Vision-Based Guidance of a Six-Legged Robot

Alexander Bekiarski[1], Mladen Milushev[2], Plamen Petrov[2]

Abstract – **The legged robots belong to the bio-walking robots, which imitates the walking styles of multi-leg animals in the nature. There are many studies of the technologies concerning to the walking bio-robots. The six-legged robot is a concrete realization of a multi-leg walking bio-robot, which is chosen in this article as a part of a audio visual moving robot. The audio visual robot can be a real working combination from different sensors, intelligent and knowledge systems, moving and orientation systems etc. Each of these systems cab be investigate separately, but the results of these investigations and experiments from each of these systems can be proven ensemble or in conjunction in a real working audio visual moving robot. The goal of this article is focused just in this direction – to combine the information derived from audio or visual robot sensors and to use this information, practically as space co-ordinates of observed from the robot object, for guidance of the six-legged robot.**

Keywords – **Audio Visual Moving Robots, Bio-walking robots, Multi-legged robots**

I. Introduction

The audio visual robot is a combination from a lot of different systems: audio, video, communications, moving system etc. The main goal of the work of an audio visual moving robot is to observe with some sound and image sensors the objects in the area of observation or in a room, to process this audio and visual information, to calculate the space co-ordinates of the observed object and finally to guide the moving system of the robot, in the case of this article – a six-legged moving robot system.

Of course, each of these systems is investigated, designed and tested separately. For example there are the results of the calculation of the direction of arrival of sounds, speech or noise from the audio robot system [8] or the information for the co-ordinates of a visual object recognized from the video robot system [9].

On the other hand there are many investigations and result for methods, algorithms and technologies for simple or more complex guidance of multi-legged robots [7]. All of these results can be combined to work together in an audio visual moving robot equipped with a multi-legged walking system and especially here with a six-legged mechanism.

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The proposition in this article to do this combination from some of the moving robot systems, i.e. audio, video and walking six legged mechanism is shown as a block schema in the Fig.1.

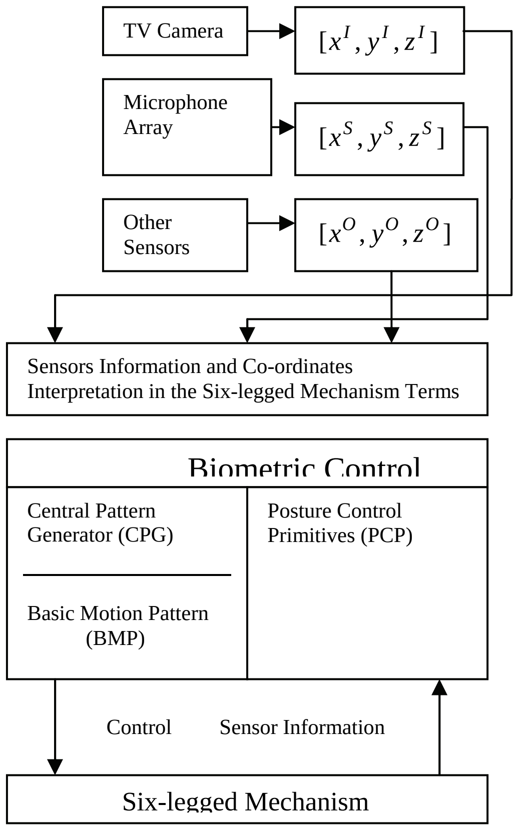

Fig.1. The proposed block schema

If in the area of observation of the robot there is a visual object the visual sensor gives their space co-ordinates $[x^I, y^I, z^I]$. In the same time, if the microphone array perceives a sound, speech or noise signals it calculate the direction of arrival of the sound and finally the space co-ordinates $[x^S, y^S, z^S]$. In the Fig.1 it is shown also the existing of other types of sensors, which too gives the coordinates $[x^O, y^O, z^O]$. All calculated coordi-nates are selected and interpreted as the common and useful information for biometric control of six-legged mechanism of the robot. The final executive control of six-legged mechanism depends from the situation and can be performed both from of Central Pattern Generator (CPG) in concurrence with Basic Motion Patterns (BMP) or Posture control Primitives (PCP). A more detailed description of this part is given next in this article.

II. APPROACH FOR BIOMETRIC CONTROL

The control approach proposed in this paper (Fig.1) combines the conceptions of two approaches: the conception of Central Pattern Generator (CPG) in concurrence with Basic Motion Patterns (BMP), Posture control Primitives (PCP) and Reflexes (Fig.2.).

