MERO MODULAR WALKING ROBOTS CONTROL[*]

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Starting from the standard MERO walking modular robot, which is a robot on 3x6 degrees of freedom, autonomous, being able to interact with the environment, are presented the results obtained by the improvement of the structural and real time control performances. For this purpose kinematics and kinetostatics analysis are performed, and the mathematic model of the inverted kinematics is determined for controlling the main trajectory that defines legs' support and weigh centre positions. Related to this there is presented an Open Architecture system for the MERO robot position control in Cartesian coordinates through real time processing of the Jacobean matrix obtained out of the forward kinematics using the Denevit-Hartenberg method and calculating the Jacobean inverted matrix for feedback. The obtained results prove a significant reduction of the execution time for the real time control of MERO robot's position in Cartesian coordinates and increased flexibility.

1. INTRODUCTION

The improvement of performances concerning the possibility of moving the walking robots on ground with realistic configuration, in order to increase the mobility and stability in real conditions, have been realized by developing the control system in real time of the robot movement trajectory [1, 2, 3, 5]. Finding the mathematical model allows for knowing the legs coordinates against robot's body and the body position during walking against the support points.

The mechanism within the shift system of MERO modular walking robot served as an experimental basis [2, 4], being presented in Fig. 1. The mechanism is formed by 3 serially connected active groups of type RRR. The last two groups form a flat kinematics chain, functioning in vertical plane. The elements of the first group are connected to the platform and move in horizontal plane.

This kind of structure imitates quite well the shape of the human leg, is very simple and reliable, ensuring multiple possibilities of robots' manoeuvres [4, 5].

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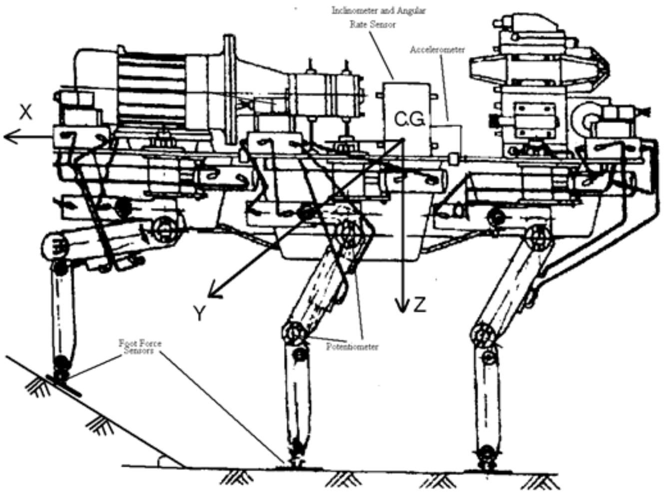

Fig. 1 – The shift mechanism of the MERO standard modular walking robot.

2. KINEMATICS MODELING OF MERO ROBOT

Kinematics modelling of the legs' mechanisms related to the main system attached to the MERO modular walking robot is presented in Fig. 2. There are 3 modules with 2 legs each, connected by 3 joint angles. Each leg is composed by a mechanism with 3 elements connected by 3 rotation actuators.

The Denovit-Hartenberg matrix method in homogenous coordinates is used in order to determine the legs position against the platform. Following the analysis of the Hartenberg-Denavit links system for the robot leg mechanism we have found a quite particular position, characterized by the following values: $\alpha_1 = 900$, $s_3 = 0$, $\alpha_2 = 0$, $a_1 = 0$, $\alpha_3 = 0$, $a_2 = l_1 = 250$ mm, $s_1 = 30$ mm, $a_3 = l_2 = 250$ mm, $s_2 = 0$. This led to decreasing the number of parameters of the transformation matrix A_i from six to four.

The work presents both the transforming connections of the a point's coordination – from system (i+1) to the system (i), that are realised by a transformation matrix A_i – as well as the transforming relations of the P_i point's coordinations from the system attached to the element (3) of the leg in the platform system. Considering as already known the legs coordinates $\mathrm{X}_{\mathrm{OiP}}$, $\mathrm{Y}_{\mathrm{OiP}}$, $\mathrm{Z}_{\mathrm{OiP}}$, the mathematic model with variable parameters of the leg joint angles θ_{ij} (j=1,6, i = 4,6) have been determined by inverted kinematics analysis. Thus, knowing the trajectory that the legs should describe, the parameters necessary to the control system in real time of the robot could be established. By direct kinematics analysis are calculated X_{OiP}, Y_{OiP}, Z_{OiP}, and by inverted kinematics analysis are calculated

θ_{4i}, θ_{5i}, θ_{6i}. The relative speed is calculated by derivation of movement equation and the relative accelerations by double derivation.

