Design Dynamic Models for Cable Robot Spraying Pesticides in Agricultural Production

Tai Duc Nguyen
An Giang Vocational College, An Giang, Viet Nam
Email: ductai.mec@gmail.com

Phuc Thanh Phan and Thinh Truong Nguyen
Ho Chi Minh City University of Technology and Education, Ho Chi Minh City, Viet Nam
Email: phanthanhphuc@gmail.com, thinhnt@hcmute.edu.vn

***Abstract*—The objective of the paper is our research on the application of cable robots in spraying pesticides in agricultural production. In this paper, research study our Robot Cable is a flexible system support jobs in agricultural production flexibility and efficiency. It uses four cables to control the working head in a space that is a quadrilateral. Besides, the experimental results on the deviation of the cable length and the actual calculation.**

***Index Terms*—cable-driven robot, farm robot, robot in agricultural**

I. Introduction

The issue of food security and food safety is one of the issues that countries around the world care about. It is one of the issues to be addressed by the Millennium Development Goals program of the United Nations Organization. The shift of labor from agricultural groups to industrial workers and services is increasing. This has caused a shortage of human resources in agricultural production. The need to apply robots to agricultural production is increasing to offset the shortage of human resources in agricultural production. The types of robots used in agriculture currently have some limitations. For flying robots, there is limited time to use, when using plants affected by the wind generated by the rotor. As for 3T robotics, it is difficult in the operating space. Robot Cable overcomes the weaknesses of the aforementioned robots when it can operate in a wide space with a simple structure.

With the aim of supporting agricultural producers to reduce the labor load and the impacts of agricultural production in addition to improving product quality. We have conducted research, calculation and design of cable robot application in agricultural production (Fig. 7).

Cable robot is a cable-driven robot with a large range of simple mechanical mechanisms suitable for applications that work on a large range such as fields and greenhouse.

This article describes the principle of operation of Cable Robot and the direction of its application to agricultural production as well as other similar production fields. We design based on the characteristics of agricultural production in Vietnam. Research results showed that the application of Cable Robot to agricultural production is in line with production needs. Besides, we pointed out the points to consider when designing a robot cable that we found in conducting empirical research.

II . Mechanical Structure

With the requirement of moving in a 3-degree free space x, y, z, we found that it is necessary to use at least 3 cables to control the position of the work head. Also, we will not use the structure with cables stretching downward, due to limited space activities below, in a gravity model will play that role.

However, during the design process, we found that the 3-cable control model is not entirely suitable for the following reasons. Operating space is limited in triangles with 3 vertices, A1, A2, and A3. With triangular operating space, the robot will operate with many limitations, the total 3 angles θ_i is always 180°. Besides, most of the working areas in agriculture are a quadrilateral, so when using triangular workspace is not suitable. About tension, during our research shows that tension is affected by gravity main. This means, when using 3 cables we have to choose a cable with a large cable diameter to ensure the strength of the cable. This will affect the cable sag during robot controller. In order to structure in accordance with the operation process, we will choose a 4-wire cable robot. Besides, using 4 cables to control will reduce the string tension on each wire, thus reducing the specific wire diameter and volume according to the length of the wire. This is a parameter that greatly affects the deviation of the wire causing an error during the control.

With the model of controlling 4 cables we can meet the requirements set forth in the space in three x, y, z axes.

To determine the degrees of freedom we calculate the following (Fig. 1): At each end, we see it as an equivalent of a bridge joint (type 3) and 4 ends connected to point O we have 8 bridge joints (type 3).

Manuscript received April 5, 2019; revised January 21, 2020.

doi: 10.18178/ijmerr.9.4.516-520

Since the cable is released by the collector motor, we have 5 more joints of type 5.

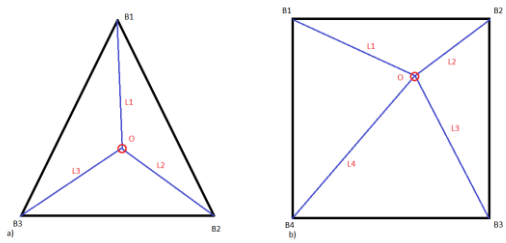

Figure 1. Operating space limit a) 3 cables b) 4 cables.

Applying the formula for calculating the degrees of freedom [1] we have

$$F = \lambda(k - j - 1) + \sum_{i=1}^{6}(f_i * i) - f_p = 6$$

So, our tissue has 6-Dof. Including 3-Dof linear motion and 3 3-axis rotating motion x, y, z coordinates.

