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STRUCTURAL-KINEMATIC MODELING OF HUMAN BODY ANKLE JOINT MECHANICAL SYSTEMS – PART I

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ABSTRACT

In the paper, on the grounds of the bone structure of the human foot, are presented the articulated mechanical models – moved by linear actuators, like the mechanical models with cogged sprockets, models which can be accepted at biped robots, respectively for modeling the articulated shank.

Keywords: human foot, articulated model, gear model.

1. THE ARTICULAR BONE STRUCTURE OF THE HUMAN FOOT

It’s well known that the bone structure of the human foot is especially complex, starting from the ankle towards the toe we meet the bones: calcaneus, talus, cuboideum, navicularis, 3 cuneiformia and 5 metatarsus (fig. 1), [3].

Their shape, the disposing pattern and the joints make a perfect structure for adapting and biped motion, for taking over the weight of the body and of the reactions from the ground. Through the double concavity vault which it forms, the weight of the body is transmitted to the ground through 3 support points (fig. 2, a), a hinder (la calcaneus) and two front ones (at the head of metatars) building itself up like a twisted board of resistance and support (fig. 2, b).

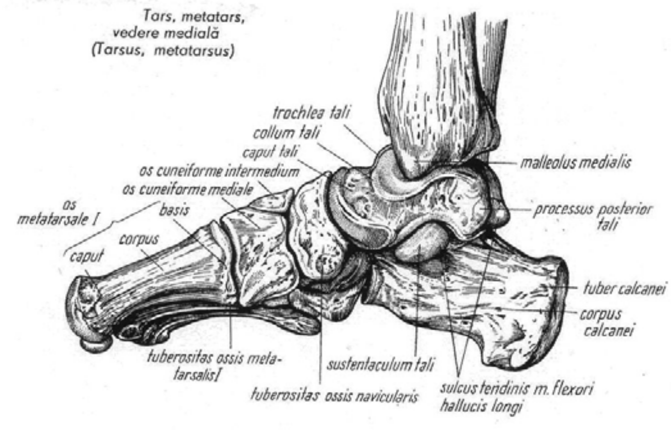
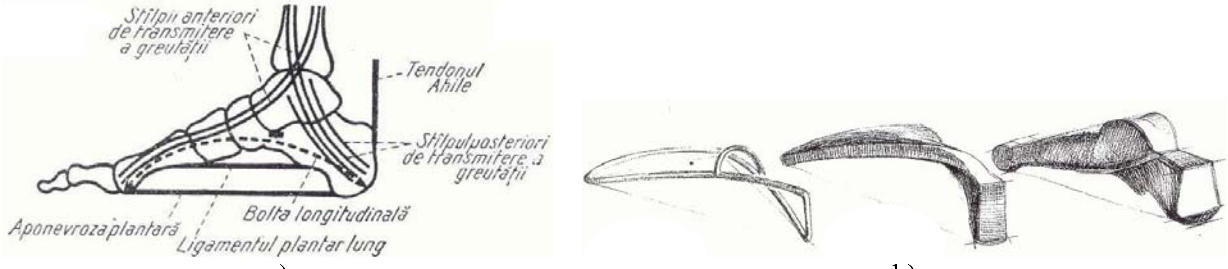


Figure 1.



a) b)

Figure 2.

The talus bone together with the ankle’s bones (tibia-fibula) build the ankle’s articulation / joint, allows the foot to have two main rotations: a flexion-extension rotation around the transversal axes y and a pronation-supination rotation around an approximate longitudinal axis x (fig. 3).

