies have confirmed the adequacy of the logical-linguistic model of MS. A direction of further research will be improvement of the model accuracy for chosen mechatronic object [20].

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MEASURING THE CHARACTERISTICS OF VOLTAGE SOURCE – REMOTE PHYSICAL EXPERIMENT CONTROLLED VIA INTERNET

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Keywords: remote controlled experiment with ISES kit, internal resistance, electrical DC-source, pedagogical research
Abstract: The article describes the incorporation of pilot experiment of remotely controlled laboratory task into physical education at the Faculty of Materials Science and Technology. It deals with the measurements of the basic characteristics of electrical voltage source. The individual parts of arrangement were realized by the ISES-kit that is capable to command the measuring procedures and to transform the corresponding values via computer. We present an evaluation of the test, completed by students included to the process. It has been realized in the mentioned laboratory experiment by two different methods – via classical measurement and via internet. Relevant results have been evaluated by Kolmogorov's-Smirnov´s statistical method.

1 Introduction

Remote real laboratory is a modern device of current cognition, representing a new strategy of current e–learning [1]. Therefore, there exists a growing application of it in education, including the teaching process at the universities, too.

Also our department participates in the preparation of remote experiments – in the framework of international cooperation. We have prepared the experiment "Measurements of the Characteristics of DC-Voltage Source". The complete device had been connected to the internet network so that users can remotely control the experiment. In this article we describe the principle of operation of such device when operating over this way.

This task is usually being a part of common education in other technical and natural-science faculties, and at the secondary level, too. It is also contained in the contents of our teaching programme. The article describes a comparison of both methods of measurement – the classical one and through local computer - and the expression of students.

2 Physical Theory and Technical Description of Measurements

The voltage U_s being applied to the external resistor R_z is always less than the electrical voltage on the vacant source of U_o. If we should use the connection as in Figure 1, the competent relationship between these quantities has the form

$$U_0 = r.I + R_z.I_A = r.I + U_S. \quad (1)$$

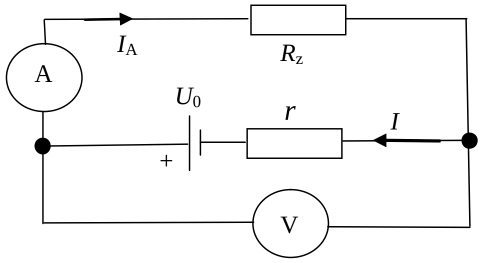

Figure 1 Basic classical connection for measuring of the characteristics of the DC- electrical source

Here $U_s = R_z I_A$ and I_A is the current that runs by resistor R_z. (It is not necessary to take to account the resistances of measuring instruments because of the resistance of ammeter is considered to be equal to zero, and similarly, the resistance of voltmeter is considered to be infinite). On the basis of this relationship, it is possible to measure the internal resistance r of the source.

The measurements of basic characteristics of the voltage source can be done either by using a classical involvement (that is in principle identical with Figure 1), or by the computer-supported experiment, respectively. The corresponding scheme of it in the block representation is depicted below (Figure 2).

It consists of the following parts: DC-voltage source with the internal resistance r, ammeter A, voltmeter V, load resistance R_z, ohmmeter Ω and switching relay. In our experiments they had been realized by modules ISES [2], [3], [4], that are controlled directly by computer

(Figure 2). The load resistance R_z has been changed in continuous steps by the switching relay.

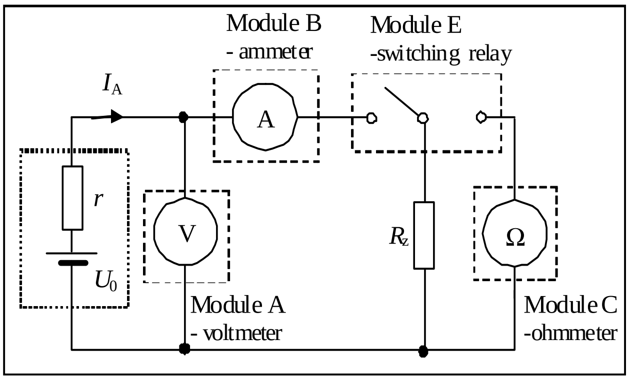

Figure 2 Block scheme of the measuring arrangement, suitable for computer cooperation, realized by ISES-components (indicated by dashes)

The arrangement and integration of individual modules and other components of the experiment, corresponding to this scheme, is presented on photo (Figure 3). We have investigated the characteristics of voltage source LABORATORY POWER SUPPLY, where the set point of 2 V has been fixed (this value is equal to the electromotive voltage).

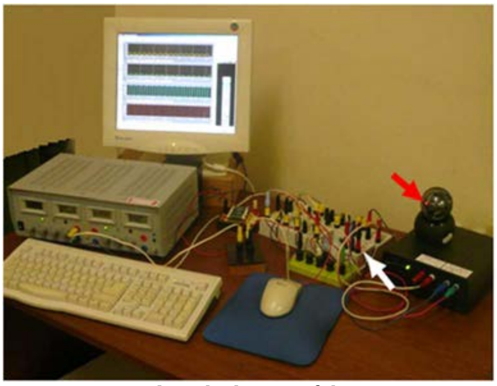
Figure 3 Look at the layout of the experiment.