III. Kinematics

In the previous section, we selected the structure of the cable robot. We conduct research and build a dynamic model of cable robots. Considering the robot cable model with 4 roots hanging from the fixed wire Bi with the fixed coordinate system {B}, we have P working with the coordinate system {P}, the hanging wire is hook to the Mi point, which is 4 Fixed of working head P (In Fig. 3). The coordinates of the working head are determined by the vectors. With the vector model, we can determine the length of the cable needed so that the head can move to the required point [2], [3].

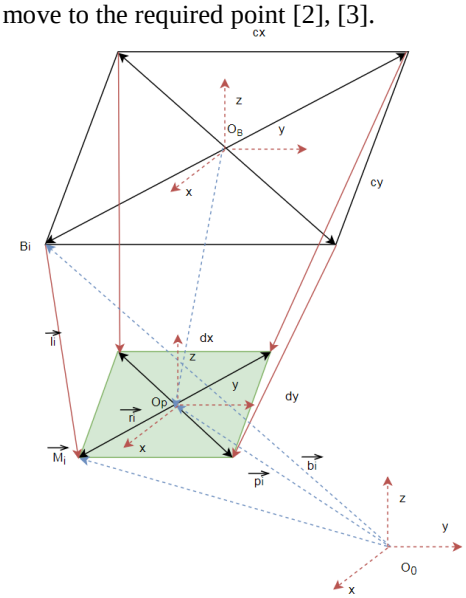

Figure 2. Vector diagram of the robot cable model.

According to the diagram (Fig. 2), we have Mi point coordinates:

$$\overrightarrow{O_0M_i} = \vec{r_i} + \vec{p_i} \quad \text{with i=1,2,3,4}$$

Because vector $\vec{r_i}$ creates with a root O_0xy a root, we have a rotating matrix that is represented in the form.

$$\vec{r_i} = R_{B,P}.\vec{r_i^p}$$

$$R_{B,P} = \begin{bmatrix} C\alpha S\beta & (C\alpha S\beta S\gamma - S\alpha C\gamma) & (S\alpha S\gamma + C\alpha S\beta C\gamma) \\ S\alpha C\beta & (C\alpha C\gamma + S\alpha S\beta S\gamma) & (S\alpha S\beta C\gamma - C\alpha S\gamma) \\ -S\beta & C\beta S\gamma & C\beta C\gamma \end{bmatrix}$$

$R_{B,P}$ is a rotating matrix with angles α, β, γ corresponding to the axis of rotation Z, Y, X.

$$l_i = \|\vec{p} + R_{B,P}.\vec{r_i^p} - \vec{b_i}\| \quad (1)$$

$$l_i^2 = [p + R_{B,P}.r_i^p - b_i]^T [p + R_{B,P}.r_i^p - b_i]$$

$$[p + R_{B,P}.r_i^p - b_i]\,[p + R_{B,P}.r_i^p - b_i]^T - l_i^2 = 0 \quad (2)$$

The vector model is built in (Fig. 4), we set the O_0 angle (coordinate system {B}) at the center of the rectangular shape is the bottom of the Sunday block [4].

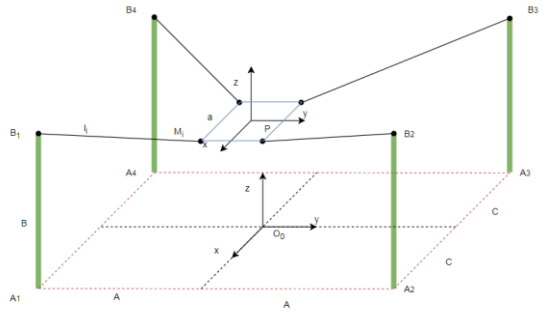

Figure 3. 4-Wire robot cable model.

where, B_1, B_2, B_3 B_4 are four Sunday blocks of size (*length, height, width*) of 2A, B, 2C (Fig. 3). The work head is a square with sides of 2a, with 4 vertices M1, M2, M3, M4 and the center is the coordinate system {P}. The rotation angles between {P} and {B} systems are α, β, γ [5].

where is:

$$\vec{p} = (x_p, y_p, z_p)$$

$$\begin{cases} \overrightarrow{OB_1} = (-A, -C, B) \\ \overrightarrow{OB_2} = (A, -C, B) \\ \overrightarrow{OB_3} = (A, C, B) \\ \overrightarrow{OB_4} = (-A, C, B) \end{cases}$$

$$\begin{cases} \overrightarrow{r_1^p} = (-a, -a, 0) \\ \overrightarrow{r_2^p} = (a, -a, 0) \\ \overrightarrow{r_3^p} = (a, a, 0) \\ \overrightarrow{r_3^p} = (-a, a, 0) \end{cases}$$

where the kinetic equation (1) and the inverse kinetic equation (2).

