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# Design of Humanoid's Lower Limbs Model and Phases of Walking

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## BIOGRAPHICAL NOTES

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## KEY WORDS

Humanoid, Robosoccer

## ABSTRACT

This paper describes basic principles of the kinematic structure design for two - leg walking robots. The article deals with the design of walking phases detailed, which is described in sagittal and frontal plane so that movement of the centre of gravity was outside the support polygon and also offers the model of walk for the concrete construction of the two - leg walking robot. This article is the result of research activities of our department in humanoid robotics.

## 1. Introduction

In recent years come to the forefront the humanoid robots. The aim of the humanoid robotics is to approximate a bipedal principle of human walk. At our workplace, at The Department of Production Systems and Robotics deals with the small humanoid robot intended for robosoccer. The fundamental phenomenon of the robot's design is the solution of walking and stability securing.

Versatility and terrain adaptability is limited up to certain level due to the complexity of the walking principle and the control of robot movement alone. This paper deals with the particular solution of the principles problem and design of the mathematical model of walking of the designed two-leg walking robot [11].

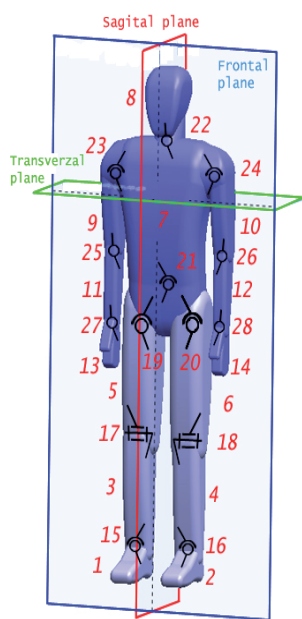
## 2. The principle of human walking

When designing the structure of walk for bipedal walking robot constructed according to human as a model, it is necessary to choose the type of robot's walk and to define the fact up to which level we wish to imitate the human walk [4]. There is necessary to take into consideration the dynamic body stability of the human being using by walking. That means that in any phases of movement the centre of body gravity doesn't appear the bearing surface. Dynamic stability uses the potentiality of inertial body strength and their parts so to avoid

the overturning into uncontrolled position (falling). Used are the principles of counterbalance's transmission and affect of inertial moments, for example the arms swing contrary with the opposite leg. Human being uses by the movement the mammals' posture which is characteristic in legs' holding and motion in sagittal plane Fig. 1 square with longitudinal body axis. The legs of mammals have a pendulum motion, what achieve to reach the high speeding with low energy consumption for the movement. The animals with mammal's posture are able to move by walking, fast walking, running and jumping [9]. All the movements operated by human being during the motion are complicated. These movements consist of motion of individual body parts. These body parts are designated as the locomotive segment. In Fig. 1 are depicted the locomotive segments of human being, which are able to applied just for our walking humanoid robot.

## 3. Design of humanoid's lower extremities model

The design of walking structure for the robot with twelve-grade movement freedom of lower extremities Fig. 2 and Fig.3 is shown at the picture Fig. 4. It is a stationary steady way of walking, where in every moment of system's movement the robot's centre of gravity will be above the bearing surface of foot.



LOCOMOTIVE SEGMENTS	JOINTS
1 – Foot of right leg	15 – Ankle joint of right leg with 3° movement freedom
2 – Foot of left leg	16 – Ankle joint of left leg- 3° movement freedom
3 – Shank of right leg	17 – Knee joint of right leg -1° movement freedom
4 – Shank of left leg	18 – Knee joint of left leg with 1° movement freedom
5 – Thigh of right leg	19 – Hip joint of right leg with 3° movement freedom
6 – Thigh of left leg	20 – Hip joint of left leg with 3° movement freedom
7 – Trunk	21 – Movement of trunk with 3° movement freedom
8 – Head	22 – Movements of neck with 2° movement freedom
9 – Arm of right upper extremities	23 – Shoulder joint of right upper extremities with 3° movement freedom
10 – Arm of left upper extremities	24 – Shoulder joint of left upper extremities with 3° movement freedom
11 – Forearm of right upper extremities	25 – Elbow joint of right upper extremities with 2° movement freedom
12 – Forearm of left upper extremities	26 – Elbow joint of left upper extremities with 2° movement freedom
13 – Right hand	27 – Carpal joint of right hand with 2° movement freedom
14 – Left hand	28 – Carpal joint of left hand with 2° movement freedom

Fig. 1: Coordinate system and basic locomotive segments of human body.

