Controllability of Complex Dynamic Objects

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Abstract. Quality requirements for mobile robots intended for both specialized and everyday use are increasing in step with the complexity of the technological tasks assigned to the robots. Whether a mobile robot is for ground, aerial, or underwater use, the relevant quality characteristics can be summarized under the common concept of agility. This term denotes the object's (the robot)'s ability to react quickly to control actions (change speed and direction), turn in a limited area, etc. When using this approach in integrated assessment of the quality characteristics of an object with the control system, it seems more constructive to use the term "degree of control". This paper assesses the degree of control by an example of a mobile robot with the variable-geometry drive wheel axle. We show changes in the degree of control depending on the robot's configuration, and results illustrated by calculation data, computer and practical experiments. We describe the prospects of using intelligent technology for efficient control of objects with a high degree of controllability.

1. Introduction

Quality requirements for mobile robots intended for both specialized and everyday use are increasing in step with the complexity of the technological tasks assigned to the robots.

Whether a mobile robot is for ground, aerial, or underwater use, the relevant quality characteristics can be summarized under the common concept of agility. This term denotes the object (the robot)'s ability to react quickly to control actions (change speed and direction), turn in a limited area, etc.

Therefore, increasing agility is currently relevant for mobile robots and other land, air and underwater-based objects, since it essentially describes the object's speed of response to a technological or special task. However, performance of maneuvers increases energy consumption, which is especially critical for autonomous mobile robots with a limited power supply (batteries).

2. Statement of the problem

The concept of agility is to a great extent linked to the concept of controllability, widely used in the theory and practice of automatic control. As a rule, developers pay attention to "controllability" during preliminary analysis of the automatic control system, solving the problem in general settings – whether the system (object) is controlled or not, or controlled by different inputs. In other words, the concept of controllability, by force of established practice, is not very important for robot design, and requires deep further research and quantitative interpretation.

When using this approach, it seems more constructive to use the term "degree of control" in integrated assessment of the quality characteristics of an object with the control system.

3. The degree of control of a mobile robot with variable-geometry drive wheels

To illustrate this problem, we will consider a model of a mobile robot with variable geometry drive wheels. Fig. 1 presents three variants of the robot: a) wheel at front, b) wheel at center, c) wheel at rear. A mathematical description of the motion of these objects and the degree of control calculation are described in detail in [1].

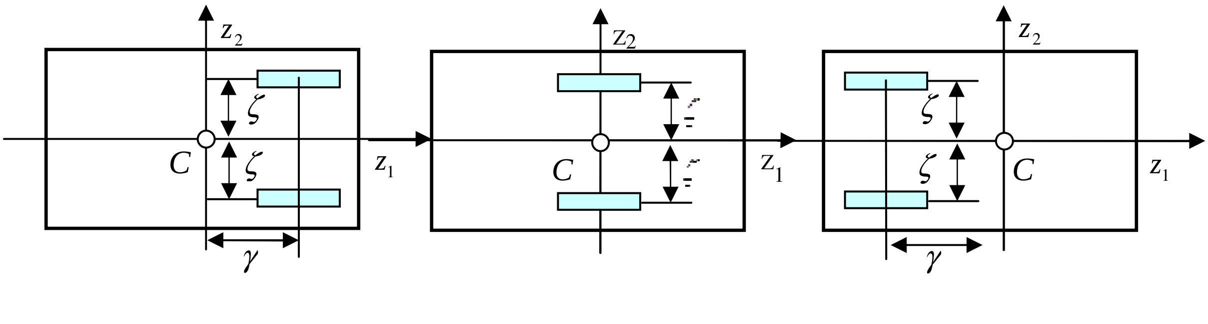


Figure 1. Schemes of three variants of the mobile robot.

Fig. 2 presents a graphical interpretation of the degree of control calculations for the different drive wheel axle positions.

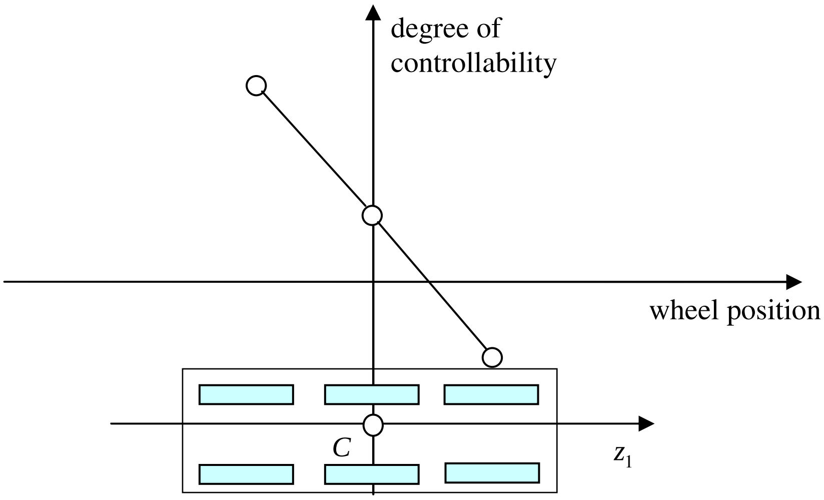


Figure 2. A graph of the dependence of the degree of controllability on the location of the drive wheel axle.

