ISSN: 0975-766X
CODEN: IJPTFI
Available Online through
www.ijptonline.com
Research Article

THE GENERALIZED MODEL OF AUTOMATICALLY GUIDED VEHICLE MOTION CONTROL SYSTEM BASED ON TRANSFER FUNCTIONS

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Received on 14-08-2016 *Accepted on 20-09-2016*

Abstract.

This paper describes the developed model of a mobile vehicle controlled by the difference in speeds of the two drive wheels. The model includes a mathematical description based on the transfer functions of three subsystems: control of the lateral deviation from the target track, the speed control of the longitudinal movement along the straight and curvilinear sections, and positioning control in places to stop automated guided vehicle (AGV) for loading and unloading operations. The model takes into account the movement of the vehicle along a curved path, which is set in deviations from the rectilinear motion. The simulation results of the transport robot movement relative to a given path represented using of Matlab software. Proposed structural schemes of the control subsystems allows to use both of classical and modern control theory methods for the synthesis of vehicle motion control devices.

Keywords. Mobile robot, transport vehicle, movement trajectory, modeling, transfer function, simulation.

Introduction. Control of mobile vehicles in the transport and warehousing operations is widely used in automation systems of technological processes [1]. In the development of vehicle control systems should take into account many factors that affect their work. Mathematical modeling and computer simulation allows to analysis of control systems, as well as the synthesis of control devices without the needing of expensive physical model experiments [2]. There are a large number of vehicle models, which are based on certain assumptions and, accordingly, have its advantages and disadvantages [3]. Proposed mathematical model of the vehicle motion control system based on transfer functions.

Main Part. There are various designs of mobile vehicles intended for the transportation of load at intra shop operations, and wheeled vehicles are most frequently used. The use of automation allows to create automatic guided vehicles (AGV) [4]. Computer-aided design of such systems requires the computer modeling for analysis and synthesis of AGV motion control systems. Various authors have carried out the construction of models using different approaches [5–8]. Among the large variety it should be noted the mathematical model developed in [9] and based on the transfer functions.

This model has been revised and expanded, whereby there was developed a generalized mathematical model of a wheeled vehicle. Modeling was based on the following basic assumptions [10–13]:

— The AGV is moving in a horizontal plane;

— effects related to the dynamic load distribution on the wheel when maneuvering, are disregarded;

— the vehicle body is absolutely solid;

— the movement of the wheels going without slipping;

— influence on the direction of the driven wheels can be neglected.

The movement trajectory of a wheeled vehicle with two wheels on the cross shaft and two passive wheels on the longitudinal axis is determined by difference wheel rotational speeds. During movement of the AGV with a longitudinal speed V_T lateral deviation Δ from the desired trajectory measured by a sensor located on the longitudinal axis at a distance d from the center of mass C (see Fig. 1).

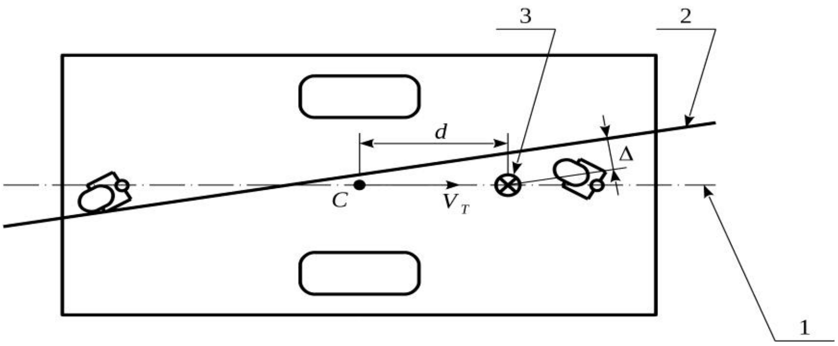

Fig. 1.Scheme of AGV with two-wheel differential.

1 – longitudinal axis of the AGV; 2 – kinematic trajectory of movement; 3 – lateral deviation sensor

Functional diagram of the control subsystem of lateral deviation is shown in Fig. 2.

