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An Approach to the Design of a Light-Weight Reconfigurable Robot Arm for a Mobile Robot

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1. Introduction

The expansion of industrial robotic systems in manufacturing and assembly is well known and significant. It appears to be common that the robotic systems are preferred to be assembled from off-the-shelf components. Many of these components are massive and heavy and this implies a lot of unnecessary design constraints. One example is when the robotic links are driven by electric motors with respective gearboxes mounted directly at the link. Then the torque inertia becomes larger as the mass is concentrated at the far end of the link. Alternatively, the electric motor can be mounted away from the joint and connected to the joint by a long rod or transmission mechanism. These types of robots sustain a limited range of motion of the robot arm and configurations of such type have to be used in dedicated applications.

Such constraints might become crucial in the case when the robot arm has to be allocated on a mobile platform with small size of the fundament and limited payload. Then reducing the weight of the entire construction becomes essential requirement since the power supply cannot provide enough power to the motors for long time of operation.

Several prior art configuration concepts that are used in the design of the constructions of robot arms are known. The first prior art construction is presented in [2] where an industrial robot arm for spot welding is described. The arm assembly includes a first link and a second link, each having a longitudinal axis. The first link is mounted at a lower end portion on a base for a swivelling movement in a substantially vertical plane about a substantially horizontal first axis. The second link is provided adjacent to an upper end portion of the first link to extend in a direction crossing the longitudinal axis of the first link. A pivot means is provided between the first and second links for allowing swivelling movements of the second link with respect to the first link about a second axis which is perpendicular to the longitudinal axis of the first link and a third axis which is in a plane containing the longitudinal axis of the first link. There is also a driving means for selectively effecting the swivelling movements of both links.

The drawback of this prior art is that the construction cannot be used for mobile platform as it has large own weight which can cause lower stability of the entire robotic system, the required power is far beyond the capacity of the mobile platform as it has large own weight which can cause lower stability of the entire robotic system, the required power is far beyond the capacity of the mobile platforms usually driven by batteries, the robot has a very simplified wrist that cannot satisfy the general requirements for manipulating operations of mobile platforms.

Second prior art that complements the first prior art in providing a wrist for robot manipulations is presented in [3].

A wrist for articulated robot having an operative member which is rotatable about three mutually perpendicular axes and three motor units each of which can cause the operative member to rotate about only one of the three axes without causing any rotation about the other axes is described. It includes a support structure, a first drive unit fixed to the support structure and a member driven by the first drive unit and supported by the support structure for rotation about a first axis. Then, the driven member supports a further wrist portion for rotation about a second axis perpendicular to the first axis and carries a second drive unit for rotating further wrist portion about the second axis. Then, the further wrist portion is carrying a third drive unit for driving an operative member of the robot about a third axis radial to the second axis.

The disadvantage of this prior art is that the shaft of the second drive unit carries the rest of the wrist construction, namely the third drive unit and the respective portions of the wrist construction. This shifts the center of mass to the outer end of the robot link and increases the torque inertia. Also, the mentioned construction is complicated as it includes many wheels and transmissions.

All pointed prior art constructions have the disadvantage of being characterised by a large total weight and a rigid configuration of the first link of the robot arm that restricts its application in the case of manipulating peripheral device of smaller mobile robot platforms. With different grade of satisfaction, any of the referred existing constructions provides either accommodation of less heavier arm construction with the expense of using a rigid configuration of the link, or providing certain degree of flexibility in the construction of the link with the expense of larger total weight of the whole arm. Hence, the existing solutions so far involve limitations both in weight and flexibility to adapt the robot arm configuration to the specific application on a small mobile robot platform.

2. Summary of the design of a light-weight reconfigurable robot arm for mobile robots

An objective of the paper is to present a mechanical construction of a lightweight robot arm for mounting on a small mobile robot platform. The second object is to provide a mechanical construction of a robot arm with a reconfigurable architecture that can be easily adapted to the particular construction of the mobile robot platform or to the specific need of the application task.

Fig. 1 represents a general view of the manipulator mounted on the top of Nomad 200 mobile robot.

Fig. 1

The technical parameters of the lightweight robot are presented in Table 1.

The robot is a 6-degree of freedom manipulator consisting of anthropomorphic arm and an Euler type of wrist. The manipulator also employs four-bar linkage to drive the third joint. This does not change the kinematics of the manipulator although it introduces some constrains in the motion trajectory planning.

