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# Design Of Humanoid's Lower Limb Model

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**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 sagital 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.

**Keywords:** humanoid, robosoccer.

## 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. The Technical University of Košice 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 concrete solution of the principles problem and design of the mathematical model of walking of the designed two-leg walking robot.

## 2. The motion characteristics of human

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. 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, as 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 mammal´s posture which is characteristic in leg´s holding and motion in sagital plane Fig. 1 square with longitudinal body axis. The legs of mammal´s 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. 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.

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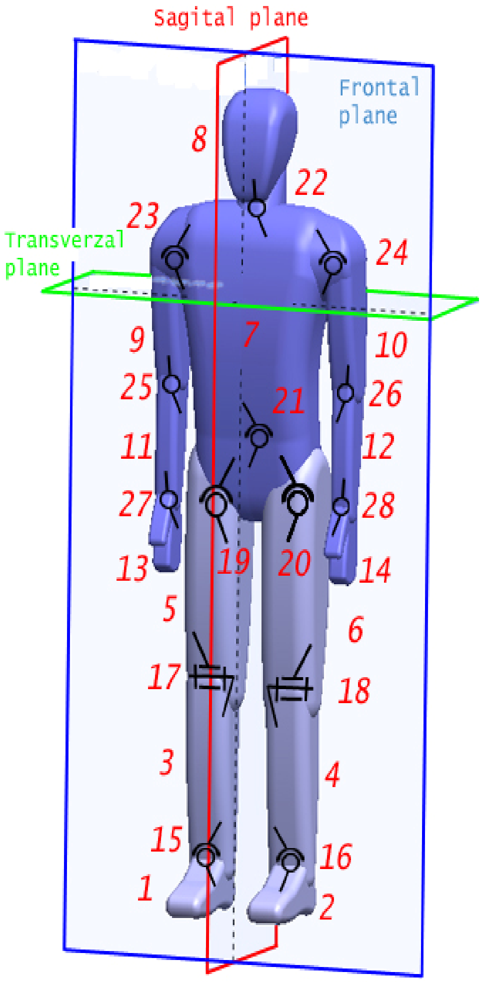



| LOCOMOTIVE SEGMENTS | JOINTS |
|---|---|
| 1 – Foot of right leg | 15 – Ankle joint of right leg with 3° movement freedom |
| 2 – Foot of left leg | 16 – Ankle joint of left leg- 3° movement freedom |
| 3 – Shank of right leg | 17 – Knee joint of right leg -1° movement freedom |
| 4 – Shank of left 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

The walk is complicated succession of the lower extremities´ movements, which follow consecutive one by one and repeat regularly. By walking is minimally one leg steadily in contact with pad and the second leg make the transmission phase. The structure of walking chassis mainly depend on complexity of used kinematic chain in given mechanism, also mainly on number of grade robot's movement freedom.