$\alpha_R, \alpha_L, \beta_R, \beta_L$  - angles of movement of the legs to the side;  $\delta, \varphi, \lambda$  - angles when moving to the front,  $k$  - lenght step

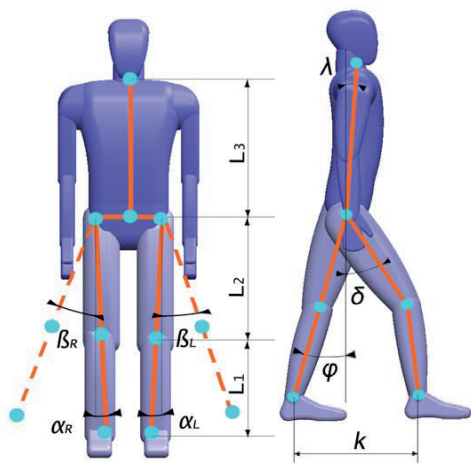


Fig. 2: Kinematic scheme of human for our designed robot.

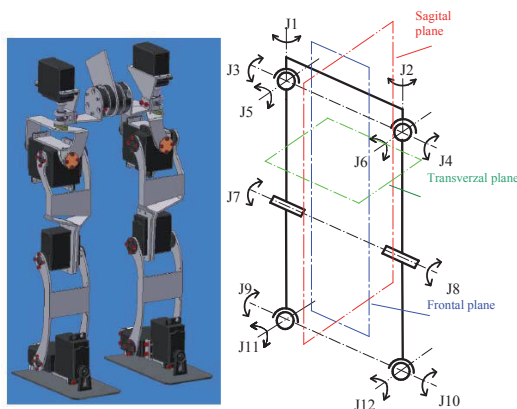


Fig. 3: 3D model and kinematic scheme of designed robot.

Legenda: J1 – J12 – grades of robot's movement freedom

This modified walking has significantly smaller claim to control and mathematical depiction [2]. The walk has in this design firmly determined step's parameters, which are during the walking unchangeable. The step cycle is divided into 13 phases. In individual phases of robot's step the legs occur in bearing or in transferable phases, in which they change their position in space [7]. The individual end parts and knots are in motion in elliptical, circular and linear trajectories, which are bound in motion of kinematic structure's end point.

#### 4. Mathematical calculation of the robot's trajectory - phase No.3

To calculate the individual robot movements within the space applied have been the calculations using the vector method of the inversion kinematics [3]. Known are the parameters of the end element trajectories of the kinematic chain and applying the goniometrical functions and cosine theorem calculated can be the angular displacement of the individual robot joints. Application of the vector method calculation of the angular coordinates significantly simplified the overall calculations of the robot movements and the drives control as well. To illustrate the calculation was chosen phase No. 3 set off by left leg, because in this phase is showed the motion trajectory of robot's leg.

The step length used in the calculation is  $k = 240$  mm. During the transfer phases of legs the ankle with the foot move parallel with the support along ellipse with the shorter axis 30 mm long, and therefore the step height is  $v = 30$  mm [6]. The length of the thighbone is  $a = 110$  mm, length of calf bone

Phase	Plane	Representation	Phase	Plane	Representation
1. Move to crouch	S		2. Tilt right	F	
3. Sidestepping left foot	S		4. Straightening the right leg at the knee	S	

<p>5. Tilted to the left leg</p> <p>F</p> <p>axis in motion axis at rest</p> <p>J5 J6 J11 J12 J1 J2 J3 J4 J7 J8 J9 J10</p>	<p>6. Sinking hip</p> <p>S</p> <p>J3 J4 J7 J8 J9 J10 J1 J2 J5 J6 J11 J12</p>
<p>7. Sidestepping the right foot</p> <p>S</p> <p>axis in motion axis at rest</p> <p>J3 J7 J9 J1 J2 J4 J5 J6 J8 J10 J11 J12</p>	<p>8. Hip pitch</p> <p>S</p> <p>J3 J4 J7 J8 J9 J10 J1 J2 J5 J6 J11 J12</p>
<p>9. Tilted to the right leg</p> <p>F</p> <p>axis in motion axis at rest</p> <p>J5 J6 J11 J12 J1 J2 J3 J4 J7 J8 J9 J10</p>	<p>10. Sinking hip</p> <p>S</p> <p>J3 J4 J7 J8 J9 J10 J1 J2 J5 J6 J11 J12</p>
<p>11. The inflow of the left foot robot</p> <p>S</p> <p>axis in motion axis at rest</p> <p>J6 J8 J10 J1 J2 J3 J4 J5 J7 J9 J11 J12</p>	<p>12. Straightening robot</p> <p>F</p> <p>J5 J6 J11 J12 J1 J2 J3 J4 J7 J8 J9 J10</p>
<p>13. Straightening legs robot</p> <p>S</p> <p>axis in motion axis at rest</p> <p>J3 J4 J7 J8 J9 J10 J1 J2 J5 J6 J11 J12</p>	<p>Legend:</p> <ul style="list-style-type: none"> <li>---- Free leg</li> <li>— Ground leg</li> <li>— Right leg</li> <li>— Left leg</li> <li>• CoG</li> </ul>

Fig. 4: Phases of step of modified robot walking.

