SIMULATION AND OPTIMIZATION OF THE TRAJECTORY FOR HEXAPOD MINI-ROBOT HEXI

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Abstract - The research paper analyses the structure and kinematics of the mechanisms in the composition of mobile mini-robots, as well as the architecture of a mobile mini-robot model to optimize and correct performance. There are many approaches to mobile robots, there are several types of mobile robots, and the paper addresses the construction and programming of a moving mobile robot with a serial structure, intended for carrying out operations of transporting objects and inspecting surfaces with a high degree of danger. The research paper addresses parallel structures of mobile robots, thus drawing a parallel between the two major types of robots: serial and parallel. Research on parallel structures highlights the advantages of serial structures. The stepping robot is equipment that does not operate in isolation but works with other robots and/or special devices. To obtain flexibility in use, together with autonomy and safety in operation, a unitary approach of both structural parameters (elements that make up the mobile structure of the robot) and kinematic parameters (angular displacements offered by actuators, including the mode of motion transmission) as well as the control parameters.

Keywords: Mobile mini robot, Structure and kinematics of hexapod mini-robot, Angular displacements of hexapod mini-robot, Serial structures.

1. Introduction

Nowadays, there are several types of equipment that can be seen in terms of structure, kinematics, and dynamics as in fact robotic systems. The field of robots is booming, so in 2019, there was a record of 2.7 million industrial robots operating in factories around the world – an increase of 12% in comparison with 2018 (According to the International Federation of Robots).

Japan is the world´s predominant robot manufacturing country, where even robots assemble robots – 47% of the global robot production are made in Nippon. The electrical and electronics industry has a share of 34%, the automotive industry 32%, and the metal and machinery industry 13% of the operational stock.

In total, around 230,000 industrial robots are in use in Germany, in present.

According to a recent report by the Robotic Industries Association, several industries have seen a surge in robotics use in the last year or so. The industries who are seeing the most robotics growth right now are the top 6 industries:

1. Life Sciences and Pharmaceutical
2. Food and Consumer Goods
3. Plastics and Rubber
4. Automotive
5. Semiconductors, Electronics, and Photonics
6. Metals

There has been a strong increase in sales of autonomous robots, especially stepping robots and wheeled robots.

It was estimated in 2021, based on mathematical analysis and reports received by the IFR (International Federation of Robotics), that 345 million autonomous robots or capable of behaving autonomously will be in operation by 2030, a ten-fold increase over the decade.

2. Status of Achievements in the Field

Over time, many researchers have tried to define the term "robot" in the most complete and complex way possible. Thus, the robot is:

- a high-level automated system whose main role is the handling of parts and tools, replacing human action;

- "an automatic system that works according to an established work schedule or reacts to specific external stimuli, giving the impression of human actions"*[3]*;

- "a machine seemingly independent of the human operator, intelligent and obedient, but impersonal"*[4]*;

- "automatically controlled, reprogrammable, programmable multi scope manipulator, in three or more axes, which can be fixed in one place or can be mobile for use in industrial automatic applications";
- "an automatic handling mechanism, controlled in position, reprogrammable, versatile, capable of positioning and orienting specialized materials, parts, tools or devices, during variable and programmed movements, intended to perform various tasks"*[5]*;
- "universal mobile automaton, with several axes, whose movements are freely programmed on the trajectories or angles, in a certain sequence of movements and certain cases, controlled by sensors. It may be equipped with gripping devices, tools, or other means of manufacture and may perform handling of technological activities." (German standard VDI 2860 BI.1)*[6]*;
- "an automatic machine that represents the assembly of the robot and the reprogrammable control device, for the realization in the production process of the motor and control functions, replacing the analogous human functions in the movement of parts and/or technological tools." (Russian standard GOST 25685-83)*[7]*;
- "a mechanical system equipped with flexible motor functions analogous to those of living organisms or combines such motor functions with intelligent functions, systems that act according to human will." (Japanese standard JIS B 0124/1979). In the context of this definition, the intelligent function is the ability of the system to perform at least one of the actions of judgment, recognition, adaptation, or learning" *[8]*;
- "a programmable multifunctional manipulator, oriented towards the transport of specialized materials, parts, tools or systems with a variety of programmable movements to perform various tasks"*[9]*;
- that programmable automaton, which handles objects, handles technological tools, supervises the workplace (machines and the environment), controls and sorts of objects, an automaton that performs the following functions in a manufacturing system: programming, handling, handling, supervision, and control.