The CPG model controls the motion using phase displacement of the legs in normal conditions. Normal conditions mean that there are no obstacles blocking the robot path or terrain irregularities. The second part which is represented by BMP is used for controlling the rhythmic control of the robot. The BMP describes the rhythmic space trajectory of the leg done by means of the joint angles, which determine the step (amplitude) and frequency (period) for the leg's displacement, thus permitting an Omni-directional motion of the system.

By activating more than one of these BMP the effects can be combined and superposed. For example, if a forward motion is activated with different amplitude, the resulting motion is straight and leftward. The process of superposition guarantees that change from one motion to another is smooth and the system is stable. The advantage is that the change in heading is possible without stopping the robot in advance.

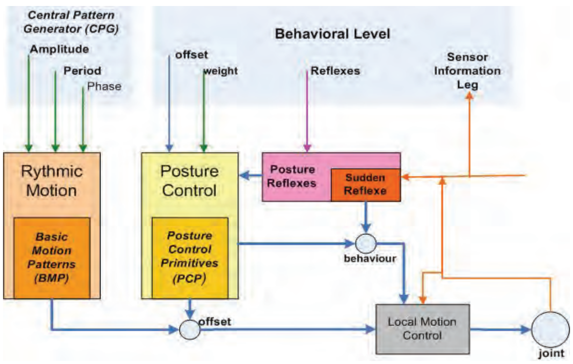

Fig. 2 Conception Scheme for a Biologically Motivated Robots Control

In addition to the BMP, the architecture of motion behavior PCP guarantees higher behavior level of the module which is used for pose control of each leg by controlling the primitive of the posture.

For example, the behavior control of lifting up and inclination of the central body utilizes PCP for stabilizing the walking system. In such way, it is possible to change height of the main body only by stretching of the leg.

The reflexes are used in two directions: sudden reflexes, which bock the corresponding joint in case of collision, and posture reflexes serve the posture control primitive module. The reflexes are activated only by exception and are used for dealing with them, for example, when a reflex moves the leg up to avoid an obstacle. These mechanisms altogether will permit the system to keep relatively constant speed during the motion on irregular terrain. Consequently, it is possible to walk with the same software architecture in case of different kinds of terrains.

This paper addresses the changes of step, respectively the amplitude in the basic motion pattern in reference to coordinates aiming a trajectory generation on a flat terrain.

III. KINETIC EQUATIONS OF MOTION

In this paper, we consider a walking robot with six identical legs equally distributed along both sides of the robot body in three opposite pairs. Each leg consists of three links and three revolute joints as shown in Fig. 3.

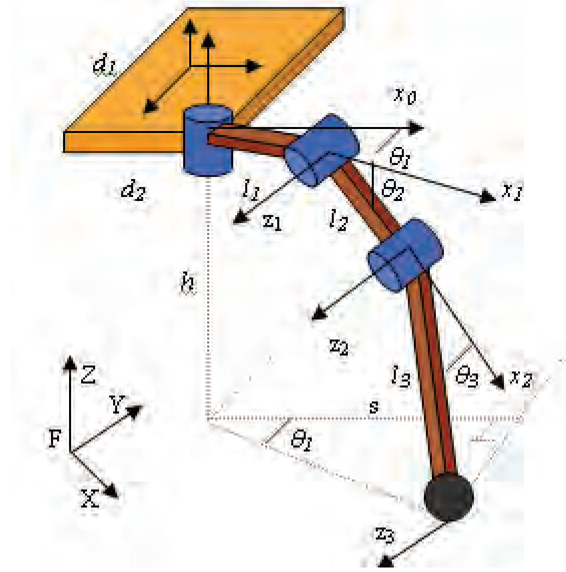

Fig. 3 Link frame attachment to the 3 degrees-of-freedom leg

The first two (thoracic denoted by θ_1 and hip denoted by θ_2) are orthogonal to each other, and the third (knee denoted by θ_3) is parallel with the second. In our previous paper [….], the Denavit-Hartenberg convention was used for the description of the vehicle kinematics. The link parameters of each leg are denoted as follows: θ_i, (i = 1,2,3), are joint variables, and l_i , (i = 1,2,3), are the lengths of the links (Fig. 3).