The electrical source (gray-coloured box on the left hand) being measured is located between the keyboard and the computer monitor. Motherboard and the retracted ISES modules are on the right side of monitor. Resistance decade with the remote switching resistors is located in the black box on the right side a web camera is imaged by red arrow. White arrow shows the red control light of switching relay. The time traces of voltage, current, load resistance and switching relays are imaged in monitor, simultaneously.

3 Measuring Procedures

The task has been located in the world-wide internet network for six years (2008 – 2014), in present it is allowed in our local school network.

The installation of the compilation language Java is necessary for user for correct compatibility of the computer with experiment (as it is warned in the title-page). Web page is presented in three languages – Slovak, Czech and English. Now we are dealing with English mutation. After clicking on the address, the following sub-page will appear (Figure 4):

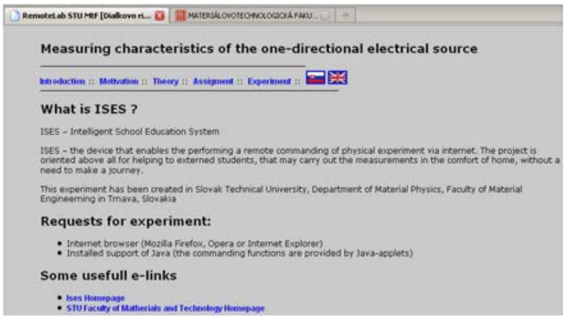

Figure 4 Title page

This window is identical with the sub-page *Introduction*, too. The dealing with the site *Theory* is not necessary, because of it has been described above. The following items *Motivation* and *Assignment* have the forms which are imaged in the next sites (Figure 5, Figure 6).

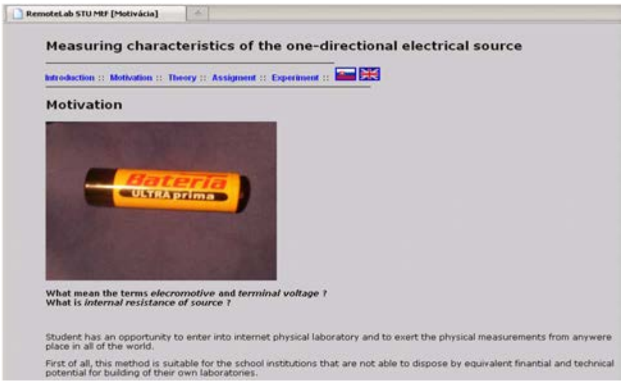

Figure 5 The page ***Motivation***

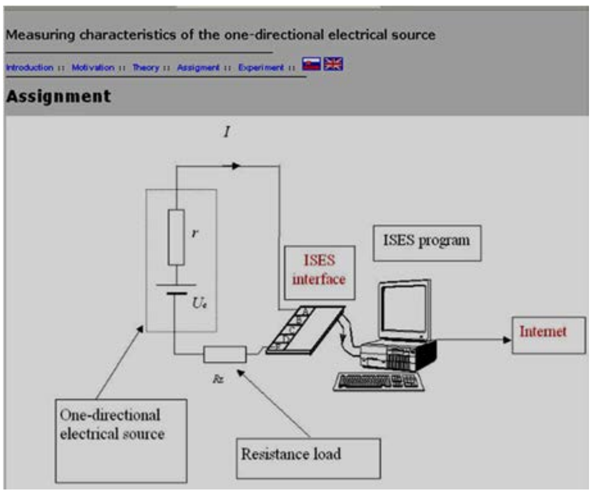

Figure 6 The page ***Assignment***

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The page *Assignment* also offers guidance on the measurement procedure:

1. Learn more about the experiment, aimed at determining the characteristics of DC- electrical source.
2. Perform the measurements of electromotive and terminal voltage of source with various resistive sizes of load resistance R_z.
3. Using the measured values of ε, U_s, R_z and I determine - on the basis of the formula (1) - the value of internal resistance r of the source for each measurent, with following determining of the arithmetic average.
4. Draw the graphical records of terminal voltage and current in the circuit on the load resistance. Identify the approximate value of the internal resistance of the source from the current dependence.
5. Discuss the size of power and efficiency of the source on the size of a resistive load.
6. Draw up a paper with the following points:
   a. Physical introduction
   b. Description of the experiment and layout
   c. Measurement procedure
   d. Table of measured values of ε, U_s , I and R_z with the relevant calculation of the resistance r, including the arithmetic average
   e. Graphical dependences:
      - terminal voltage U_s as a function of load resistance R_z,
      - current in the circuit I as a function of load resistance R_z, with the extrapolation of estimate r
      - power P_e as a function of load resistance R_z
      - efficiency η as a function of load resistance Rz.

The actual process of measurement can be made through site *Experiment*. When you click on it, the next sub-page will appear (Figure 7):

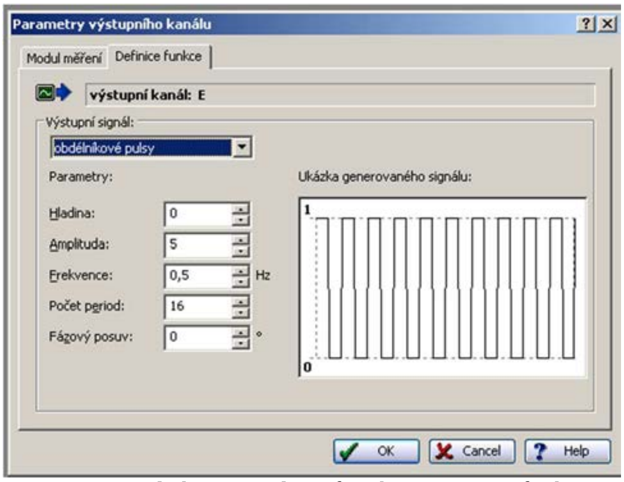

Figure 7 A dialogue window after the activation of relay; the rectangle pulses being commanding the experiment are imaged in right white window (the description in the picture is made in Czech language, given by producer of an ISES-kit)

We had chosen the following parameters:

Rectangular pulses in the role of commanding signal (appointed by relay). The total measurement time could be in interval of 32 sec. It is appropriate value because of the fact, that there are the kit of 16 resistors (totally), included in measurement and a duration of each simple pulse is 2 sec. (it represents the opposite value of frequency). In the same time period, the rolling of relay happens, too.

