Manipulator Mechanism for the Mobile Robotic System

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Abstract

The aim of this article is to describe the creation of manipulation device with three degrees of freedom as a superstructure for wheeled robotic undercarriage. The main task is to analyse the actuators used for each of rotary units, calculate the kinematics of the entire mechanism, choose the configuration and construction of the manipulator. The result is a 3D computer model and the manipulation device realization.

Key words: DC motor, servomotor, stepper motor, direct current motor, 3D Arduino, model

1. Introduction

This article is a part of a 3 years long project, where the wheeled robotic undercarriage was developed at the department of Air Defence System, University of Defence. This was made as an autonomous mobile system with modular platform for various types of sensors and actuators. This article deals with the design and construction of the mechanical manipulator as a stand-alone module for the wheeled robotic undercarriage, which can be mount or dismount in a short time period.

Manipulation device for the wheeled robotic undercarriage should provide several types of manipulation tasks. For example, removing obstacles in a path of robot, manipulation with dangerous substances and explosives, etc. Based on these tasks and the dimensions of the robotic undercarriage platform the requirements of the mechanical manipulator were set, especially the dimensions of the robotic arm, angles and rotation of every rotation part of the mechanism (rotors). Dimensions were also set based on ability to reach the area around the robot. Depending on properties of common used manipulation mechanisms (spherical, cylinder and joint) as an appropriate for our task is a joint manipulation mechanism. The structure schema is based on (1).

$$\bar{R}_z - \bar{R}_x - \bar{R}_x \tag{1}$$

This manipulation mechanism consists of three rotary elements. Every element has independent drive. Usage of movable (telescopic) elements seems to be unsuitable. There is a possibility to extend the maximum range of the robotic arm, but their usage is excessively complicated and uneconomic.

2. Manipulator drives

The main criteria for manipulator drive design were the position sensing requirement. Because of the manual control of the manipulator (during the initial stage of development) the velocity control requirements were unimportant. The lower velocity was requested for better evaluation of the movement.

Three DC motors were used in initial stage of development. For rotation speed drop, the transmission was used. During the manual control of the robotic arm the problem with accuracy of the control arise. The control was provided directly without the position feedback. For further development a position sensors were included. This leads to the more accurate control but the construction is more complicated, bigger and heavier. Therefore the drive changes were made.

Using stepper motors brings the necessity of the powerful and heavy power source (with frequency changer). Other difficulty is a problem with the motor position information saving in case of power outage. The economic aspect is also important. Because of these disadvantages the usage of stepper motors was rejected.

In the final stage, the electric servomotor was used. This type of the motor can be controlled by digital pulse wide modulated (PWM) signal. Depending on the PWM parameters the motor shaft rotates by defined angle. The rotation velocity can be also controlled. Usage of this type of motor leads to several simplifications:

- construction simplification,
- unneeded position sensor,
- unneeded transmission,
- possible usage of power source of undercarriage.

Manipulator used HYTEC servomotors with ranked power. Servomotors with higher power (HS-755HB) were used for manipulator rotation and for the entire arm rotation and the lower power servomotor (HS-645MG) were used for second part of robotic arm rotation.

3. Definition of kinematic variables

Solution of kinematic variables is done for the end-point of robotic arm *M*,. Description and visualisation of the used parameters is in Fig. 1.

For kinematic solution of the leg, the matrix method was used. Description of this method is in [1] or [2]. Calculation was provided in MATLAB (version 2015b) software. Set dimensions of particular parts of the arm are: K = 0,065 m, L = 0,06 m, N = 0,16 m, P = 0,2 m. The ranges of angle values for the joints are: $\varphi_{21} = \pm 120$, $\psi_{32} = \pm 60°$, $\vartheta_{43} = \pm 90°$. Kinematic chain is visualised in position with zero angle values (initial position of mechanism).

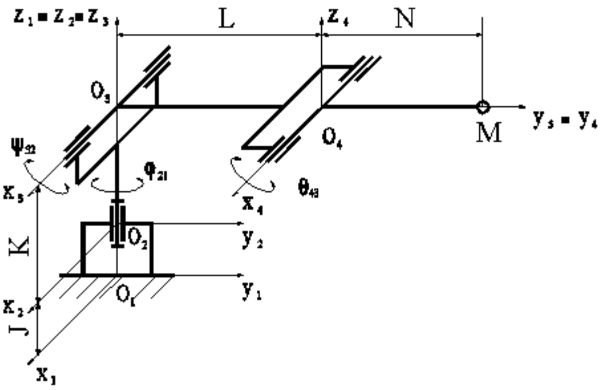

Fig. 1. Kinematic chain of manipulator

a) Position

Final position of end-point of the robotic arm *M* (depending on origin of coordinates system of manipulator $O_1x_1y_1z_1$) is:

