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Fuzzy control of mobile robot in slippery environment

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Abstract:-

The problem of independent motion control of mobile robot (MR) in conditions when unforeseen changes of conditions of interaction of wheels with a surface are considered. An example of such changes can be sudden entrance MR a slippery surface. The deployment of an autonomous unmanned ground vehicle for field applications provides the means by which the risk to personnel can be minimized and operational capabilities improved. In rough terrain, it is critical for mobile robots to maintain good wheel traction. Wheel slip could cause the rover to lose control and become trapped. This paper describes the application of fuzzy control to a feedback system within slippery environment. The study is conducted on an example of MR with two driving wheels.

Keywords: mobile robot, fuzzy control, wheel-ground contact modeling, dynamic model

1. Introduction

The classical control theory which relies on the mathematical model of the underlying system has been successfully applied to the control of a large variety of simple, non-linear processes. However, it has not been as widely used with complicated, nonlinear, time varying systems or with processes suffering from noisy measurements. The main idea of fuzzy control is to build a model of an expert operator who is capable of controlling the plant without thinking in terms of a mathematical model. The problem of independent motion control of mobile robot (MR) in conditions when unforeseen changes of conditions of interaction of wheels with a surface are considered. An example of such changes can be sudden entrance MR a slippery surface. Mobile robots are increasingly being developed for high-risk missions in rough terrain environments. One successful example is the NASA/JPL Sojourner Martian rover[1]. Other examples of rough terrain applications for robotics systems can be found in the forestry and mining industgyries, and in hazardous material handling applications, such as the Chernobyl disaster site clean-up[2]. In fuzzy logic (FL) control [3,4], PD-type and PI-type FL controllers are the best-known counterparts of the PID controller. They are used to achieve better performance with nonlinear processes. Good experiences have been obtained especially with the PD-type FL controllers in servo applications [5,6]. Future planetary missions will require mobile robots to perform difficult tasks in more challenging terrain.

In addition to the importance of the perception system, mainly visual guidance, motion planning is a key function in preparing locomotion tasks and enhancing the capability of the autonomous vehicle to move safely toward its target position. The response of the vehicle when evolving in an unstructured or partially structured outdoor environment depends on the combination of several geometric and physical criteria. These include the mechanical structure of the vehicle, the geometric and physical features of the terrain, wheel ground interactions, characteristics of the received commands and the applied motion control law[7].

In most cases, base control which is intended for normal modes of interaction of wheels with a surface, in such situation is not capable to keep MR on a program trajectory. In work [8] the structure of a control system was proved and the base logical algorithms allowing effectively to operate by moving the MR on a program trajectory under enough good conditions of coupling of wheels with a surface. In work [9] base algorithm was added with the logic blocks intended for correction of control at deterioration of conditions of coupling of wheels with a surface. It was shown, that even under very bad conditions of coupling (for example, the movement of MR on a slippery surface), correction of control allows to keep MR on a program trajectory. Two circumstances are important: a choice of adjusting control and diagnostics of occurrence slippery.

Today, fuzzy logic has been widely used in automotive control applications and has transformed many commercial product markets in Japan and Germany. Many experts predict that fuzzy technology is on its way to becoming a multibillion-dollar industry. The main idea behind fuzzy control is to model an expert operator who is able to control the process, instead of using a mathematical formalization of the process as in modern control theory. Although there are many practical successes, fuzzy control has not been viewed as a rigorous science due to a lack of formal synthesis techniques. Fuzzy control should be useful when a workable mathematical model for a plant is very difficult or impossible to derive or the mathematical model is complex and computing it in real time would require expensive processors.

This paper describes the application of fuzzy control to a feedback system within slippery environment where the basic attention is given to a problem of diagnostics. Study is conducted on example of MR with two driving wheels.