Regarding the characteristics of the robots, they are:

- made to perform mainly handling, movement, and transport operations that require speed and accuracy, with limited forces;
- equipped with several degrees of freedom, so that they can perform complex operations, each movement being controlled by the command-and-control unit;
- are equipped with a reprogrammable memory that can be changed by modifying the initial program;
- endowed with a rather low logical capacity, with the help of which they can perform tests and can choose between two alternatives, as well as exchange approval signals with other devices;
- autonomous, functioning without the systematic intervention of man;

In principle, mobile robots should perform general functions, such as:

- acting on the environment with the help of gripping devices;
- obtaining by the perception the information about the environment and one's state and the processing of this information, according to the requirements of the central control system;
- communication with the human operator or other robots, including for his training;
- making decisions to accomplish the desired tasks;

The technical characteristics of pedicular robots include:

- dimensions - which can vary from nanometers (nanobots, nanorobots) to tens of meters (robotic equipment for construction, installations in amusement parks);
- achievable size values - robots can perform operations at distances from nanometers (nanorobots that perform transformations of the input signal into mechanical displacement which is then transformed into a form of the input signal, for example, processing of electrical signals in communications or microsensors) and up to tens of meters (facilities in amusement parks can move people);
- accuracy - depends a lot on the size of the robot and is a qualitative feature that refers to how well the robot operates. For example, for an amusement park installation, the accuracy is several tens of centimeters and refers to the location of vehicles as close as possible to the point of embarkation of passengers;
- repeatability - is a feature that depends on the accuracy and refers to the fact that an operation can be performed under the same conditions with the same results no matter how many times it is repeated;
- number of degrees of freedom - refers to the number of types of movement that can be performed;
- a type of drive - refers to the type of actuator or motor that drives the moving elements of the robot (can be electromagnetic, pneumatic, hydraulic, etc.);
- robot weight - is closely related to the dimensions of the robot and the materials from which it is made;
- the volume of the workspace - is closely related to the values of the achievable dimensions because it depends on their maximum values;
- the capacity of the command-and-control system - refers to the degree of "intelligence" integrated with the robotic equipment and the flexibility of the control mode;

- speed - depends on the dimensions of the robot, the values of achievable dimensions, the volume of the working space, the type of drive, the transportable load, and the working conditions;

- transportable load - is also called transport capacity and refers to the maximum weight of the object carried by the effector element;

- working conditions - refers to the robot's ability to work in a working environment that can be: special conditions (clean room: temperature-controlled and varying very little, no disturbing electric or magnetic field, no dust, with a humidity-controlled and which varies very little, sometimes controlled ambient pressure), normal conditions (temperatures: -20oC to + 50oC, maximum humidity 80%, etc.) or harsh working conditions (high pressures, strong electric or magnetic fields, etc.);

- the possibility to have more arms - has implications on productivity, the degree of mobility, and the number of degrees of freedom;

- modularity - it is possible that, depending on the type of application, the robots may require detachable terminals, respectively for gripping or for the tools that are attached to the mechanical interface.

3. Robot Classification

The explosive development of robots has led to the emergence of a very large number of them with different shapes and structures.

Thus, the need arose to classify robots according to certain criteria:

1) According to the input information and the learning mode of the robot:

- Manual manipulator, which is operated directly by man, being an extension of it and not having embedded intelligence;
- Sequential robot, which for a certain working procedure performs only certain predetermined steps and can be:
    - fixed sequential robot, in which the default information cannot be changed;
    - variable sequential robot, at which the default information can be changed.
- Repeater robot, the so-called "playback" robot - where man sequentially controls the working procedure while the robot executes and stores this procedure and can repeat it as many times as needed. The disadvantage of this robot is that if you want to perform a new procedure, then the robot must be reprogrammed. Such robots are used in amusement parks to draw users' attention to a particular means of entertainment.
- Numerical control robot - where the robot performs the required operations according to the numerical information it receives, which is taken from a program entered by the user.
- Intelligent robot, based on the information received from the embedded sensors and according to the mini-programs with which it is provided, has certain possibilities of recognizing the world around it and can perform certain operations when it receives certain levels of information. The robot has a certain level of intelligence given by the IT components in the structure: processor, memory, and bandwidth of control and data buses.

2) Classification of robots according to the shape of the movement:

- Cartesian robot - operating in a space defined by Cartesian coordinates;
- The cylindrical robot - is similar to the Cartesian one, but the working space of the arm is defined in cylindrical coordinates;
- Spherical (polar) robot - in which the workspace is defined in spherical (polar) coordinates and has a movement in the plane;
- The orthotic/prosthetic robot - is an articulated arm that performs as realistically as possible the anatomical movements of the replaced limb;
- Industrial robots incorporate at the joint level several types of coordinates.

3) Classification by a number of degrees of mobility:

- With a degree of mobility.
- With two degrees of mobility.
- With three degrees of mobility.
- With four degrees of mobility.
- With five degrees of mobility.