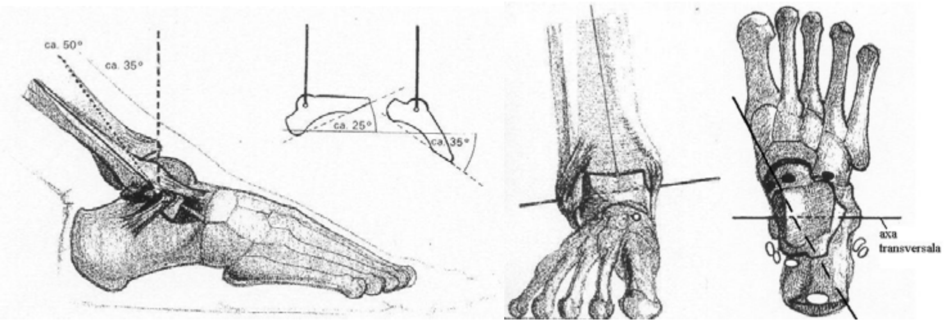
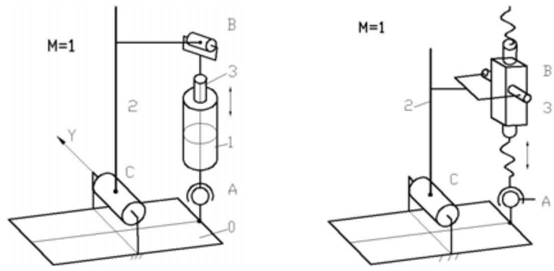


Figure 3.

Obviously the modeling can be made also with only rotation joints in the ankle.
If we shouldn't take into consideration the multitude of ligaments, tendons and the complexity of the contact shapes, but just the foots bones, the deduction would still be that a mechanical structure which is able to equal the biological structure is impossible to realize, continuing to propose us to follow just the pattern of the ankle's main movements.

2. THE ARTICULATED MECHANICAL MODELS FOR THE ANKLE

Any mechanical structure which is able to mould the ankle's joint must first allow the **flexion-extension** rotation around the transversal axis z. such a articulated structure is presented in figure 4, with an action through linear actuators (fig. 4,a) or with a screw (fig. 4,b), to which the mobility degree $M = \Sigma f_i - S$, f_i – the coupling's mobility and $S = 3$ respectively 4: $M = 4 - 3 = 1$, respectively $M = 5 - 4 = 1$, [1].
In these models the foot (the instep) has been considered as fix, and the shank 2 gets the flexion-extension rotation at the relaxation-compression of the third (3) actuator.
A structure with spherical joint at the ankle needs stabilization springs in transversal plane (fig. 5), the mechanism having the spatiality $S = 6$ and 4 couplings (STRS), so $M = \Sigma f_i - S = 8 - 6 = 1^a + 1^c$, meaning an active and a compliant mobility.



a) b)

Figure 4.

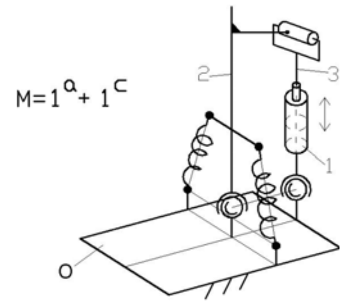
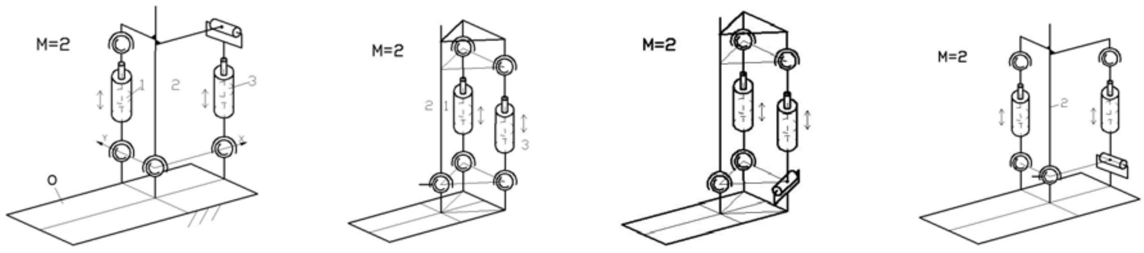


Figure 5.