The coordinates of the foot (leg tip) in the frame $O_0x_oy_0z_0$ attached to the robot body are

$$
\begin{aligned}
x_3^o &= \cos\theta_1(l_1 + l_2\cos\theta_2 + l_3\cos(\theta_2+\theta_3)) \\
y_3^o &= \sin\theta_1(l_1 + l_2\cos\theta_2 + l_3\cos(\theta_2+\theta_3)) \qquad (1) \\
z_3^0 &= l_2\sin\theta_2 + l_3\sin(\theta_2+\theta_3)
\end{aligned}
$$

Remark 1. To complete the kinematics modeling, the six legs and the robot body must be integrated to solve the global kinematics problem of the robot. It is important to be able to compute the robot coordinates and orientation (the frame $Cx_cy_cz_c$ attached to robot body, Fig. 3) with respect to an inertial coordinate frame *FXYZ*. The homogeneous transformation matrix between $Cx_cy_cz_c$ and *FXYZ* (which is not presented in this paper) depends of the six degrees of freedom of the robot body (three angles describing the angular position of the body in the inertial frame *FXYZ* and three coordinates of the mass center *C* in *FXYZ*).

Equations (1) determine the foot position in $O_0x_oy_0z_0$ in terms of the joint variables. In order to solve the inverse kinematics problem, i.e., the problem of finding the joint variables in terms of the top position, we solve Eqs. (1) in closed-form for θ_i , (i = 1,2,3).

$$\theta_1 = a\tan\frac{y_3^0}{x_3^0} \quad (2)$$

$$\theta_3 = a\cos\frac{a_5^2 + a_6^2 - l_2^2 - l_3^2}{2l_2l_3} \quad (3)$$

where

$$a_5 = \frac{x_3^0}{\cos\theta_1} - l_1 = l_2\cos\theta_2 + l_3\cos\theta_{23};$$

$$a_6 = z_3^0 = l_2\sin\theta_2 + l_3\sin\theta_{23}$$

and

$$\theta_2 = a\cos\frac{a_3a_1 + a_4a_2}{a_1^2 + a_2^2} \quad (4)$$

where

$$a_1 = l_2 + l_3\cos\theta_3; \qquad a_2 = l_3\sin\theta_3 \;;$$

$$a_3 = a_1\cos\theta_2 - a_2\sin\theta_2; \qquad a_4 = a_1\sin\theta_2 + a_2\cos\theta_2 .$$

In order to derive expressions for the joint angles θ_i ($i=1,2,3$) in terms of the desired changes in robot heading θ with respect to an inertial frame, we consider a circular motion of the robot, as shown in Fig.4.

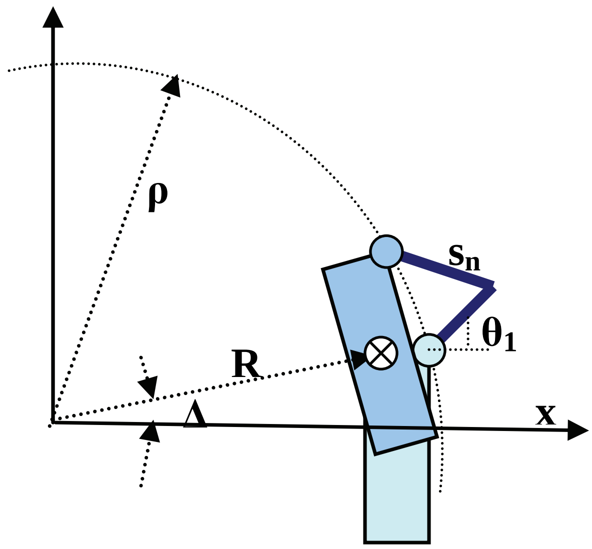

Fig. 4: Circular motion of the robot

Denoting by b_1 - the half of the body length, and by b_2 – the half of the body base, first, we obtain an expression for the thoracic joint angle θ_1 as a function of the change in heading θ during the support phase of the front right leg of the robot as follows

$$\theta_1 = \xi - \theta \quad (5)$$

where

$$\xi = a\tan(m/n)$$

and

$$m = ((R + b_2/2) + s - \rho\cos(\theta + \psi)$$

$$n = \rho\sin(\theta + \psi) - b1 - s\tan\theta_{10}$$

Similar expressions can be derived to all legs of the robot. Next, we express the two joint angles θ_2 and θ_3 as functions of the thoracic joint angle θ_1 and the change of heading θ. For circular motion of the robot at a constant height *H* of the body with respect to the ground, we obtain