The automatic measuring procedure is activated by the clicking on the item *Start* and it is directed by switching of the relay. The time operation of the circuit can be presented as a set of four courses - voltage, current, resistance load and switching pulses. Their shapes are – in case that all the four modules are activated simultaneously - illustrated in Figure 8 (they are identical with the pictures on the monitor in the background in Figure 3).

The first graph represents the electromotive voltage (in the 1st, 3rd, 5th....etc, i.e. the odd intervals, when the load resistance has been disconnected from the source by means of relay), and the applied voltage (in the 2nd, 4th, 6th...etc, i.e. in the even intervals, when the load has been connected to the source).

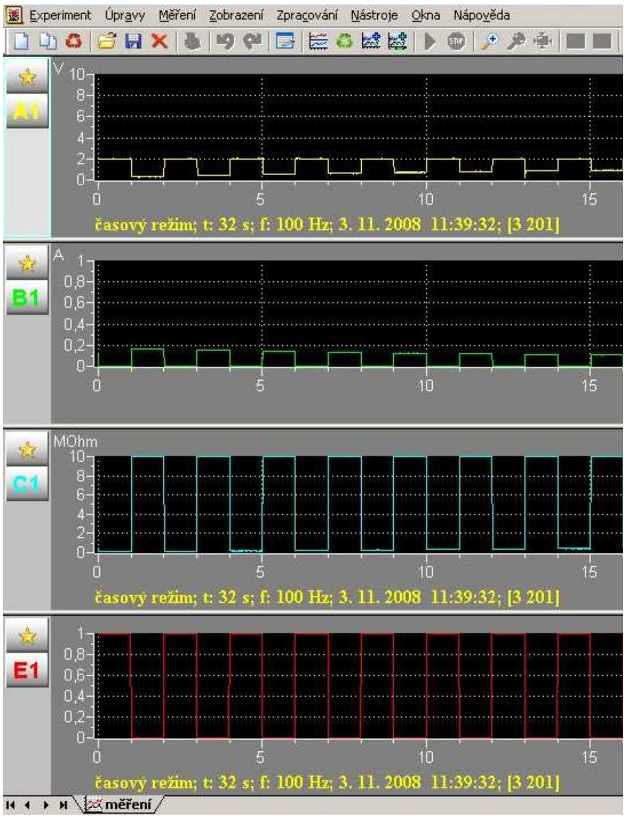

Figure 8 The time courses for the quantities being measured, as they were recorded and imaged in the screen of local computer (it is visible on the background in Figure 3, too).

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In the second graph we can see the change of current passing through the resistance load; the single steps are synchronized with the previous case.

The third graph reflects the size of load resistance being used (the corresponding values are laying in the bottoms of rectangular pulses in each odd interval, when the load has been disconnected from the source; it is true a small value, but by means of enlargement of graph it is possible the corresponding determination to make easy).

The fourth graph shows the switching of relay. The odd and the even steps have the same sense as in the cases mentioned above.

The results having obtained have confirmed the known fact that the current is declining with increasing load resistance, while the accompanied applied voltage is growing. The time courses also show the expected result, that the applied voltage increases with increasing size of the load resistance, and that the current, in turn, decreases. As we found from the measured values, the size of the internal resistance is equal to 10 Ω. It is possible to calculate an internal resistance of source, and to plot the dependences of the performance of consumer and the efficiency of source to the size of the load resistor - from relevant numerical results. It would be a task for students to conclude experimental procedure.

4 Pedagogical View

The pilot implementation into education at technical university has been realized in Faculty of Materials Science and Technology of Slovak University of Technology in Trnava, Slovakia. Fifty students were measuring the internal resistance of the source in the framework of laboratory exercises. Students were enable to measure the physical quantity by both of methods, by classical way (using their own connection and hand controls) and also by mentioned manner with using a computer. Students have expressed their opinions considering these methods in a questionnaire after absolving the measurements. Related answers were processed and evaluated statistically using the Kolmogorov's-Smirnov's correlation test [5].

Students were asked by following question:

"Does the remote-controlled method present a better possibility for understanding of the theory like classical method?"

The percentage distribution of responses to this question is depicted on the pie chart (Figure 9).