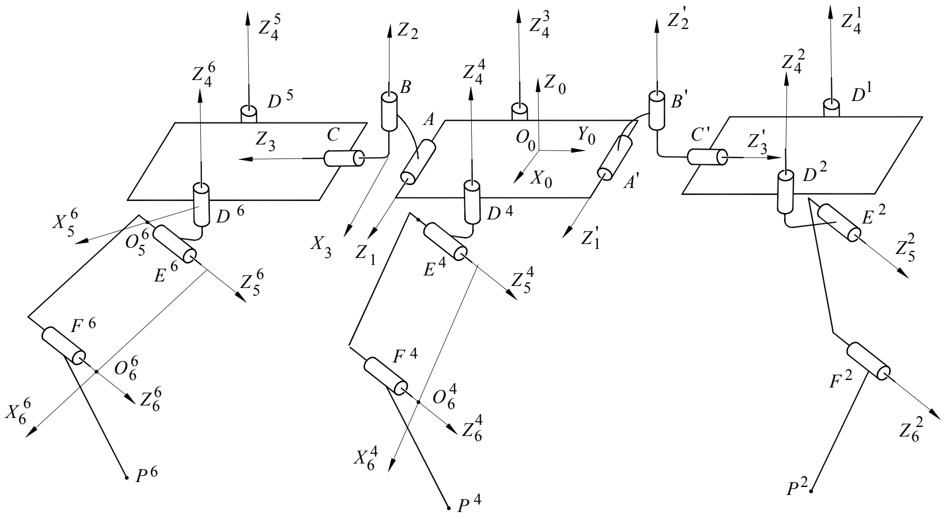

Fig. 2 – The Hartenberg-Danavit axis system attached to the leg of MERO modular walking robot.

In the general case of the walking robots with $2n$ legs – the “myriapod” robots having n connected modules – the legs kinematics related to the environment system have been determined by the same algorithm.

Mathematic modelling of the gravity centre position, which allows the walking robots to shift on ground with difficult configuration, is presented in the Fig. 3. The geometric centre position O is defined as the diagonals intersection point of the polygon formed by the points where the legs are connected to the platform, and $G_{(Gx,Gy,Gz)}$ as the gravity centre position of robot.

Considering the positions of the walking robot’s legs as X_{Pi}, Y_{Pi}, Z_{Pi} a mathematic model has been developed in order to express the kinematics characteristics of the walking robot’s gravity centre. In order to determine the position of the supporting polygon against the platform, through the Denevit-Hartenberg method, where Z_{ij} ($i = 1, 6$ or $1, 4$; $j = 1, 3$), and m_{ij} ($i = 1, 6$; $j = 1, 3$) the leg mechanism mass, the coordinates of $\mathrm{P_i}$ have been transformed from the system $O_{4x4y4z4}$ into the system $O_{x\mathrm{O}y\mathrm{O}z\mathrm{O}}$. The coordinates of P_i have been transformed from the system $O_{4x4y4z4}$ into the system $O_{x\mathrm{O}y\mathrm{O}z\mathrm{O}}$ for to determine the position of the support polygon against the platform.

The vertical projection of the G system gravity center on the supporting surface must be inside the supporting polygon in order to obtain stability.

