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KINEMATIC DESIGN OF A HYBRID LOCOMOTION MOBILE MANIPULATOR FOR AGRICULTURAL APPLICATIONS

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Abstract: *In agriculture, one of the future solutions to eliminate the negative effect on the environment of the classical machineries is to use mobile robots (MRs). Small groups of MRs will interact with each other in order to inspect, to process or to harvest crops. These robots will have to work in a changing environment, in terms of terrain or road surfaces, the light of the ambient, animals, etc., aspects that will pose challenges for mobile robots. To facilitate the use of robots in agriculture, they must have a simple construction, be extremely reliable, flexible and, last but not least, cheap. These aspects have as effect new challenges for robot manufacturers to find technical solutions to meet the mentioned requirements. In this paper, a conceptual design of a mobile manipulator, which may be used in agriculture for applications, such as tilling, seeding, fertilization, weeding, harvesting, etc, will be discussed.*

Key words: *mobile manipulator, hybrid locomotion, agricultural applications.*

1. INTRODUCTION

The demand for food is growing worldwide. This demand will involve a much more efficient use of agricultural land, with as little effect on the environment as possible. Factors with a negative effect on the environment include the use of agricultural machinery that uses fossil fuels, as well as other technical fluids for engines and mechanical transmissions, problems arising from the cultivation of monoculture [1].

One of the future solutions to change the presented situation is the use of mobile robots in agriculture, following that small groups of robots will interact with each other to process, inspect or harvest crops. These robots will have to operate in a changing environment, such as terrain, road surfaces, ambient lighting, biological objects, etc., aspects that will pose challenges for mobile robots [2]. To allow robotics to enter the agricultural sector, robots must have a simple construction, be extremely reliable, flexible and, last but not least, cheap. This is a challenge for robot developers to design various technical solutions.

Mobile robots for agriculture are not widely available on the market today. The most popular and accessible are barn feeding robots, lawn mowers [3] and drones for field imaging in precision agriculture. There are numerous scientific articles that discuss various concepts of mobile robots for agriculture. Some well-known companies in the agricultural industry, such as John Deere, Bosh, Monsanto, have also made large investments in their development [4].

In automating greenhouse operations, where the environment is more predictable, stationary industrial manipulators are used. Mobile robots for consumers are still in the development phase [5].

In this paper, a conceptual design of a mobile manipulator, which may be used in agriculture for different applications, will be discussed.

2. DESIGN CRITERIA

The mechanical architecture of the agricultural robot should consist in a manipulator and a mobile platform that should support it. The idea is to use the manipulator in a static position for realizing different agricultural operations but this manipulator should be moved in a next position, in order to cover a bigger surface of the land or of a greenhouse.

The locomotion of the mobile platform will be chosen according to the following criteria:

- the mobile platform should damage as less as possible the environment (legs have a discontinuous contact with the ground and they are damaging less the environment comparing with wheels and tracks);
- the mobile platform should be able to move faster during changing the land/greenhouse (wheels offer a bigger speed to the mobile platform comparing to legs);
- it should have a good mobility, allowing an omnidirectional movement;
- the platform should move efficiently on the land (wheels or tracks are less efficient than legs on soft ground or on land with vegetation);
- the legs allow a more precise positioning of the platform compared to the wheels, as they are slipping less in contact with the ground than the latter (slippage is an unwanted and difficult to control phenomenon).

Based on the previous criteria, the mobile platform will have hybrid locomotion (legs with wheels as feet). During walking, the wheels will not be actuated. During the transfer of the robot from one land to another (from one greenhouse to another), the wheels will be used.

The number of legs will be chosen taking into account the stability criterion (to assure a static stability, the mobile platform will have six legs).

A solution to reduce energy consumption is to adopt the gravitational decoupling technique [6]. Based on this criterion, a structural synthesis of the leg mechanism will be discussed in the next paragraph.

Overall, the mobile manipulator (manipulator and mobile platform) should be as simple as possible, in order to reduce the price and to increase the robot reliability. In this sense, the manipulator will have a structure in Cartesian coordinates.

The gripper should be easy to change, so that the robot can be used for as many agricultural operations as possible.