2. Wheel-ground contact model

Numerous approaches to Wheel-ground modeling are documented in the literature. simple one is adopted here to describe tire forces in the vertical (i.e., normal to the road surface) and longitudinal (in the tire plane, tangent to the road surface) directions. In development of the model of wheel we shall take into account two main effects[9]: effect of pseudo-sliding, type creep and withdrawal which are coherent with deformation of periphery of a wheel [10], and also the effect of full slip condition type and the lateral drift for which deformation of periphery of a wheel is the minor factor. In both cases there is an infringement of the connections describing ideal contact of a wheel with a surface. However, at pseudo-sliding a deviation of parameters of movement in comparison with infringement as a case are considered small, and at full slipping unlimited deviations basically are possible.

The control problems of rolling wheels model of MR for cases of pseudo-sliding were considered by many authors [11,12,13] Usually pseudo-sliding is considered in the assumption of independence creep and withdrawal [14]. The model of a wheel at full slipping when deformation of periphery of a wheel can be neglected, is presented in work [9]. In [15] the wheel is considered as a thin hard disk, and interaction in a point of contact of a wheel with a surface is described by model of friction with a falling site of the characteristic, such as creep-effect. Thus longitudinal and wheels cross slipping interference is taken into account. In work [9] standard coordination was used for the model of a wheel at pseudo-sliding and model for a wheel at full slipping conditions. This problem is offered to be solved within the framework of rolling wheel model algorithmic, providing a continuity of change of the force characteristic in a point of contact of the wheel with a surface. The friction force R (with components R1 in $i1$ direction and R2 in $i2$ direction, figure 1) parallel to the road surface is[9]

$$
\begin{aligned}
&R = R_1 i_1 + R_2 i_2 \\
&R_1 = \min\left(-Nm(|V_S|)\frac{V_{S1}}{|V_S|}, \quad -C_1 \begin{cases} V_{S1}/|wr_w| , |V_1| < |wr_w| \\ V_{S1}/|V_1| , |V_1| > |wr_w| \end{cases} \right) \\
&R_2 = \min\left(-Nm(|V_S|)\frac{V_{S2}}{|V_S|}, \quad -C_2 \frac{V_2}{|V_1|} \right) \\
&V_S = V_{1S} i_1 + V_{2S} i_2 \\
&V_1 = V_{S1} + wr_w , \\
&V_2 = V_{S2}
\end{aligned}
\tag{1}
$$

Where N - normal reaction; $m(|V_S|)$ - factor of a sliding friction with the account of creep effect; V_S – a vector of speed of sliding of a wheel in a point of contact; V_1 , V_2 are the longitudinal and cross speeds of the centre of a wheel; ω - angular speed of a wheel; r_w - radius of a wheel; C_1 and C_2 - factors of resistance creep and to withdrawal.

Algorithmic model (1) expresses the dependence of horizontal reaction on three independent parameters of movement of a wheel $R = R(w, V_1, V_2)$. Integration of eq.(1) is carried out with suitable time step, providing a continuity of transition from the description of pseudo-sliding to the description full slipping.

3. Dynamics model of MR

The dynamic model is obtained from the kinematics model by adding dynamics properties to the robot model such as mass, inertia moments, friction as well as by extending the virtual environment with gravitation field and ground contact forces. Kinematic and drive motor circuits of the MR are shown in figure 1.