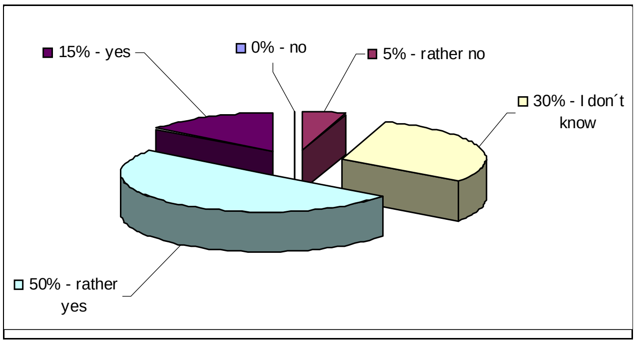

Figure 9 Graphical illustration of responses distribution corresponding to the question

As we can see, the most numerous part of students would prefer to measure the internal resistance of resource by means of computer. As it results from these examinations, the value of the test criterion D_1=0,35 and critical value of $D_{1;0,05}$= 0,294. Because of $D_1 \geq D_{1;0,05}$, we reject the null hypothesis (it supposed that the amount of students prefering some of both methods will be divided equally on all five possible responses) at the significance level of 0,05.

Conclusions

The experiment being presented above belongs to the file of Czech and Slovak physics tasks, controlled via internet, which set is constantly replenished. The filling of this task can be applied in teaching on physics lectures concerned with the topics on power supplies, as so as in the labs. The pilot implementation into the education, that has been realized in our faculty and it is described here, confirms the fact that this form of practical exercises is attractive and suitable for students. It can be applied as a filling work for student groups being interested in physics in secondary schools, too.

Acknowledgement

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NAVIGATION OF THE AUTONOMOUS GROUND VEHICLE UTILIZING LOW-COST INERTIAL NAVIGATION

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Keywords: inertial navigation, automated vehicle, sensors, sensor fusion
Abstract: This article discusses usage of the inertial navigation combined with one or multiple odometers for precise navigation of the autonomous ground vehicle. Such navigation does not require any kind of external signal; therefore it is resistant against external disturbance and might be used in harsh industrial environment. Using low-cost MEMS gyroscope and accelerometer provide only attitude and heading reference; the odometers are responsible for measurement of the dislocation and the vehicle's speed.

1 Introduction

Current development in industry encounters change of focus from static robotics (automated manipulators) to the mobile robotics. Mobile robot is capable to provide its services in almost unlimited working range but does not offer such precision of the movement control. Therefore it is very suitable for basic manipulation with completed components and their transportation inside the manufacturing facility. For such purpose the autonomous ground vehicles (AGVs) utilizing some form of wheels are being widely used due to their power efficiency and simplified construction. In order to control the movement of such vehicle it is required to have precise estimation of its location in 2D space including its orientation (heading). Widely used satellite navigation systems (GPS, GLONASS) cannot be used inside buildings or underground, which restricts their usage in the mentioned industrial environment [1]. These satellite navigation systems also do not provide enough accuracy and sampling rate for real-time navigation in their civil versions. Available extensions are licensed, which makes them quite expensive. Development of the MEMS technology recently allowed manufacturing of precise and relatively low-cost inertial sensors (gyroscopes, accelerometers) [3][4]. These sensors are the basic component of any inertial navigation system.

2 Low-Cost Inertial Navigation

According to the kinematic theory it is possible to estimate the velocity vector of the object by time integration of its acceleration regarding object's attitude (lateral inclination called roll, longitudinal inclination called pitch and horizontal direction called heading). The dislocation could be then estimated by time integration of the obtained velocity. This approach requires excellent precision of the used accelerometers or special integrative accelerometers like Pendulous Integrating Gyroscopic Accelerometer (PIGA) which are complex and expensive or does not provide required precision [4]. Otherwise any error of the accelerometer's reading will be integrated into velocity and dislocation vector. In case of sensor bias (non-zero output at zero acceleration) the resultant position error will increase with square of the run-time. In case of an accelerometer with the digital output the best achievable bias varies around 1 LSB. The position error is then:

$$d_{\mathrm{drift}}(t) \approx \frac{a_{\mathrm{FS}}}{2^{N-1}} \frac{t^2}{2} \qquad (1)$$

where $d_{\mathrm{drift}}(t)$ - error of the position estimation in one axis [m], a_{FS} - full-scale of the accelerometer [m.s^{-2}], N - resolution of accelerometer's the digital output [bits], t - run-time of the integration since last reset [s].

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Rastislav Pirník; Marián Hruboš; Dušan Nemec; Pavol Božek

On the other hand, inertial sensors can be used for very precise measurement of the attitude. Attitude (rotation of the object in 3D space) defines the rotational transformation between the static global coordinate system (in our case it is bound with the floor inside facility) and local coordinate system (bound with the vehicle). It can be computed in real time from the initial attitude and readings of 3-axial gyroscope (measures angular velocity in local system), see [7]. Since the reading of the gyroscope is integrated only once the error of the attitude estimation caused by gyroscope bias increases only linearly. If the floor were perfectly planar (not necessarily horizontal), the single-axis gyroscope mounted on the vehicle in vertical direction (with respect to the vehicle's local coordinate system) would be sufficient for estimation of the heading. If the floor is not planar the 3-axial gyroscope or 3 pieces of perpendicularly oriented single-axis gyroscopes are necessary to be used for reliable and complex attitude estimation in 3D space. Note that without knowing the initial heading it is impossible to determine actual absolute heading.

Available MEMS motion sensors sometimes incorporate 3-axis accelerometer and 3-axis gyroscope inside one integrated module. Accelerometer is not meant to be used for position estimation. Since it measures the sum of the gravitational acceleration vector (constant in global coordinate system, defines vertical direction) and the system's own acceleration (can be arbitrary but its mean value in long terms is zero) it can be used as a secondary sensor for compensation of the errors caused by gyroscope bias in horizontal axes. In order to compensate errors of the gyroscope's vertical axis and to provide absolute heading reference (with respect to the magnetic North) one can use a magnetic compass. Please note that the magnetometer is not an inertial sensor since it does not measure kinematic variable. Available magnetometers can be used for mentioned purpose but they are very sensitive to the presence of an external magnetic field or larger metal objects. In the industrial harsh environment both mentioned disturbance sources will be typically present.

