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Robotic electromechanical object control by means of variable structure system

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Abstract. The practical purpose of robot design is to transfer types of complex human activities that require much effort, are monotonous and harmful. The robotic systems differ from traditional automation measures in terms of their universality and the possibility to reconstruct them quickly which enables them to create flexible automation production measures on the basis of universal equipment. Therefore, the subject matter of the present article is constituted by manipulator robot control system methods (semi-continuous control method, coordinator parameter control method and adaptive control method etc.) and the aim of the present study is to cover the said manipulator robot control system methods in order to assess the problems relating to their application and to provide the potential solutions. In analysing studies by other authors and assessing the results based on them, the following results of the present article were obtained: having regard to the peculiarities of control object model, due to their universality, theoretical methods of systems with semi-continuous control are the most attractive. The approach of other studies is also improper as it is claimed that the dynamics of electric executive equipment may be neglected and control moments can be formed in the same way as breakage functions and the problem which occurred may partly be solved, by using the advantages of the system with semi-continuous control in the pre-limiting situation which occurs by approximating semi-continuous control by means of continuous functions. The fundamental gap of the majority of electromechanical object control studies is, first of all, related with the fact that the phase variables are considered measurable, so the necessity arises to note that the entire complex of measurement equipment may lead to a significantly more expensive control system; moreover, measurement equipment adds additional dynamics to the control system and makes the synthesis procedure even more complex.

Key words: manipulative robot chains, slip mode, coordinate parametric control, adaptive control, approximating semi-continuous control.

INTRODUCTION

Robotics has recently turned into a large-scale scientific and technological field developing rapidly which encompasses issues of kinematics, dynamics, strategy planning, programming languages and artificial intelligence. In the present paper robot manipulators are analysed as a control object, i.e. mechanisms characterised by several degrees of mobility intended the motion of objects and orientation in working environment (Fig. 1). The multi-chain manipulator construction ends at a gripper or a replaceable tool which are intended to grasp objects of a particular shape and to perform particular operations.

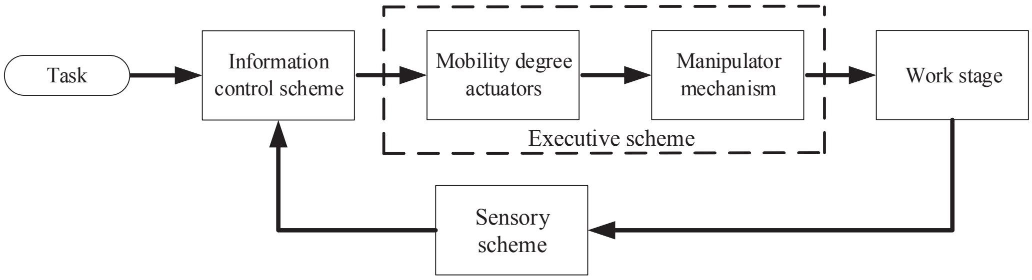

Figure 1. Functional robot control scheme.

The manipulator chains are interconnected by means of joints. The engines which make the chains move can be distributed in these joints or the respective powers and torques can be transmitted by means of movement mechanisms which do not change manipulator kinematic systems (Boujnah & Knani, 2015).

The engines of one model or another are usually produced as a module containing a movement transmission mechanism (redactor), feedback sensors (potentiometers, tachometers, rotary transformers (resolvers) etc.), whose signals are processed by microprocessors or analogue devices creating the control effect to the engine (Sassi & Abdelkrim, 2015). This system is referred to as the manipulator motion degree actuator (see Fig. 1). The executive system (see Fig. 1) is a control system consisting of actuators affecting the general mechanic load and ensuring the necessary movement of the manipulator and working organ respectively.

