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Modeling, Simulation and GUI Control of a Hexapod Walking Robot

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***Abstract* — The present work involves the modeling, simulation and control of a hexapod robot as well as the development of the cyclic movement of its leg. The study focuses on the integration of the 'Toolbox-robot' into 'Matlab' to simulate the walking procedure in its different stages along with the 'GUI' control of the hexapod while respecting the kinematics imposed by the leg.**

Keywords— Hexpod Robot, Kinematics, Walking robot, Kinematics, Mechanism, Gui Control

I. INTRODUCTION

Inaccessible or risky missions for humans such as volcano exploration, nuclear power plants maintenance or disaster rescue may be performed by multi-legged robots whose technology rapid development and applications resulted in a wide range of autonomous robotic systems that can be used as substitute for mankind [1-2-3-4]. Classified essentially into three major areas represented by the LSL (Less inputs–Single end-effector–Less outputs), the MSM (Multiple inputs–Single end-effector–Multiple outputs) and the MMM (Multiple inputs–Multiple end-effectors–Multiple outputs), the multi-legged robots whose anatomy holds many degrees of freedom (DOF) leading them to be closer to handling robots are typical of the MMM systems. A wide and interesting review of dynamic multi-legged robots has been performed [5] and discusses the state of the art in terms of multi-legged autonomous robotic systems.

The hexapod robot has redundant degrees of freedom due to its multiple joints whose control method defines the pace ensuring a balanced movement of the whole body. The diverse techniques that have been investigated so far seem to be close to the walking progress inherent to animals and notably that of insects [6-7]. Accommodation to ground is specific to walkers consisting of choosing the best contact area through combining forward movement and stability using proximity, contact or vision sensors [8].

Robot mechanics are usually designed specifically for the applications and tasks they are assumed to perform. In manufacturing, manipulator arms are the most commonly used as their main tasks are linked to assembly and handling [9]. For transportation and service applications, it is most often necessary to use on-wheels mobile robots capable of carrying out heavy loads [10]. However, being unable to move on uneven terrains or obstructed environments, they require accessible flat grounds or rails and hence the need to consider alternative modes of transportation dependent on the nature of the terrain of operation. The solution has been found by inspiration through nature.

A large number of researches have been interested in the locomotion of humans and animals using legs, and legged robots (biped or quadrupeds) seem to have various advantages over wheeled ones. They offer superior maneuverability and higher speed in unbalanced environments such as stairs, slopes, congested grounds ... etc. as a result of the intermittent and non-permanent contact. This allows the robot to overcome obstacles giving it a higher mobility in a crowded or chaotic environment and leading to various applications particularly in the field of intervention in hostile environments. To this end, legged robots have been investigated for several decades [11-12-13] through trying to imitate the flexibility, robustness and adaptability of walking humans. Due to the complexity of the models, tremendous computing power is needed and this partly explains why these types of robots are still largely confined to laboratory experiments with little use in practical life.

The present investigation performed the modeling, simulation and control of a hexapod walking robot through the application of the MATLAB Robotics Toolbox. Both direct and inverse leg kinematics that refer to the conversion of joint angles to end effectors position and that introduces the conversion of world co-ordinates of end effector to joint angles respectively are presented. The cyclic movement of the hexapod leg is obtained through decomposing it into two main phases representing a support and a backing.

II. THE BIOLOGICAL INSPIRATION

Biology-inspired robotics [14-15] mimicking animal motions and trying to implement them into artificial machines have revolutionized the field of robotics. The human principles linked to muscles and skeleton are transferred into conventional motors and mechanical linkages. To date, the bio-inspired robotics research has achieved solutions that have shown abilities to tackle various contemporary challenges. It however has a long way facing it in order to be able to design, build and control robots inspired by nature, and this needs a deep collaboration between roboticists and biologists.

Fig. 1 Inspiring insects: a- Cockroach, b- Ant [16]

A. Hexpod Robots

The idea to design a hexapod walking robot was developed through imitating insects such as a cockroach or an ant that are illustrated in Figure 1 [17]. Their movement is based on the alternate motion of three legs. Hexapod robots are considered more stable than quadrupled and bipedal robots

[18]. They integrate six legs, and constitute a mechatronic system that combines concepts inherent to mechanical, electronic and computer engineering. The interest of studying such robots is mainly justified by their stability along with their terrestrial applications. Their mobility is indeed stable their operation efficient and managed by its supporting polygon. The applications involve, among other operations, collecting data in remote, disaster and dangerous areas along with the possibility of adopting them as domestic robots (cf. Figure 2).