An analysis of the calculated data (Fig. 2) shows that the degree of control value is greatest with the axle in the rear position, and that the opposite value is received with the axle in the front position. From the standpoint of agility, this result can be interpreted as follows: the reaction of the robot in Fig. 1C to control input or external influence is faster than that of the robots in Figs. 1B and 1A. To check this assumption, we will carry out further computer and practical experiments.

4. Experimental data

Fig. 3 shows a model of a mobile robot with a trajectory-tracking control system with the drive wheel axis at center (fig. 1B). Corresponding models for the other two robot types have been omitted for space considerations.

As an experiment, we observe the movement of the center of mass of three variants of the mobile robots, while they are completing a maneuver at different radii of the turn curvature. The results are presented in Fig. 4.

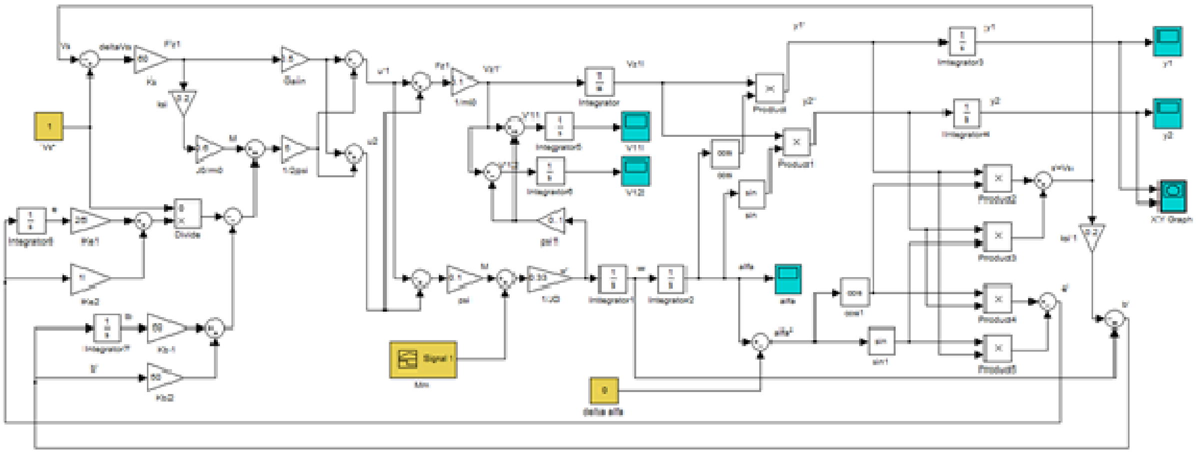
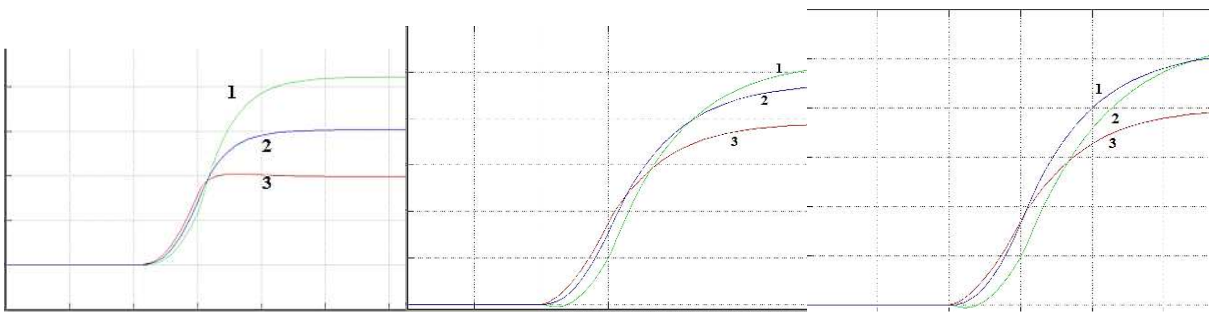


Figure 3. A model of the mobile robot from fig.1B.

