Embedded Control of Pneumatic Muscles

Mladen Milushev[1], Todor Djamiykov[2] and Marin Marinov[3]

Abstract – **In this report we present a base module for synchronal control of a six-legged robot. The starting point is maiking the same kind of module using a microcontroller (made by RENESAS) for the controlling of a three-joint leg, with a reflex implementation capatability.**
Presented is the research on the PWM muscles' control. The hardware and software components of the base module and algorithms are shown in the present report. The results from the real-time tests of their cooperation are given as well as the according parameters.
The end-goal is to achieve the quickest possible adaptation in the process of creating different set variants of autonomous multilink architectures for mobile robots' control.

Keywords – **Mechatronics System, Walking Robot, Embedded Control, Modular Control, Fluidic Muscles.**

I. Introduction

Anyone developing a mobile robot needs to solve the problems related to locomotion in a specific environment. The nature of environment where the robot is supposed to be functioning is the crucial criterion for the driving force type. On an uneven surface the robot can move if its locomotory is very flexible and adaptive to every change in the terrain profile. Such a moveable machine is mostly based on the joints, aka leg. The larger the number of legs used, the more reliable the accomplished movements.

The efforts towards coordination of the legs increase significantly with the implementation of more legs. For a robot carried out with six legs with six joints each eighteen degrees of freedom must be calculated. The coordination and control through a centralized control system of those 18 freedom degrees provides for the anticipation of considerable difficulties. The present study deals with some of the tasks and problems-to-be-solved mostly related to the development of a system for the six legs' control.

The developing of control systems recently employs hierarchical principles based on two antagonistic approaches: *composition* and *decomposition*, (aka Top-Down- and Bottom-Up-principles) applied in an appropriate proportions. The Bottom-Up-principle helps identify the basic Mechatronic functions and add relevant Mechatronic structures. Thus a unified structural model is established and can further be applied with the Top-Down principle. The structural model describes the basic functions used as targets by the latter principle. In the defined Mechatronic circumstances the Bottom-Up-principle allows to fix the related joint's bending angle. Through the three joints forming a leg the position of that leg can be also set. If a gait and a respective posture of the body have to be realized by using the Top-Down principle, first the gait has to be distributed to that leg's locomotive functions and subsequently disintegrated to individual speeds for the separate joints. In case of some cross basic mechatronic functions, aka abstract functions stemming from the Bottom-Up principle, it's presumable for the Top-Down principle to initiate a preparation for them.

II. System Description

In this paper we consider a walking robot with six identical legs equally distributed along both sides of the robot's body in three opposite pairs. The leg's joints are driven by pneumatic muscles (FESTO). So far the six-legged walking robot (Fig. 1.) has been developed using Solid Woks.

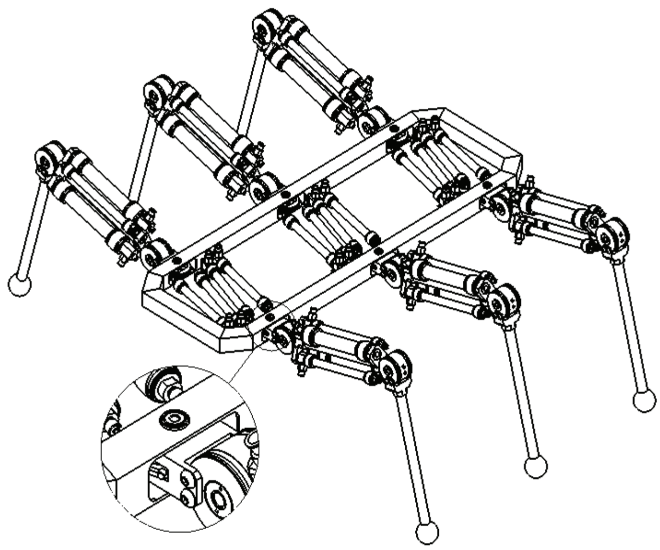

Fig.1. Leg-to-body attachment design.