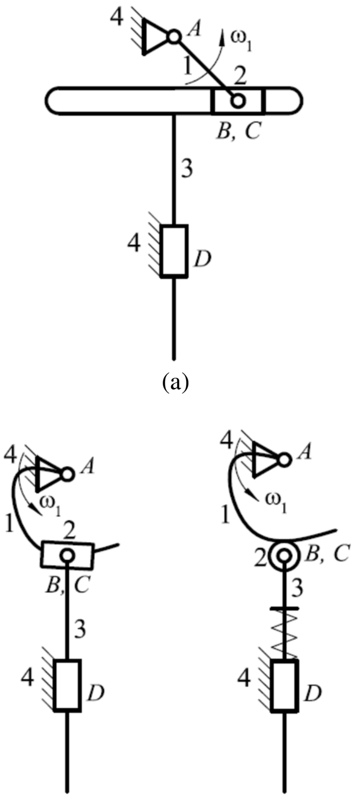
Concerning the power supply of the mobile robot, it will be provided from a solar panel mounted on the platform, to ensure its energy autonomy.

3. STRUCTURAL LEG SYNTHESIS

As starting points of designing the leg mechanism are:

- a simple and reliable mechanism;
- a minimum number of actuators;
- low energy consumption during the stationary of the mobile platform (time in which the manipulator performs a certain operation); if possible, during this phase, the actuators of the legs should not be actuated;
- as far as possible, the foot should be perpendicular to the ground surface.

There are three possible planar mechanisms that could ensure mentioned criteria (see Figure 1), which may be used in the leg structure.



(a)

(b)

Fig. 1. Planar mechanisms as possible part of the leg structure: a) Scotch Yoke mechanism; b) cam mechanims

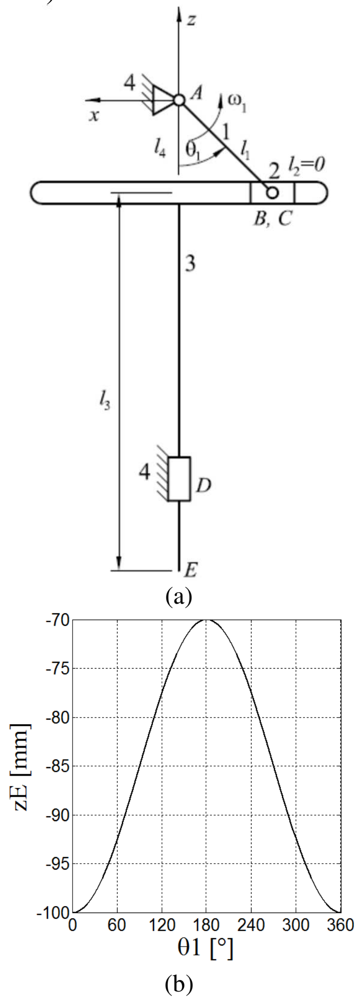
All of these three mechanisms could ensure the above mentioned criteria but, thanks to its simpler manufacturing solution, comparing to the others, the Scotch Yoke mechanism will be adopted.

3. WHEEL-LEG ARCHITECTURE AND KINEMATICS

It exist different solutions of hybrid locomotion for MRs. One of these solutions is consisting in legged platforms using driving wheels as feet. The legs are providing active suspension and they are making the robot able to climb over higher obstacles [7, 8]. This solution was adopted for our mobile platform. Its locomotion solution is consisting six legs based on the Scotch Yoke mechanism, and driving/steering wheels as feet.

3.1. Kinematics of the Scotch Yoke linkage

Let us consider a planar Scotch Yoke linkage (see Figure 2).



(a)

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Fig. 2. Scotch Yoke linkage: a) mechanism kinematics; b) vertical stroke of the *E* point [9].