In the process of mechanical design, we realized that the radius of the pulley has an effect on the value of the wire length used to control the position of the head, especially for large distances.

Since our pulley has a radius of r_R, the value of L_t is the ACM wire length.

The length of the cable is calculated from ACB point so where is:

$$Lt_i = \beta_{Ri} r_R + l_{fi} \tag{3}$$

$$b_{xyi} = \sqrt{(B_{xi} - M_{xi})^2 + (B_{yi} - M_{yi})^2}$$

$$b_{zi} = B - B_{zi}$$

$$l_{fi} = \sqrt{{b_{xyi}}^2 + b_{zi}^2 - r_R^2} \tag{4}$$

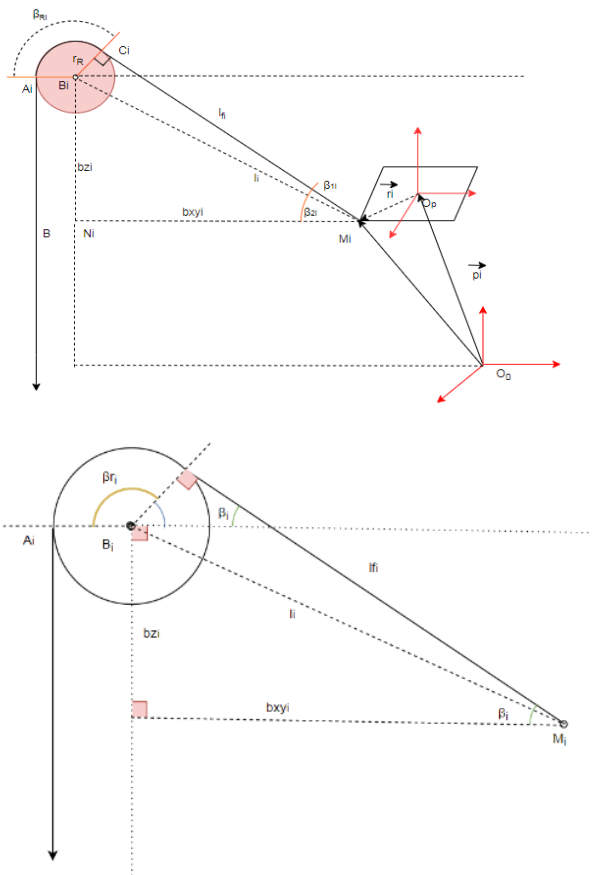

Figure 4. Diagram of kinematic location of robot cable.

$$l_i = \sqrt{{b_{xyi}}^2 + b_{zi}^2}$$

To Fig. 4, Where is:

$$\beta_{Ri} = \frac{\Pi}{2} + \operatorname{arcos}\left(\frac{l_{Fi}}{Li}\right) + \operatorname{arcos}\left(\frac{b_{xyi}}{Li}\right) \tag{5}$$

Flowing (3),(4) and (5)

$$Lt_i = \left(\frac{\Pi}{2} + \operatorname{arcos}\left(\frac{l_{Fi}}{Li}\right) + \operatorname{arcos}\left(\frac{b_{xyi}}{Li}\right)\right) r_R + \sqrt{{b_{xyi}}^2 + b_{zi}^2 - r_R^2} \tag{6}$$

Velocity Jacobian matrix is shown in equation

$$\begin{bmatrix}\dot{x}_p & \dot{y}_p & \dot{z}_p & \dot{\alpha} & \dot{\beta} & \dot{\gamma}\end{bmatrix}^T = J_L\begin{bmatrix}\dot{l}_1 & \dot{l}_2 & \dots & \dot{l}_n\end{bmatrix}^T$$

$$\begin{bmatrix}\dot{l}_1 & \dot{l}_2 & \dots & \dot{l}_n\end{bmatrix}^T = J_X\begin{bmatrix}\dot{x}_p & \dot{y}_p & \dot{z}_p & \dot{\alpha} & \dot{\beta} & \dot{\gamma}\end{bmatrix}^T$$

where:

$$J_X = \begin{bmatrix} \frac{\partial L_1}{\partial x} & \frac{\partial L_1}{\partial y} & \frac{\partial L_1}{\partial z} & \frac{\partial L_1}{\partial \alpha} & \frac{\partial L_1}{\partial \beta} & \frac{\partial L_1}{\partial \gamma} \\ \frac{\partial L_2}{\partial x} & \frac{\partial L_2}{\partial y} & \frac{\partial L_2}{\partial z} & \frac{\partial L_2}{\partial \alpha} & \frac{\partial L_2}{\partial \beta} & \frac{\partial L_2}{\partial \gamma} \\ \frac{\partial L_3}{\partial x} & \frac{\partial L_3}{\partial y} & \frac{\partial L_3}{\partial z} & \frac{\partial L_3}{\partial \alpha} & \frac{\partial L_3}{\partial \beta} & \frac{\partial L_3}{\partial \gamma} \\ \frac{\partial L_4}{\partial x} & \frac{\partial L_4}{\partial y} & \frac{\partial L_4}{\partial z} & \frac{\partial L_4}{\partial \alpha} & \frac{\partial L_4}{\partial \beta} & \frac{\partial L_4}{\partial \gamma} \end{bmatrix}$$

$$J_L = \begin{bmatrix} \frac{\partial x}{\partial L_1} & \frac{\partial x}{\partial L_2} & \frac{\partial x}{\partial L_3} & \frac{\partial x}{\partial L_4} \\ \frac{\partial y}{\partial L_1} & \frac{\partial y}{\partial L_2} & \frac{\partial y}{\partial L_3} & \frac{\partial y}{\partial L_4} \\ \frac{\partial z}{\partial L_1} & \frac{\partial z}{\partial L_2} & \frac{\partial z}{\partial L_3} & \frac{\partial z}{\partial L_{n4}} \\ \frac{\partial \alpha}{\partial L_1} & \frac{\partial \alpha}{\partial L_2} & \frac{\partial \alpha}{\partial L_3} & \frac{\partial \alpha}{\partial L_4} \\ \frac{\partial \beta}{\partial L_1} & \frac{\partial \beta}{\partial L_1} & \frac{\partial \beta}{\partial L_3} & \frac{\partial \beta}{\partial L_4} \\ \frac{\partial \gamma}{\partial L_1} & \frac{\partial \gamma}{\partial L_2} & \frac{\partial \gamma}{\partial L_3} & \frac{\partial \gamma}{\partial L_4} \end{bmatrix}$$

And inverse Jacobian matrix is:

$$\ddot{L} = J_X.\ddot{X} + \dot{J}_X.\dot{X}$$

$$\ddot{X} = J_L.\ddot{L} + \dot{J}_L.\dot{L}$$

Tension on the strings

$$T = -\tilde{J}^{-1}\begin{bmatrix} P \\ I\dot{\omega} + \omega \times (I\omega) \end{bmatrix} \tag{7}$$

with

$$\tilde{J} = \begin{bmatrix} u_1 & u_2 & u_3 & u_4 \\ r_1 \times u_1 & r_2 \times u_2 & r_3 \times u_3 & r_4 \times u_4 \end{bmatrix}^T;$$

$u_i = -\frac{\vec{l_i}}{\|l_i\|}$ is the vector indicating the unit direction of l_i

$$P = [0 \quad 0 \quad m.g \quad 0 \quad 0 \quad 0]^T;$$
$$T = [t_1 \quad t_2 \quad t_3 \quad t_4]^T$$

Thus for equation (6), we have solved the inverse problem. That is, when we have the input coordinates (x, y, z) we will get the required li value to bring the head to the desired position. After, we have the calculation results we have conducted to build the real model to test the calculation results and actual results. We conducted experiments on two orbits with two circles. The first circle has the center point M(0,0,500), radius R = 500 (Fig. 5) and the second circle has the center point M (300,-200,500), radius R = 500 (Fig. 7). Parameters of Cable Robot model follow the table below.

We have conducted the experiment process as follows (Table I): We divided the circle into 41 coordinate points marked on a plane. After that, we moved the work to each point marked and proceeded to measure the experiment. After obtaining the results of the matrix L, we proceed to load the data into MATLAB software and compare the results we calculated by the formula and the results we measured. The calculation on the graph is a solid line while the experimental part is a symbol '*'.

TABLE I. ACTUAL RESULTS

Variable	Values	Remark
Size	2900x2900x3000mm	(Horizontal, wide, high)
Mass	3 Kg	size 40x40
Pulley radius	10mm	

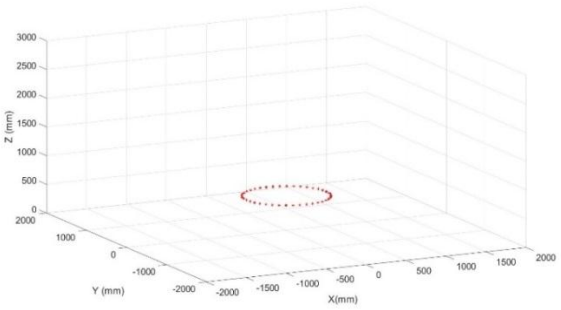

Figure 5. Trajectory of circle have center M (0,0,500), R = 500.