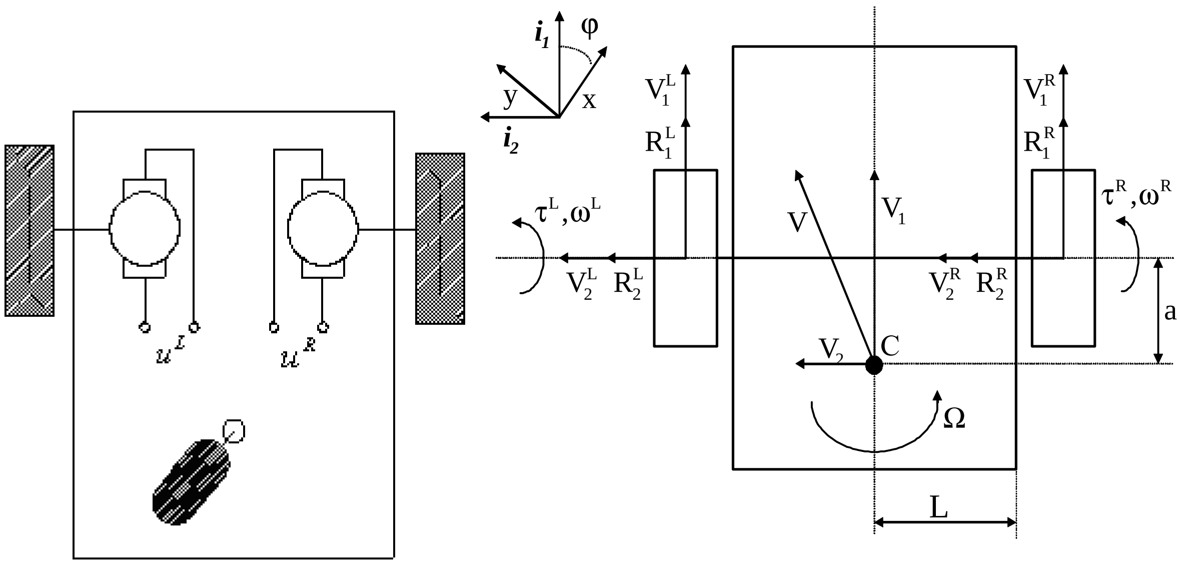


Fig.1 Kinematic and drive motor circuits of MR

The dynamics model of MR with the use of slipping model algorithmic (1) is[9]

$$
\begin{aligned}
& m\dot{V}_1 = R_1^R + R_1^L + m\Omega V_2, && \dot{x} = V_1 \cos j + V_2 \sin j \\
& m\dot{V}_2 = R_2^R + R_2^L - m\Omega V_1, && \dot{y} = V_1 \sin j - V_2 \cos j \\
& J\dot{\Omega} = L\left(R_1^R - R_1^L\right) + a\left(R_2^R + R_2^L\right), && \dot{j} = \Omega \\
& J_w \dot{w}^R = t^R - R_1^R r_w, && t^R = du^R - hw^R \\
& J_w \dot{w}^L = t^L - R_1^L r_w, && t^L = du^L - hw^L \\
& R^L = R_1^L i_1 + R_2^L i_2 = R^{(L)}\left(w^L, V_1^L, V_2^L\right) && \\
& R^R = R_1^R i_1 + R_2^R i_2 = R^{(R)}\left(w^R, V_1^R, V_2^R\right) && \\
& V_1^R = V_1 + L\Omega, \quad V_1^L = V_1 - L\Omega, \quad V_2^R = V_2^L = V_2 + a\Omega, &&
\end{aligned}
\tag{2}
$$

Where m, J - weight and the moment of inertia MR; J_w - the moment of inertia of a wheel; t^L, t^R - the moments, developed by the drives of the left and right wheel; u^L, u^R - the controls acting on drives; d, h - parameters of drives.

4. Fuzzy Control

An alternative approach to the control of any processes is to investigate the control strategies employed by the human operator. An operator usually expresses his control strategy linguistically as a set of heuristic decisions. The fuzzy logic provides the means of expressing linguistic rules in a form suitable for computer implementation. In this section, the design and implementation of a fuzzy controller for the mobile robot in slippery environment is presented. Zadeh [16] expanded the concept of the traditional Boolean logic set to that of a fuzzy set. He stated that a fuzzy set is a class of objects with a continuum of grades of membership. Fuzzy logic is based on fuzzy set theory and provides means for representing partial belief situations. It is a generalization of a conventional Boolean logic. It defines the union, intersection, etc. operations of fuzzy sets in a similar way to Boolean logic and classic set theory.