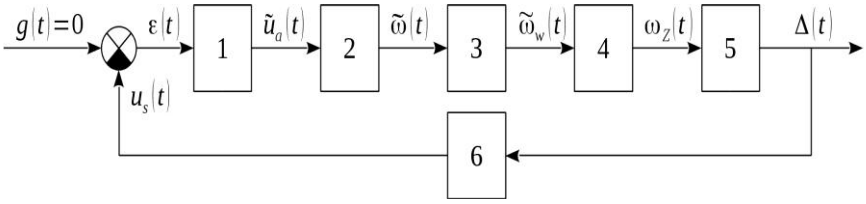

Fig. 2. Functional diagram of the lateral deviation control subsystem:

1 – amplifier; 2 – electric motors; 3 – gears; 4 – chassis; 5 –vehicle; 6 – lateral deviation sensor; $g(t)$ –lateral deviation setpoint; $\varepsilon(t)$ – error signal; $\tilde{u}_a(t)$ – difference between the motors voltages; $\tilde{\omega}(t)$ – difference between the motors rotational speeds; $\tilde{\omega}_w(t)$ – difference between driving wheels rotation speeds; $\omega_Z(t)$ – rotation speed of the platform relative to the center of mass; $u_s(t)$ – output voltage of lateral deviation sensor

The block diagram (Fig. 3) of the lateral deviation subsystem obtained by substituting the transfer functions instead of the corresponding functional diagram blocks.

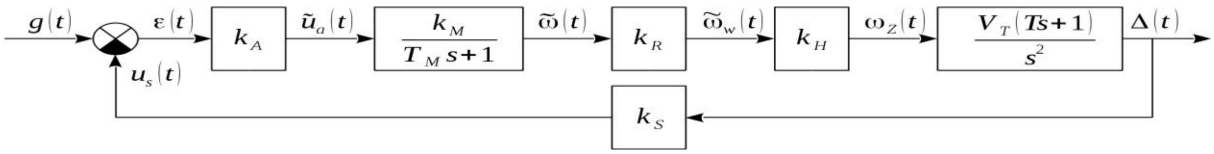

Fig. 3.Block diagram of the lateral deviation control subsystem.

k_A – amplifier gain; k_M , T_M –coefficient gain and time constant of the electric motors; k_R –gear coefficient; k_H coefficient of chassis; T – mobile platform time constant, which is equal $T = d / V_T$; k_S – sensor coefficient

Mathematical model of the longitudinal motion control subsystem is obtained with the same basic assumptions. The appointment of the subsystem, firstly, is stabilizing the longitudinal speed on straight and curve sections of trajectory, and, secondly, is a longitudinal positioning in breakpoints of the load and unloading. Thus, it is necessary to obtain the two models for a mobile vehicle: 1) longitudinal velocity control subsystem; 2) positioning control subsystem.

Process of longitudinal motion control can be expressed as a functional diagram (Fig. 4).

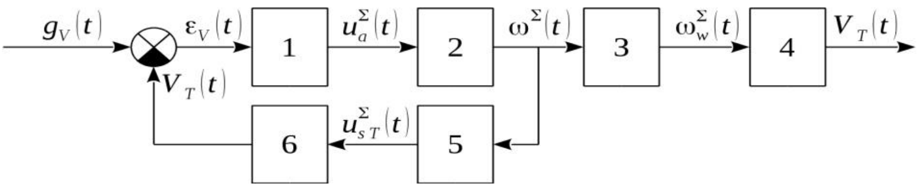

Fig. 4. Functional diagram of the control system of longitudinal velocity:

1 – amplifier; 2 –electric motors; 3 – gears; 4 – chassis; 5 –rotational speeds sensor; 6 – longitudinal velocity calculating unit; $g_V(t)$ – longitudinal velocity set point; $\varepsilon_V(t)$ – error signal; $u_a^{\Sigma}(t)$ – sum of the motors voltages; $\omega^{\Sigma}(t)$ – sum of the motors rotational speeds; $\omega_w^{\Sigma}(t)$ – sum of the drive wheels rotational speeds; $V_T(t)$ – longitudinal velocity; $u_{sT}^{\Sigma}(t)$ – sum of voltages of the rotation speed sensors

Block diagram of the longitudinal speed control system obtained based on the functional diagrams after converting it to the form of closed-loop system with a negative feedback is shown in Fig. 5.