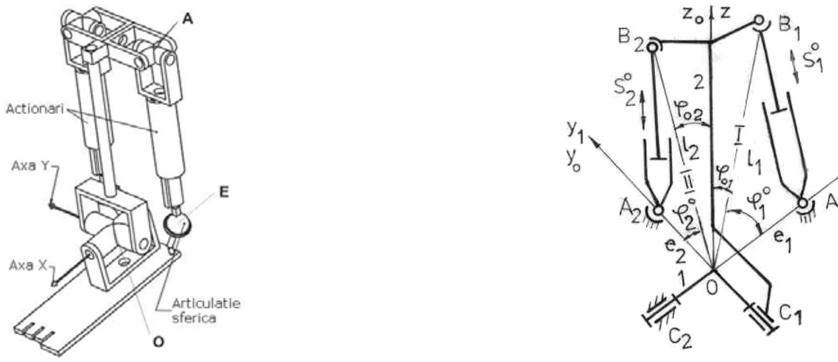
The structures with two active mobilities, meaning with 2 motor sources, which produce both the flexion-extension around axis y, and the pronation-supination around axis x, are spatial, with two outlines, having 7 couplings (4S2T1R – fig. 6,a): $M = \Sigma f_i - kS = 15 - 2 \cdot 6 = 2^a + 1^p$. Scuh structures are presented in figure 6.



a) b) c) d)

Figure 6.

A spatial articulated structure ($S = 6$) with the modeling of the ankle C through cardanic joint is presented in figure 7 (6R2T2S) the structure having M = 2, able to realize both the flexion and the pronation. The structure can have cardanic joints also at the actuator (fig. 7, a) or just at ankle (fig. 7, b).



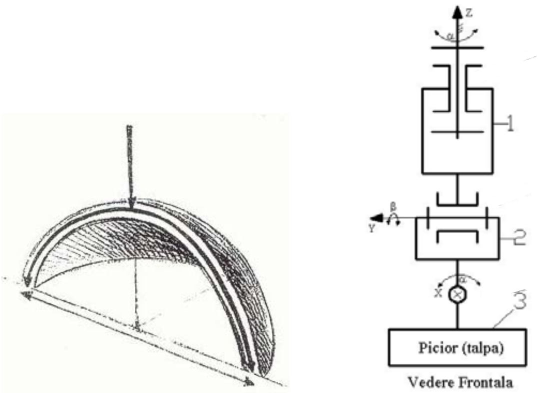
a) b)

Figure 7.

3. MECHANICAL MODELS WITH GEARS FOR THE ANKLE

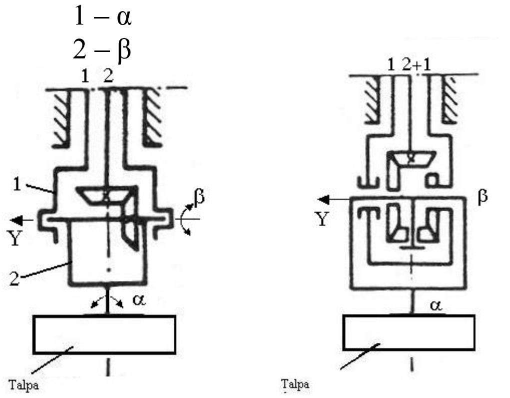
A classical solution for biped robots is the disposing of motoreduction gears directly on the axis' x, y, z of the inferior limb for the realization of the rotation α – pivoting, γ – pronation (fig. 8).

In the case of disposing the engine with the axis along the shank, the model for the realization of the **flexion β** can contain a conical gear or a conical planetary (fig. 9) – to which the rotation axis of the driven wheel, respectively that of the satellite's arm, is the axis y of the joint [2].



a) b)

Figure 8.



a) b)

Figure 9.

A similar construction can be imagined for the realization of the **pronation γ**, with the specification that the driven wheel's axis, respectively that of the postsatellite arm, should be disposed after the longitudinal axes x of the foot.