Rotation of the Earth around its axis causes systematic error of the attitude estimation (orbital movement of the Earth around the Sun is negligible). This rotation influences all axes of the gyroscope (see Fig. 1) but is well defined. Therefore it can be easily compensated:

$$\boldsymbol{\omega}_{\mathrm{comp}} = \boldsymbol{\omega}_{\mathrm{raw}} - \boldsymbol{R}.\omega_{\mathrm{Earth}}\left[-\cos\phi \quad 0 \quad \sin\phi\right]^{\mathrm{T}} \qquad (2)$$

where: $\boldsymbol{\omega}_{\mathrm{raw}}$ - angular velocity vector obtained from gyroscope [3x deg.s^{-1}], $\boldsymbol{\omega}_{\mathrm{comp}}$ - compensated angular velocity vector in local frame of reference [3x deg.s^{-1}], ω_{Earth} - angular rate of the Earth's axial rotation (approximately 0.0042 deg.s^{-1}), $\boldsymbol{R}$ - rotational matrix expressing current attitude of the vehicle [3x3], ϕ - geographical latitude.

Our research has shown that after compensation of the Earth's rotation the heading error is not critical only if the AGV is not moving continuously longer than few minutes (depending on precision of the used gyroscope). For example, the gyroscope with 16-bit signed resolution and dynamic measurement range ± 250°/s which theoretical precision is 1 LSB drifts in heading estimation by approx. 0.5° per minute in the worst case. In order to eliminate this error it is possible to measure and reset the heading of the AGV while passing a gate or door. Since the INS is incremental the next attitude changes will be added to the precisely reset attitude.

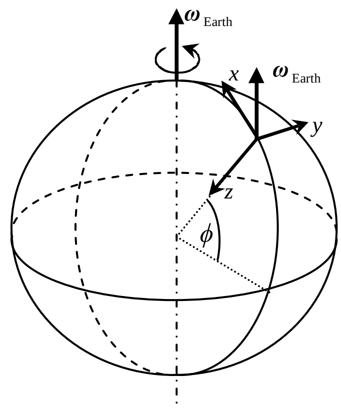

Figure 1 Influence of the Earth's rotation in specific location

Precisely estimated attitude itself is not sufficient for navigation inside the facility. It is necessary to measure distance ran by the vehicle. This can be achieved by an odometer bound with any of the vehicle's fixed wheels (which rolls along axis x). Position estimation algorithm should run in discrete time and its one step can be described by following formula:

$$\boldsymbol{d} \leftarrow \boldsymbol{d} + \Delta\boldsymbol{d} \qquad (3)$$

where $\Delta\boldsymbol{d}$ is a dislocation vector ran by the AGV during one step and is equal to:

$$\Delta\boldsymbol{d} = \boldsymbol{R}^{-1} \cdot [\Delta s \quad 0 \quad 0]^{\mathrm{T}} \qquad (4)$$

where: $\boldsymbol{d}$ - position vector [3x m], $\boldsymbol{R}^{-1}$ - inverse rotation matrix expressing attitude of the object with respect to the global frame of reference [dimension 3x3], Δs - change of the distance measured by odometer [m].

The equation (4) does not consider position of the wheel with odometer with respect to the origin of the local coordinate system. In case of a vehicle with one steerable and one fixed axle it appears to be convenient to place the origin to the centre of the fixed axle. During turns the outer wheel runs greater distance than the inner wheel which will corrupt the overall position estimation. Equation (4) should be then modified:

$$\Delta \boldsymbol{d} = \boldsymbol{R}^{-1} \cdot \left[[\Delta s \quad 0 \quad 0]^{\mathrm{T}} - \left(\boldsymbol{\omega}_{\mathrm{comp}} \times \boldsymbol{r} \right) \Delta t \right] \qquad (5)$$

where: $\boldsymbol{r}$ - dislocation vector of the wheel with odometer in local coordinate system [3x m], Δt - sampling period of the algorithm [s].

Second term expresses false velocity contribution caused by rotation of the vehicle. Equation (5) is valid only if the odometer is mounted on the fixed wheel (non-steerable). Otherwise the equation has to be modified considering the steering angle:

$$\Delta \boldsymbol{d} = \boldsymbol{R}^{-1} \cdot \left[\Delta s [\cos\psi \quad \sin\psi \quad 0]^{\mathrm{T}} - \left(\boldsymbol{\omega}_{\mathrm{comp}} \times \boldsymbol{r} \right) \Delta t \right] \qquad (6)$$

where: ψ - steering angle of the wheel on which the odometer is mounted [rad].