4) Classification by workspace and weight of a handled load:

- Small robots (weighing no more than 5kg);
- Medium robots (weighing between 5kg-50Kg);
- Large robots (weighing no more than 50kg)

5) Classification by method of control:

- Simple manipulators (those in cylindrical coordinates);
- Programmable robots (those in Cartesian coordinates);
- Intelligent robots.

6) Classification of manipulators and robots by generations. This uses as a basic criterion for the machine's ability to perceive and interpret signals from the external environment, as well as to adapt to the environment during the work process.

- First-generation robots are programmable automatic manipulators with at least 3 axes (of which at least 2 axes are programmable by learning or by symbolic language).
- Second-generation robots.
- Third-generation robots are equipped with intelligent sensors (local information processing) and use elements of *artificial intelligence*. Robots are equipped with advanced artificial intelligence programs with the ability to self-train.

7) Classification according to *the system that allows them to move* in the environment in which they operate exists for example for movement on the ground:

- Robots on wheels or tracks. They have great mobility but a limited number of degrees of freedom;

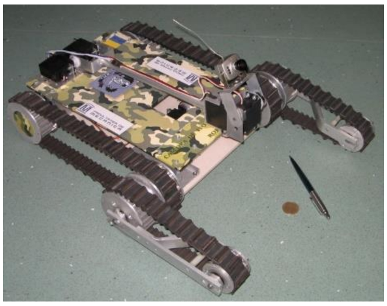

Figure 1: Track robots [10]

- Stepping robots: bipeds, quadrupeds, hexapods, myriapods. They have superior mobility and can overcome obstacles.

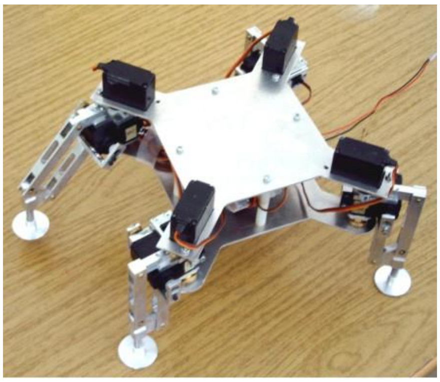

Figure 2: Stepping robots [11]

- Crawling robots: imitating the movement of a snake, imitating the movement of a worm, etc. They are made up of several articulated bodies, like a snake. They are used for the inspection of narrow spaces.

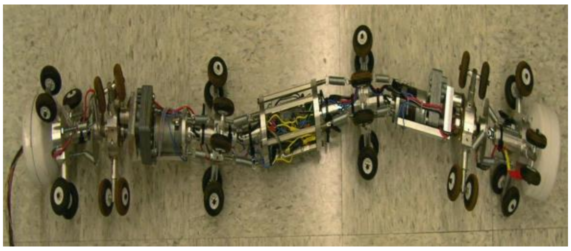

Figure 3: Crawling robot [12]

- Jumping robots, which mimic the movement of frogs, kangaroos, etc.

Figure 4: Jumping robot [13]

- Manipulators.

Figure 5: Manipulator type robot [14]

From the category of mini robots, the most common types are:

- RCX 1.0 Mini robot.

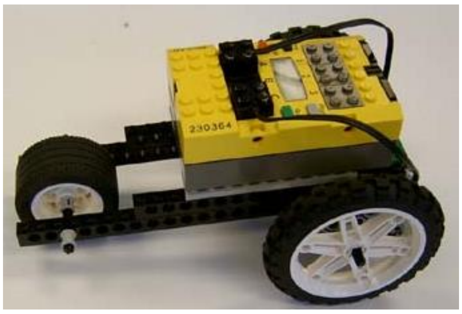

Figure 6: ACURA RCX 10 robot [15]

One of the main mobile robot structures used in the tests includes two active wheels at the rear, each driven by a DC motor mounted in a LEGO piece, and a passive wheel at the front. The active wheels are driven by two gears with gears.

- Manroot AIRAT 2

AIRAT 2 is a microhouse robot that uses an 8051 CPU. AIRAT 2 uses sensors to receive it when it returns. The CPU board uses a JS8051-A2 board. The JS8051-A2 board is very well built. Uses external power resources such as LCD, ADC, two external clocks, auto-flash writing and more.

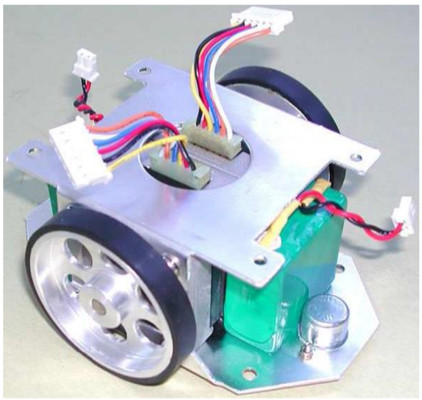

Figure 7: Mini robot AIRAT 2 [16]

AIRAT 2 uses six sensors, giving it the ability to move diagonally.