In order to get the height of the maximum obstacle over which the foot passes, the vertical displacement of the *E* point extremity of the link 3 should be determined (see Figure 2.a). As input variables for solving the problem are the next parameters: θ_1, l_1 and l_3. Direct kinematics of the planar Scotch Yoke mechanism leads to

$$\begin{bmatrix} x_E \\ z_E \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ -\cos\theta_1 & -1 \end{bmatrix} \cdot \begin{bmatrix} l_1 \\ l_3 \end{bmatrix}, \tag{1}$$

while solving the inverse kinematics problem will lead to

$$\theta_1 = \arccos\left(-\frac{z_E + l_3}{l_1}\right). \tag{2}$$

3.2. Mechanism of the leg

Usually, a complete leg of a walking robot must have three degrees of freedom (d.o.f.), but there are also situations in which the legs of the robot can only have two d.o.f. Using more than three d.o.f. per leg does not provide essential benefits compared to the additional problems that would occur in terms of robot control [10].

Robots having legs with two d.o.f. need a simpler control system compared to the case when the legs of the robot have three d.o.f., because the leg has one less actuator. Using only two actuators per leg, it slides slightly along the ground during walking [10], which is undesirable in terms of control. In order to correct the lateral displacement of the robot body, additional sensors are required.

Furthermore, one of the main problems for autonomous MRs is their power consumption, which has to be as small as possible. We may use powerful batteries but they are expensive or they are heavy, which has as effect a bigger mass of the robot. But a heavier robot needs more powerful actuators and more power consumption, and so on. One of the solutions to reduce the power consumption is to select an optimal mechanism for the leg. In our case, a leg based on Scotch Yoke linkage was selected (see Figure 3).

The main advantage of the proposed leg is a minimum resistant torque (zero on a flat terrain) on the motor acting on θ_2 axis. This has as positive effect smaller power consumption for supporting the robot.

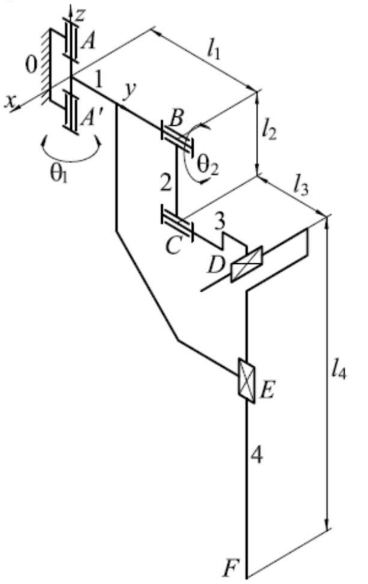


Fig. 3. Leg mechanism kinematics.

Direct kinematics problem leads to

$$\begin{bmatrix} x_F \\ y_F \\ z_F \end{bmatrix} = \begin{bmatrix} -\sin\theta_1 & -\cos\theta_1 \cdot \sin\theta_2 & 0 \\ \cos\theta_1 & -\sin\theta_1 \cdot \sin\theta_2 & 0 \\ 0 & -\cos\theta_2 & -1 \end{bmatrix} \cdot \begin{bmatrix} l_1 + l_3 \\ l_2 \\ l_4 \end{bmatrix} \quad (3)$$

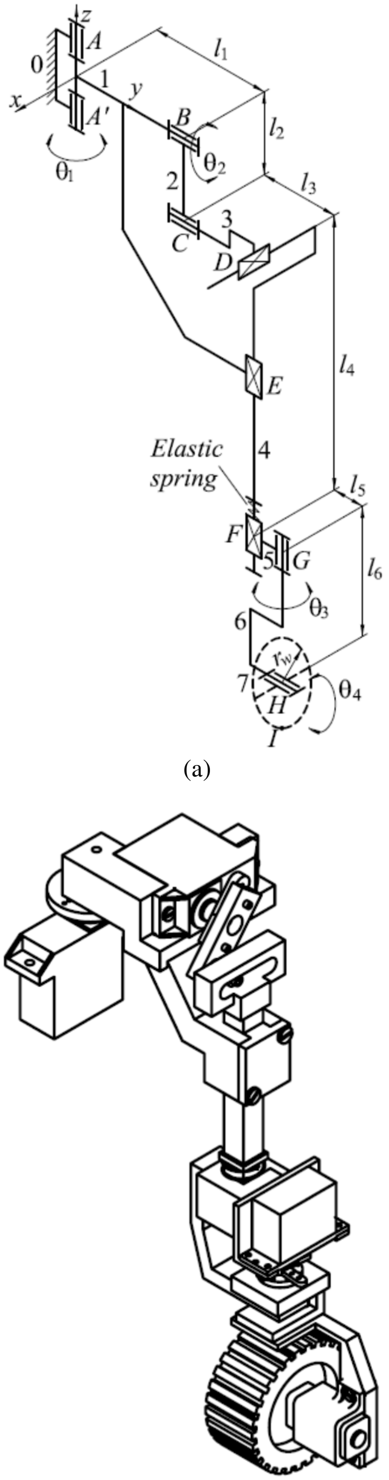
while the inverse kinematics will lead to