Equations (4), (5) and (6) consider that both global and local coordinate system are Cartesian in NED convention (x – North or forward, y – East or right, z – down). If multiple wheels are equipped with odometers, it is possible to improve the precision of the position estimate by performing fusion between all odometers' readings. The differences among odometer readings are usually caused by sliding of the wheels. It is more likely that the driven wheels slide more than non-driven; therefore the fusion weight η_i of the driven wheels is lower. The equation (6) has to be applied separately to each measured wheel and the resultant dislocation vector is then equal to the weighted average of all wheels:

$$\Delta \boldsymbol{d}_{\mathrm{fusion}} = \frac{\sum_{i=1}^{n} \eta_i \Delta \boldsymbol{d}_i}{\sum_{i=1}^{n} \eta_i} \qquad (7)$$

Velocity vector of the vehicle in the global coordinate system is then equal to:

$$\boldsymbol{v} = \frac{\Delta \boldsymbol{d}_{\mathrm{fusion}}}{\Delta t} \qquad (8)$$

Sliding of the wheels (skid) is necessary if the mobile platform does not have any steerable or omnidirectional wheels. Such chassis is controlled by different rotation between right and left wheels (or tracks) and is suitable for off-road terrain. We can assume that the distance slid by wheels on one side of the chassis is opposite to the distance slid by the wheels on the other side. After the fusion according to the formula (7) the resultant error caused by sliding is compensated. Also note that usage of skid-controlled mobile platforms for transportation of some heavy components may cause rapid degradation of the road's surface.

3 Navigation by Waypoints

Control system of the autonomous vehicle has to affect the steering and propulsion of the vehicle in order to run along the pre-set trajectory considering possible deviations while maintaining safe distance from both static and moving obstacles. The moving obstacles are usually unpredictable and the vehicle has to incorporate non-tactile sensors (e.g. laser scanners) to detect their presence. This article discusses only navigation in the static map. The trajectory can be defined as a series of waypoints in 2D space and the vehicle has to reach each waypoint (or its close neighborhood) in given order at given speed. Proposed inertial navigation to the waypoints is different from commonly used navigation along the trajectory which is determined physically by magnetic or optic tapes (path following). Path follower does not need to know the map of the environment which makes its controller simpler. On the other hand, this approach depends on the leading tape which requires maintenance and lacks flexibility.

Waypoints have to be placed considering the physical constraints of the AGV (its dimensions and minimal turning radius). In order to optimize the trajectory (by maximizing the turning radius) the waypoint might define not just its coordinates (x, y) but also the recommended turning radius to the next waypoint. Greater turning radius allows higher speed with the stability maintained. The relation between steering S (dimensionless number from -1 to 1), vehicle's horizontal speed v_{xy} and the heading rate $d\gamma/dt$:

$$\frac{d\gamma}{dt} = k_{\mathrm{S}} v_{xy} S \qquad (9)$$

where k_{S} is constant steering gain in [rad.m^{-1}] and depends on the dimensions and construction of the vehicle. If the vehicle is running backward the steering gain is negative. The relation (9) can be used for detection of the wheel skid since the heading rate is also obtained by INS.

Now we can design the steering controller. If we label the current position of the vehicle as X = [x, y] and the next waypoint as W = [x_{W}, y_{W}], then the heading to the waypoint is:

$$\theta = \mathrm{atan2}(y_{\mathrm{W}} - y,\, x_{\mathrm{W}} - x) \qquad (7)$$

Regulation error γerr is an angular difference between actual heading γ of the vehicle and heading to the waypoint θ. A proportional regulator appears to be the simplest solution. Simplified schema of the system is shown in Fig. 2. In order to avoid saturation of the steering control near the waypoint we have to define tolerance for reaching the waypoint. If the vehicle reaches the circular area around the waypoint with given radius, next waypoint has to be activated.

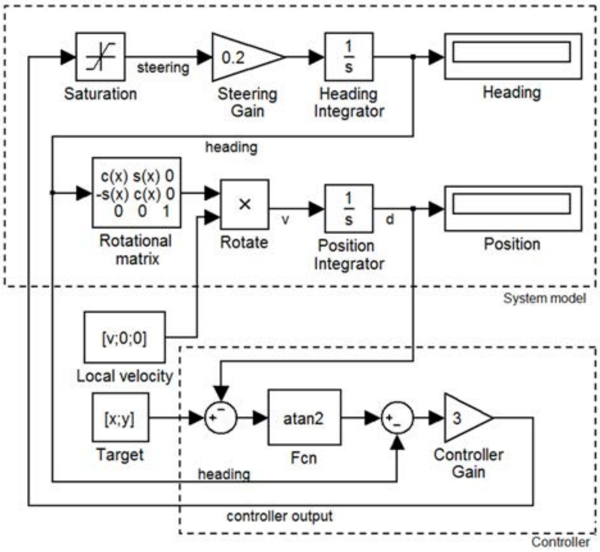

Figure 2 Simplified simulation schema of the vehicle and the controller

In order to verify proposed navigation scheme we have constructed small 4-wheeled mobile platform based on the chassis taken from R/C car. The platform is equipped with IMU unit MPU-3050 manufactured by InvenSense. Platform itself handles only wireless communication and basic hardware control, navigation and control algorithms are implemented in PC wirelessly connected to the platform. In real system the control algorithms would be implemented inside the platform; only the waypoint information would be transferred wirelessly (in road traffic a VANET could be used [8] [9]). For an illustration we have created model scene with few obstacles and pre-defined waypoints (displayed in Fig. 3).