## 3. Design of humanoid's lower limb of model and phases of walking

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

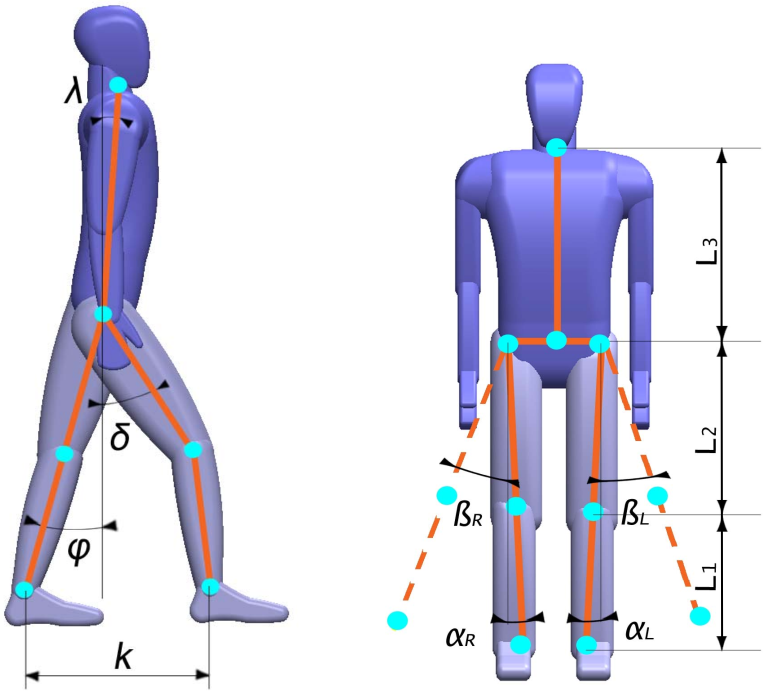



Fig. 2: Kinematic scheme human for our designed robot

$\alpha_R$, $\alpha_L$, $\beta_R$, $\beta_L$ - angles of movement of the legs to the side; δ, φ, λ - angles when moving to the front, k - lenght step

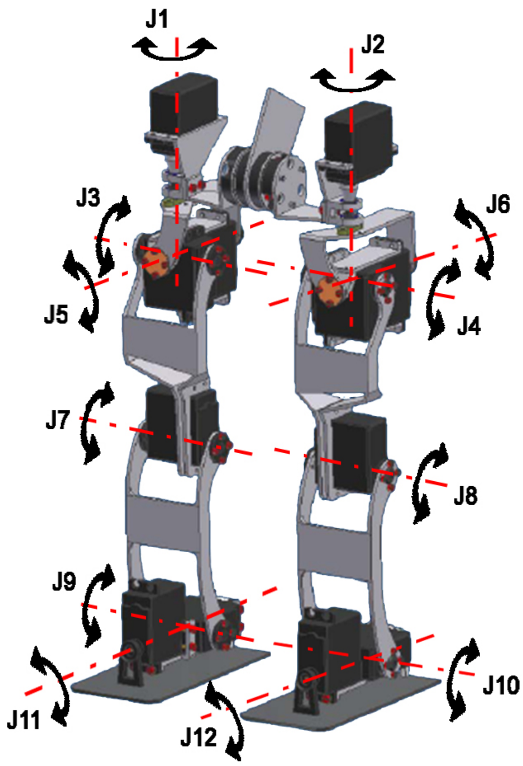
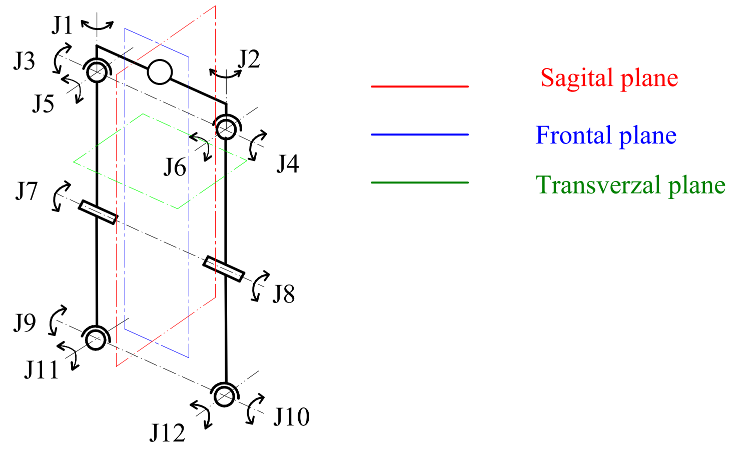
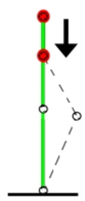
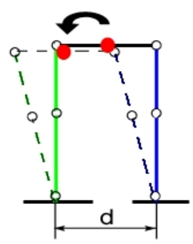
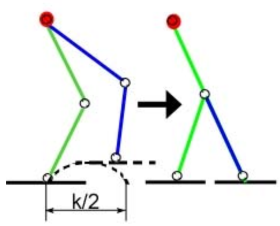
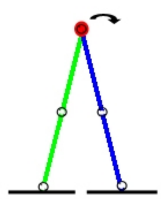
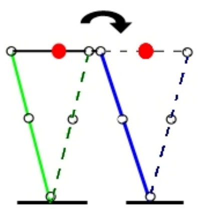
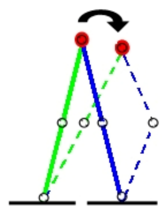



