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MODELLING A BIPED MONOMOBILE MECHANICAL SYSTEM ADDITIVE MANUFACTURED

Ileana DUGĂEȘESCU, Vlad-Cristian ENACHE

Abstract: *Monomobile mechanical systems are composed of an active modular group and one or more passive modular groups such as dyad, triad s.a. This paper presents the modelling of the component parts of a mobile biped mechanical system with one degree of mobility, as well as the assembly proces. Afterwards the paper presents the 3D printing parameters and the stages for achieving the experimental model. The biped monomobile mechanical system obtained after printing and assembly of the kinematic elements can be actuated with an electric motor connected to an Arduino Uno board. Various sensors can be mounted on the experimental model, depending on the specific need of the user.*
Key words: *planar mechanical system, biped, modelling, additive manufacture, 3D printing*

1. INTRODUCTION

The main objective of this paper is the development of a prototype using additive manufacturing. In recent years, the additive manufacturing technologies have seen significant improvements, which gave users the possibility of making products that are more complex. The newest 3D printing technologies are now portable and can produce a part faster than conventional methods.

The first automated biped robot was built by Kato and his group from Wasada University [7]. Biped robots can be smaller and lighter and can avoid certain obstacles as well as measure distances [7]. The structural analysis is presented at the beginning of this paper in order to establish the steps for kinematic analysis for end-effector mechanical systems.

The modeled kinematic elements and resulting mechanical system obtained after the assembly process are the subject of the subsequent chapters. Following the modelling phase, the 3D printing and assembly of the components represent the next step.
Finally, the electronic components are mounted and connected to the Arduino UNO board.

2. STRUCTURAL ANALYSIS OF THE MECHANICAL SYSTEM'S LEG

The kinematic scheme of the leg can be seen in figure 1.

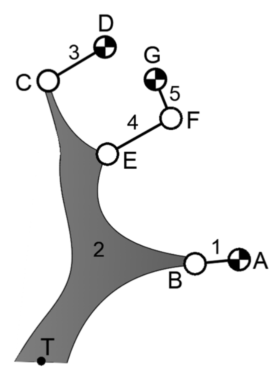


Fig. 1. The kinematic scheme of the leg.

Formula (1) can be used for computing the degree of mobility for the mechanical system, where m represents the number of mobile kinematic elements and i is the number of inferior joints [1,2].

$$M = 3 \cdot m - 2 \cdot i \quad (1)$$

The planar mechanism has five mobile kinematic elements (m=5) and seven rotation kinematic pairs (i=7), therefore the system has one degree of mobility (M=1).

This end-effector has one active modular group (AMG) and thus a single motor can operate two identical parallel mechanisms.

The kinematic scheme of the planar system is used to elaborate the structural scheme. The structural model presented in figure 2 is obtained from the Stephenson fundamental chain [1,2].

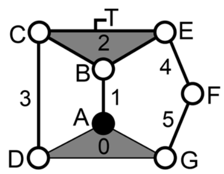


Fig. 2. The structural scheme corresponding to the kinematic scheme from Fig. 1.

Figure 3 illustrates the modular group connections: one active modular group (AMG) and two passive modular groups, which are dyads with three rotational joints (RRR).

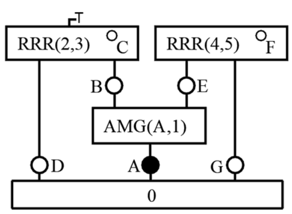


Fig. 3. The modular group connections.

3. KINEMATIC CHARACTERISTICS OF THE MECHANICAL SYSTEM'S LEG

The known prerequisites for computing the kinematic parameters of the active modular group AMG(A,1) and the passive modular groups are: the length of the kinematic elements, positions (Φ), velocities (ω), accelerations (ε) of points A and the coordinates of joints A, D and G, as presented in table 1.

Table 1

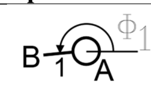
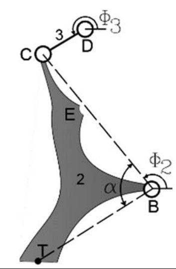
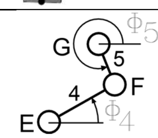
Input data of mechanical system.

Description	Parameters
Length of kinematic elements	AB, BC, DC, BE, BT, EF, GF
Coordinates of points A, D and G	XA,YA; XD,YD; XG,YG
The values of angle for kinematic element 1	ϕ_1
Velocity of point A	ω_1
Acceleration of point A	ε_1

Table 2 presents the modular groups and the positional parameters.