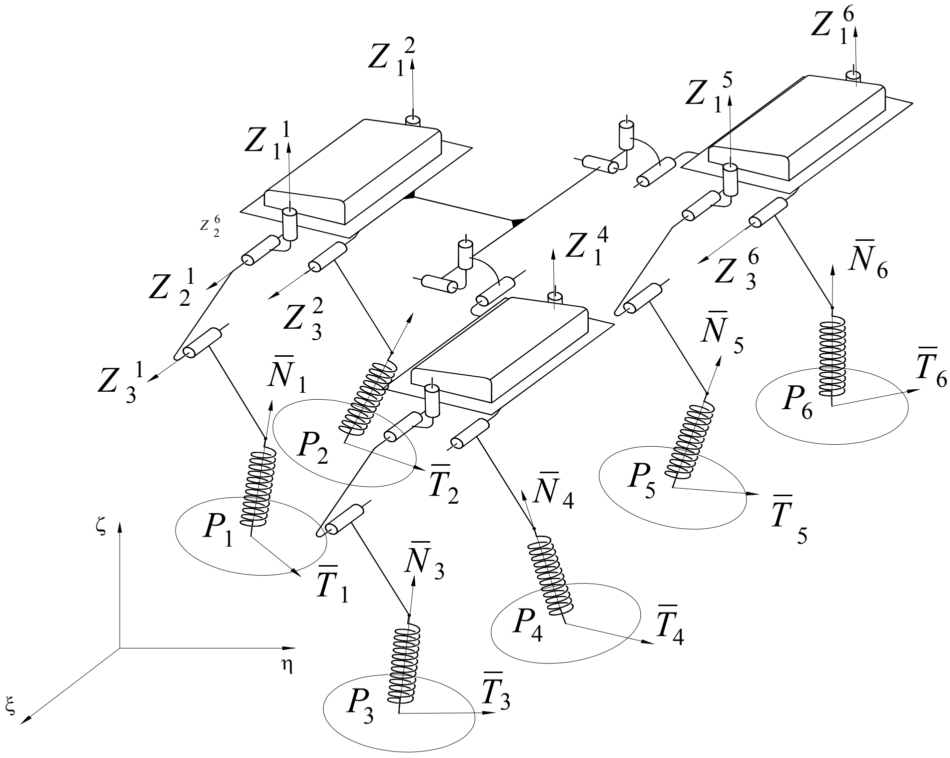

Fig. 3 – Mathematical modelling of the gravity centre for the MERO modular walking robot.

Because the gravity centre positions of each legs mechanism element against the own system are known, the relations for the gravity robot centre coordinates, necessary for the stability control of the robot in real time have been established:

$$X_G^k = \frac{m_0 \cdot X_O^k + \sum_{i=1}^{6}\sum_{j=1}^{3} m_j^i \cdot X^k \cdot G_j^i}{\sum_{i=1}^{6}\sum_{j=1}^{3} m_j^i}, \tag{6}$$

where, $X^k = \{X, Y, Z\}$; $k = 1, 2, 3$; $j = 1$–4 and $i = 1$–6 for the option hexapod walking robot, and $i = 1$–4 for the quadruped walking robot. Knowing the gravity centre position, the speed $\dot{X}_G^k$ and the acceleration $\ddot{X}_G^k$ have been established by derivation.

3. OPEN ARCHITECTURE SYSTEM FOR THE MERO ROBOT POSITION CONTROL

As a result of the studies, for the position control of the MERO walking robot (Fig. 4) a real time control system with open architecture OAH has been conceived. The system has four main components: the programmable logical controller (PLC0), PC system with open architecture (PC-OPEN), multiprocessor system PLC (SM-PLC) and the position control system (CP*ki*, $i = 1–3$, $k = 1–6$). The system ensures the implementation of the algorithm for robot position control in Cartesian coordinates through real time processing of the Jacobean matrix obtained by direct kinematics of the robot, respectively of the invert Jacobean matrix for feedback. The method consists in reducing the matrix $J(\theta)$ to an upper triangulate form and finding errors in $\delta\theta$ joint coordinates using back-substitution. The joint angle errors $\delta\theta$ can be used directly as control signals for robot actuators. Joint angular errors for actuators on each robot freedom axis corresponding to the robot's new desired position generated in Cartesian coordinates are obtained by processing of Jacobean and inverted substitution.

The programmable logical controller in decentralized and distributed structure (PLC0) ensures the control of the freedom axis for the robot execution elements. The current angle motion values in absolute value $\Sigma\theta_{ci}$ are transmitted from PLC0 to PC-OPEN. From the PC to the PLC are continuously transmitted the reference positions on each axis XD*i* according to the trajectory generating program XP*i*. The PLC0 is processing 24 analogue inputs, 24 digital output, 18 analogue outputs for robot position and stability control, and other 64 digital inputs/outputs configurable for auxiliary functions: the hydraulic group control, motion limitation devices, limitation devices for homing etc. Moreover, the following analogical and digital input signals are controlled: position transducers (TP*ki*, $i = 1–3$, $k = 1–6$), proximity transducers, 2*x*D*k* horizontal and 2*x*D*k* on vertical for orientation, force transducers (TkF, $k = 1–6$), vertical control transducers (XM, Ym) for robot stability.