For the walking robot ***BiMoR*** (**B**iologically **M**otivated **R**obot) a hierarchical and distributed computing architecture has been selected (Fig. 2.). By distributing the possibility of concurrent control functions is implemented on various micro-

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controllers. Through the concept of distribution the need for communication is generated. The communication based on the master-slave principle with provides a suitable option for the control system for keeping the protocol economical and within the determined time limits for securing safety to the critical functions. It is important that the used sensors provide information about the absolute coordinates.

The hardware of the slave control system must fulfill the following tasks:

- collection and analysis of the measured variables;
- calculation of tax information;
- output control signals to the actuators.

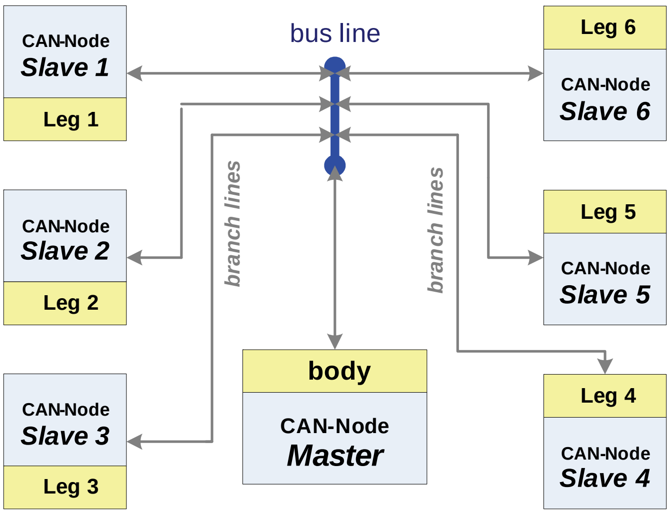

Fig.2. The Master in connection with all six slaves

For executing the basic legs functions like the closed-loop joint control (valve control, recording signals from the joint encoders) six R8C/23-microcontrollers are installed. On a basic level each sensor and actuator are connected with the interface board to the micro-controller board. The R8C/23 microcontroller is installed on industrial controller boards and contains one Full CAN module, which can transmit and receive messages in both standard (11-bit) ID and extended (29-bit) ID formats.

III. Synthesis and Structure of a Control Algorhithm

In the six-legged walking robot, subject of the present study, for the purpose of creating antagonistic actors pneumatic muscles are put into use. The task to control a muscle-joint comprises several partial loops aimed at controlling the strength and pressure of the antagonistic actors as well as the angle's position of the joint. The only variables that can be affected by the close loops are the air flows going in and out of the muscle in three stages: enter-close-exit. The possibilities for controlling the speed of the in and out airflows through the pressure within every muscle of the joint as well as the position of the latter are described by the "equality of forces" of the muscles and the outside forces affecting the joint.

$$F_a + F_S \equiv F_p \tag{1}$$

Equation (1) shows that such a system needs to point out not only the joint's position but also the resultant force acting in the entire system. In the applied control system the input quantity is not the force but the max pressure $\boldsymbol{p_s}$. Subsequently, the joint can be controlled with the next sequence:

For certain values of $\boldsymbol{\theta}$ and $\boldsymbol{p_s}$ the required pressure for both muscles is calculated with equations (2) and (3):

$$\theta \geq \theta_{med} : p_a = p_s \cdot (\theta_p - \theta / \theta - \theta_a)\ ,\ p_p = p_s \tag{2}$$

and for

$$\theta < \theta_{med} : p_p = p_s \cdot (\theta - \theta_a / \theta_p - \theta),\ p_a = p_s \tag{3}$$

Where $\boldsymbol{\theta_p}$ and $\boldsymbol{\theta_a}$ the minimal values of the joints angles in the opposing positions, while $\boldsymbol{p_p}$ and $\boldsymbol{p_a}$ are the pressure values in both muscles.