Fig. 2 MX-Phoenix hexapod robot [19]

III. DIRECT GEOMETRIC MODEL APPLIED TO HEXAPODS

A. *Structure and Model*

One of the characteristics inherent to hexapods is their ability to walk even if one or more of their legs are disabled. This is the result of the fact that a robot can be statically stable on three or more legs, and a hexapod walks on six.

Typically, individual legs range from two to six degrees of freedom and integrate at least three joints. A representative isostatic structure of a walking robot is shown in Figure 3 illustrating the model of one leg.

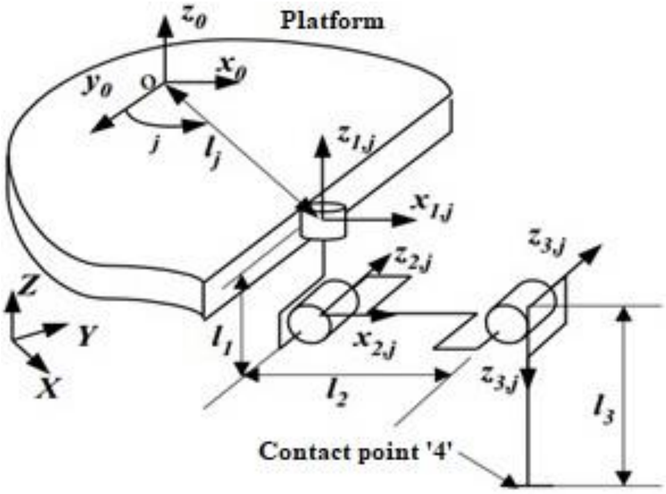


Fig. 3 Model of a hexagon leg [20]

Figure 4 introduces the configuration of the structure adopted for the hexapod. This is the result that most often, forward turn and side-steps locomotion are needed.

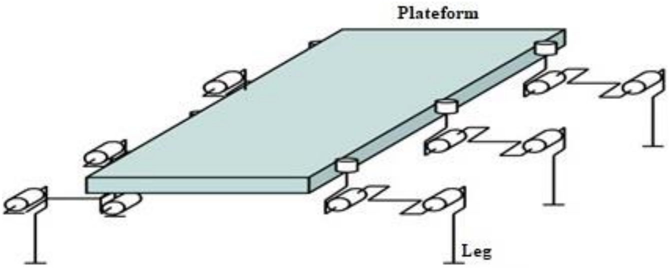


Fig. 4 General view of the hexapod [20]

B. *Hexapod Direct Geometric Model*

Direct Geometric Modeling along with its automatic implementation requires an approach for the description of the morphology of the robots represented by the method of Denavit-Hartenberg [20] which states that all bodies should be perfectly rigid and connected through ideal joints (noted *j*) rotating by an angle (θ_j) as illustrated in Figure 5.

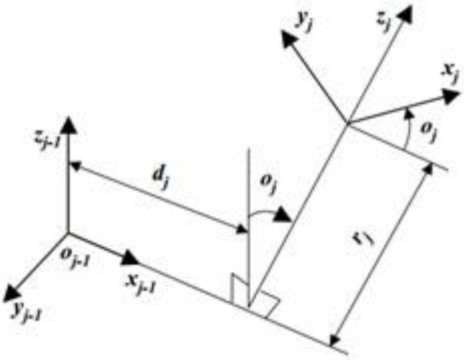


Fig. 5 Geometric parameters of a simple open structure [21]

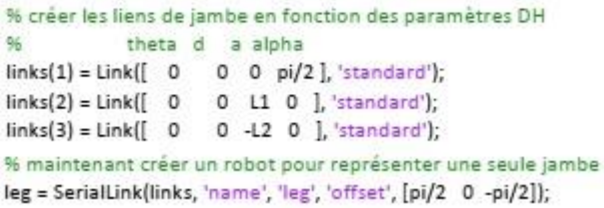
Taking (α_j) as the angles between the axes (Z_{j-1}) and (Z_j) corresponding to a rotation around (Xj_{-1}), (d_j) as the distances between the axes (Z_{j-1}) and (Z_j) along (X_{j-1}), and (θ_j) as the angles between the axes (X_{j-1}) and (X_j) corresponding to a rotation around (Z_j), the geometric characteristics of the hexapod may be illustrated in Table I [21].