Table 1

No	φ_i	Motion, degree	Speed, degree per s	Motors, N.m	Harmonic drives – *I*	Torque moment, N.m
1	φ_1	360	100	DC 1	86	86
2	φ_2	90	100	DC 1	86	86
3	φ_3	90	100	DC 1	86	86
4	φ_4	360	120	DC 0.330	80	26.4
5	φ_5	180	120	DC 0.330	80	26.4
6	φ_6	360	120	DC 0.050	80	4

Fig. 2 shows the kinematic scheme of the manipulator.

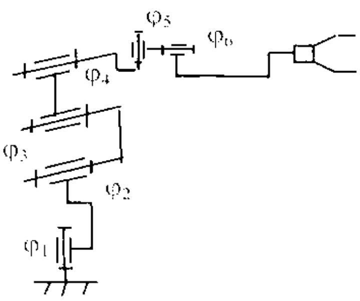

Fig. 2

The lightweight reconfigurable robot arm is realised based on the idea that a simplified arm scheme can be achieved by using of separate links each constructed by more than one parts with variable length and adjustable angle between the links. In such case each link can obtain a dedicated profile of the construction just by rearranging few interconnecting components.

In the preferred embodiment, a lightweight reconfigurable robot arm for mobile robots comprising can achieve the above-mentioned objects:

- a stationary base supporting a rotating about a vertical axis swivel body;
- a first reconfigurable link for fore-and-aft swivelling movements about a first horizontal axis;
- a second link for swivelling movements about a second horizontal axis;
- a robot wrist;
- a pivoting link which is parallel with the first reconfigurable link;
- three motors for driving the robot wrist;
- three motors for driving the first and second link and the rotation of the swivel body about the vertical axis.

The first link of the robot is composed by three bodies the relative angle between which can be adjusted and fixed, so that the arm can be reshaped depending on the allocation where it is mounted in order to optimise the working space of the entire arm. The simplified construction of the first and the second link gives the possibility to reduce significantly the robot's own weight. It also makes possible that the center of mass of the lightweight robotic arm can be allocated very low that increases the stability of the mobile robotic platform. In addition the wrist provides all three degrees of freedom by simplified construction, also reducing the overall own weight of the robot arm.

It has been demonstrated that the present robot arm is very effective and simplified as: the total number of components is relatively low and all they have a simple construction; the configuration of the robot arm can be simply adjusted to the needs of each application and the particular construction of the mobile platform; there is no need to use expensive materials to implement the components of the robot arm.

Lightweight robot concept. The combination of the lightweight motors, lightweight harmonic drives and light materials for the links of the arm yields an extremely powerful lightweight jointdrive with a related mass of just 50% of the weight of the conventional robots arm. A joint quality measure J is defined as:

$$J = \frac{T}{W} . \frac{V_{\max}}{180} ,$$

where: T is the output torque (max), N.m; W – weight of joint, kg; $V_{\max}$ – maximal rotational speed, degree per 1 s.

If we give an account of the correlation of torques and speeds of the DRL`s light weight robot [1] and our robot, the results show that the quality measures are approximately identical.

3. Direct and inverse kinematics

To investigate the kinematics of the robot first we assign co-ordinate frames to each link following the Denavit-Hartenberg convention as shown in Fig. 3.

As one can see, the z-axes of the first co-ordinate frame chosen to be along the first joint axis. The second and the third joint axes are parallel to each other with offset distance a_2 and the perpendicular to the first one. The fourth joint axis is perpendicular to the third one with a small offset a_3. The last three joints intersect each other in point P. The distance between the tool center point P and the end-effector point Q is given by d_4.

Once D-H coordinate systems are established, the relation between two successive coordinate can be given by 4x4 homogeneous matrix of the form