$$\bar{\mathbf{r}}_1^{\,M} = \mathbf{T}_{41} \cdot \bar{\mathbf{r}}_4^{\,M} = \mathbf{T}_{21} \cdot \mathbf{T}_{32} \cdot \mathbf{T}_{43} \cdot \bar{\mathbf{r}}_4^{\,M}, \tag{2}$$

where T_{41} is total transformation matrix for whole system movement and T_{21},T_{32} and T_{43} are transformation matrixes of movement of nearby parts. Forms of these matrixes for the suggested manipulator are:

$$\mathbf{T}_{21} = \begin{bmatrix} \mathbf{S}_{21} & \mathbf{r}_1^{O_2} \\ \mathbf{0} & \mathbf{1} \end{bmatrix}, \tag{3}$$

$$\mathbf{T}_{32} = \begin{bmatrix} \mathbf{S}_{32} & \mathbf{r}_2^{O_3} \\ \mathbf{0} & \mathbf{1} \end{bmatrix}, \tag{4}$$

$$\mathbf{T}_{43} = \begin{bmatrix} \mathbf{S}_{43} & \mathbf{r}_3^{O_4} \\ \mathbf{0} & \mathbf{1} \end{bmatrix}, \tag{5}$$

Directional matrixes for coordinate system are:

$$\mathbf{S}_{21} = \begin{bmatrix} \cos\varphi_{21} & -\sin\varphi_{21} & 0 \\ \sin\varphi_{21} & \cos\varphi_{21} & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$\mathbf{S}_{32} = \begin{bmatrix} 0 & 0 & 0 \\ \cos\psi_{32} & -\sin\psi_{32} & 0 \\ \sin\psi_{32} & \cos\psi_{32} & 1 \end{bmatrix} \tag{7}$$

$$\mathbf{S}_{43} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\vartheta_{43} & -\sin\vartheta_{43} \\ 0 & \sin\vartheta_{43} & \cos\vartheta_{43} \end{bmatrix} \tag{8}$$

Equations of position vectors of coordinate system are:

$$\mathbf{r}_1^{O_2} = [0, \quad 0, \quad J]^T \qquad \mathbf{r}_2^{O_3} = [0, \quad 0, \quad K]^T$$
$$\mathbf{r}_3^{O_4} = [0, \quad L, \quad 0]^T \qquad \mathbf{r}_3^{M} = [0, \quad N, \quad 0]^T \tag{9}$$

Final matrix for position of end-point of robotic arm *M* is:

$$\boxed{\bar{r}_1^M = \begin{bmatrix} -N\cdot\sin\varphi_{21}\cdot\cos\psi_{34}\cdot\cos\theta_{43} + N\cdot\sin\varphi_{21}\cdot\sin\psi_{34}\cdot\sin\theta_{43} - L\cdot\sin\varphi_{21}\cdot cos\psi_{34} \\ -N\cdot\cos\varphi_{21}\cdot\cos\psi_{34}\cdot\cos\theta_{43} - N\cdot\cos\varphi_{21}\cdot\sin\psi_{34}\cdot\sin\theta_{43} + L\cdot\cos\varphi_{21}\cdot cos\psi_{34} \\ N\cdot\sin\varphi_{21}\cdot\cos\theta_{43} + N\cdot\cos\psi_{34}\cdot\sin\theta_{43} + L\cdot sin\psi_{34} + K + J \end{bmatrix}}$$

b) Velocity

Initial equation of velocity of end-point of robotic arm *M* is:

$$\bar{\mathbf{v}}_1^M = \mathbf{T}_{41} \cdot \mathbf{V}_{41_4} \cdot \bar{\mathbf{r}}_4^M, \tag{10}$$

where V_{414} is a velocity matrix of whole system and consists of:

$$\mathbf{V}_{41_4} = \mathbf{V}_{21_4} + \mathbf{V}_{32_4} + \mathbf{V}_{43_4} \tag{11}$$

Matrixes V_{214}, V_{324} and V_{434} represent the values of velocities of nearby parts in coordination system $O_4x_4y_4z_4$.

Initial forms of these matrixes are:

$$\mathbf{V}_{21_2} = \begin{bmatrix} 0 & -\varphi'_{21} & 0 & 0 \\ \varphi'_{21} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \tag{12}$$

$$\mathbf{V}_{32_3} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & -\psi'_{32} & 0 \\ 0 & \psi'_{32} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \tag{13}$$

$$\mathbf{V}_{43_4} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & -\vartheta'_{43} & 0 \\ 0 & \vartheta'_{43} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \tag{14}$$

