DOUBLE-WHEELED MOBILE ROBOTS. SELECTED PROBLEMS AND PROPOSED SOLUTIONS

Invited paper

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Abstract:

The paper introduces selected problems from the theory of robotics related to the designed construction of double-wheeled mobile robotic equipment, supported by own experience. The knowledge is compiled into recommendations for practical design and construction of robotic means.

Keywords: *service robots, mobile robots, inverse pendulum, balance, stability*

1. Introduction

Mobile robots represent the most widespread part of newly founded category of robotic systems – service robots. Mobility of these autonomous systems in their operative range is provided by the mechanisms built on different principles of locomotion (biological models – walking, crawling, climbing, flying, swimming robots, artificial models – wheeled and tracked robots). Present approaches to robotic systems define mobile robot as a structured technological system built up on functionally and constructionally linked subsystems. The function of locomotion is provided by subsystem of mobility (locomotion parts, chassis). The statistics of present production of mobile robots confirm that the most used principle of locomotion is the principle of artificial set wheeled chassis.

The primary problem of constructing wheeled mobile robot is the concept design of wheeled chassis (number and configuration of driving, driven and direction wheels), control conception and whole mobile robot construction. When designing the configuration, control and double-wheeled mobile robot construction concept, it is necessary to take into account the specifications of the principle of function and work of double wheeled chassis itself.

2. Double-wheeled mobile robots

The present manufacturers of robotic technology offer relatively wide assortment of two-wheeled mobile robots for different applications, see Table 1.

Table 1. Selection of double-wheeled mobile service robots.

Robot model	Technological parameters
	**PIONEER 2-DXE** Manufacturer: Active Media Robotics; Application: inspection; Basic parameters: load capacity 23 kg; speed 1.6 m/s^{-1}; wheel diameter 190 mm.
	**PIONEER 3-DX8** Manufacturer: Active Media Robotics; Applications: inspection, competition Robo Cup (robotic football); Basic parameters: load capacity 23 kg; speed 1.6 m/s^{-1}; wheel diameter 165 mm; dimension 440 x 330 x 220 mm; two motors with gear 19,5: 1; radius of revolution 320 mm; climbing ability 25%.

Robot model	Technological parameters
	**MICROMOUSE** Manufacturer: Airat; Applications: inspection, competition tracker, labyrinth; Basic parameters: barrier contact monitoring sensors; line tracking sensors; two motors with gear.
	**SEGWAY** Application: human transport; Basic parameters: load capacity 110 kg; two DC motors; power 110 kW; speed 3 m/s^{-1}; stability through operator; control through control wheel.

3. Selected problems of double wheeled robots

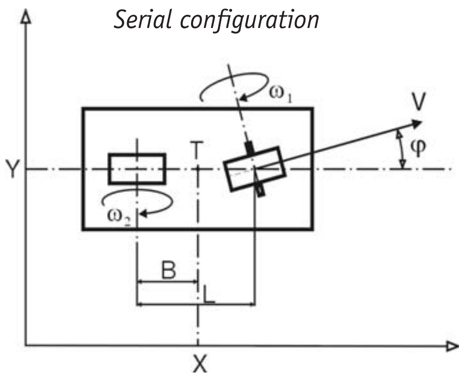
The problems (theoretical, engineering) related to the design and construction of mobile robots based on the principle of double-wheeled chassis can be found out on the comparison of their basic abilities with the abilities of triple or quadruple-wheeled mobile robots, see Table 2.

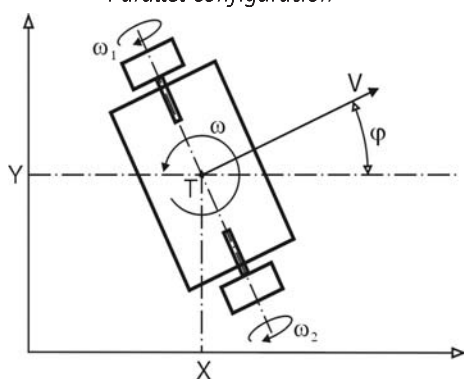
Table 2. Double-wheeled chassis properties.