In problems involving signal processing, the signal is usually transformed to the frequency domain, processed and then transformed back to the time domain. This allows the use of processing techniques which would otherwise be too complicated in the time domain. Similarly, fuzzy control system design (see fig.2), consists of a fuzzification step, fuzzy inference and a defuzzification step. Fuzzification involves transforming inputs from crisp values to fuzzy variables. Fuzzy inference is the process of applying fuzzy rules to the fuzzified input values and calculating the fuzzy outputs. In the last step, a defuzzifier transforms the fuzzy outputs back to the crisp values. Figure 3 shows the configuration of a PID type fuzzy controller of the form.

$$u = K_P e + K_D \dot{e} + K_I \int_0^t e(t)\,dt \tag{3}$$

Where K_P, K_D and K_I are the proportional, integral and derivative gains, respectively, u and e are the control signal and the error between the reference signal and the plant output.

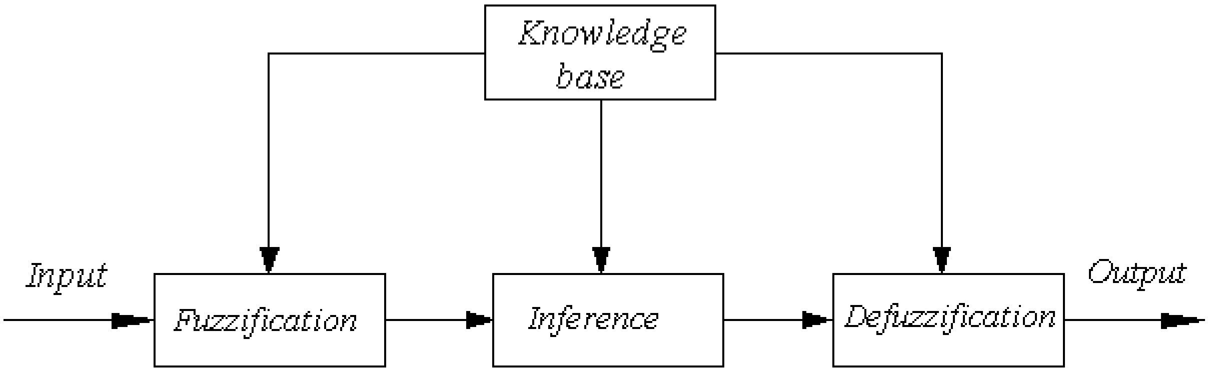


Fig.٢. Fuzzy Logic Controller Architecture

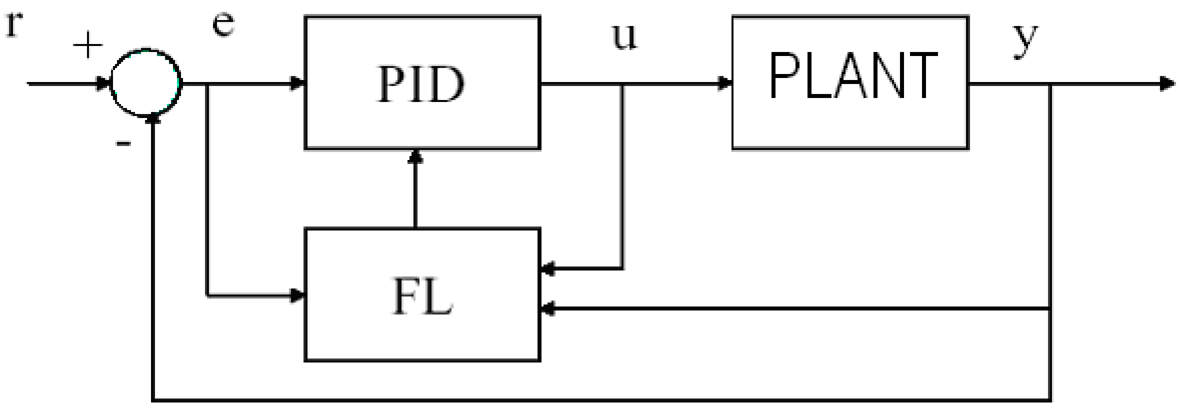


Fig.٣ PID type fuzzy logic.

Imagine that you are the operator who is trying to maintain programmed trajectory by varying the controls acting on drive motors, you will come up with some control rules similar to what follows to drive the mobile robot.