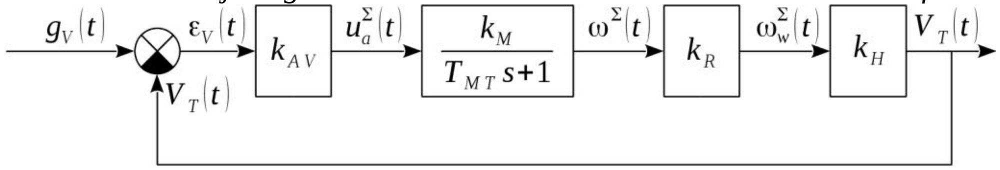

Fig. 5. Block diagram of the longitudinal velocity control closed loop subsystem with a negative feedback.

k_{AV} –gain of control subsystem longitudinal velocity amplifier; T_{MT} – electric motor time constant depending on the longitudinal movement resistance

It can be seen that, in addition to the longitudinal speed control, must be the position control system at theaccess to the stopping point. Functional diagram of the longitudinal position (Fig. 6) is similar to the scheme shown in Fig. 9, and the difference between them:

— set point is a initial distance from the AGV location on the trajectory to the stopping point $g_X(t) = 0$;

— system's output considered the passed distance from the beginning of deceleration to the stopping point $x(t)$;

— the computing unit based on the motor speed have to form instead of the longitudinal velocity of the passed distance;

— error $\varepsilon_x(t)$,supplied to the amplifier device, is the distance on the trajectory of movement from the current location to the AGV stopping point.

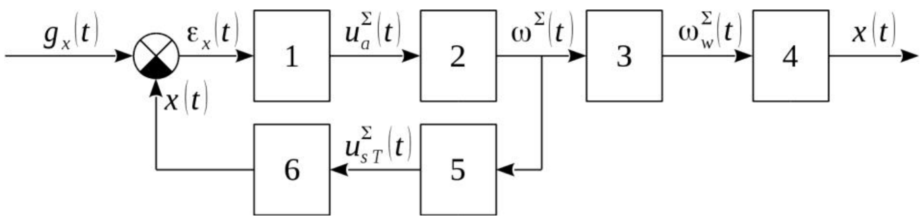

Fig. 6.Functional diagram of the longitudinal position control subsystem:

1 – amplifier; 2 – electric motors; 3 – gears; 4 – chassis;5 – rotational speeds sensor; 6 – distance traveled calculation unit;

As it's known, the block diagram of the longitudinal positioning with a single negative feedback is usually used to simplify analysis (Fig. 7).

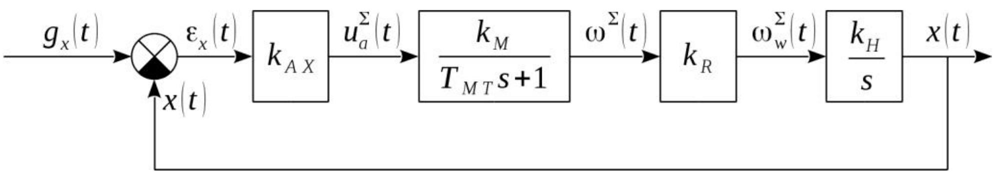

Fig. 7.Block diagram of the longitudinal position control closed loop subsystem with a negative feedback

k_{AV} – gain of control subsystem longitudinal position amplifier

Models which are considered the lateral deviation and the longitudinal movement give all information about the position of the mobile robot relative to a given trajectory. Return to the block diagrams in Fig. 3, Fig. 5 and Fig. 7 it's easy to see that the speed obtained at the output of the second model, it's a parameter of the first model. This relationship leads to the necessity of analyzing the general model AGV that takes into account both the lateral and longitudinal movement. By entering additional elements and connections, we get a block diagram of a generalized model (Fig. 8).