The actual value for $\boldsymbol{F_S}$ is calculated according to equation (4) with $\boldsymbol{\theta_n}$ being the true value of the joint's angle:

$$F_S = p_p \cdot \{(\theta_p - \theta_n) - p_a \cdot (\theta_n - \theta_a)\} / (\theta_p - \theta) \tag{4}$$

Recalculating $\boldsymbol{p_p}$ and $\boldsymbol{p_a}$ according to equations (2), (3) and (4): the presented relationship provides for carrying out the algorithm controlling airflows that enter and exit the muscle according to the joint's position $\boldsymbol{\theta}$ and the muscle's pressure $\boldsymbol{p}$.

Each leg's control can be devised in two stages. On the first stage the leg, without coming in contact with the surface, from the far back position, aka the Posterior Extrem-Position (PEP) moves forward to a front position, aka the Anterior Extrem-Position (AEP). This stage is known as passive phase, aka Protraction. In the next stage defined as active phase, aka Retraction, the leg is moved from a front position Anterior Extrem-Position (AEP) backwards to the Posterior Extrem-Position (PEP). During the active phase the leg touches the ground; the body is supported and pushed forward by the leg. The sequence of both phases is cyclically performed by each of the six legs.

For a successful walk the passive (Protraction) leg must rapidly move to the next constant position. On an even surface a precise positioning of the legs is not necessary. For the executing of the outlined stages following strategies are applicable:

- The active-leg-control is done as a time-function or as a function of another active leg.
- The passive leg is freely forwarded to ensure contact with the ground

The leg's movement in the passive phase must and in a way allowing the speed and body angle to steady. In case of unevenness the control height and perpendicularity axe of the body are compensated by the joints of the leg closing the passive phase. The switching from one supporting leg to the next must follow at a strictly defined moment.

Fig. 3 shows the control structure of a leg and respective joint.

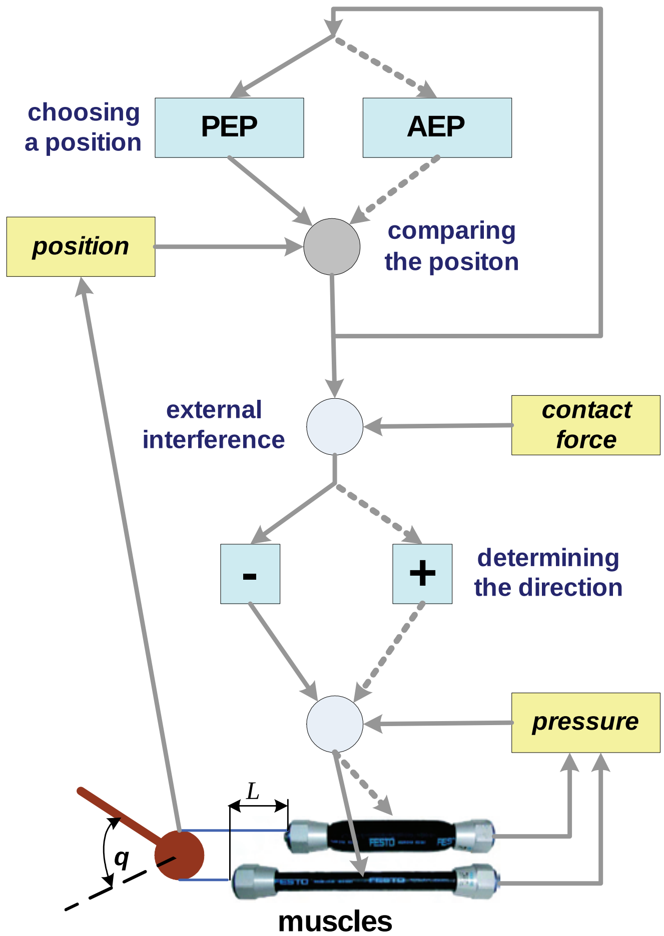

Fig.3. Model for control and regulation of the leg

The model comprises several control loops using current information about the joint's position, the pressure in the two muscles and the effort related to the force of contact with the surface.