A PC simulator is provided, allowing the user to better understand the high level of algorithmic mouse search.

The C source code is implemented so that the programmer can more easily develop algorithms that can be tested using a simulator and then implemented with the mouse.

In addition, LCD, serial communication, mouse control, and other functions are provided in the form of a library and source files. For those who want to learn the mouse at a high level, AIRAT2 provides an excellent development environment, algorithmic tests, and much more.

Features of the AIRAT 2:

• Capable of self-adjustment. Learn on the go;
• Uses 6 sensors giving it the ability to move diagonally;
• Easy to assemble/disassemble;
• Recharging port;
• Assembly instructions and user manual;
• Includes a PC simulator for accelerating development;
• Libraries, source codes C;
• AIRAT2 battery (NiMh-450).
• Robot mobile ROBOTINO

Robotino is a mobile robot with artificial vision and programming possibilities.

Figure 8: ROBOTINO [17]

• CYCLOPS MK 3C mobile robot. The CYCLOPS MK 3C mobile robot is remotely controlled for hazardous environment inspection.

In the following, we will focus on stepping robots, which we will call stepping robots.

In addition to serial topology and parallel topology robots, stepping robots have proliferated in recent years, due to their advantages that recommend them in certain types of activities.

The areas in which they are more and more present are planetary explorations, medicine (assisting people with disabilities), underwater explorations, nuclear activities, military applications, (anti-personnel mine detection) as well as the exploration of areas dangerous to humans.

Figure 9: CYCLOPS MK 3C [18]

Stepping robots have the following characteristics:

• They can move on rough terrain;
• Needs low energy consumption;
• High ground clearance allows them to overcome obstacles;
• Contact with the ground is discontinuous foot with the possibility to select the point of contact (support);
• The possibility of perceiving the contact with the ground;
• Can move on soft ground;
• Slightly damages the soil on which it moves (important aspect in forestry);
• Travel speed is low;
• Gait control is complicated due to the high number of degrees of freedom;

8) Classification of stepping robots in terms of locomotion.

Maintaining the balance of a mobile robot is a major issue. According to this criterion, stepping robots are classified as follows:

• Statically stable robots = are in constant balance, having at least 3 feet in contact with the ground during locomotion;

• Quasi-stable static robots = have an unstable configuration for a very short time;

• Dynamically stable robots = do not have stable configurations during locomotion.

The static balance of a stepping robot can be checked using the support polygon, which is the polygon formed by the horizontal projections of the foot support points in the support phase. The gait is statically stable if at any time the vertical projection of the center of gravity G is inside the supporting polygon.

Another problem that can occur is the geometric interference of the legs. If the travel of the legs is greater than the distance between two adjacent legs, the workspaces of the feet intersect, which means that interference is possible. The geometric interference of the legs can be avoided by the correct correlation of some parameters that characterize the gait.

Types of Walking

Keeping the robot in balance and moving it at a certain speed are the hardest steps in designing a stepping robot.

These goals can be achieved using several types of walking, such as:

Periodic walks - all the legs of the robot have the same duration of a complete cycle.

Adaptive wave mode - allows the use of fixed sequences of motion in omnidirectional movements. This type of gait is characterized by the fact that the transfer phases propagate from one foot to another like waves. Depending on the direction of propagation of the transfer phases we can have:

- Going forward = the transfer phases propagate starting from foot 5 to foot 1;
- Going backward = the transfer phases propagate from foot 2 to foot 5;
- Freewheeling = ensures the control of the robot according to the imposed speed and the obstacles encountered;
- The parameters that characterize a walk are:
  - *Transfer phase;*
  - *The support phase;*
  - *Duration of a cycle;*
  - *The use factor;*
  - *The phase of a leg;*
  - *Footstep;*
  - *Race;*
  - *The pace of the race P.*

The Kinematic System

Regardless of the objective (positioning, performing technological or fun operations), robots must position and orient an object in space. Fixing and orienting a body in space is done with the help of six parameters: three for position and three for orientation.

This can be done by rotations, translations, or rotations combined with translations. A rigid solid can be defined by a point belonging to it, called a characteristic point (most commonly, the center of gravity of the rigid solid), and a line containing the characteristic point called the characteristic line. A characteristic material point and a characteristic line define a rigid solid.

The three degrees of freedom of the trajectory generating mechanism can be rotational or translational couplings, while the orientation mechanism generally consists of three kinematic rotational couplings.

The path generating mechanism can be separated from the orientation mechanism, in which case the structure of the robot is called a "decoupled structure".

The positioning movement can be performed using three kinematic torques of rotation (R) or translation (T). There are 8 possible combinations of rotations and translations.