The model which should combine the two rotations **rotations β-γ** (fig. 10), the **flexion-pronation** around the axis' y-x, can have the structural alternatives form figure 11, in which:

a) – the action 1 brings about directly pronation γ, and the action 2 brings about the flexion β through conical gears;

b) – the two actions 1 and 2, through the conical wheels, produce the rotation γ and β;

c) – the actions 1 and 2, as the precedent ones, can be separated or combined;

d) –the actions 1 and 2 are differentially combined, the satellite arms rotations marks the angle γ, and the revolution rotation of the arm causes the rotation of the frame with the angle β.

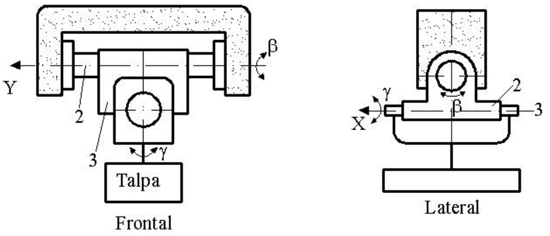
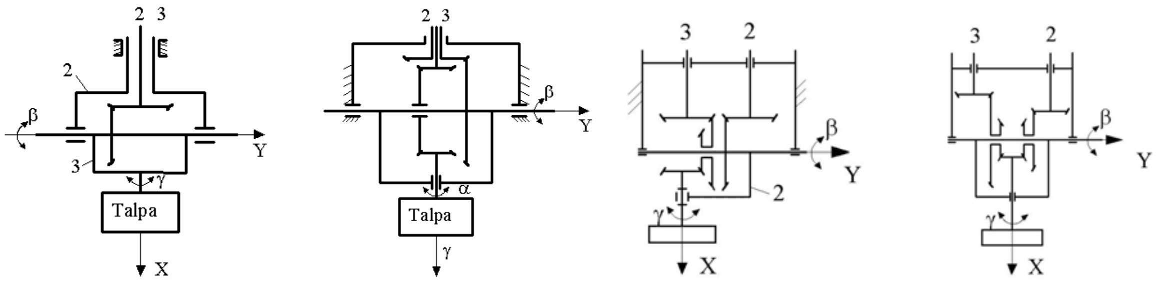


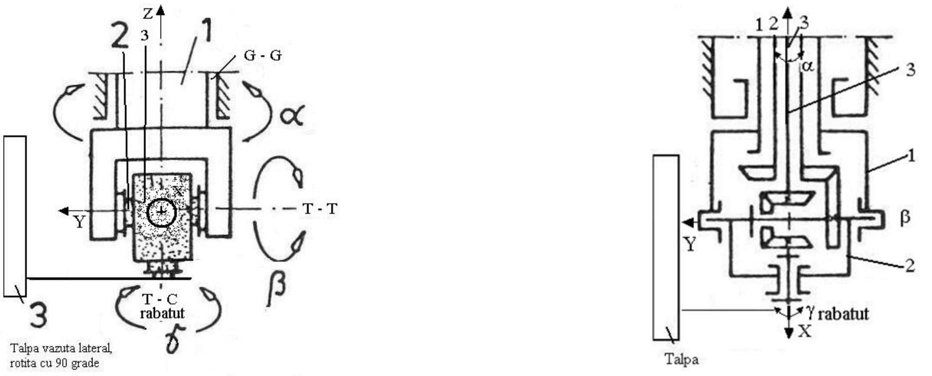
Figure 10.



a) b) c) d)

Figure 11.

Also the inclusion of the **pivoting α** around the axis z (fig. 12), would lead to a pretty heavy structure.



a) b)

Figure 12.

4. CONCLUSIONS

The modeling of the biological structure of the human foot and of it's movements through mechanical structures is quite hard to do, due to the structure and action's complexity. Mechanical system solutions with articulated rods or with gears, respectively through linear or rotative actuators, presented in the paper, can build up the ground for the kinematic modeling of these ones, with the view to establish the best variant.

5. REFERENCES

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