Fig. 3 3D model and kinematic scheme of designed robot J1 – J12 – grades of robot's movement freedom

This modified walking has significantly smaller claim to control and mathematical depiction. 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. 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.

| Kinematic scheme of designed robot | | | | | |
|---|---|---|---|---|---|
|  | | | | | |
| **bPhase** | **Plane** | **Representation** | **Phase** | **Plane** | **Representation** |
| **1. Move to crouch** | **S** |  | **2. Tilt right** | **F** |  |
| **axis in motion** | J3 J4 J7 J8 J9 J10 | | | J5 J6 J11 J12 | |
| **axis at rest** | J1 J2 J5 J6 J11 J12 | | | J1 J2 J3 J4 J7 J8 J9 J10 | |
| **3. Sidestepping left foot** | **S** |  | **4. Straightening the right leg at the knee** | **S** |  |
| **axis in motion** | J4 J8 J10 | | | J7 J9 | |
| **axis at rest** | J1 J2 J3 J5 J6 J7 J9 J11 J12 | | | J1 J2 J3 J4 J5 J6 J8 J10 J11 J12 | |
| **5. Tilted to the left leg** | **F** |  | **6. Sinking hip** | **S** |  |
| **axis in motion** | J5 J6 J11 J12 | | | J3 J4 J7 J8 J9 J10 | |
| **axis at rest** | J1 J2 J3 J4 J7 J8 J9 J10 | | | J1 J2 J5 J6 J11 J12 | |

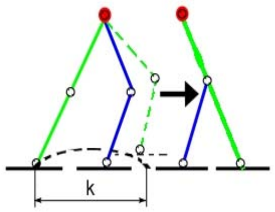
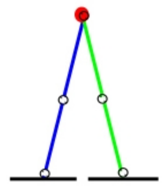
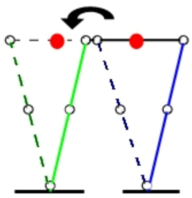
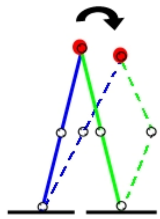
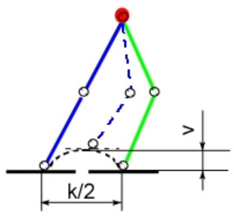
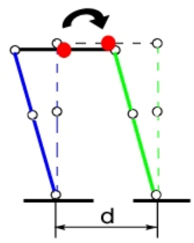
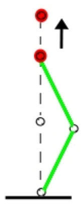
| | | | | | |
|---|---|---|---|---|---|
| **7. Sidestepping the right foot** | **S** |  | **8. Hip pitch** | **S** |  |
| **axis in motion** | J3 J7 J9 | | | J3 J4 J7 J8 J9 J10 | |
| **axis at rest** | J1 J2 J4 J5 J6 J8 J10 J11 J12 | | | J1 J2 J5 J6 J11 J12 | |
| **9. Tilted to the right leg** | **F** |  | **10. Sinking hip** | **S** |  |
| **axis in motion** | J5 J6 J11 J12 | | | J3 J4 J7 J8 J9 J10 | |
| **axis at rest** | J1 J2 J3 J4 J7 J8 J9 J10 | | | J1 J2 J5 J6 J11 J12 | |
| **11. The inflow of the left foot robot** | **S** |  | **12. Straightening robot** | **F** |  |
| **axis in motion** | J6 J8 J10 | | | J5 J6 J11 J12 | |
| **axis at rest** | J1 J2 J3 J4 J5 J7 J9 J11 J12 | | | J1 J2 J3 J4 J7 J8 J9 J10 | |
| **13. Straightening legs robot** | **S** |  | **Legend:**<br>----- Free leg<br>—— Ground leg<br>—— Right leg<br>—— Left leg<br>• CoG | | |
| **axis in motion** | J3 J4 J7 J8 J9 J10 | | | | |
| **axis at rest** | J1 J2 J5 J6 J11 J12 | | | | |

Fig.4 Phases of step of modified robot walking

### 3.1 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. 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 co-ordinates 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 **d** = 30 mm. The length of the thighbone is **a** = 110 mm, length of calf bone is **c** = 110 mm and distance of the hip joint is **p** = 115 mm.