TABLE I. GEOMETRICAL CHARACTERISTICS [21]

I	*θ*	*d*	*a*	*α*
1	Q_1=0	0	0	π/2=1.571
2	Q_2=0	0	L_1=0.1	0
3	Q_3=0	0	L_1=0,.1	0

For the robot's body to move in a linear and continuous way, the support polygon should proceed in the adverse direction to that of the body. The leg should be raised looking for support through the next contact point. Modeling of the contact points with the ground has been simplified through taking into account solely the positional constraints thus neglecting the orientation values. This leads to generating both translations and rotations to the supporting polygon without distorting it. As a consequence, the trajectories of the resulting polygons will allow the body to move according to the direction required by the external environmental conditions.

An appropriate mechanism for the present spider-like robot having six legs with three DOFs each is introduced. Eighteen activated DOFs will constitute the platform reproducing the walking. A tripod approach ensures stability while having the least amount of legs simultaneously in contact with the ground. With three legs in ground contact, nine actuators will be in action in order to react to the six DOFs related to both orientation and translation of the body with respect to the supporting polygon. This led to the development of the MATLAB software inherent to the walking approach of one leg shown in Figure 6.



```
% créer les liens de jambe en fonction des paramètres DH
%                 theta   d    a  alpha
links(1) = Link([   0     0    0   pi/2 ], 'standard');
links(2) = Link([   0     0   L1   0  ], 'standard');
links(3) = Link([   0     0  -L2   0  ], 'standard');
% maintenant créer un robot pour représenter une seule jambe
leg = SerialLink(links, 'name', 'leg', 'offset', [pi/2  0  -pi/2]);
```

Fig. 6 Screen capture of MATLAB software for one leg [21]

IV. INVERSE GEOMETRIC MODEL APPLIED TO HEXAPODS

The control of hexapod legs is performed on the basis of the ground contact position of the leg (c.f. Figure 7). The procedure leading to the solution of its kinematics is performed through (1) describing the leg in terms of the Denavit-Hartenberg procedure in order to achieve a generic solution for serial manipulators with 3 DOFs, and (2) finding out the articular values associated with the Cartesian coordinates position of the leg end contact with the ground.

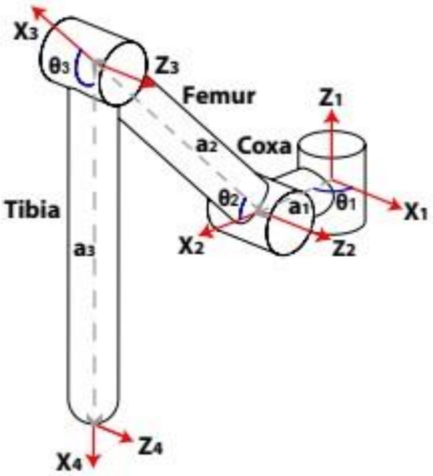


Fig. 7 Schematic shape of a leg [21]

The architecture has been selected to allow the reduction of the calculations since they should be performed in real time on the robot embedded unit. The first two axes are coincident ($a_1=0$) and that leads to a great reduction of the number of possible solutions to the inverse geometric problem.

TABLE II. LIMITING JOINT VALUES

Limiting joints	***Left legs***	***Right legs***
θ_2	[-π/4 , π/4]	[-π/4 , π/4]
θ_3	[-3π/4 , -π/4]	[-3π/4 , -π/4]
θ_2	[-π/4 , π/4]	[-π/4 , π/4]

The desired articular deflections performed on the joints are of the order of (π/2). The limiting joints and DH parameter values are presented in Tables II and III respectively.