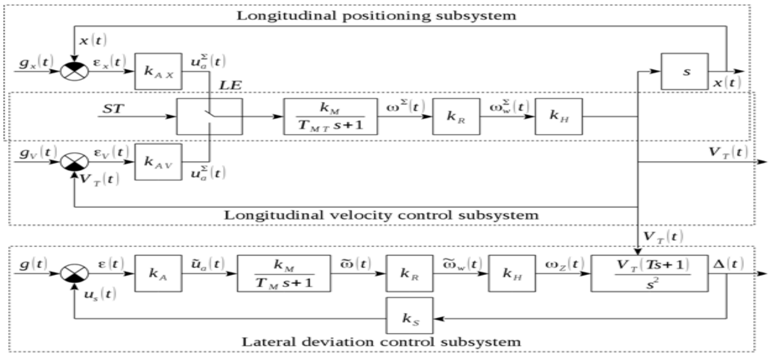

Fig. 7.Block diagram of the generalized model of AGV motion control system.

Presence logic element (LE) in the block diagram in Fig. 8, caused by the logic value of the signal ST, corresponds to the fact that, during declaration in the stopping place the control system of the longitudinal movement should carry out the positioning of the mobile robot along the coordinate $x(t)$, and during acceleration and movement on the sections of trajectory, it's necessary to control of the longitudinal velocity. Physically, the switching of control system should occur by the presence of the marker (optical, inductive, electromagnetic, infrared, and so on) which previously reported on the need to stop the AGV, and back switching – before initial moving from stop position.

Let us consider the simulation of cases movement, when part of the track is not straight. This deviation of the trajectory at each time point from the straight direction that a trajectory had it in previous time will be disturbance for a control system of lateral deviations AGV (Fig. 9).

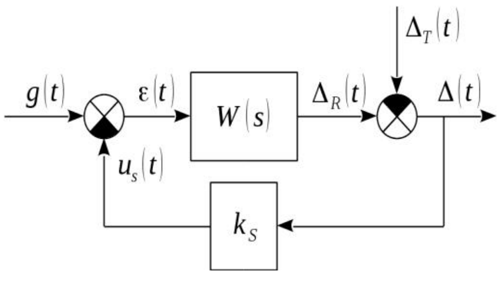

Fig. 8.Lateral deviation control subsystem considering disturbance, which is a consequence of the nonlinearity trajectory:

$W(s)$ – open loop transfer function of the lateral deviation control subsystem; $\Delta_R(t)$ – AGV deviation from the straight movement direction; $\Delta_T(t)$ – trajectory deviation from the rectilinear direction; $\Delta(t)$ – AGV lateral deviation from the predetermined route

The concept of deviation from a straight line direction will be regarded as the distance from the point, which is considered at the next moment t_{i+1}, on track to a straight line passing through the points of the track, which correspond to the current t_i and previous time t_{i-1} (Fig. 10).

For a short period of time interval $[t_{i-1};t_i]$, the current rectilinear direction and connecting point of the track for the previous and the current moment time will be approximately coincided with the curved section of the track.

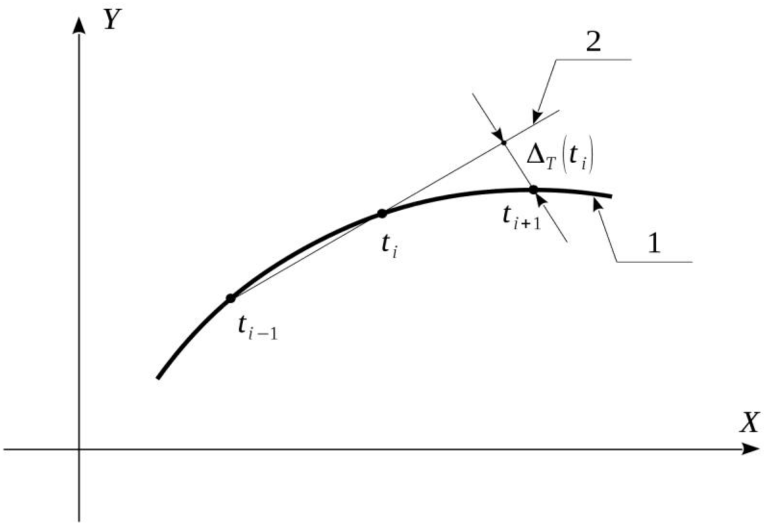

Fig. 9. Deviation to the rectilinear direction of the track:

1 — defined track; 2 — rectilinear direction of the track at time t_i

Simulation of AGV movement relative to the track, it's necessary in the first, displaying the model of track, specified in the deviation of the corresponding curve of the coordinate plane (XY), and in the second, finding the AGV position in a plane XY, relative to a point on the trajectory based on lateral deviation from it.Sequential changes in the time of the AGV position coordinates, which depend on the configuration, the longitudinal speed and other parameters, generate the trajectory of the AGV.