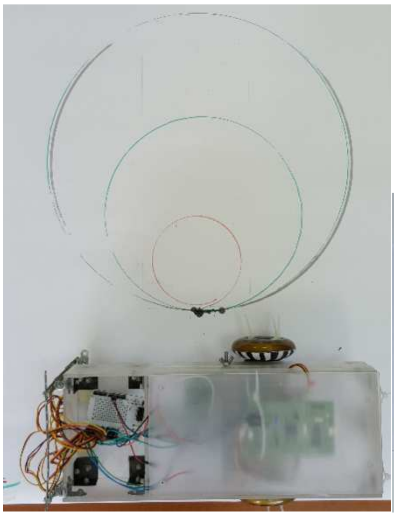


a b c

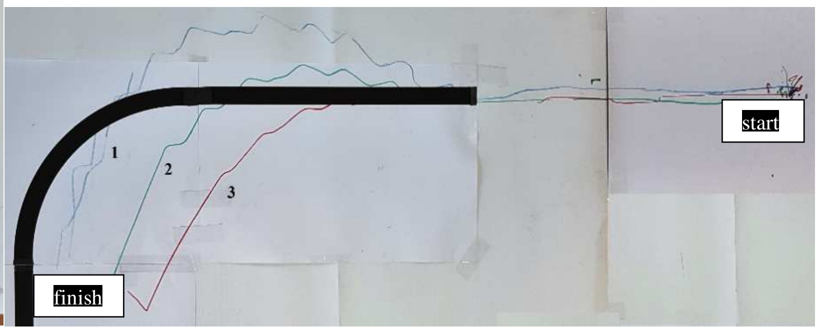
Figure 4. The results of the computer simulation: a – R=1, b – R=5, c – R=10. Control signal responses of mobile robots with wheel axle positions: 1 – front, 2 – central, 3 - rear.

For the practical experiment, we designed a hardware suite for a mobile robot with reconfigurable drive wheel kinematics (Fig. 5A), including feedback sensors and a computer module made up of a STM32F407VG microcontroller with the following characteristics: 32-bit ARM Cortex-M4F core with 1 MB of Flash memory, and 192 KB of RAM. The results of the experiment, similar to that of the computer experiment, are shown in Fig. 5B.

Analysis of the results confirms the calculated results, showing that the response to the control signal is fastest in a mobile robot with a drive wheel configured to the rear; that is, this robot has higher agility. Moreover, the computational experiments, in conjunction with the practical, show the relationship of the degree of control with the object’s real dynamics. As such, a deeper study of this subject is of interest. In particular, it is important to consider the issue of the link between the degree of control and the actual data on the quality of control, and the impact of the degree of controllability on the system’s dynamics and a zone of stability. Such investigations are not only of theoretical interest, as an important part of Active Control Theory, but also for practical use. For example, these studies are vital in solving the issue of reducing energy use when completing a maneuver, which is especially critical for autonomous mobile robots with a limited power supply (batteries).



a



b

Figure 5. The results of the practical experiment: a – hardware, b – control signal responses of the mobile robots with wheel axle positions: 1 – front, 2 – center, 3 - rear.

Analysis of the literature [2-4] and experience with different types of mobile objects [5-7] shows that the problem of increasing agility is systemic, and needs to be addressed not only in terms of structural changes in the object (which, in many cases of increased agility, also reduce the system's stability zone), but also through development of new control algorithms, providing both high stability and high performance of the control process.

5. Intelligent control algorithms for complex objects with a high degree of controllability

Another set of challenges that must be addressed to improve the agility of mobile objects is associated with the use of classic control algorithms, which are clearly becoming ever more inadequate for the growing demands of new technology for both specialized and everyday use. The use of various adaptive control algorithms, especially for fast-moving objects, turned out to be unpromising due to the complexity of their digital implementation and consequent delays in the loop system, which impair objects' dynamic properties.

Separate attempts to improve agility through object structural changes only, without improving control algorithms, have not delivered significant results, particularly because of the problem of ensuring system stability. The problem in scientific terms has been formulated by Kalman as "the contradiction between agility and stability".

Fundamental research in the field of intelligent control systems conducted in many countries of the world, as well as MIREA's twenty years of experience of work in this direction clearly show the prospects of applying intelligent technologies to the development of control algorithms for complex dynamic objects, especially in situations where the parameters of the object and control system, or functional environment, or diversity of functional tasks, are uncertain.

6. Conclusion

Russian science has accumulated a sufficient fundamental basis for the solution of a wide range of current practical problems, including in particular the control of mobile objects with a high degree of controllability. Many of the results of Russian research, as demonstrated by extensive literature review and detailed study of various types of equipment, are of a leading nature. This applies, in particular, to fast-moving control algorithms implemented on the basis of associative memory, complex obstacle avoidance algorithms, methods for the synthesis of intelligent systems with neuro fuzzy controllers [8], and controllers based on expert technology systems and associative memory.

The application of the intelligent control algorithms proposed in this paper, in conjunction with structural solutions for ensuring a high degree of controllability, will significantly improve the performance and reduce the energy consumption of future autonomous and semi-autonomous objects for specialized and industrial use..

7. Acknowledgments

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