TABLE III. LIMITING JOINT VALUES

Bones	***a***	***d***	***α***	***θ***
Coxa-1	0	0	π/2	θ_1
Femur-2	a_2	0	0	θ_2
Tibia-3	a_3	0	0	θ_3

A summary of the procedures leading to the solution of the kinematics of a leg is presented below. The expression is that of Denavit-Hartenberg. It allows a generic solution for serial manipulators at 3 DOFs and leads to finding out the joint values associated with the end-leg position in Cartesian coordinates:

$$\left[\theta_1 \;\; \theta_2 \;\; \theta_3\right] = \mathrm{PGI}\left[X,\; Y,\; Z\right] \tag{1}$$

The coxa rotation matrix relatively to the robot body is:

$$[Q_1] = Q_1 = \begin{bmatrix} cos\theta_1 & -sin\theta_1 & 0 \\ sin\theta_1 & cos\theta_1 & 0 \\ 0 & 1 & 0 \end{bmatrix} \tag{2}$$

The femur position vector may be expressed as (Figure 7):

$$[a_2] = a_2 = [a_2 cos\theta_2 \quad a_2 sin\theta_2 \quad 0]^T \tag{3}$$

The tibia rotation matrix relatively to the coxa is:

$$[Q_2] = Q_2 = \begin{bmatrix} cos\theta_2 & -sin\theta_2 & 0 \\ sin\theta_2 & cos\theta_2 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{4}$$

The tibia position vector is found to be (Figure 7):

$$[a_3] = a_3 = [a_3 cos\theta_3 \quad a_3 sin\theta_3 \quad 0]^T \tag{5}$$

The tibia rotation matrix relatively to the femur is:

$$[Q_3] = Q_3 = \begin{bmatrix} cos\theta_3 & -sin\theta_3 & 0 \\ sin\theta_3 & cos\theta_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

By integrating all the components of the vectors, it becomes possible to express the three DOFs as:

$$\begin{bmatrix} a_3 cos\theta_2 + a_3 cos\theta_2 cos\theta_3 - a_3 \sin\theta_2 \sin\theta_3 \\ a_2 \sin\theta_2 + a_3 \sin\theta_2 cos\theta_3 - a_3 \cos\theta_2 \sin\theta_3 \\ 0 \end{bmatrix} = \begin{bmatrix} Xcos\theta_1 + Y\sin\theta_1 \\ Z \\ X\sin\theta_1 + Y\cos\theta_1 \\ 0 \end{bmatrix} \quad (7)$$

The solutions represented by the three degrees of freedom noted (θ_1, θ_2 and θ_3) can be expressed within the limits of the intervals expressed in Table I for the left and right legs.

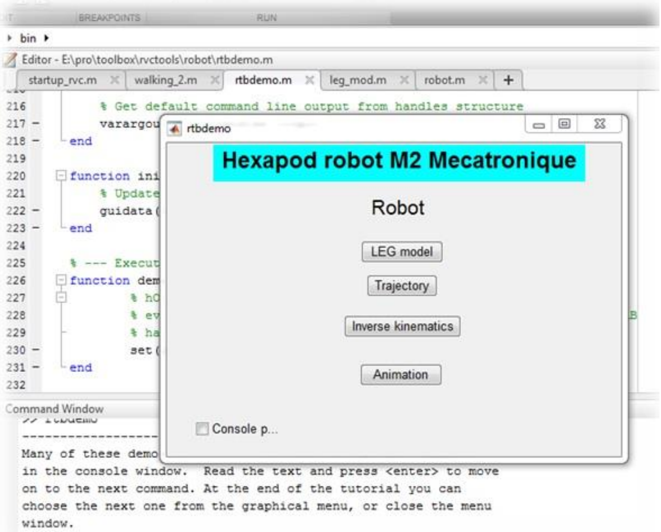
V. RESULTS AND DISCUSSION

A. *CompensationPrototype Using a Deployable Mechanism*

The three DOFs (θ_1, θ_2 and θ_3) are required for each leg. They are needed for the arrangement of the ends of the legs in the support and return polygons. For a hexapod robot, the most common walking procedure is that of a tripod. It involves the lifting of three legs at a time i.e. the two extremes on one side and the central leg on the opposite side.

B. *Application to Hexapods*

The walking robot software on MATLAB has been applied along with the 'Robot Toolbox' [22]. The 'GUI' integrates facilities that lead to creating a model, a trajectory, an inverse kinematics or performing an animation (Figure 8).



```
        % Get default command line output from handles structure
        varargou
    end

    function ini
        % Update
        guidata(
    end

    % --- Execut
    function dem
            % hO
            % ev
            % ha
            set(
    end
```

```
------------------
Many of these demo
in the console window.  Read the text and press <enter> to move
on to the next command. At the end of the tutorial you can
choose the next one from the graphical menu, or close the menu
window.
```

Fig. 8 Command 'GUI' of the hexapod

The validation of the developed procedure is carried out through the simulation of a tripod-like walking step taken by the hexapod.