The following graph (Fig. 11) shows the results of simulation of AGV movement along the curve trajectory segment,every point on this curve has a deviation (0,004 m) from the rectilinear direction when the velocity of AGV is 1 m/s. Other simulation parameters are initial lateral deviation (0,2 m), initial and target value of the longitudinal speed respectively 0 m/s and 0,5 m/s.

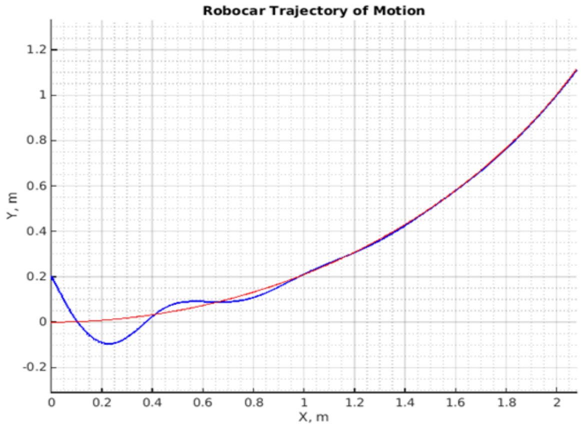

Fig. 10. Simulation of AGV movement along the curve trajectory segment with zero initial lateral deviation.

Combining between straight segments and turning segments, where a trajectory has a deviation from the rectilinear movement of the path,can be simulated by different configurations of track. In addition, on the track will be noticed the point that initial stop positioning for AGV. Thus, depending on the current position of the vehicle, which is determined by the passed distance, the model of the track should provide for model of AGV following information:

— vehicle's current lateral deviation Δ from the route, which is equal to the difference $\Delta_R - \Delta_T$;

— the task for the longitudinal velocity g_V , that can determine AGV, for example, in the content of the information of the mark, which situated on the track;

— it is essential to have a speed control system or position control system;

— the distance from the initial mark of stopping to the point stopping.

In this turn, according to the model of the vehicle, except of the information's coordinate x_R , a lot of information used in the model of the track, specifically:

— the lateral deviation of AGV from the rectilinear movement Δ_R ;

— presence completely stopping for AGV, i.e. point where vehicle is ready to carry out loading and unloading operations.

It can be noticed that, the complete stop can be determined, for example,by the equality of a given error rate to zero, by the acceleration and change of vehicle acceleration. Through some period of time, corresponding to the execution time of loading or unloading, after a stop signal ST ,that simulates the beginning of a subsystem speed control and starting of the movement AGV.The interaction model of the trajectory and model of the mobile robot(AGV) shown in Fig. 12.

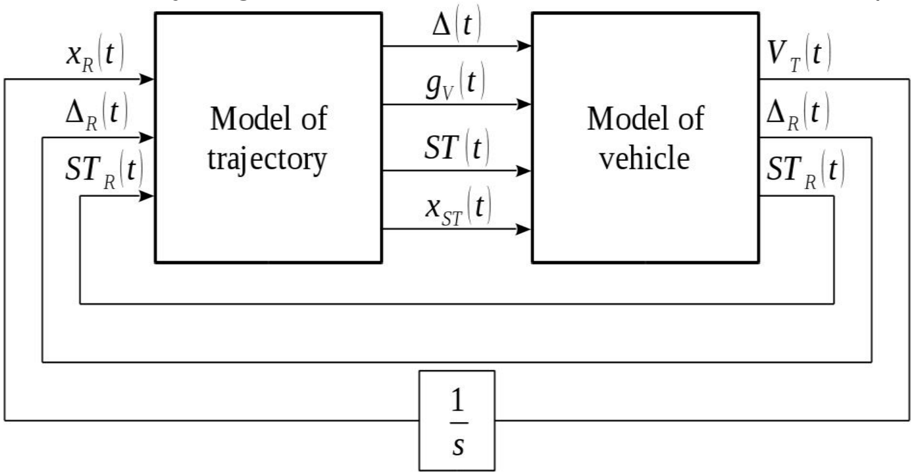

Fig. 11. The interaction model of the trajectory and the AGV generalized model

The result of the simulation in Matlabof movement along the complex trajectories shown in Fig. 13.