If e is $\langle \; \rangle$ and Δe is $\langle \; \rangle$ and Δ^2e is $\langle \; \rangle$ then Δu is $\langle \; \rangle$ (4)

Each rule takes three inputs and produces one output, control action for the left and right drives.

5. Slipping diagnostics

The control system structure for MR with various chassis configurations are described in detail in works [4,5]. It includes the block of base control providing improvement of a program trajectory in the assumption of absence full slipping and the block of suppression of sliding which in case of occurrence slipping corrects or completely changes base control so that whenever possible is fast to restore the normal coupling wheels with a surface. The information of occurrence is necessary for algorithms of correction of base slipping control and, whenever possible, the information on type slipping. Thus, the system of diagnostics which should establish the fact of occurrence slipping and classify its type will be necessary.The system of diagnostics assumes to install on a MR accelerometers, the position and orientation of which axes of sensitivity, depend on the MR layout.

The system consists of several channels depend on the number of accelerometers used. Accelerometers are designed to measure the angular speeds of wheels in the assumption of absence slipping and then compared to the appropriate programmed acceleration. If movement of MR occurs without slipping signals differences (errors) are close to zero. Acceptable signals differences of allowable levels are fixed by threshold devices. After filtering the information from the block of diagnostics, the possibility of occurrence slip and its type are determined automatically.

6. Results of modelling

The dynamics behavior of MR eq(2) when moving on a circle of radius ρ^d with constant speed V^d will studied. Where illustrating, the behavior of the system of diagnostics for the elementary case when fuzzy base control uses only a proportional regulator of speed

$$u^L = \frac{1}{d}\left(\tau^L + h\,\omega^L\right), \qquad \tau^L = \frac{-K_V\left(\hat{V} - V^d\right) - K_\Omega\left(\hat{\Omega} - \Omega^d\right)}{2}, \qquad \hat{V} = \frac{\left(\omega^R + \omega^L\right) r_w}{2}$$
$$u^R = \frac{1}{d}\left(\tau^R + h\,\omega^R\right), \qquad \tau^R = \frac{-K_V\left(\hat{V} - V^d\right) + K_\Omega\left(\hat{\Omega} - \Omega^d\right)}{2}, \qquad \hat{\Omega} = \frac{\left(\omega^R - \omega^L\right) r_w}{2L} \tag{5}$$

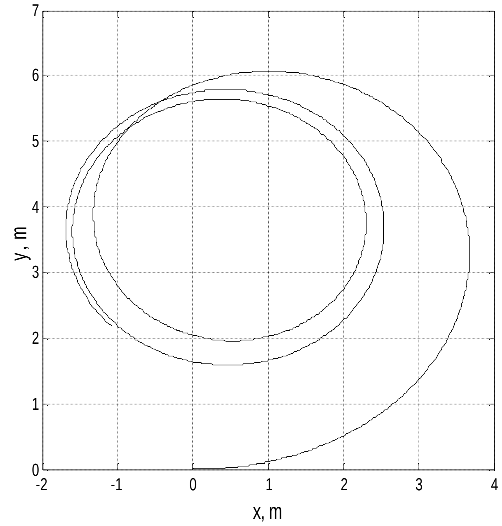
Where K_V, K_Ω - factors of strengthening; $\Omega^d = V^d/\rho^d$ - program angular speed.

In the considered example, two accelerometers where suggested to use with mutually perpendicular axes of sensitivity placed at the centre of weights on longitudinal and cross axes of MR. Measured signals from accelerometers, calculated in the assumption of absence slipping, and look like displacement of the centre of weights