These are: RRR, RRT, RTR, RTT, TRR, TRT, TTR, TTT. As for the guide device, it can exist in 27 variants. Combining the 8 possibilities with the 27 variants results in 8 x 27 = 216 kinematic chains.

However, not all of these options lead to a three-dimensional workspace, and as a result, they will be eliminated, leaving 37 possible options.

Of the 8 possible structures of the trajectory generating mechanism, 4 are preferably according to GOST 25685/83 and JIS 0134/86: TTT, RTT, RRT, RRR.

Each of the 37 kinematic chain structures can be the basis of a robot determining a specific architecture. The degree of maneuverability of the guide device means the number of degrees of mobility of the kinematic chain underlying it.

The degree of mobility of the kinematic chain means the number of possibilities of movement that the kinematic chain has to the reference system in solidarity with one of its elements.

Drive System

The drive system of a robot comprises all the energy sources of the robot as well as their direct control elements. The drive system shall mean the set of motors and converters by which the mechanical energy necessary to move the robot is obtained, as well as the additional devices that control this energy transfer.

Such a system will include:

- a primary source of energy;
- a system for converting primary energy into mechanical energy;
- a system for the transmission of mechanical energy to the corresponding joint;
- a control system of the characteristic parameters of these systems.

The usual drive systems use **three primary energy sources**:

1. Electrical

Although less used than hydraulic drive, electric drive occupies a large enough area for industrial robots due to the following main advantages:

- the primary source of electricity is easy to find;
- the control systems are precise, safe, and relatively easy to connect to high numerical control;
- autonomous operation can be ensured by battery power;
- no specific pollution problems are required.

In electric drive we find 2 types of drive systems:

- DC motors - have the important advantage that the moment created is practically independent of the position and speed of the motor depending only on the winding field and the current in the fittings. If the field windings are replaced with a permanent magnet, then the developed moment is proportional to the value of the current in the armatures and therefore to the applied voltage;
- Stepper motors - are synchronous systems that make a direct correlation between the ordered quantity and the obtained position. These motors provide direct conversion of the input signal, given

in the numerical form, into an angular positioning motion by incremental cumulation. This property is widely used by stepper motors in all open loop positioning systems. The intrinsic conversion of the control into position ensures simple control schemes, efficient both technically and economically.

2. Pneumatics

The main feature of these devices is the use of air as a compressible fluid in the drive system. The operating functions of the pneumatic systems are like the hydraulic ones, their specific technological and constructive particularities being due to the change of the fluid, with its specificity and properties.

Among the factors that argue in favor of the use of pneumatic systems can be noted:

- simplicity of the drive equipment;
- the robustness of the devices used;
- non-pollution of the working environment; simple control systems;
- relatively high power / weight ratio;
- resistance to high-value overloads.

3. Hydraulics

The largest number of modern industrial robot systems use hydraulic drive due to the special characteristics that this equipment offers in terms of the ratio between the force exerted on the motor device and its weight.

Electric drives are also widely used, mainly due to the control facilities they can provide.

The pneumatic drive occupies a small weight in this direction, it is usually used in the control systems of auxiliary devices.

These devices are based on the principle of converting the energy of an incompressible fluid into mechanical energy. The liquid used is a mineral oil that acts at pressures up to 100 atm.,

The source of hydraulic pressure is incorporated in the robot's drive system or belongs to a centralized system. The most widely used device in these systems is the linear hydraulic piston.

The Sensory System

Orientation in an unknown environment, using sensors to detect obstacles, and communication with a remote computer are two important aspects to consider when working with a mobile robot.

Without sensors, robots could only perform pre-set tasks by repeating the operations for which they were performed, but if they are equipped with sensors, robots can do much more than that.

The specific issues that arise with mobile robots are the following:

- avoiding the impact with stationary or moving objects;
- determining the position and orientation of the robot on the field;
- planning an optimal trajectory of movement.

Movement planning does not consist of a single, well-defined problem, but of a set of problems, some of which are more or fewer variants of others.

Avoiding collisions with fixed or mobile obstacles in the robot's workspace can be done through several methods: making a mechanical guard that stops the robot from deformation, using sensors that measure the distance to obstacles in the direction oftravel, using proximity sensors, the use of related information from several types of sensors.

The location of objects can also be achieved by physical contact, but this imposes restrictions on the speed of movement of the manipulated structure. Physical contact between the robot and objects in the environment generates reaction forces that change the state of the robot.

High working speeds make the dynamic effects of physical contact with obstacles or manipulated objects risky (they can lead to damage to objects or serious injury to users, as is the case in amusement parks when the manipulated object is a person eager for fun).

The sensory system is also called the measurement system. It ensures the measurement of some physical quantities and possibly the perception of some significant changes in these quantities.