IV. Experiments and Results

As main module of the structure a EVBR8C/23 microcontroller produced by the RENESAS company is applied. The module performs the basic functions of the close loop control, which depend on the information about the joint position and pressure within the muscles. On this level every sensor and actor (a pair distributed to every joint) are connected over an interface module, which contents scaling precise amplifiers for the signals coming from the joint's sensors; six electronic keys for the joints power distributors and three input PWM (Pulse Width Modulation) channels for each of the joints. For obtaining the PWM signals needed to control the muscles pressure altering speed, for every one of the three joints a separate programmable pulse with modulator is foreseen. The parameters of the PWM signals for every joint are given separately by the output ports of the microcontroller and the pressure values within the applied muscles are taken into account. The programmable pulse with modulator includes three programmable timers based on the free programmable logic FPGA.

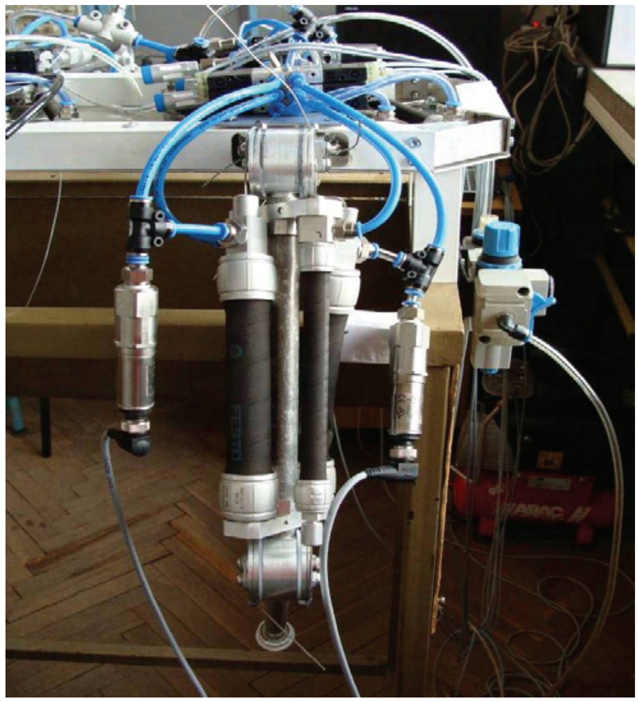

Fig.4. Experimental set

The experiment shown in Fig. 4 uses following components:

FESTO pneumatics:

- Valves type CPE10-M1BH-5/3G-GS6-B
- Inductors type GRU 1/8B with linear features
- Sensors for pressure type SDET-22T-G14-U-M12

Velleman Measuring equipment:

- Functional generator and transient recorder type PCSGU250
- Measuring and processing software Pc-Lab2000LT

The experiments carried out included:

Processing the valve under constant powering and inducting of the airflows: Fig. 5 and Fig. 6 show the change in pressure under that type of valves control.

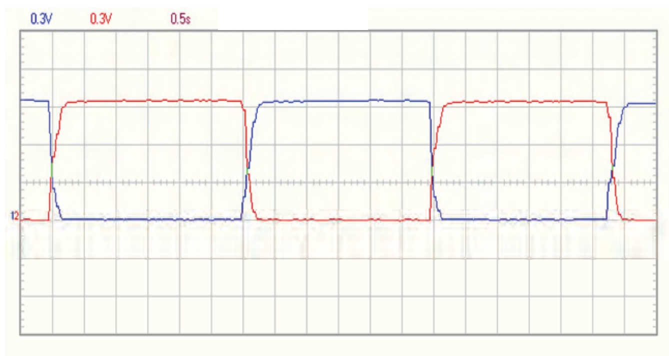

Fig.5. Without throttling

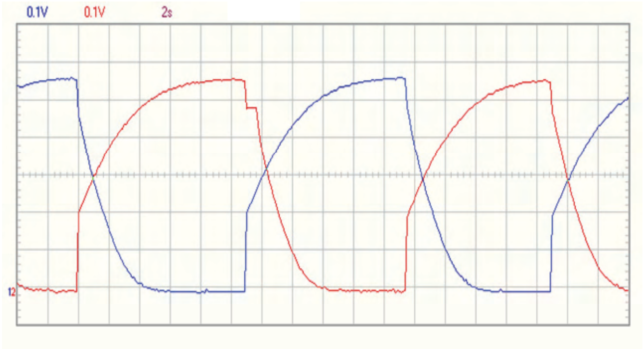

Fig.6. With throttling

The inducting shown in Fig. 6 goes in opposite directions. The shortage is in the non-linear features at the start of both processes and the uneven change of the in and out airflow over a certain time period.