The first tactical manipulator control stage is trajectory planning (Jazar, 2010; Bazylev et al., 2014), i. e. setting the movement of manipulator chains or movement organ programmed movement at a certain period in off-line mode. The robot movement shall be modelled considering the limitations at the working zone. It is determined that the following aspects are known at the movement planning level: the purpose of movement, the description of the working space with the existing limitations (obstacles) and the capabilities of the robot capabilities. Moreover, when forming a continuous movement trajectory, the following requirements are considered: acceleration and braking mode, implementation of critical conditions etc. In the systems containing programmed control the entire trajectory (in the general case, movement and the existing working organ orientation) shall be programmed in advance. Provided that this is not possible, the technical vision system is applied (the entirety of visual information system), whose signals are used to either correct robot movement trajectory or to calculate it (Boujnah & Knani, 2015). The planning of industrial robot manipulator movement trajectory shall be carried out by means of control algorithms. These control algorithms shall be analysed as non-linear command movement designation algorithms according to the manipulator motion degrees. Their actualisation is related with the solution of non-linear equations describing the configuration of the mechanism upon the determined position of industrial robot working organs. Either ESM or imitation modelling shall be employed for such non-linear tasks, by also using actual manipulator system models. The second strategic phase is the performance of the determined programmed trajectory with actuators joints at the online mode.

MATERIALS AND METHODS

In analysing the tasks of manipulator robot control, it is, first of all, necessary to determine the aim of the control. The aim in the most common solutions is to ensure the movement from one given point to another in terms of its sufficient speed and accuracy. Another task is to ensure the 'practical stability' of manipulator gripper movement along the determined special trajectory which stands for a requirement that actual deviations from the given (nominal) trajectory shall be limited. It shall be noted that a high positioning accuracy (i. e. statistical accuracy) manipulator robot, for instance, PUMA–560, may also be not characterised by sufficient dynamic accuracy. The control task is to form a required manipulator actuator functioning algorithm based on the respective manipulator control methods (Dong et al., 2018).

The essence of the speed vector control method is to determine the speeds of the robot system working objects as a six-dimensional vector representing the projections of the working object angular velocity and the speed vectors of its certain point in any coordinate system which are the planned control algorithms so that it is possible to determine the speed of the working object in the current trajectory point. The direct application of this solution is limited by degenerate configurations of the mechanism which shall be considered by the control algorithm. The above-mentioned method which is actualised in a relatively complicated manner is effective in order to quickly move the working object from one position to another if necessary when there are no high positioning requirements.

The successive situation adjustment method is used most widely in different numerical control systems. In this case the control algorithm according to the speed vector shall be formed as a manipulator coordinate variation during one algorithm calculation cycle. The disadvantage of the method is a frequent selection of nodal points in a complex trajectory so that the transitions from one point to another do not alter the necessary picture of the movement essentially when planning the movement trajectory.

In performing the synthesis of manipulator control system, the approximative methods are employed, which originate from the setting of limited coordinate values. Three values are usually taken: two outermost and one middle value; then the inverse Jacobian matrix is calculated on the basis of them which depends on the manipulator configuration, while for all other coordinate values (including the nodal ones, the necessary points of the trajectory) the inverse matrix is calculated by means of interpolation. In many cases, especially in the case of feedback according to the position, this is absolutely enough in order to achieve the final control goal. The disadvantage of the method is the errors which occur during the interpolation which become significant in case there is no feedback according to the position (Jazar, 2010).

The following shall also be classified as a disadvantage of the power vector control method: it is impossible to guarantee the formalisation of robot working object movement approaching the given direction provided that the given trajectory contains points at which the manipulator configuration matrix is degenerate. The trend of control process simplification and its resulting calculations led to the power vector control method where the idea of control on the basis of the given direction is simulated. In reality, no power is directed/added to the manipulator, but the tracking actuators create the entirety of generalised powers which are dynamically equivalent to the given powers simulating their adding/directing to the manipulator. As the calculator receives the set signal at the entrance, it sets the generalised powers attributed to the coordinates which are directly controlled by actuators. The actuators, on their turn, constantly create such generalised powers which are obtained at the exit of the calculator. These generalised powers can be clarified automatically by regulators and compensators.