Control and Programming System

Flexibility, reliability, sensitivity to disturbances as well as several requirements regarding the facilities offered when introducing or modifying work programs are some of the basic characteristics that are currently required of control equipment for most applications that use robots. To a large extent, these requirements are covered by PLCs. A series of such automata are modeled and simulated by Megahed, S. M. in the book Principles of Robot Modeling and Simulation.

In conventional manufacturing systems, the human operator is the only component of both the processing and handling subsystems.

In the mechanized ones, the industrial robot is missing, and in the state-of-the-art mechanized ones, the industrial robot is at most a manipulator. The human operator is missing in the automatic ones.

4. The Proposed Solution

The mobile robot platform consists of 6 identical legs articulated on a final platform called a six-point end-effector distributed in the shape of a hexagon.

There are several types of mechanisms that can be used to operate a foot.

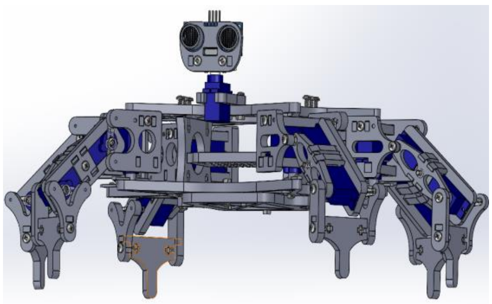

Figure 10: Robot platform for hexapod mini-robot HEXI

Among these we mention the most used:

- mechanisms derived from the quadrilateral mechanism,
- mechanisms from the pantograph family,
- more complicated mechanisms derived from kinematic chains with several independent contours.

One of the considerable problems is the structural pattern of the foot, due to the complexity of walking kinematics. There are types of mechanisms used to operate the foot.

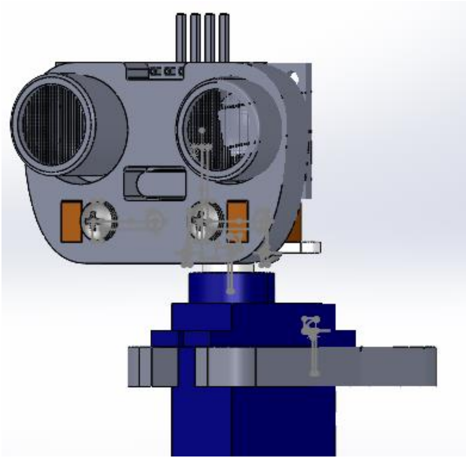

Figure 11: The head of mini-robot HEXI

The foot is not an element of continuous locomotion and therefore it must be lifted at the end of the race, turned, and placed at the beginning of a new race.

This creates problems with the coordination of the legs, the coordination described by the term "walking". That is why it is necessary to define walking.

A good understanding of gait is required to design a walking robot, as the number of legs, the structure, and the performance of the foot depends very much on the selected gait.