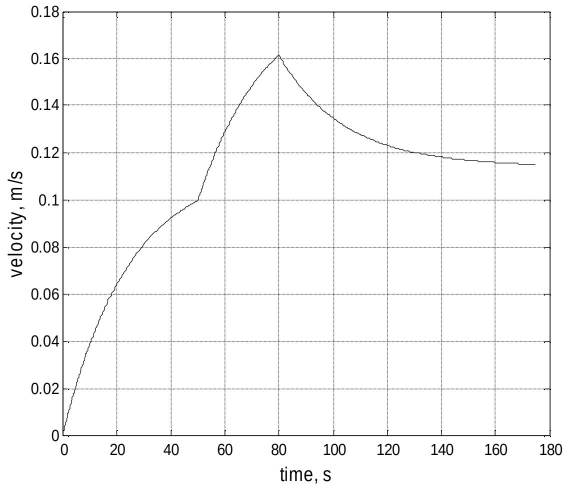
$$\hat{e}_\Omega = \frac{\left(\hat{\dot{w}}^R + \hat{\dot{w}}^L\right) r_w}{2}, \qquad \hat{e}_V = \frac{\left(w^R - w^L\right)\left(w^R + w^L\right) r_w^{\,2}}{4L} \tag{6}$$

The fuzzy logic block of a system of diagnostics forms a target signal from threshold devices of each of channels. Such simplified procedure quickly allows to determine the fact of occurrence slipping, but does not allow to classify its type. At the beginning of slipping (occurrence of slip) the block of suppression of sliding in coordination reduces the program linear and angular speeds acting on a regulator of speed (5).

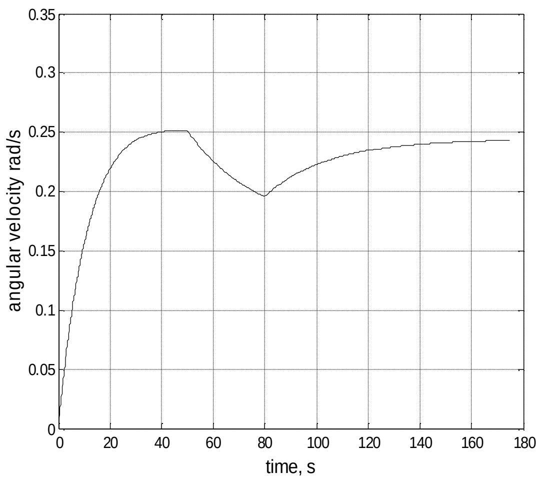
The following situation was modelled. Within first 55 seconds MR moved on a circle in conditions of good coupling wheels with a surface. Further these conditions have changed to the worse, i.e. sudden entrance a slippery surface was modelled. Figure4 illustrates process of MR movement with a control system in which the system of diagnostics of suppression of sliding does not work. In figure4a, the trajectory of movement of MR is given. It is visible, that at deterioration of conditions of MR leave its trajectory and move with new trajectory of smaller radius circle. In figure4b, the longitudinal velocity of the MR. It is visible, that it precisely reflects the fact of occurrence slipping and fully complies with diagrams of right and left wheel speeds and the trajectory of the MR(fig. 4,c and d).



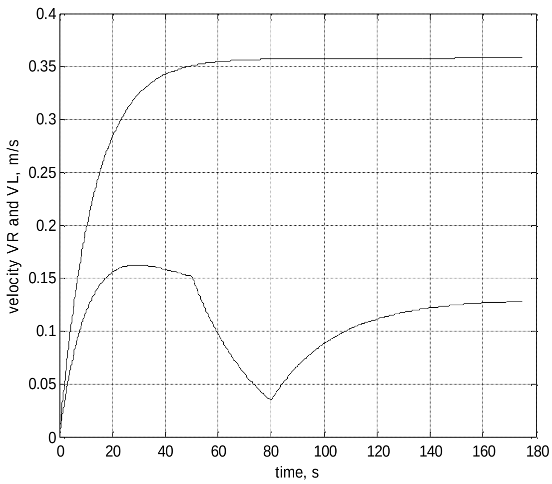
(a)



(b)