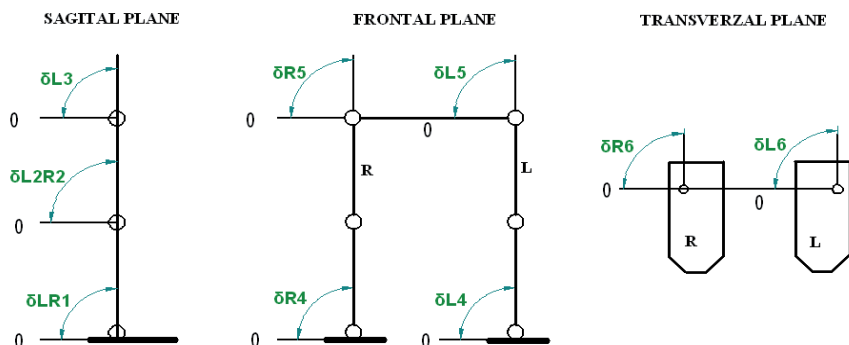


Fig. 5: Marking and orientation of calculation's angles of individual joints and the basic extent of robot.  
 $\delta R$  - angles of motors' slewing in the right foot; angles of motors' slewing in the left foot

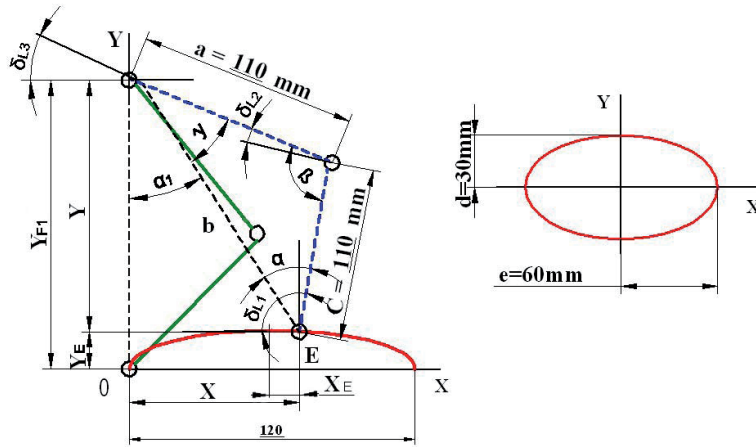


Fig. 6: Graphical demonstration of the movements in phase No. 3 and description of the trajectory parameters.

is  $c = 11$  mm and distance of the hip joint is  $p = 115$  mm. the designation of the calculation angles needed for the drives movement and basic dimensions of the kinematic structure are given in Fig. 5.

Phase No. 3 is step out with robot's left leg by the half step length  $k/2 = 120$  mm, Fig. 5. As the trajectory selected was the ellipse with the parameters given in Fig. 6. The controlling parameter for the calculation of the angle co-ordinates is the value  $X_E = (-60/+60)$ . Values  $d$  and  $e$  are the constants given by the ellipse dimensions [5]. Value  $a$  represents the length of the thighbone and value  $c$  is the length of the shank bone. Value  $Y_{F1}$  is the last value of the co-ordinate  $Y$  in phase No. 1.

From equation follow [8]:

$$Y_E = d * \sqrt{1 - \left(\frac{X_E}{e}\right)^2}, \quad (1)$$

$$X_E = (-60/+60)$$

■ **For the co-ordinate of the ankle holds:**  $Y = Y_{F1} - Y_E$ ;  $X = 60 + X_E$

■ **for the created triangle with sides  $X, Y, Z$  holds:**

$$b = \sqrt{Y^2 + X^2} \quad (2)$$

■ **from cosine theorem for the angles  $\alpha, \beta, \gamma$  holds:**

$$\alpha = \arccos\left(\frac{b^2 + c^2 - a^2}{2 * b * c}\right) \quad (3)$$

$$\beta = \arccos\left(\frac{a^2 + c^2 - b^2}{2 * a * c}\right) \quad (4)$$

$$\gamma = \arccos\left(\frac{a^2 + b^2 - c^2}{2 * a * b}\right) \quad (5)$$

■ **for the auxiliary angle  $\alpha_1$  holds:**

$$\alpha_1 = \arccos\frac{Y}{b} \quad (6)$$

■ **for the angles of the drives rotation hold:**

$$\delta L1 = 90 + \alpha - \alpha_1 \quad (7)$$

$$\delta L2 = \beta - 90 \quad (8)$$

$$\delta L3 = 90 - \gamma - \alpha_1 \quad (9)$$

## 5. Conclusion

The aim of this paper was to describe the principle of the locomotive apparatus based on the human biology, design of the appropriate model of walking and its mathematical description. This walk is solved as the statically stable in each instant of movement [10]. Designed system of robot walking provides the sufficient stability in its movement by the centre of gravity transfer above the individual supporting areas of feet. After detailed analysis of walking system's acting with designed walk's type we will to develop the new walk's types with respect to optimise and to keep the stability of two-leg robot's step.

## 6. Acknowledge

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