The main task of manipulator control is to generate external moment in such a way that the robot movement takes place in the chosen trajectory. The robot movement usually is implemented in two different controllable phases. During the first control phase (approximate movement) the robot shall move from the initial position to the environment of the location of the set goal alongside it from the pre-determined trajectory. The second control phase is a precise movement phase where the robot working object is dynamically interacting with the object, by also using the external sensor feedback information channel in order to perform the task. In case the traditional tracking system is used in the robots, the non-linearity and interaction which depend on the manipulator dynamics cannot be compensated at the approximate movement phase. As the requirements for industrial robot performance characteristics are increasing, it is necessary to consider the above-mentioned dynamic effects. Therefore, many improvements have recently been proposed to the schemes and algorithms of industrial robot direct control (Han et al., 2017).

Some researchers (Bazylev et al., 2014; Lee et al., 2018) have suggested that linear system models should be used as a basis for further actualisation of regulation dissociation. It is understood that the regulation system based on the linear model may seem to be unacceptable if the actual working conditions are different from the conditions determined during linearisation.

One of the first methods where the robot is analysed as a non-linear interrelated system with a variety of entrances and exits was the torque calculation methodology (Bazylev et al., 2014). Moreover, it was believed that inert reaction powers can be precisely calculated, Korol powers inert powers and gravity powers. Therefore, the operational characteristics of this regulation system basically depend on the accuracy of the model used. The moment identification method requires a high number of calculations which is often regarded as a disadvantage.

The regulation of the motion designed is the identification methodology of joint movement speed variables necessary for ensuring the robot terminal point movement at the given direction. In the case of such control scheme, all the trajectories set are expressed in Descartes coordinates. It is a particular advantage because for many users it is much simpler to determine the sequence of movement in Descartes coordinates as compared to joint position variable coordinates. The regulatory methods of torques and the designed movement speed are reconciled by means of the designed movement acceleration control method (Lee et al., 2018). This method provides that the user shall determine the necessary positions, speeds and accelerations of the arm of the determined. The above-listed methods are also notable for the disadvantages: it is necessary to have a detail dynamic model and to delegate much time for machinery calculations.

Another group of methods is focused on the compensation of the existing indefinite uncertainties. These are the following methods: coordinate parametric control (Shakibjoo & Shakibjoo, 2015), methods of adaptation to unknown parameters (Huang

& Liu, 2017). In the case where external disturbances are described by the known dynamic model with unknown initial conditions, the external disturbance dynamic compensation principles are applied (From et al., 2014; Mustafa et al., 2017).

The main reason for the interest in the adaptive robot control methods is that some of the practical robototechnics solutions for the technological tasks require very precise restitution of the determined trajectory (for instance, the pilot stand robots, assemble robots, low flight robototechnical root simulators, laser technological stand robots, emergency robots, space robots etc.). In order to perform these tasks, it is impossible to achieve the required accuracy by means of linear feedback due to the fundamentally non-linear nature of manipulator equations as well as due to the dependence of these equations on the load transferred.

In the adaptive control with a benchmark model a model corresponding to the benchmark is chosen and the adaptation algorithm modifies the strengthening coefficients in the controller feedback channels. The adaptation algorithm is determined by the difference between benchmark model output signals and the actual parameters of the robot. The robot is controlled when the strengthening coefficients are regulated in the feedback channels with regard to the position and the speed so that the close contour characteristics are close to the benchmark model. Currently quite many different universally stable manipulator adaptive control algorithms are known already, the majority of which may be received by applying the standard procedures of speed gradient method, by also properly selecting the target functionality and phenomena for an error. It is necessary to note that the majority of the existing adaptive cannot fully solve the problem of designing the manipulator automatic control systems intended for particular application (including the industrial one).

First, the fact that it is complicated to perform as many calculations at the real time as it is needed in order to actualise at least the simplest Slotine-Li algorithm (Zhang & Wei, 2016) intended for six-degree anthropomorphic manipulator PUMA–560 constitutes a considerable obstacle for the actualisation of universally stable adaptive manipulator control algorithms. The second reason has to do with the fact that all the universally stable adaptive algorithms are focused on the so-called object equation parametric indeterminacy, i. e. on the mathematical object description, which would be precise until the final number of stable parameters. Upon such access, all the components of the non-linear description of the object shall be repeated in the control principle which means that these components need to be known exactly. It is quite difficult and sometimes even impossible to design an object model which is precise enough in practice. In other words, universally stable adaptive algorithms are calculated with regard to lower-degree indeterminacy as compared to the one which is usually encountered in practical tasks. Therefore, it is reasonable to base the design of control adaptive systems of manipulators which are intended to be applied in real conditions on totally different principles which do not require the restoration of object non-linearity and the calculated higher degree indeterminacy as well.