Double-wheeled chassis advantages	Double-wheeled chassis disadvantages
• Motion in a limited space; • Radius of revolution is directly proportional to chassis's floor projection; • Simplicity of construction, low manufacturing costs; • Possibility of effective experimental testing.	• Instability of the chassis; • Start impulse is required to ensure balance; • High sensibility to sudden speed change; • Problematic motion through slant plane.

The major problem of double-wheeled chassis is its instability and consequent need to balance it. This attribute is able to show itself with different seriousness and expression in direct dependence on the concept of double-wheeled chassis construction, see Table 3.

Table 3. Chassis concepts.

Chassis concept	Characteristics
Serial configuration 	• Static instability; • Dynamic stability; • Need for gyroscopic stabilization; • Dynamic forces; • Moments of inertia; • Keeps vertical position when moving through slant plane; • Change of direction by wheel revolution; • Little sensibility to uneven terrain.

Chassis concept	**Characteristics**
Parallel configuration 	• Static instability; • Dynamic stability (gyroscopic stabilization); • Load on zero radius around vertical axe passing centre of gravity; • No possibility to ensure vertical position when moving through slant plane; • No sensibility to uneven terrain.

For robot motion control it is necessary to define its behaviour by the variable values of status space in dependence on input values (dynamic system model). The control is based on controlling two separate status spaces. The first one controls the stability around cross-flow axis of robot (wobble), the second one controls mobility of turning around vertical axis. System model, Fig.1. is characterized by parameters of chassis J_{RL}, and J_{RR} moment of inertia of rotating weights to Z axis, M_{RL} and M_{RR} weight of rotating weights focused into left and right wheels, $J_{P\theta}$ moment of inertia of chassis to Z axis, $J_{P\delta}$ moment of inertia of chassis to Y axis, M_P chassis weight, R wheel radius, D wheel tread width (ground contact point), L distance of centre of gravity from Z axis. Status space variables are defined by linear distance x_{RM}, linear velocity v_{RM}, inclination angle θ_P, angular velocity ω_P, turning angle δ, turning speed δ.

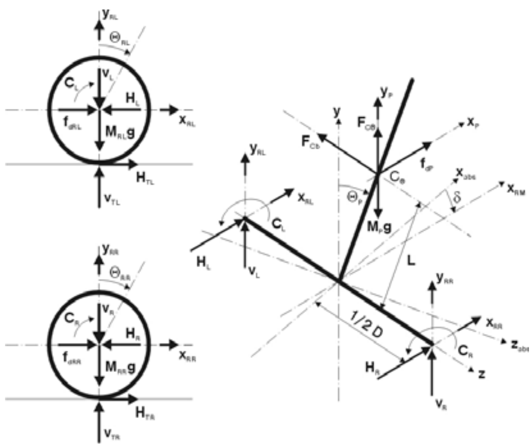


Fig. 1. Model of two-wheel carriage.

A kinetic formula of the left side (wheel) of the chassis (for left wheel only) and whole chassis can be constructed according to what has been said above:

$$x_{RL}M_{RL} = f_{dRL} - H_L + H_{TL} \qquad x_P M_P = f_{dP} + H_R + H_L$$
$$y_{RL}M_{RL} = v_{TL} - M_{RL}q - V_L \qquad y_P M_P = V_R + V_L\ M_P q + F_{C\theta}$$
$$\Theta_{RL}J_{RL} = C_L - H_{TLR}$$
$$\Theta_P J_{P\theta} = (V_R + V_L)L\sin\Theta_P - (H_L + H_R)L\cos\Theta_P - (C_L + C_R)$$
$$\delta J_{P\delta} = (H_L - H_R)D/2$$

The state space of systems can be described by matrix. (linearization around working point $x_{RM}=0$, $\Theta_P=0$, $\delta=0$, A_{23} up to B_{65} function of system parameters).