Transformation of velocity matrixes into the final matrix of velocity of end-point of robotic arm V_1^M:

$$\mathbf{V}_{21_4} = \mathbf{T}_{43}^{-1} \cdot \mathbf{T}_{32}^{-1} \cdot \mathbf{V}_{21_2} \cdot \mathbf{T}_{32} \cdot \mathbf{T}_{43},$$

$$\mathbf{V}_{32_4} = \mathbf{T}_{43}^{-1} \cdot \mathbf{V}_{32_3} \cdot \mathbf{T}_{43} \tag{15}$$

$$\mathbf{v}_1^M = \begin{bmatrix} A \\ B \\ C \end{bmatrix}$$

Velocity vector parameters are:

$$\boxed{\begin{gathered} A = \varphi'_{21} \cdot \cos\varphi_{21} \cdot (-N \cdot \cos\psi_{32} \cdot \cos\vartheta_{43} + N \cdot \sin\psi_{32} \cdot \sin\vartheta_{43} - L \cdot \cos\psi_{32}) + \\ +\psi'_{32} \cdot \sin\varphi_{21} \cdot (N \cdot \sin\psi_{32} \cdot \cos\vartheta_{43} + N \cdot \cos\psi_{32} \cdot \sin\vartheta_{43} + L \cdot \sin\psi_{32}) + \\ +\vartheta'_{43} \cdot \sin\varphi_{21} \cdot (N \cdot \cos\psi_{32} \cdot \sin\vartheta_{43} + N \cdot \sin\psi_{32} \cdot \cos\vartheta_{43}), \\ B = \varphi'_{21} \cdot \sin\varphi_{21} \cdot (-N \cdot \cos\psi_{32} \cdot \cos\vartheta_{43} + N \cdot \sin\psi_{32} \cdot \sin\vartheta_{43} - K \cdot \cos\psi_{32}) - \\ -\psi'_{32} \cdot \cos\varphi_{21} \cdot (N \cdot \sin\psi_{32} \cdot \cos\vartheta_{43} + N \cdot \cos\psi_{32} \cdot \sin\vartheta_{43} + L \cdot \sin\psi_{32}) - \\ -\vartheta'_{43} \cdot \cos\varphi_{21} \cdot (N \cdot \cos\psi_{32} \cdot \sin\vartheta_{43} + N \cdot \sin\psi_{32} \cdot \cos\vartheta_{43}), \\ C = \psi'_{32} \cdot (N \cdot cos\,\psi_{32} \cdot cos\,\vartheta_{43} - N \cdot sin\,\psi_{32} \cdot sin\,\vartheta_{43} + L \cdot cos\,\psi_{32}) \end{gathered}}$$

c) Acceleration

Total acceleration of end-point M is calculated from:

$$\bar{\mathbf{a}}_1^{\mathrm{M}} = \mathbf{T}_{41} \cdot \boldsymbol{B}_{41_4} \cdot \overline{\boldsymbol{r}_4^{\mathrm{M}}}, \tag{16}$$

where B_{41_4}, is a matrix of total acceleration of end-point M and is calculated as a sum of matrix of velocity square and matrix of acceleration of the system.

$$\boldsymbol{B}_{41_4} = \boldsymbol{V}_{41_4}^2 + \boldsymbol{A}_{41_4}. \tag{17}$$

Matrix of system acceleration is:

$$\boldsymbol{A}_{41_4} = \boldsymbol{A}_{21_4} + \boldsymbol{A}_{32_4} + \boldsymbol{A}_{43_4} + \boldsymbol{A}_{\mathrm{RC}_4} \tag{18}$$

More detailed description is beyond this article range and can be found in [3].

4. Manipulator realisation

As a first step, the 3D computer model of manipulator was made. For 3D modelling the CAD software SolidWorks was used in version 2016. Based on this model, technical documentation for realisation was made. Movement possibilities of the manipulator were verified on animation of 3D model. Model is in Fig. 2 and final realisation in Fig. 3.

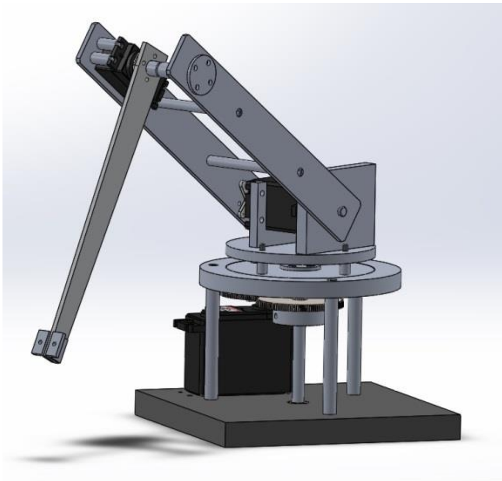

Fig. 2. 3D model of manipulator

Fig. 3. Manipulator realization

5. Conclusion and future work

This article describes the creation of manipulation device with three degrees of freedom with electric servomotors. This article relates to a previous project, which deals with wheeled robotic undercarriage with modular platform and robotic arm with electric DC motors. New construction with electric servomotors leads to a more simple construction and control of robot arm movement. Other benefit is a lower weight of a robot arm and simplification of regulators compared to electric DC motors usage.

Rotation base and total weight was also optimized because of bearings load.

Current difficulties of this construction are: not completely balanced robotic arm which leads to a high load of second servomotor (higher noise and motor heating).

These difficulties should be removed in a future and also program control for autonomous control should be realized.

References

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