The modern trend of mechanical object control is to design multi-regime multi-functional widely applicable system control principles which are universal enough which should not be cumbersome, and which should not require enormous calculation costs. For this purpose, it is necessary to reduce the dependence of control principles on the dynamic parameters of the control object.

RESULTS AND DISCUSSION

Another trend in designing robot systems is basically related with the theory of variable system structure. In the systems containing the variable structure, the slip mode occurs on the surface of the switch (Han et al., 2017; Jung & Jeon, 2017). When the system is working at the slip mode, the system remains insensitive to variations of parameters and disturbances. In order to achieve control indicating the slip mode no precise modelling is needed; it is enough to know the ranges of model parameter measurements. This access provides that control principles need to be established in the breakage function class, by also assuming that the execution equipment dynamics is low, and it cannot basically affect the mechanic system movement. Some studies will be mentioned where the methods of systems with semi-continuous control were used in robot systems. In the studies by V. Utkin external powers affecting the mechanical system are considered unknown but limited (Liu et al., 2017a). It is assumed that control impacts are dominating. The control principles obtained (by also having regard to the common limitations of phase variables and control impacts) determine the tasks of terminal control upon the application of game access, i. e. uncontrollable disturbances are treated as manifestation of the opponent's actions. In the studies by A. Mustafa the unknown also refers to mechanical inert characteristics (Liu et al., 2017b). Only the interval where the energy matrix real values may vary is known. The presumptions submitted contain the sectionally continuous principle. J. Juang has formulated the task of the black box control of mechanical nature has been formulated in his works (Xiao et al., 2017). Critical situations were analysed where information on the dynamic parameters of the system was basically unavailable were analysed. The principle of division has been set which is one of the accesses in order to solve a control task under indeterminacy conditions. The principle of division has been elaborated on by B.T. Kulakowski in his works, where not only the very fact of the presence of final intervals of the change of the inertial characteristics of external powers and the mechanical system is known. Universal control principles which stabilise any potential movement of the mechanical system in practice were obtained (Raj et al., 2016; Yagur & Belov, 2018).

Manipulators as control objects are multi-chain non-linear interrelated systems. Although, in order to facilitate control tasks, it is required to somehow dissociate manipulator motion degrees to make them controllable independently, such access is not the best one from the control quality perspective in general. Two groups pf motion degree interrelate influence compensation methods exist:

Constructive, based on the alignment of chain mass of the manipulator;

Algorithmic, actualised control systems, the above-mentioned distribution principle in particular.

The general measure intended for the reduction of self-imposed influence is the increment of manipulator motion degree control system functioning increases the efficiency of retraction of the disturbances affecting these motion degrees (including their mutual influence).

CONCLUSIONS

Considering the peculiarities of control object model, a conclusion can be made that, due to their universality system, semi-continuous control theory methods are the most attractive. These methods enable suppressing of a wide class of both parameter and external disruptions and ensuring durable properties of a closed system, especially because they are much simpler to realise as they do not need a detailed dynamic model and much time for performing machinery calculations.

The majority of the above-mentioned studies have proven that the dynamics of electric executive equipment may be neglected and control moments may be formed in the same way as breakage functions. However, these results are impossible to actualise these results in practice directly due to the powers evolved by executive equipment and physical limitations of the moments. However, having employed the advantages of the system with semi-continuous control in the pre-limiting situation which occurs upon the approximation of semi-continuous control by means of continuous functions one can partly overcome this problem.

The main gap of electromechanical object management research is related with the fact that phase variables (generalised coordinates, their speeds, acceleration, actuator variable states) are considered measurable, i.e. no objective to observe is set and solved. It shall be noted that the entire complex of measurement equipment may lead to a significantly more expensive control system; moreover, measurement equipment adds additional dynamics to the control system and makes the synthesis procedure even more complex.

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