$$\begin{bmatrix} x_{RM} \\ v_{RM} \\ \dot{\Theta}_P \\ \dot{\omega}_P \\ \dot{\delta} \\ \ddot{\delta} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & A_{23} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & A_{43} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_{RM} \\ v_{RM} \\ \Theta_P \\ \omega_P \\ \delta \\ \dot{\delta} \end{bmatrix} +$$
$$+ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ B_{21} & B_{22} & B_{23} & B_{24} & B_{25} \\ 0 & 0 & 0 & 0 & 0 \\ B_{41} & B_{42} & B_{43} & B_{44} & B_{45} \\ 0 & 0 & 0 & 0 & 0 \\ B_{61} & B_{62} & B_{63} & B_{64} & B_{65} \end{bmatrix} \begin{bmatrix} C_L \\ C_R \\ f_{dRL} \\ f_{dRR} \\ f_{dP} \end{bmatrix}$$

The robot's stability can be solved by the application of direct and indirect methods of kinematics. The indirect task is solved by the inverse pendulum method with servo control, Fig. 2., in basic expression like system S.

$$\chi(S): \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} x \\ K_1 \sin x + K_2 x_3 \\ K_3 x_2 + K_4 x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ K_5 \end{bmatrix} u$$

$x_1=0,\ x_2=0,\ x_3=1,\ K_1=10Km/l^2m,\ K_3=-10k_3/L,$ $K_4=-R/L, K_5=1/L$

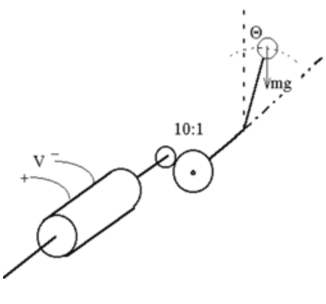


Fig. 2. Pendulum with servo control.

Regulating and control depends on pendulum position, represented by ${}^2\eta$ down (stabile) and ${}^1\eta$ up (instable) balanced position. Deciding whether the concrete point is stabile

$$ {}^1\eta \cong [{}^1\eta_1\ {}^1\eta_2\ {}^1\eta_3]^T = [0\,0\,0]^T \qquad {}^2\eta \cong [{}^2\eta_1\ {}^2\eta_2\ {}^2\eta_3]^T = [0\,0\,0]^T $$

or instabile can be based on: appropriation of the linearity and dissipative representation of losses.

4. Solution of double-wheeled chassis

It is suitable to unwind the concept of design and construction of double-wheeled chassis of mobile robot from the solution of the transfer of the drive on the driving wheel, Table 4., and solution of the pendulum, Table 5.

Table 4. Driving performance transfer – variants of solution.

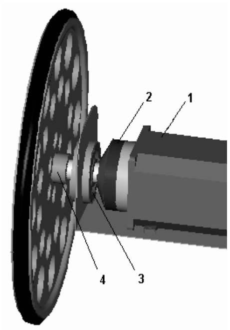
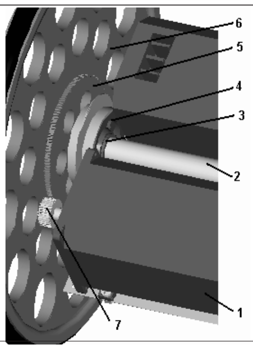
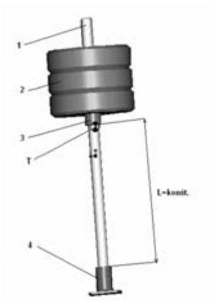
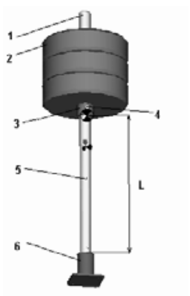
Drive performance transfer concept	Characteristics
	*Direct connection drive - wheel* The output of the motor is directly connected to the axis of driving wheel. Rotation is controlled by slowing down of one wheel (disconnecting, motor disengagement) and driving the second wheel. Reverse motion is made by motor reverse drive. Sudden change of the movement direction evokes chassis instability. Wheel gauge of the chassis is large (serial connection). Assembly of one gyroscopic sensor.
	*Indirect connection motor - gear - wheel* The output of the motor through the gearbox (according to the type) connected to the driving wheel axis. Turning and reverse motion is controlled similarly like in the previous case. The wheel gauge can be smaller if there is a possibility to place the motors in parallel. Higher weight of the chassis. Assembly of two gyroscopic sensors.

Table 5. Pendulum – variants of solution.