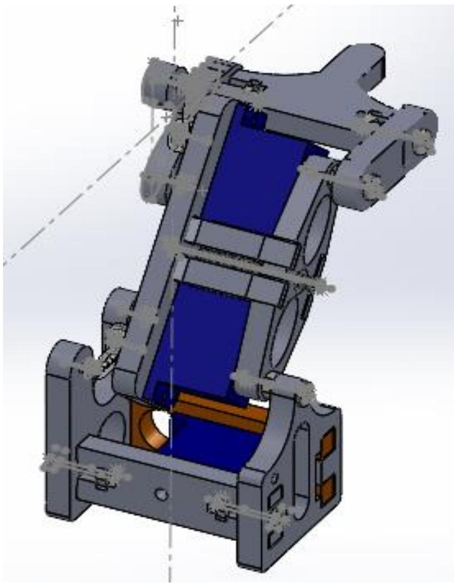

Figure 12: The foot of mini-robot HEXI

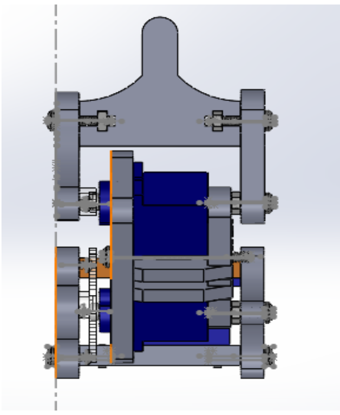

Figure 13: Mini-robot leg - actuation presentation

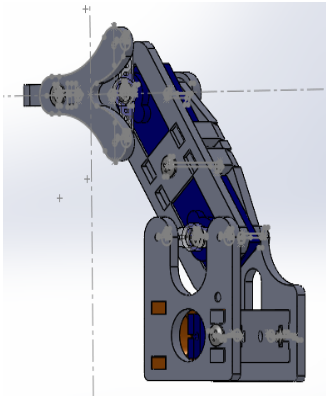

Figure 14: Mini-robot leg - side view

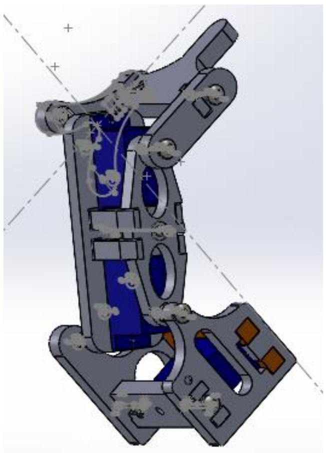

Figure 15: Mini-robot leg - top view

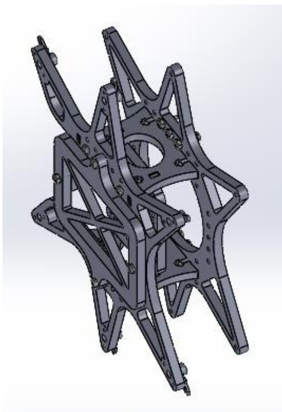

Figure 16: The Mini-robot's body

5. Structural Analysis of the Stepping Mini-robot HEXI

Mechanisms are mechanical systems that can transmit forces or motion in machines.

The topological structural analysis [1] studies the composition of the mechanisms, as well as their mobility.

The topological structure of the mechanisms [1] deals with the way the mechanisms are designed. Usually, the character of the connections between the material bodies that compose the mechanisms is studied and the structural equations are established that allow the determination of the operation in optimal conditions of the mechanical systems.

The topological structure studies the classification of the mechanisms based on criteria that allow the unitary study from a structural, kinematic, and dynamic aspect.

The topological structural synthesis of kinematic mechanisms and chains represents, in the specialized literature, the second big problem, the objective of the structural analysis being the establishment of the relations and the methods necessary to obtain the kinematic chains with a certain number of elements and given mobility.

The structural topological analysis of the mechanisms and manipulators will study the composition of the already existing mechanical systems, and their possibilities of movement, as well as the obtaining of the structural scheme.

This paper uses a series of theoretical notions from the literature. Highlighting the kinematic aspects of structural groups, in the order in which they are on the flow of motion, define the structural relationship of the mechanism.

Mobility of mechanisms - is expressed by an integer and positive number, this being the number of geometric and kinematic parameters necessary to uniquely determine the displacements (implicitly of positions, speeds, and accelerations) of all kinematic elements in the composition of a mechanical system.

Since the mechanism is a particular case of a kinematic chain, when an element of it is fixed, the notion of degree of mobility will be introduced.

The degree of mobility (M) of a mechanism means the number of its possibilities of movement or the degrees of freedom of the moving elements concerning the fixed element.

One of the elements of the kinematic chain of the mechanism being fixed results from the total number of elements that subtract the fixed kinematic element.

$$M = 6(e-1) - \sum_{m=1}^{5} m \cdot C_m \quad (1)$$

If we denote e −1 = n (n - the number of moving elements), it results:

$$M = 6n - \sum_{m=1}^{5} m \cdot C_m \quad (2)$$

For plane mechanisms, the relationship becomes:

$$M = 3n - \sum_{m=1}^{3} (m-3) \cdot C_m = 3n - 2C_5 - C_4 \quad (3)$$

Considering the general case of an associated space that has f = 0 ... 5 common constraints, in this situation, the degree of mobility M is obtained as the difference between (6-f) n potentially available degrees of freedom and the sum of degrees of freedom $(k-f)\cdot C_k$ canceled by kinematic couplings used having class k> f. Thus, the degree of mobility can be determined using the following formulas:

$$M = (6-f)\cdot n - \sum_{k=1}^{5} (k-f)\cdot C_k \quad (4)$$

$$M_0 = 6 \cdot n - 5 \cdot C_5 - 4 \cdot C_4 - 3 \cdot C_3 - 2 \cdot C_2 - C_1$$
$$M_1 = 5 \cdot n - 4 \cdot C_5 - 3 \cdot C_4 - 2 \cdot C_3 - C_2$$
$$M_2 = 4 \cdot n - 3 \cdot C_5 - 2 \cdot C_4 - C_3$$
$$M_3 = 3 \cdot n - 2 \cdot C_5 - C_4$$
$$M_4 = 2 \cdot n - C_5$$

In the general case of a complex mechanism with two or more closed contours of different ranks, the degree of mobility can still be calculated and verified very easily with the help of the formula:

$$M = \sum_{m=1}^{5} mC_m - \sum_{r=2}^{6} rN_r \quad (5)$$

In the formula (5) the notations were used:

m - mobility of a kinematic coupling that defines the functional class.