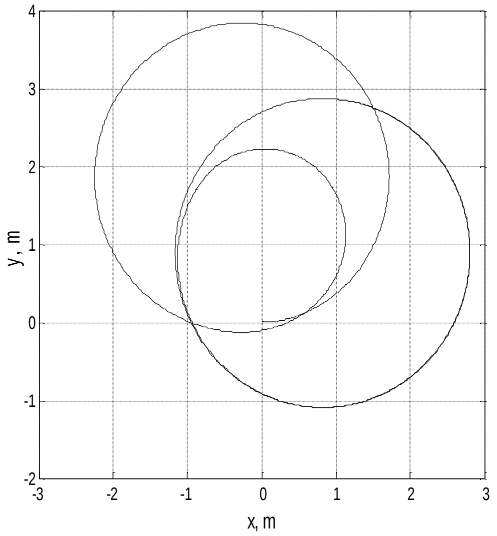
(c)



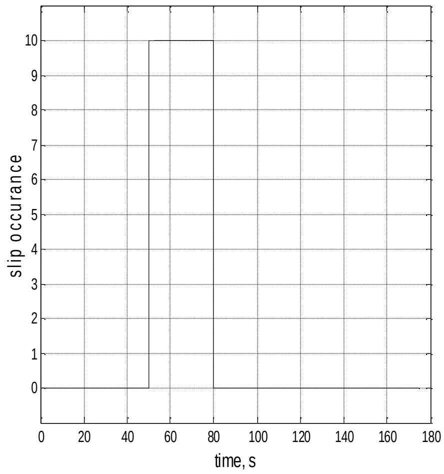
(d)

Fig. ٤. Movement MR with the switched - off system of slip diagnostics

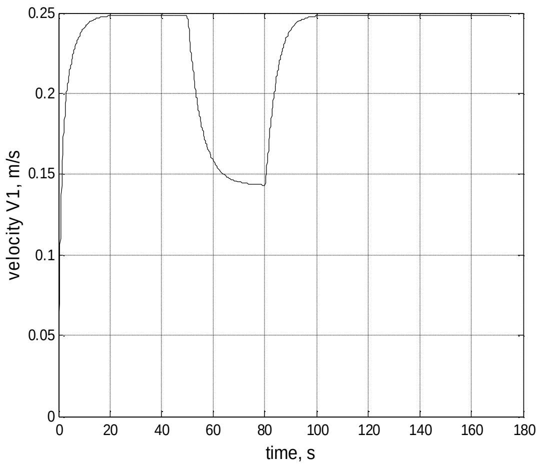
Fig.5 illustrates the process of MR movement with switching on the system of diagnostics and the block of suppression of sliding. Under same conditions, it is shown that the trajectory of motion is not broken. Because of inertia, within several seconds, MR goes with allowable slipping, then again starts to move without slipping on a circle of the given radius ρ^d, but with smaller speed which size is set by the block of suppression of sliding. From diagrams it is visible, that the logic signal on an output of a system of diagnostics (figure5f) fully complies with the movement described above (see fig 5,b,c,d and e).


y , m
x, m

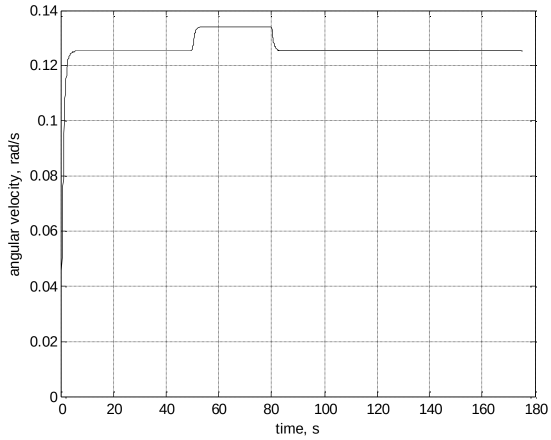
(a)