Phase No. 3 is step out with robot's left leg by the half step length **k/2** = 120 mm. As the trajectory selected was the ellipse with the parameters given in **Fig. 5**. 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. Value **a** represents the length of the thighbone and value **c** is the length of the shank bone. Value $\mathbf{Y_{F1}}$ is the last value of the co-ordinate Y in phase **No. 1**.

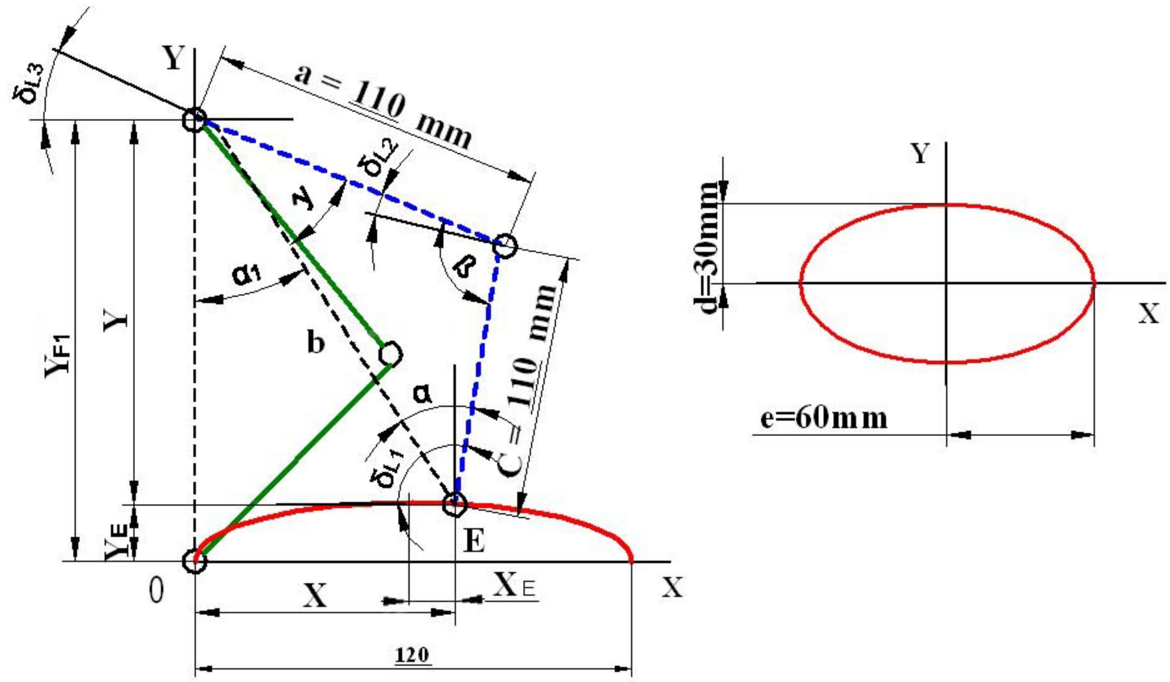



Fig. 5 Graphical demonstration of the movements in phase No. 3 and description of the trajectory parameters

From equation follow:

$$Y_E = d * \sqrt{1-\left(\frac{X_E}{e}\right)^2}\ , \quad X_E = (-60\,/\,+60) \tag{1}$$

-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:

$$b = \sqrt{Y^2 + X^2} \tag{2}$$

-from cosine theorem for the angles α, β, γ holds:

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

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

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

for the auxiliary angle α1 holds:

$$\alpha 1 = \arccos\frac{Y}{b} \tag{6}$$

for the angles of the drives rotation hold:

$$\delta L1 = 90 + \alpha - \alpha 1\ ; \tag{7}$$

$$\delta L2 = \beta - 90; \tag{8}$$

$$\delta L3 = 90 - \gamma - \alpha 1 \tag{9}$$

The model of robot's walk designed in the Fig. 4 maintains at any moment instant the static stability, that means, that the perpendicular projection of the centre of gravity into the horizontal plane still exists above the supporting area formed by one or two feet.

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