Valve functioning with an altering power supply – PWM and using the data from the sensors for pressure and position: Figure 7, 8 and 9 display the change in pressure while controlling the valves over a width modulated signal.

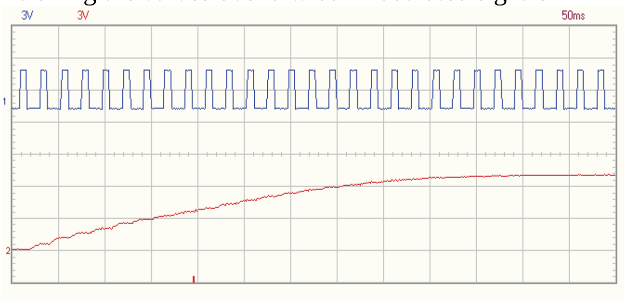

Fig.7. Entering flow, pulse width of 1 / 3T

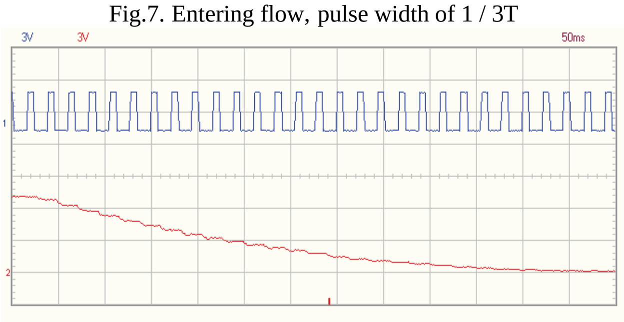

Fig.8. return flows, pulse width of 1 / 3T

In that case the pressure change in both directions is close to linear and with the same shape and duration. With changing the duration of the impulse the possibility to change the speed and reach the pre-given position arises. In Fig. 7 and Fig. 8it is 500 mS and in Fig. 9 – 200 mS.

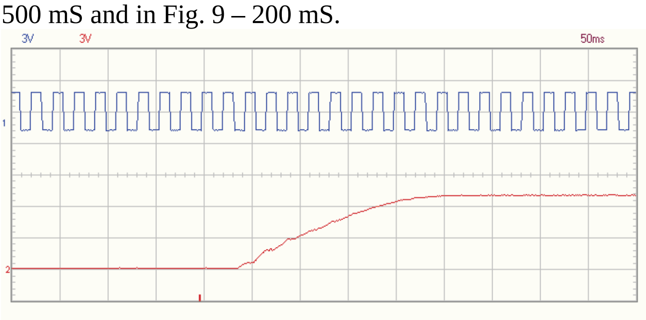

Fig.9. Enter flow, pulse width of 1 / 2T

V. Conclusion

In consequence of the experiments and measurements carried out as well as the analyses of the obtained parameters from practical tests, the accomplishing of a functioning valves control over a width modulated signal can be reported. The results obtained with the valves of the available type proves beyond doubt that the maximal frequency should not exceed 47Hz and the optimal value for the impulse lies between 18% - 34% of the duration, while the duration itself should not fall bellow 27mS.

Created is an algorithm for accounting of the pressure within both muscles – the protagonist and the antagonist respectively. Hence, we can correct their similar behavior in regard of the entering and exiting airflows, which is a condition for testing new control algorithms.

The further development and testing of the programmable width modulator (PWM) will provide for the realization of various speeds over PWM signals for the separate joints. That in turn would allow a better coordination of the leg as a whole.

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