Table 2

Modular groups.

Name	Representation
AMG (A, 1)	
Dyad RRR(2,3)	
Dyad RRR(4,5)	

The figure 4 illustrates the positional dependent parameters of the passive modular group formed by kinematic elements 2 and 3.

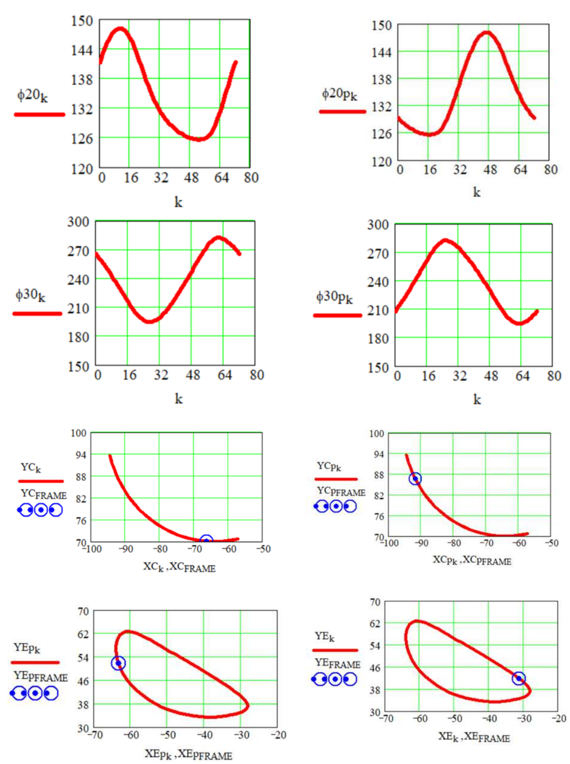


Fig. 4. Dependent parameters of the passive modular group RRR (2,3).

Figure 5 illustrates the positional dependent parameters of the passive modular group formed by kinematic elements 4 and 5. The trajectory of the legs extremities for the parallel mechanisms are presented in figure 6, where the initial position of each leg extreme point is marked.

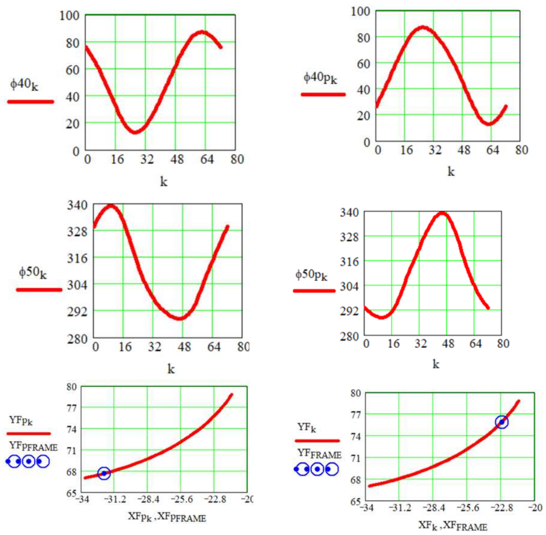


Fig. 5. Dependent parameters of the passive modular group RRR(4,5).

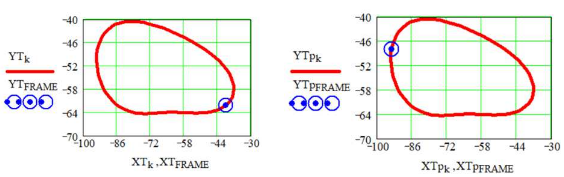


Fig. 6. The trajectories of legs extremities.

3.1 Modelling the components of the mechanical system

The next step in the development of the mechanical system is represented by the modelling of its components. These components are depicted in table 3. The following step is the assembly of the components that were previously modelled. The assembled parts are presented in the figure 7.

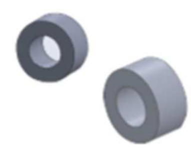
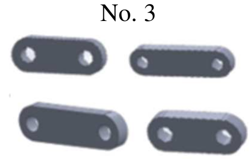
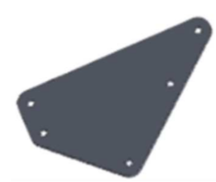
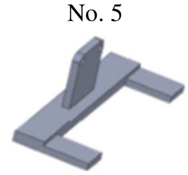
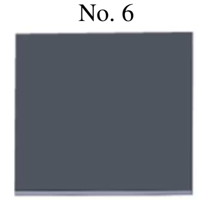
Starting from this model, two parts were chosen as subject for further modification – elements 04 and 06 (Table 3). These components needed some modifications due to their dimensions, so that they would be more suitable for additive manufacturing.