$$\theta_2 = 2a\tan\left(\frac{b}{a+c} + sqrt[(\frac{b}{a+c})^2 - (\frac{c-a}{c+a})]\right) \quad (6)$$

$$\theta_3 = -\theta_2 + a\sin[\frac{1}{l_2}(s_n - l_0 - l_1\cos\theta_2)] \quad (7)$$

where

$$a = \frac{2l_1}{l_2^2}(l_0 - s_n); \qquad b = \frac{2Hl_1}{l_2^2};$$

$$c = \frac{l_2^2 - l_1^2 - s_n^2 - H^2 + 2l_0s_n - l_0^2}{l_2^2};$$

H is the body height, and *s* is the foot distance from the body (Fig. 3). We also define the angle θ_{3adj} as

$$\theta_{3adj} := \pi/2 - \theta_3 \quad (8)$$

which is used in the simulations, since θ_3 is often grater than $\pi/2$. Angle θ_{3adj} is the angle between the perpendicular with respect to axis x_2 and axis x_3.

IV. Simulation Results

Our model was simulated on a flat floor. The robot parameters were chosen to be and are present in Table I.

TABLE I
LENGTH OF THE LINKS OF EACH LEG

link	1	2	3
length	0.07[m]	0.285[m]	0.31[m]

The body length is $b_1 = 0.56m$ and body base $b_2 = 0.24m$. All the time, the height of the body with respect to the ground remains constant. For the simulations, we use the inverse kinematics solution to compute the joint angles of the leg based on the desired change in the orientation θ of the robot.

The simulation is performed for circular motion of the robot with radius of curvature equal to 1m. The desire change in the orientation is Δθ=0.35rad which is on the limit in the range of motion of the joints.

The simulations are performed for the front right leg when the robot is walking at a constant height $H = l_3$ and the foot distance (in t=0) is $s = l_1 + l_2 = 0.355m$. Figure 5 plots the evolution of the thoracic (θ_1) of orientation θ of the robot during the supporting phase of the leg.

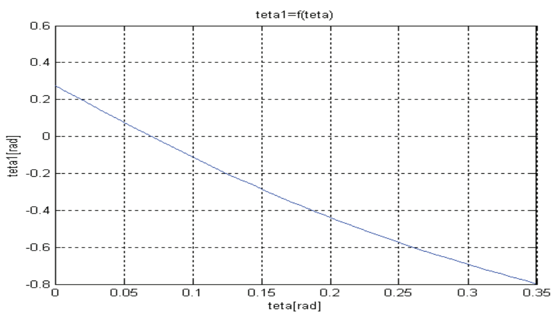

Fig.5 Circular robot motion (supporting phase): Evolution of the thoracic joint angle θ_1 as a function of the change of angle θ of the robot with respect to an inertial frame

Figure 6 plots the evolution of the hip joint angle θ_2 and knee joint angle θ_3, respectively, in the range of change of the thoracic joint angle θ_1 during the support phase of the leg.

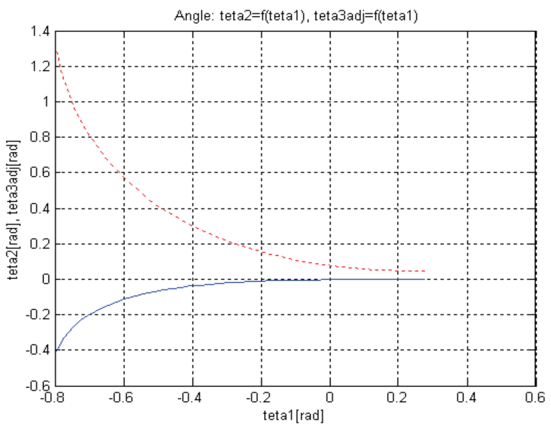

Fig. 6 Circular robot motion (supporting phase): evolution of the hip θ_2 (solid line) and the knee $\theta_{3\ adj}$ (dashed line) joint angles in the range of change of the thoracic joint angle θ_1

V. Conclusion

The proposed visual control of six-legged robot is described as a conception which is tested in some particular cases, but in the future works it must be examined for more different and complicated situations both for existing of visual and audio objects in the area of robot observation and too for more difficult moving scenarios.

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