slip occurance
time, s

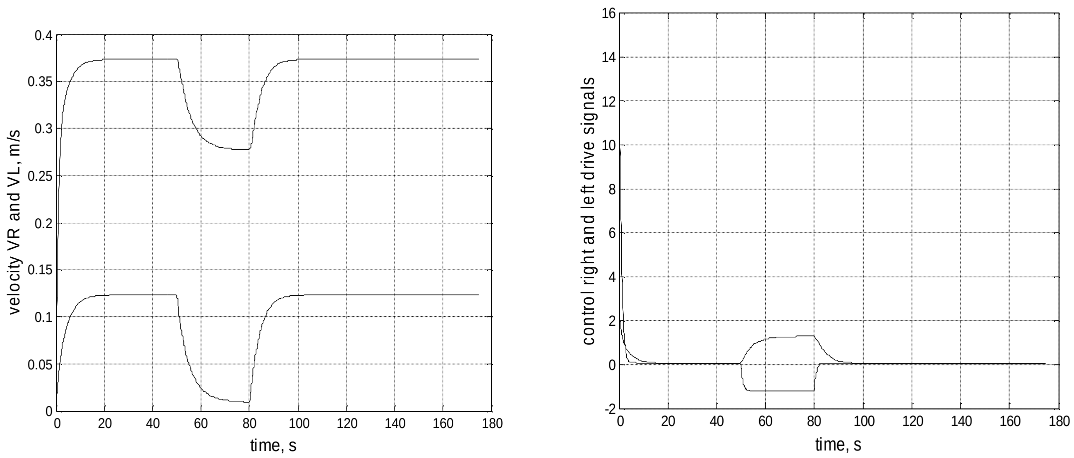
(b)


velocity V1, m/s
time, s

(c)


angular velocity, rad/s
time, s

(d)



(e) (f)

Fig. ٥. MR movement with the included system of slip diagnostics

7. Conclusions

In this paper modelling problems of control for MR with PID fuzzy logic control system, and algorithm of sliding suppression is developed. It allows to carry out researches on features of dynamics of MR with various configurations. An overall performance of a control system is studied. The study has identified some of the potential benefits of using fuzzy logic controllers. In comparison with the modern control theory, fuzzy logic is simpler to implement as it eliminates the complicated mathematics of the modelling process and uses a set of control rules instead. Fuzzy control is also more robust to parameter variations. There are numerous accelerator control problems which involve phenomena that are not amenable to simple mathematical modeling. There is also a class of problems that are simple in nature but are difficult to codify for algorithmic control. The study allow further researches by changing the characteristics and parameters of MR, the control system and conditions of interaction of wheels with a surface. Also a convenient graphic interface, will allow to analyze the diagrams of processes and to deduce animation image of MR during movement.

For MR with two-wheeled configuration the system of diagnostics carried out the functions only on an establishment of the fact of occurrence slipping. Authentic classification the slipping types was not possible because of complexity of dynamics movement of MR at the conditions of slipping. Despite of it, even the establishment of the slip occurance the control system allowes to correct the state and it is reliable to keep MR near to the programmed trajectory. For MR with the increase of number of accelerometer appeared possible not only to establish the fact of occurrence slipping, but also to allocate the basic types slipping. It has allowed to enter more effective correction of base control and to increase quality of improvement of a program trajectory.

8. References

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السيطرة على أليه باستخدام المنطق المبهم في محيط زلق

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الخلاصة:

السيطرة باستخدام المنطق المبهم fuzzy logic على الحركة الذاتية لأليه متنقلة عند تعرضها إلى حاله مفاجئه في الظروف ألتفاعليه بين العجلات والسطح , تم بحثها في هذه الدراسة. مثال على ذلك هو دخول المفاجىء للاليه منطقه زلقه. مثل هذه الآليات تكون مهمة في المحيط الذي يكون فيه تواجد الأشخاص خطرا وبالتالي يكون من المهم جدا السيطرة على هذه الآليات. في هذا البحث تم بناء ومحاكاة النموذج الديناميكي لأليه ذات عجلتي قياده two wheels driver وكذلك تم تصميم نظام السيطرة الاليه لهذه الاليه باستخدام المنطق المبهم fuzzy logic, حيث تم تطبيقه على اليه تسير في مسار دائري زلق وتمكنت من الحفاظ على هذا المسار.