$$\theta_1 = \arccos\left(-\frac{l_1 + l_3}{x_F - y_F}\right), \quad (4)$$

$$\theta_2 = \arccos\left(-\frac{z_F + l_4}{l_2}\right). \quad (5)$$

3.3. Wheel-leg architecture

MRs that should work in a natural terrain must have a high maneuverability. Legged vehicles have the ability to better adapt to the unstructured terrain, while wheeled platforms can move faster on flat terrain. Based on these aspects, MRs with hybrid locomotion have been designed. One of the possible solutions for such a robot is to use wheels at the end of the leg (see Figure 4). Using this solution design for the leg, the mobile robot can walk over obstacles on the land/greenhouse and it can move faster when the robot changes the land/ greenhouse.



(a)

(b)

Fig. 4. Wheel-leg architecture: a) mechanism kinematics; b) a 3D CAD possible design [9].

When the mobile platform is moving as a legged machine, the steering-driving wheel used as foot will not rotate/turn. This wheel will become active when the mobile robot will move as wheeled one.

Direct kinematics of the last solution leg leads to

$$\begin{bmatrix} x_I \\ y_I \\ z_I \end{bmatrix} = \begin{bmatrix} -\sin\theta_1 & -\cos\theta_1 \cdot \sin\theta_2 & 0 \\ \cos\theta_1 & -\sin\theta_1 \cdot \sin\theta_2 & 0 \\ 0 & -\cos\theta_2 & -1 \end{bmatrix} \cdot \begin{bmatrix} l_1 + l_3 + l_5 \\ l_2 \\ l_4 + l_6 + r_w \end{bmatrix}, \tag{6}$$

while inverse kinematics problem has next solutions:

$$\theta_1 = \arccos\left(-\frac{l_1 + l_3 + l_5}{x_I - y_I} \right), \tag{7}$$

$$\theta_2 = \arccos\left(-\frac{z_I + l_4 + l_5 + r_w}{l_2} \right), \tag{8}$$

where: r_w is the wheel radius; l_4 is the effective length of the 4th link, when the leg is in contact with the ground (this length becomes smaller, because of the elastic spring that "actuates" the passive prismatic joint *F*).

3. MOBILE MANIPULATOR KINEMATICS

Based on the wheel-leg mechanism shown in Figure 4, the kinematics architecture of a mobile manipulator for agricultural applications has been proposed (Figure 5).

