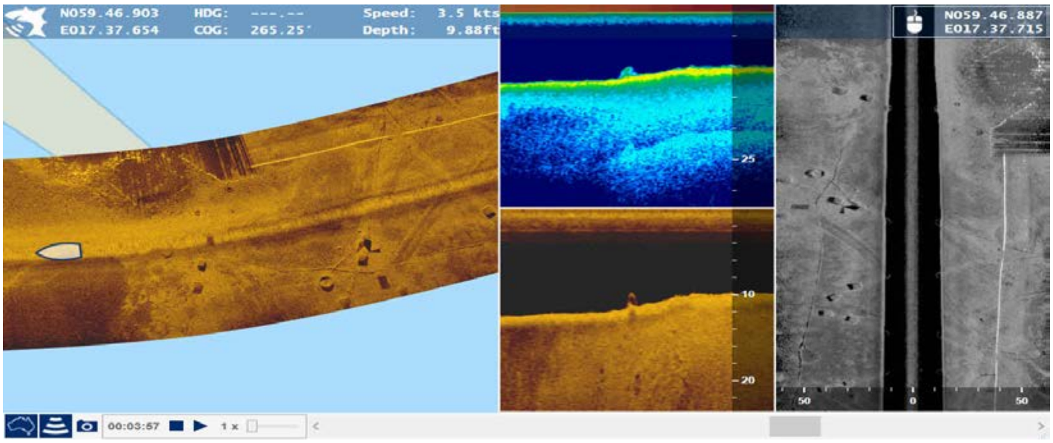

Рис. 2 – Результаты работы гидрографического комплекса

Точность геодезической привязки измерений, полученных как методом наземного лазерного сканирования, так и обследованием с помощью гидрографического комплекса делает возможным использование их при проектировании и разработке ГИС, а также при последующем анализе средствами ГИС.

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## KINEMATICS OF RECONFIGURABLE MANIPULATORS

**Plugachev Kuzma**
Autefa Solutions Switzerland, Frauenfeld, Switzerland

The traditional way of extending manipulators' abilities by means of increasing the number of controlled joints results in disproportionately rapid growth of the complexity and cost of construction. It is mainly caused by the complexity of communicating movements from the motor via the previous links to every new joint.

The other possible approach suggests that manipulator should be equipped with one or more so-called reconfigurable links (RL). The RL consists of several parts interconnected by translational or rotational passive (i.e. having no drivers) joints with the simple locks fixing a position of the RL parts in respect to each other. The idea of this approach lies in the fact that the movement in passive joints is attained not by the usage of special additional drives but by means of using already existing drives of conventional active joints between other links not only for displacement of the gripper, but also for changing the RL geometrical parameters.

Actual report is devoted to consideration of kinematic aspects of reconfigurable manipulators modelling. Let **r** be the position vector of the coordinate system $^{n+m}S$ of the gripper with respect to the base frame $^{0}S$. To describe the $^{n+m}S$ orientation with respect to $^{0}S$ the Euler angles $O=(\varphi,\theta,\phi)$ will be used. The gripper position and orientation can be presented as vector $p^T = (r^T, O^T)$.

In general case the manipulator with RL contains n+m joints and includes reconfigurable links with m passive joints, and n controlled active joints. The manipulator arm configuration at arbitrary instant of time is determined by a vector of joint variables $q \in R^{n+m}$. This vector may be organized as $q^T = (q_a^T, q_p^T)$ where $q_a \in R^n$ are joint variables of active controlled joints, $q_p \in R^m$ is a column vector of the RL joint variables.

`Taking into account the above designations, expressions for both direct and differential kinematics of the manipulator can be written as follows:

$$ {}^0p = k(q) \tag{1}$$

$$ {}^0p = \frac{\partial k(q)}{\partial q}\dot{q} = J_k(q)\dot{q} \tag{2}$$

If the end-effector velocity in the base frame ${}^0S$ is written as a vector ${}^0V^T = ({}^0r^T, {}^0\omega^T)$, where ${}^0r$ and ${}^0\omega$ are linear and angular components respectively, then

$$ {}^0v = J(q)\dot{q} \tag{3}$$

The standard Jacobian $J$ of the manipulator differs from Jacobian $J_k$ in (2), associated with accepted minimal description of orientation in (1). A derivative of the Euler angles set $O = (\varphi, \theta, \phi)$ may be transformed into the angular velocity ${}^0\omega$ in the ${}^0S$ using matrix $A^*$ whose elements are functions of the gripper orientation

$$ {}^0v = A({}^0p)\,{}^0\dot{p}; \tag{4}$$

$$ A({}^0p) = \begin{bmatrix} I_{3\times3} & 0 \\ 0 & A^*(\varphi, \theta, \phi) \end{bmatrix} \tag{5}$$

The matrix $A^*$ reflects the fact that the gripper angular velocity is not a mere derivative of minimal description of an orientation.

The manipulator Jacobian may be divided into two matrices corresponding to active and passive joint variables, so that

$$ {}^0v = J_a(q)\dot{q}_a + J_p(q)\dot{q}_p \tag{6}$$

The RE configuration at each instant of time can be described by the joint variables vector $g_d \in R^d$ The gripper and the RE in a contact form a kinematic pair with k degrees of freedom, and their relative position may be described by the vector $g_k \in R^k$. This enables the gripper position to be determined by the vector $g^T = (g_k^T, g_d^T)$, so that

$$ {}^0p = \Gamma(g). \tag{7}$$

The inverse dependence can be written as

$$ g = \Gamma^{-1}({}^0p) = \Gamma^{-1}\left[k(q)\right]. \tag{8}$$

Differentiation of (7) and its division by parameters of both RE and contact gives

$${}^{0}v = T(g)\dot{g} = T_k(g)\dot{g}_k + T_d(g)\dot{g}_d, \qquad (9)$$

where

$$T(g) = A\left[\Gamma(g)\right]\frac{\partial\Gamma(g)}{\partial g} = A(g)\frac{\partial\Gamma(g)}{\partial g};$$

$$T_k(g) = A(g)\frac{\partial\partial(g)}{\partial g_k};$$

$$T_d(g) = A(g)\frac{\partial\partial(g)}{\partial g_d}.$$

A number h of degrees of freedom of a gripper in contact with RE is determined by

$$h = \dim\left[imJ(q) \cap imT(g)\right] = \\ = rankJ(q) + rankT(g) - rank\left[J(q)T(g)\right] \qquad (10)$$

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# РОБАСТНОЕ УПРАВЛЕНИЕ ЗВЕНЬЯМИ ПРОМЫШЛЕННОГО РОБОТА

**Опейко О.Ф., Несенчук А. А.**
Белорусский национальный технический университет
Минск, Республика Беларусь

Приведенный к валу электродвигателя момент инерции любого звена промышленного робота зависит от относительных положений звеньев, а так же от массы в захватном устройстве, и потому изменяется в процессе функционирования. Применение специальных двигателей с высокими динамическими свойствами, например, синхронных двигателей с постоянными магнитами (СДПМ), позволяет уменьшить динамическую погрешность при отработке траектории, однако изменения момента инерции будут значительнее влиять на динамические свойства системы.

Для стабильности динамических свойств системы при параметрических возмущениях возможно применение методов робастного управления [1-6].

Синтез робастных ПИ регуляторов положения и скорости выполняется для линеаризованной редуцированной модели объекта управления, параметры которой, зависящие от моментов инерции, принадлежат заданным интервалам. Критерием качества является принадлежность корней характеристического полинома заданной области на плоскости корней для всех возможных значений параметров объекта.