Cm - number of kinematic torques of class m.

r - the rank of the space afferent to an independent closed contour (kinematic chain).

Nr - the number of independent closed contours.

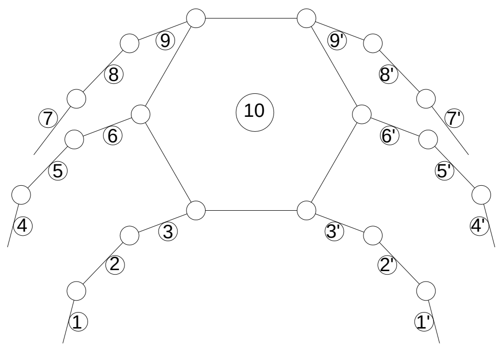

Figure 17: Structural scheme of the mobile robot

6. Robot Simulation

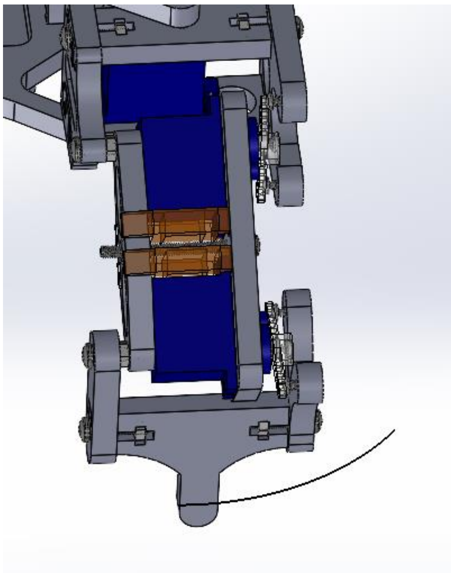

Figure 18: 3D Simulation and optimization of the trajectory

In the image above we have the simulation of one leg of the robot. It moves at 60 degrees with a frequency of 0.1 Hz.

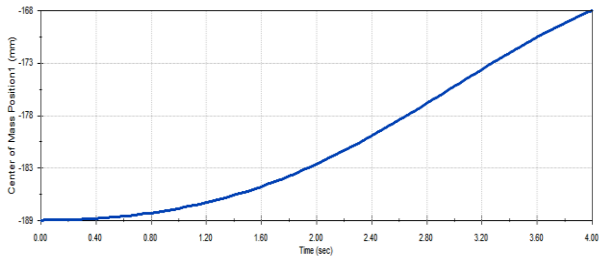

Figure 19: The result of the simulation Center of Mass Position 1

In this graph you can see how the center of gravity changes during the 4 second simulation depending on the position of the foot.

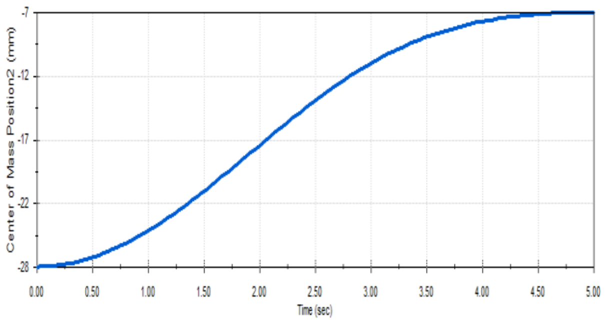

Figure 20: Result of the simulation Center of Mass Position 2

In this graph you can see how the center of gravity stabilizes after 4 seconds until it reaches 5 seconds.

7. Conclusions

Based on the extensive studies conducted by the authors on the problems related to the realization of a miniature stepping robot HEXI, with a functional role of inspection and movement of loads up to 200 ml, the authors made a mini-robot HEXI with 6 identical legs articulated on a final platform.

The authors' attention was focused in this approach on optimizing the gait of this hexapod mini-robot HEXI. In their approach, the authors analyzed with specialized software MATHCAD [2] and determined the best movements for each of the 6 legs, which go coordinated, with the same optimized parameters, to offer the mini-robot a stable and optimal movement.

The mini-robot HEXI, modeled in SOLIDWORKS, and then assembled and subjected to experiments within the T.M.R. Department of the Faculty of Industrial Engineering and Robotics, behaved as expected, optimizing the displacement assuming a displacement of 60 degrees (on a circular arc curve) with a frequency of 0.1 Hz, for each foot.

Also, the movement of the HEXI mini-robot has been optimized so that the center of gravity of each leg of the mini-robot HEXI stabilizes quickly, in time intervals of approx. 4 seconds.

The efforts of the team of authors will be directed in the near future in the development of hexapod mini-robot HEXI functions, by increasing its maneuverability, by increasing sensory performance and transmitting more accurate instant images from the field, and by increasing the ability to carry heavier objects on longer offsets.

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