The system PC-OAH (PC-OPEN Architecture) allows the introduction of new control functions based on supplementary programs. Due to the great processing speed with operating systems, which allow for programming in evolved programs, the basic functions can be implemented, using an ExTR real time multitask executive: interpolation (INP), main program (PP) of the operator interface, the movement trajectory generating program (MTG), the static stability control (SSC), robot platform control (RPT), the robot's walking shaping program (RWS), compliant function control program (CTRL C) and the prehensive control program (CTRL P). Supplementary, an interface with digital camera (IDC) could be installed, for objects recognition and the communication interface using radio modem, GSM or wireless systems. The PC-OAH system performs following operations: shapes walking stereotypes, determines the walking stability limits, ensures the horizontal position of the platform, maintains the established height of the platform and interprets the operator orders. The Interpolator modulus (ITP) provides the generating of intermediary points between two references of position. The programming is made in BORLAND C++ and allows the processing of over 200 new references in an interval of 100μs. The Main Program (PP) provides a graphic interface between operator and robot. The robot has a menu allowing him to: choose the walking program, the 3D linear and circular interpolating simulation program, generating alarms for over load parameters, trajectory generating simulation, step by step or automatic functioning. The program allows the graphical simulation of the chosen walking type.

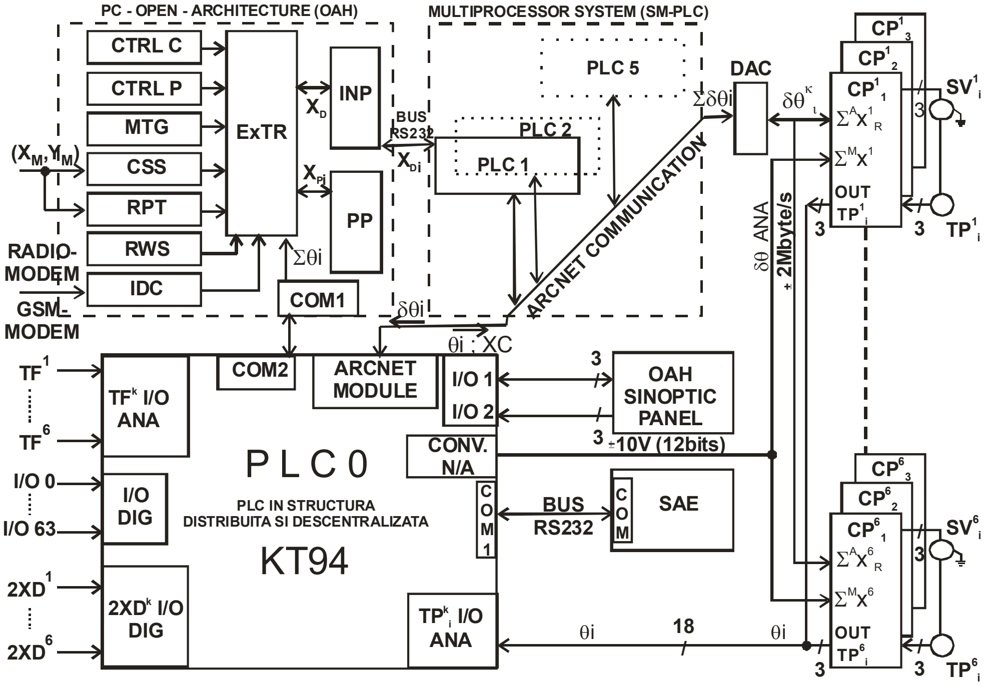

Fig. 4 – Real time control system with open architecture for the MERO modular walking robot.

The Multiprocessor System PLC (SM-PLC) and PLC0 has the role to send in real time, through the ARCNET fast communication network, the angular reference positions for the PIDT position regulator. For feedback, the current values θ^{K}_{ci} ($i = 1$–3, $k = 1$–6), received from the position transducers (TPki, $i = 1$–3, $k = 1$–6) are transmitted by PLC0 through ARCNET. Five processes for implementing the mathematical model of robot control have been identified [3]. In the active topology for (1) process, each PLC generates an ascendant data flux from PLC0 to PLC5. By calculating the transformed matrix iAj for the leg k ($k = 1$–6), from the axis i to the axis j, we obtain the coordination matrix in axis j, finally resulting the coordinates for the robot environment $XkC = 1Ak3 = A1*A2*A3$. In the active topology for the process (2), the matrix $i\text{-}1Aki$ are stored for each PLC, the Cartesian coordinates Xki in i axis, by multiplying with $1Akj{-}1$, are determined and the position variation $\delta X^{k}_{\mathrm{C}}$ is calculated. The Jacobean matrix is obtained during the process (3) by an ascending data flow, correlated with process (1). During the matricial calculation $1Akj$, the PLC0 is assigned to $J(\theta_1)$, matrix of (3×1), respectively PLC5 to $J(\theta_5)$. The active topology of process (4) brings the Jacobean matrix to triangular form by determining the pivot element and the new matrix $Akij$ elements. The active process (5) took place within a sequential process with process (4), determining the value of the angular error $\delta\theta^{\kappa}_{i}$ by inverted substitution.