Figure 9 shows the steps taken by the hexapod when walking. Figure 9-a illustrates its static position while Figure 9-b shows the two right hand side legs being lifted off along with the opposing central right hand side leg. This walking procedure is the most common tripod-like walking action.

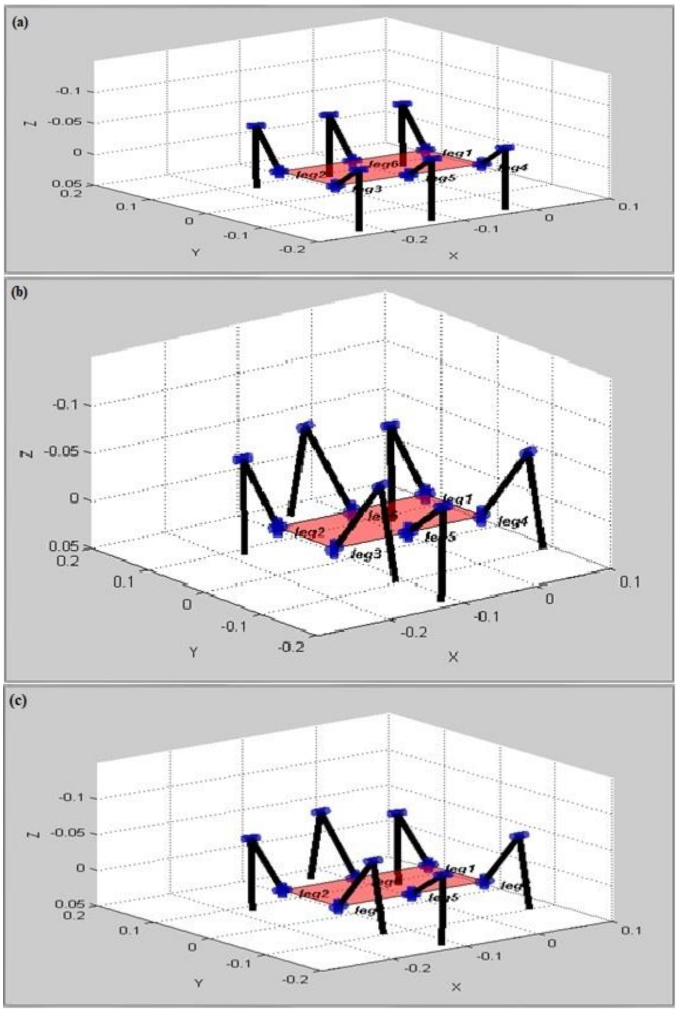


Fig. 9 Simulation of the tripod-like walking step taken by the hexapod, (a) Start,(b) 2-right side and 1-left side legs, (c) 2-left side and 1-right side legs

Figure 9-c step is similar of that of 9-b except that, in this case, the two left hand side legs are those being lifted along with the opposing central left hand side leg.

VI. CONLUSIONS

In recent years, great progress has been achieved in the field of multi-legged robots mainly due to the interest in systems able to move in a similar manner to those found in nature. However, they seem to be still far from being significantly versatile and robust. The referred aspects lead to indicate that legged robots may offer significant advantages over their wheeled counterparts as they showed interesting abilities in overcoming various obstacles and turning in much smaller perimeters.

Starting from the idea of developing a hexapod robot capable of moving on rough terrains, a design procedure is outlined along with the modeling, simulation and control of a hexapod walking robot in the robot Toolbox. The proposed design procedure was concerned with the mechanical structure and leg configuration. It developed and achieved the cyclic movement of a leg by decomposing it into two main phases representing a support and a backing. It was shown that a reduction of the functional degrees of freedom of the task may be performed. It remains that the main objective of the investigation lies in the generation of the alternate tripod-like walk inherent to the displacement of the hexapod robot and to this end; the integration of the support and backing phases was undertaken leading to the cyclic movement of the legs.

The application of the 'Toolbox-robot' v-10 integrated into ‘Matlab’ permitted both the simulation and the 'GUI' control of the hexapod while respecting the kinematics imposed by the leg. Moreover, one of the major points addressed by the present study is represented by the generation of the trajectory of the walking-advance of the hexapod within which the alternating tripod mode of its movement has been simulated. However, there are still many significant problems that need to be further investigated in order to optimize current systems including better control algorithms and more complex sensor systems.

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