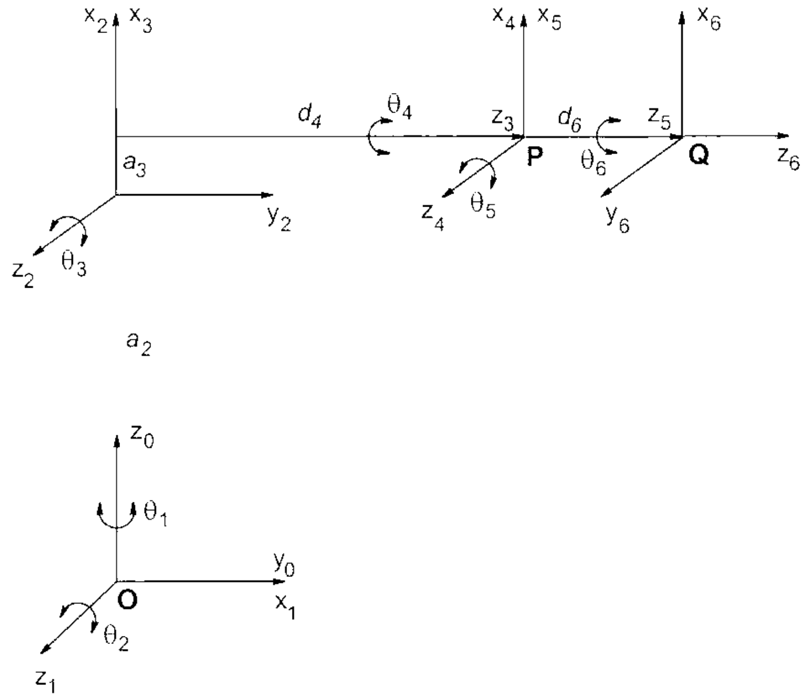

Fig. 3

$$
{}^{i-1}A_i = \begin{bmatrix} c\theta_i & -c\alpha_i s\theta_i & s\alpha_i s\theta_i & a_i c\theta_i \\ s\theta_i & c\alpha_i c\theta_i & -s\alpha_i c\theta_i & a_i s\theta_i \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}.
$$

Then the direct kinematics solution can be found by multiplying the corresponding homogeneous matrices.

The transformation matrix between the base and the end-effector is

$$
{}^{0}A_6 = {}^{0}A_1.\,{}^{1}A_2.\,{}^{2}A_3.\,{}^{3}A_4.{}^{4}A_5.\,{}^{5}A_6.
$$

When the configuration of arm is changed, this results in a change of the parameter a_2. Otherwise there are no other changes in the form of direct kinematics solution.

The inverse kinematics problem can be solved successfully with a number of methods described in the literature [4]. Due to the fact that the last tree join axes intersect in a common point the problem can be divided in two separate problems. The solution for the wrist center point can be found independently on the solution for the end-effector position. For some points in the workspace many solutions might exist, but due to some mechanical constraints only few could be feasible.

When solving the inverse kinematics problem we should point out that in some configurations numerical instability of the solution can appear. Therefore, the accuracy of the solution have to be examined for each configuration of the arm.

3. Main advantages of the Light-weight reconfigurable robot arm

The first advantage of the present robot is that it provides a mechanical construction of a robot arm with a reconfigurable architecture and sizes that can be easily adapted to the particular construction of the mobile robotic platform or to the specific need of the application task. This arm holds a highly tractable structure and does not require special tools for adjustment to the concrete mobile platform. Therefore, it can be implemented/mounted on a diversity of mobile platforms from various manufacturers.

The *Second advantage* of the present robot is that it provides a high manufacturability and maintainability of the construction achieved by small total number of components also by allocating of the motors which drive the wrist inside the body of the second link which avoids the necessity of any complicated mechanisms to transfer the movement from the motors to the wrist.

The *Third advantage* of the present robot is that it provides a lightweight of the entire construction by using light and cheap materials for components manufacturing. Hence, a lower relative price of this construction is achieved.

The *Fourth advantage* of the present robot is that the center of mass is allocated on a very low height, which ensures higher stability of the entire robotic system consisting of the mobile platform and the robot arm.

In addition, the present robot provides a construction that can be powered up by the batteries used to power the mobile platform, thus overcoming many of the known prior art constructions.

These advantages of the present robot show higher technical specifications compared to the prior art constructions.

5. Conclusions

- In this paper a new Light-weight reconfigurable robot arm is presented.
- A comparative analysis between this robot and other similar robots is made.
- Summary of the design of light-weight reconfigurable robot arm is described.
- The direct and inverse kinematics are discussed.
- The advantages of the light-weight reconfigurable robot arm for mobile robots are indicated.

R e f e r e n c e s

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Подход проектирования легкой реконфигуруемой руки для мобильного робота

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(Р е з ю м е)

Обычно индустриальные роботы способны носить 1/10 или меньше своей собственой тяжести. В тоже время, они должны встретить требования по отношении точности. Поетому очень актуальна цель проектировать улучшенную конструкцию со сравнительно малым тяжести и минимальными размерами.

Настоящая работа описывает новый подход проектирования легкой реконфигуруемой руки робота, предназначенной для работы с подвижным роботом. Рука может изменять свою конфигурацию в зависимости от целей задачи.