Drive performance transfer concept	Characteristics
	*Without the change of centre of gravity position* L=*constant* (optimal position for all robot regimes). L=*minimal* centre of gravity position moves to the vicinity of chassis axis, causes balance problem. L=*maximum*, evokes high pitching moment, increased requirement on drive performance, evokes problem of transfer of driving performance to the wheel (ground contact). Adjusting the driving chassis performance to one stabile load.
 	*Leap change of centre of gravity position* L#constant number of centre of gravity positions (L_{min},..,L_{midlle},.., L_{max}) is given by construction solution of clamping mechanism. Readjustment of the centre of gravity position is manual, i.e. it is possible only when the chassis is not moving. Adjusting the driving chassis performance should be to the maximum load.

Drive performance transfer concept	Characteristics
	*Fluent change of the centre of gravity position* $L\#constant$ number of centre of gravity positions is optional $0<L<L_{max}$. Readjustment of the centre of gravity position is automatic, i.e. the mechanism must be equipped with separate drive with control. Adjusting the driving chassis performance should be to the maximum load.

Solution based on the concept "indirect connection – leap change of the centre of gravity", Fig. 3., relevant to the construction of service mobile robots aimed at human transport. The human fulfils the role of the pendulum. Robot is able to lean around Z axis (wobble) defined by Θ_P angle, ω_P angular speed. Straight-line motion is given by position x_{RM} and v_{RM} speed. Robot rotation is able to occur around Z-axis.

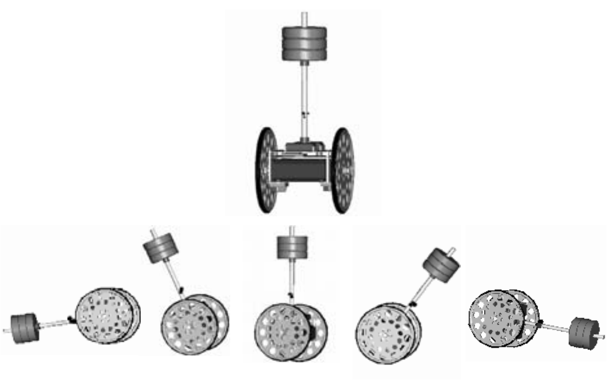


Fig. 3. The double-wheeled mobile service robot.

Robot has functional range of balance (stability) in the interval 60=120°. It is able to balance itself in the interval ±30°. In this interval of robot wobble, motors will overcome the moment of inertia and will move the wheels into the opposite direction of pitching, i.e. they will ensure running the bottom part (pendulum movement) under the upper part and by this it will move the centre of gravity into balance, Fig. 4.

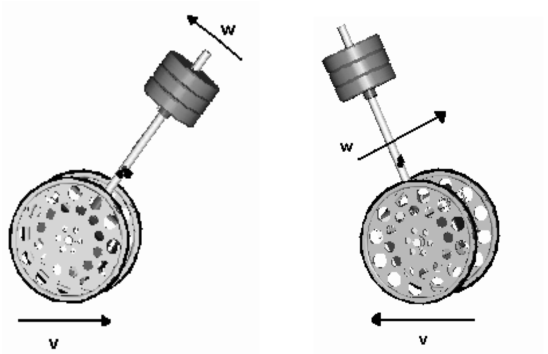


Fig. 4. Balancing of double-wheeled robot.

Functionality of the robot model being solved at the workplace of the author, apart from presented mechanical part, is guaranteed also by the drives (KH 39 EM2, stepping motor), gyroscopic sensors (Sicilian Sensing Symptom) and their connection to the control system with the possibility to disconnect the ties among the subsystems.

5. Conclusion

The contemporary dynamic progress of service robotics requires improvement and innovation of the mobile robot's principles and constructions. Design and construction of double-wheeled mobile robots, mobility subsystem (chassis) has to satisfy mobility and manoeuvrability functions of these robots effectively. Presented process of double-wheeled robot design documents the need for the wider range of expert knowledge and the application of suitable methods and means of service robots design.

This topic is one of the problems being recently solved by author's department. The aim is to create organized system of methods and means suitable for the research and development of service robots.

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