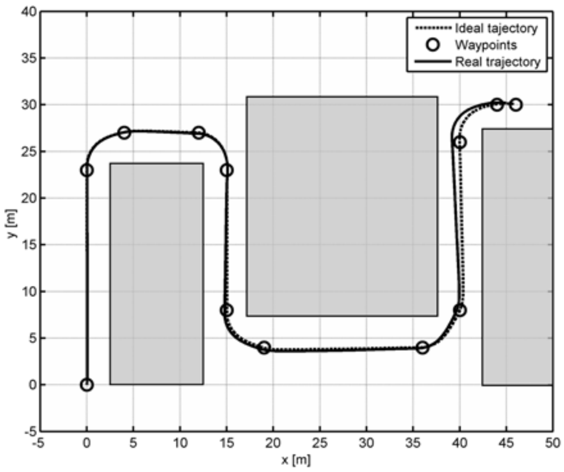

Figure 3 Example of the real and ideal trajectory among the obstacles

All dimensions in Fig. 3 are in meters and were scaled according to the scale of the mobile platform. Mobile platform successfully reached all targets. Minimal turning radius of the platform was R_{min} = 3.5m. Note that the difference between real trajectory of the vehicle and the ideal trajectory is caused by errors of the gyroscope. All errors were reset in the initial position.

4 Conclusion

Low-cost inertial navigation combined with one or multiple odometers can be used as a replacement for the industrial navigation of the mobile wheeled vehicles along some physically defined line (usually by magnetic or optical tape) inside the manufacture or storage facilities. According to the principle of the proposed navigation it does not require any external signal and is partially resistant to the wheel skid. In order to avoid increasing integrative error it is necessary to reset the error of the position and heading estimation at least in the initial location and destination. If some dynamic obstacles (persons, other unknown vehicles) might be present, it is necessary to deploy additional exteroceptive sensors to detect and avoid the collisions.

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RESEARCH AND DEVELOPMENT OF A NEW SYSTEM OF THE AUTONOMOUS CONTROL OF ROBOT TRAJECTORY

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Keywords: inertial sensor, robot, gyroscope, accelerometer
Abstract: The article deals with one of the options respectively control of the trajectory of movement of a laboratory robot with three degrees of freedom in a predefined area. To do this we used data obtained from inertial sensors, a gyroscope and accelerometer. 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 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. By processing of the signals from this equipment it is possible to watch the position and orientation.

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.

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.

Nowadays, we have experienced the expansion of industrial automated robotic workstations used in particular for mounting purposes in manufacturing enterprises. Hence is the need for management of industrial robot in a defined area. In the case of industrial robot the system has 3 or more degrees of freedom, which depends on the particular robot. In this article, we will consider the processor, which has three degrees of freedom (Figure 1), three movable arms with translation movement around the area defined by the rotation of the floor and around the normal area.

The requirement for systems that are able to continuously monitor the orientation and position of the object led to the expansion of the investigation and of the autonomous control of inertial navigation. These systems mainly contain a number of sophisticated sensors to gather data on the position of the object in all six axes of Cartesian coordinate system. From the data collected from these sensors and by using the right arithmetic operation we are able to determine the position of the object in the inertial area [8].

In the inertial sensors so far presented a diverse range of sensors, there is still a place for improvement in particular as regards the accuracy. For example, the gyros are commonly used to measure angular tilt and angular velocity. The requirements for the accuracy of the gyros are constantly increasing their price, while becoming fragile and complicated. However, there are sectors in which they are the only sensible and reliable choice of gyros. This article describes the use of inertial measurement units, mainly in the field of management of the robot by the gyro [1], [2].

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Figure 1 - Robot with three degrees of freedom

2 Analysis of Inertial Navigation System

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 (Figure 2) and a navigation computer assessing data obtained from measurement devices/instruments.

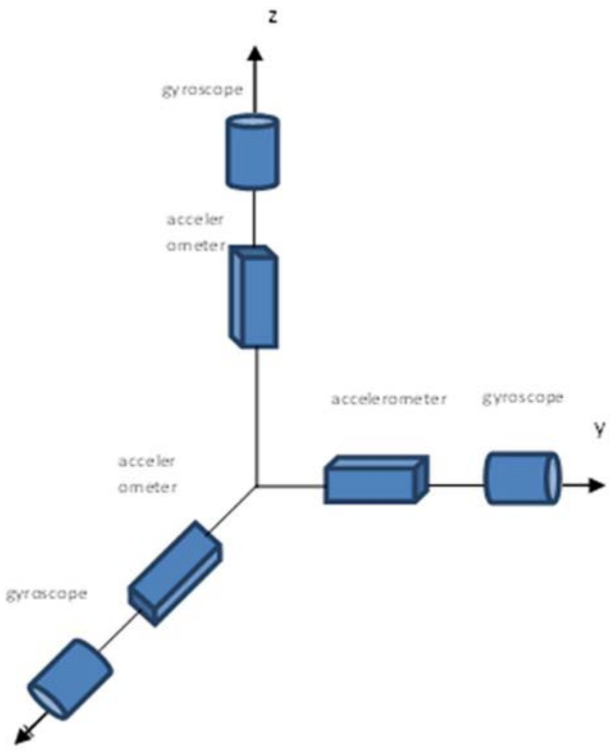

Figure 2 - Principle if inertial navigation system

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. 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. The deviation does not grow and there are no differences between the real and programmed positions of the robot [3], [4].