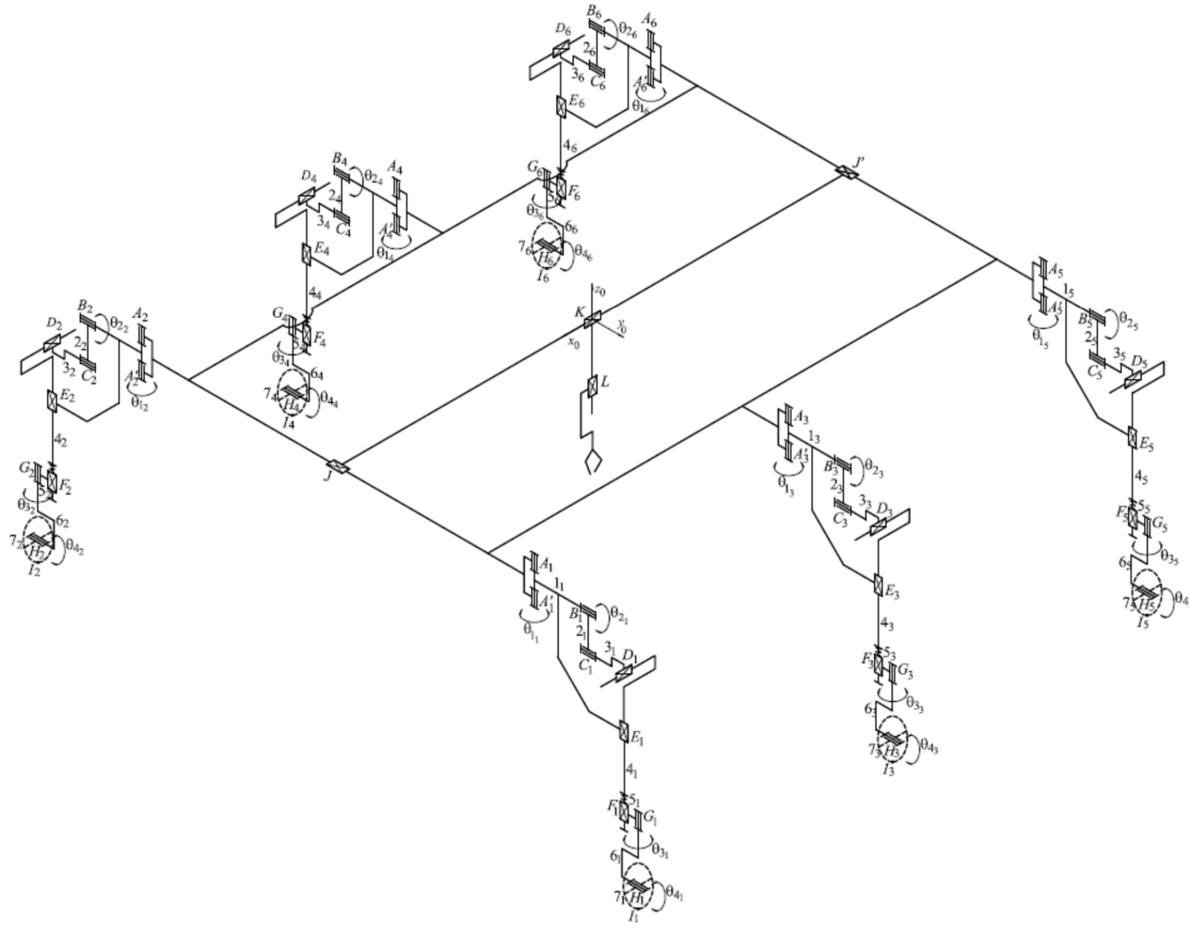


Fig. 5. Overall kinematics of the mobile manipulator.

As seen in Figure 5, a Cartesian (Gantry) manipulator (the structure using joins *J*-*J'*, *K*, *L*) is mounted on a mobile robot with hybrid locomotion.

4. CONCLUSION

In this paper, the kinematic design of a mobile manipulator for agricultural applications has been described. Due to its hybrid locomotion solution, this mobile manipulator is able to move faster on flat terrain and to change direction instantaneously, when acting as a wheeled platform, or to adapt on unstructured terrain, when acting as legged machine. Also, the legs have the role of active suspension.

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Conceptul cinematic al unui manipulator mobil cu locomoție hibridă pentru aplicații în agricultură

Rezumat: Una dintre soluțiile viitoare privind eliminarea efectului negativ asupra mediului al mașinilor agricole clasice este utilizarea roboților mobili în agricultură. Acești roboți vor trebui să opereze într-un mediu în schimbare, cum ar fi terenul, suprafețele drumurilor, iluminatul ambiental, obiectele biologice etc., aspecte care vor supune unor provocări roboții mobili. Pentru a permite roboticii să intre în sectorul agricol, roboții trebuie să aibă o construcție simplă, să fie extrem de fiabili, flexibili și, nu în ultimul rând, ieftini. Aceasta este o provocare pentru dezvoltatorii de roboți de a proiecta diverse soluții tehnice. Scopul acestei lucrări este de a prezenta proiectarea conceptuală a unui manipulator mobil pentru diverse aplicații agricole, cum ar fi lucrarea solului, însămânțarea, fertilizarea, plivitul, recoltarea etc.

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