Position Controllers $(\mathrm{CP}^{k}_{i}, i = 1\text{–}3, k = 1\text{–}6)$, have 18 hydraulic servo-valves $(\mathrm{SV}^{k}_{i}, k = 1\text{–}6, i = 1\text{–}3)$ as actuators, providing movement control on each free axis, based upon angular deviations $\delta\theta^{K}_{i}$.

The robot's walking types are issued from 3 block-programs located in PC-OAH system, namely: the block of walking shaping, which determine the succession and the way of moving the legs, the block of static stability control, granting the robot shift so that the system centre of gravity projection may remain inside the convex polygon formed by the leg's, the block of platform control, maintaining the prescribed height and the horizontal position of the platform.

4. CONCLUSIONS AND RESULTS

The results of this research have been materialized through MERO modular walking robot, presented in Fig. 5, which was built and tested at “Politehnica” University of Bucharest.

The MERO walking robot's control system in real time with Open Architecture (OAH) ensure flexibility, short time execution, the precision targets and repeatability of the moving programs, eliminating completely the closed systems with projects meant for specified applications. Supplementary developments in order to increase the performances or new functions adding are possible only by modifying the software relating to the control modules in PC-OAH for laborious computations, respectively in the PLC multiprocessor for complex real time control. Besides, addition of new physical modules could easily be done because of the communication between the programmable logical controller (PLC) and the input/output modules made by a bus with 3 torsadate conductors.

Owing to the great computation speed of microprocessor systems and serial connection links for data transmission, the time necessary for establishing the inverted matrix is short enough to allow the robot control in real time, with no influence in performing the other programs. The results show that the time necessary to perform program for the MERO robot position control in Cartesian coordinates is 80% shorter.

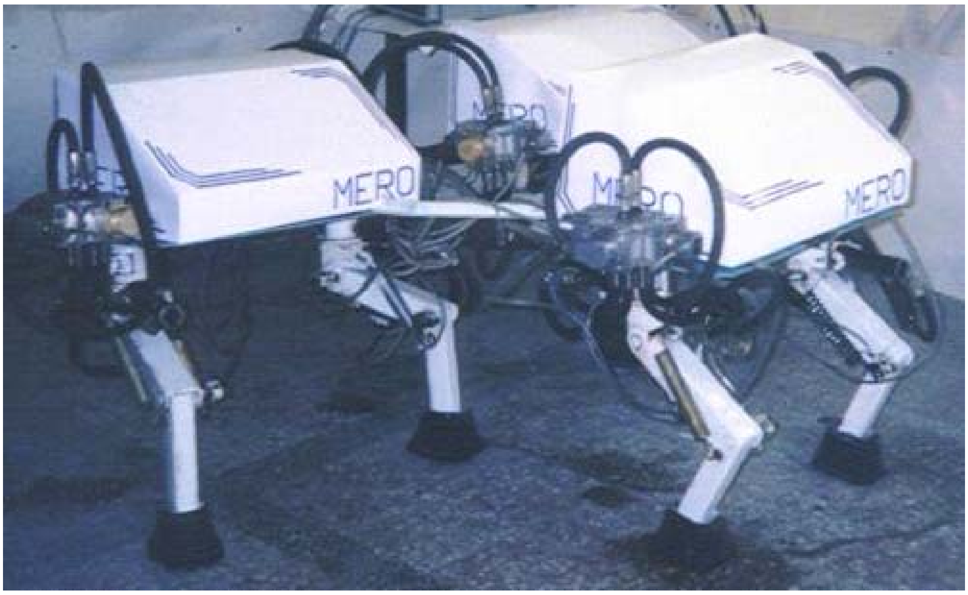

Fig. 5 – MERO modular walking robot.

Moreover, the short time execution will ensure a faster feedback, allowing other programs to be performed in real time as well, like to the prehensive force control, objects recognition, making it possible that PC-OHA system have a human flexible and friendly interface.

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