3 Determine the 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 (Figure 3) [5].

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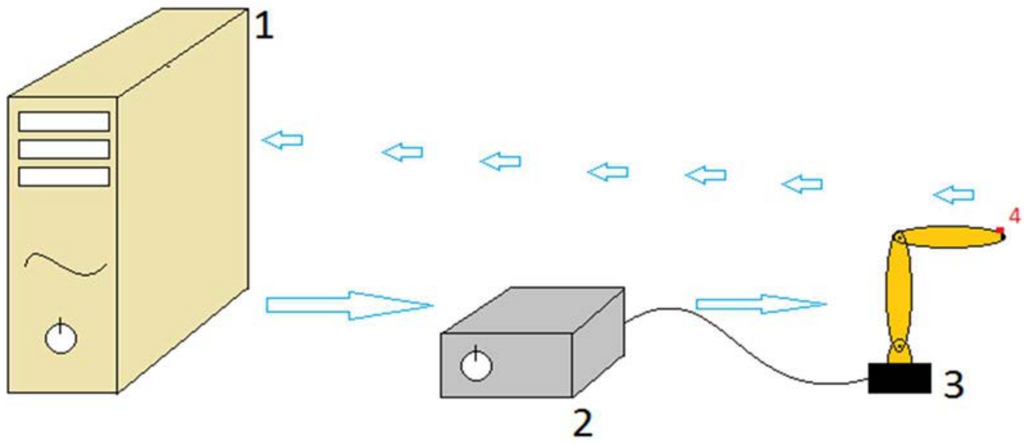

Figure 3 - Robot trajectory control, 1. -Control computer, 2. -The control system of the robot, 3. -Robot, 4. -Inertial navigation system

3.1 Determine the Position of the Robot Using the Accelerometer

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 as:

$$\mathbf{v}(t) = \mathbf{v}_0 + \int_0^t \left(\mathbf{R}(t)^{-1} \cdot \mathbf{a}_{\mathrm{local}}(t) - \mathbf{g}\right) dt \qquad (1)$$

Where g is represent the vector of gravity acceleration. It is possible to determine the location of the object:

$$\mathbf{d}(t) = \mathbf{d}_0 + \int_0^t \mathbf{v}(t)\, dt = \mathbf{d}_0 + \mathbf{v}_0 t + \int_0^t \int_0^t \left(\mathbf{R}(t)^{-1} \cdot \mathbf{a}_{\mathrm{local}}(t) - \mathbf{g}\right) dt^2 \qquad (2)$$

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 [6].

3.2 Determine the Position of the Robot Using the Gyroscope

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. 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 [6], [7].

4 The Management of the Experimental Platform of Robot

Our experimental platform (Figure 3) is designed with the ease of possible forms management model laboratory robot using inertial control system. Model of the laboratory robot consists of three dc motors. This means that the robot has three degrees of freedom; each motor is one degree of freedom. For controlling the robot is used inertial navigation system named x-IMU. Using three gyroscopes contained in an inertial navigation system we measure the rotation in three axes. These gyroscopes represent the rotation in axes x, y and z, which are arranged as in Cartesian coordinate system. By the application created in the programming language C # running on the management computer, the collected data are transferred to the degrees of rotation, and then they are sent to the control interface, which manages the individual robot motors [9].

RESEARCH AND DEVELOPMENT OF A NEW SYSTEM OF THE AUTONOMOUS CONTROL OF ROBOT TRAJECTORY
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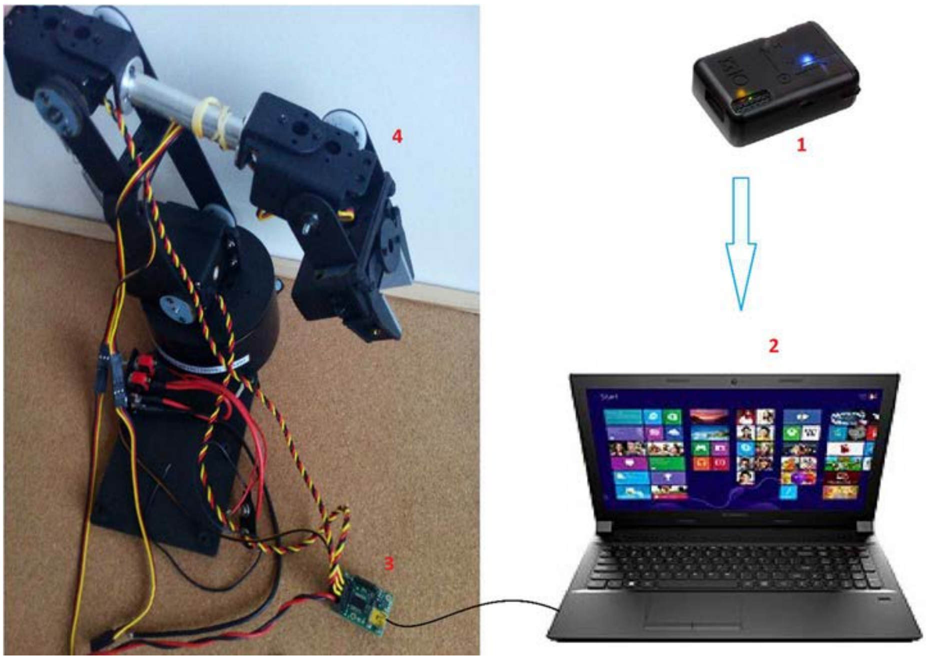

Figure 4 - The involvement of an experimental platform. 1- x-IMU, 2. -control computer, 3. - control interface, 4. - model of the robot

Conclusions

Inertial navigation placed on the robot arm allows to precise determination of its position in space. This information can be used in managing as well as the correction of the movements of the robot. The advantage of such a solution is independence from the other devices in the vicinity of the robot as well as the low intensity of the installation. The options of control the robot by using data obtained from the gyro, we have demonstrated on an experimental platform.

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