The casing needed some adjustments as to better accommodate the introduction of the electronic components. The element 04 (Table 3) had a wide area that needed to be reduced as to minimize the material quantity and the printing time.

In order to achieve this goal an Automatic design function was used in the modelling process. Inherently, Generative design requires a simulation in order to create a model. Automatic design on the other hand, does not require any forces in order to create the model. It is a design-oriented procedure where the software needs to connect surfaces and can avoid certain unnecessary features. Afterwards, based on the resulting surfaces and the original model, some iterations were randomly generated to fill the space between parts. Starting from the initial design of part04 (Fig. 8a), certain areas are preserved around the holes. After the areas were

Table 3

The modeled components.

No.1 	No. 2 
No. 3 	No. 4 
No. 5 	No. 6 

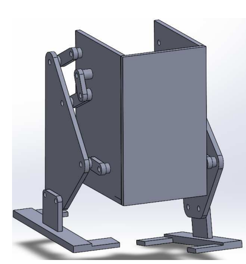
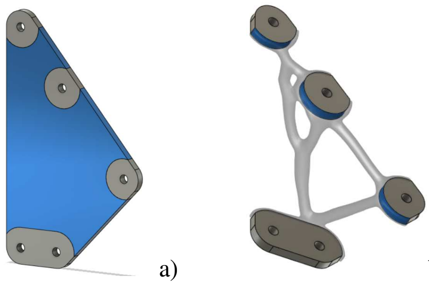


Fig. 7. The first prototype.

split, the inner surfaces of the disjoint components were selected in order to connect them. No other surface was chose as an obstacle. The resulting part can be seen in figure 8.b).



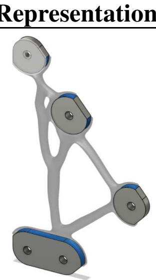
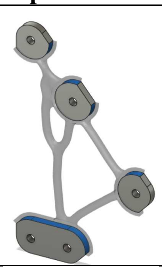
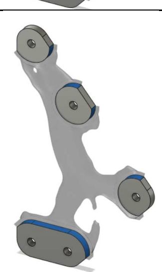
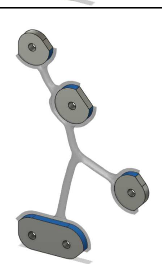
a) b)

Fig. 8. The part 04:
a) Initial form, b) Automated design form.

The Automatic design randomly generates six iterations for the part. From these iterations, the most suitable one was chosen for this model. Not coincidentally, this was the iteration with the thickest walls supporting the weight of the components. The generated iterations are presented in the table 4.

Table 4

Automated design generated iterations.

No.	Representation	No.	Representation
1		4	
2		5	
3		6	

Out of the six results, alternative 2 was chosen for additive manufacturing, as illustrated in figure 9.

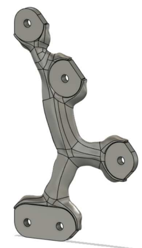


Fig. 9. The chosen element.

After the leg was redesigned, the form of the casing was also updated. The space needed for the electronic components that are going to be added inside the mechanical system was also taken into consideration. The final model is presented in figure 10.

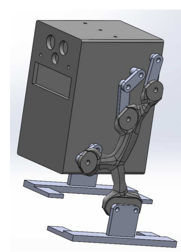


Fig. 10. The mechanical system.

3.2 Additive manufacturing the parts

The process of additive manufacturing consists of constructing an object layer by layer.

Compared to conventional techniques, where you gradually remove material from a block, in the context of additive manufacture, the object is created from scratch. Due to the time it takes to create the final product, it is also commonly referred to as rapid prototyping [3,6].

Another important part of additive manufacturing is establishing the right material for the part. The material's properties are chosen at the same time with the part's shape. Moreover, the strength of the part, its ductility and porosity are affected by the chosen material and the printing parameters [3,6]. For the additive manufacturing step, a FDM (Fused Deposition Modelling) Zortrax M300 machine was used. For the printing material, Z-Hips (High Impact Polystyrene) was chosen because it is a material that is best suited for printing casings and parts due to its high resistance to impact. Moreover, it is a material that has a low maintenance after the post processing stage. Using additive manufacturing the prototype of the mechanical system was constructed. All the files are exported as .STL as to have the ability to insert them into a specialized software for 3D printing. As for the printing parameters, a raft was used for all the parts, so that the bigger components can be removed easily from the printing bed. For infill, we chose a 40% infill so that the components can be durable enough and not suffer any warping in the process of printing.