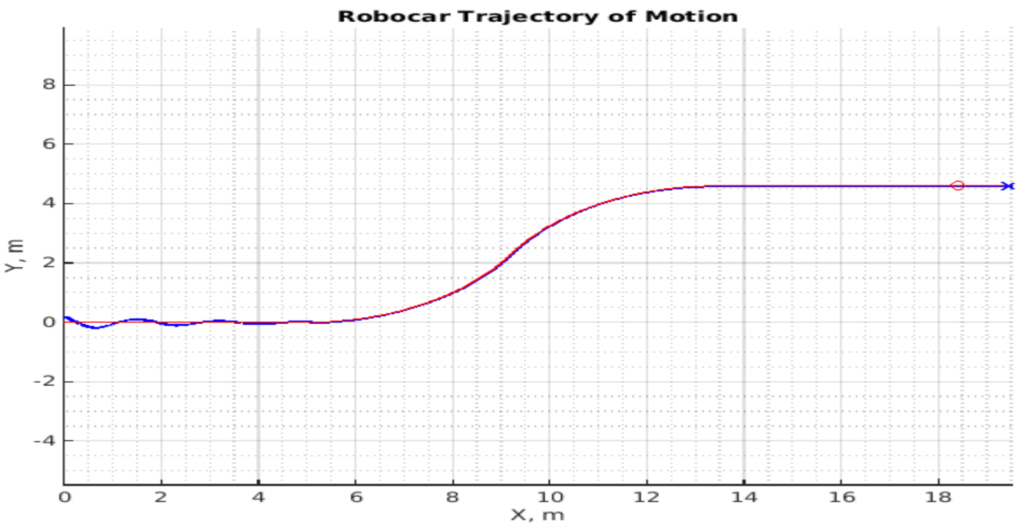

Fig. 12. Simulation of AGV movement along the complex trajectory.

The complex trajectory shown in Fig. 13, consists of a straight section of acceleration, turning to the left and turning to the right, which correspond to the positive and negative deviation from the straight track direction, on the second straight section of the movement, it can be seen the marker of initial stopping, which located at 1m from the point positioning. After a complete stop of AGV, which is determined by the zero speed and zero acceleration, is simulated delay time corresponding to the necessary time for loading/unloading of mobile carts.

Summary. The results of mathematical modeling with considering assumptions created a generalized model of the AGV motion, which includes three subsystems: lateral deviation control, longitudinal speed control and longitudinal positioning control.

For the analysis of the synthesis results is developed computer model visualization of AGV motion trajectory, which takes into account not only the relationship of subsystems, but also the disturbance that occurs when the AGV has a deviation from the straight direction.

Conclusion. The advantage of the obtained model is the representing of each subsystems in form as a block diagram, based on use of the transfer function. This allows to use model in the classical and modern control theory methods for analysis and synthesis of the AGV motion control laws. Each of the three sub-systems has disadvantages which are supposed to be eliminated by the entering correcting elements in a control loop.

Control subsystem is necessary to reduce or eliminate oscillation of the control process and reduce the settling time of the lateral deviation. In the longitudinal speed subsystem control must be static error reduced to zero, that equals to the difference between the desired and the measured speeds in steady state. For the longitudinal position control subsystem ,is necessary to completely eliminate overshoot. As a result, there is no need to reverse the engines in the field of positioning.

Acknowledgements. This article was prepared with the financial support of the Federal Target Program in the project "The development of robotic complex for the implementation of full-scale additive technologies of innovative materials, composites, constructions and buildings" (agreement # 14.577.21.0193 of 27/10/2015).

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