3.3 Sensors integrated into the mechanical system

After the 3D printing step was completed, all the components were assembled (Fig. 11.).

Fig. 11. The mechanical system.

The mechanical system illustrated above includes the following components: Arduino UNO board, a DC motor, a L293D integrated circuit, an LCD screen, a buzzer, four LEDs and resistors with a value of 220Ω, ultrasonic sensor, a photoresistor and a resistor with a value of 10kΩ (Fig. 12.).

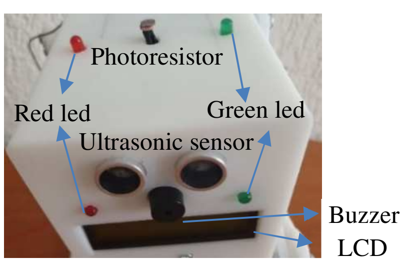


Fig. 12. The components mounted on mechanical system.

The DC motor is connected to the Arduino UNO board using L293D integrated circuit, which is a dual channel H bridge motor driver [4,5]. The ultrasonic sensor is used to measure the distance between sensor and obstacle [4,5]. The functional role of this sensor, mounted on the front surface of the mechanical system, is to stop the DC motor when the detected distance to the target object falls below a certain threshold. The distance from the object and the value from the photoresistor are displayed on the LCD screen as shown in figure 13.

a) b)

Fig. 13. The values of distance and photoresistor: a) green LED light up, b) a) red LED light up

When the crank has a rotational movement the green LED will light up, otherwise the green LED will turn off and red LED will light up. On the LCD screen, a message will be displayed as shown in figure 13. The photoresistor serves the purpose of detecting the presence/absence of light [4,5]. If there is no light in the detection range of the sensor, the green LED will light up and the buzzer will give a certain sound (Fig. 14.a). Otherwise, the green LED will turn off and red LED will light up (Fig. 14.b).

a) b)

Fig. 14. a) The green LED light up – is dark, The red LED light up – the light is present

4. CONCLUSION

The work covered in this paper presented the development process of a prototype for a biped mechanical system starting with the analysis phase up to the final assembly and integration with electronic components. The analysis stage included highlighting the kinematic characteristics of the modular groups and the trajectories described by extremities of the leg mechanisms.

The modelling stage was subsequently followed by the construction of the components by means of additive manufacturing. This in turn led to the need of finding a balance between the component topology and material resources (with respect to material used, printing time and the need to later accommodate a series of electrical components inside the casing).

The type of prototyping depicted in this paper can be adjusted in accordance with the client's needs, taking into consideration the parameters of the equipment, the material used and the sizes of the components.

The model was printed on a Zortrax M300 3D printer. The material of choice for 3D printing was Z-Hips. The printing parameters were set to obtain the best possible printing time whilst maintaining a high resistance for the components.

As mentioned previously, additive manufacturing can be especially useful for rapid prototyping. This is particularly relevant for the development of the biped monomobile mechanical system developed in this paper which needed to satisfy practical concerns in terms of material resources as well as integration with various sensors and other electrical components.

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MODELAREA UNUI SISTEM MECANIC MONOMOBIL BIPED FABRICAT ADITIV

Sistemele mecanice monomobile sunt formate dintr-o grupă modulară activă și una sau mai multe grupe modulare pasive, cum ar fi diada, triada s.a. Această lucrare prezintă modelarea părților componente ale unui sistem mecanic biped mobil cu un grad de mobilitate, precum și procesul de asamblare. În continuare, lucrarea prezintă parametrii de imprimare 3D și etaapele de realizare a modeului experimental. Afterwards the paper presents the 3D printing parameters and the stages for achieving the experimental model. Sistemul mecanic monomobil biped obținut în urma printării 3D și asamblării elementelor cinematice poate fi acționat cu un motor electric conectat la o placă Arduino UNO. Pe modelul experimental pot fi montați diverși senzori, în funcție de cerințele specifice ale fiecărui utilizator.

Ileana DUGĂEȘESCU, PhD. Eng., Lecturer, University POLITEHNICA of Bucharest, Manufacturing Engineering, ileana_d1@yahoo.com

Vlad-Cristian ENACHE, PhD. Student, Assistant, University POLITEHNICA of Bucharest, Manufacturing Engineering, enachevlad31@yahoo.com