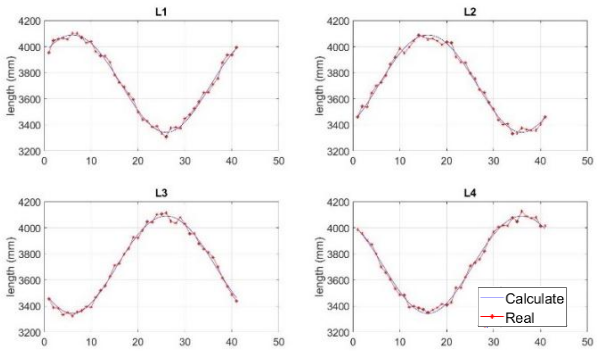

Figure 6. Graph of working space and length value, Trajectory of circle have center M (0,0,500), R = 500.

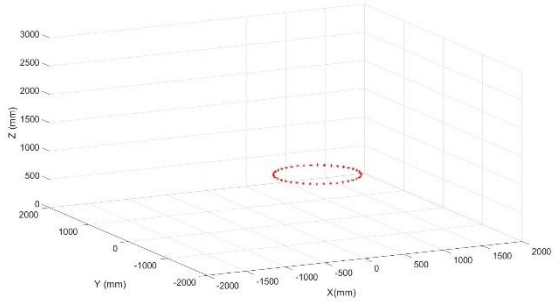

Figure 7. Trajectory of circle have center M (300, -200,500), R = 500.

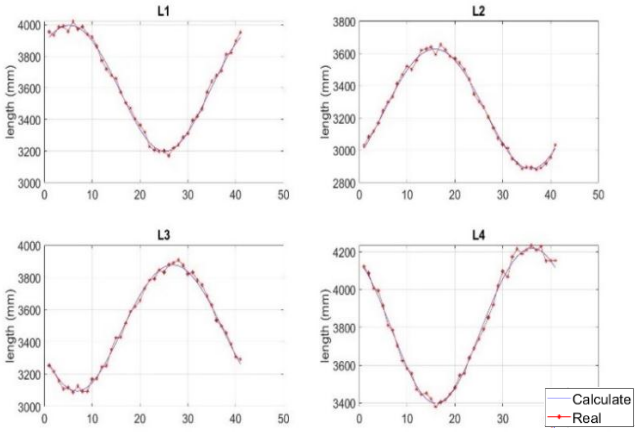

Figure 8. Graph of working space and length value, Trajectory of circle have center M (300, -200,500), R = 500.

In Fig. 6 and Fig. 8, the results showed that the error between calculation results is less than 1,0%. The cause of error is due to the extension of the wire. At each position, the ratio between the tension force and the gravity of the change. Therefore, the tension of each cable is also changing or increasing. However, for the application of robots spraying pesticides in agricultural production, this is an acceptable error.

IV. CONCLUSION

The article has constructed a structural calculation of the robot cable using 4 cables. The simulation results show us that the control ability of the 4-wire structure is feasible and the reliability of this kinetic model. The study will conduct the actual calculation of the calculation results on the real model and will provide a comprehensive control algorithm for the whole system.

Experimental results of kinetic models show us that it is possible to apply 4-cable cable robots to agricultural production.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Nguyen Duc Tai, Phan Thanh Phuc, Nguyen Truong Thinh contributed to the design and implementation of the research, to the analysis of the results and to the

writing of the manuscript. All authors discussed the results and contributed to the final manuscript. Besides, Nguyen Truong Thinh conceived the study and were in charge of overall direction and planning.

REFERENCES

[1] Lung-Wen Tsai, *The Mechanics of Serial and Parallel Manipulators*, John Wiley & Sons, 1999

[2] Prof. Bruno Siciliano and Prof. Oussama Khatib, Cable-Driven Parallel Robots- Springer, 2018;

[3] B. Zi and S. Qian, *Design, Analysis and Control of Cable-Suspended Parallel Robots and Its Applications*, Springer Science+Business Media Singapore 2017

[4] T. Muraro, H. Simas, and D. Martins, "Kinematic and static analysis of the cable driven spatial mechanism for bedridden patients," 2015

[5] D. Sridhar α & R. L. Williams II σ, Ph.D "Kinematics and statics including cable sag for large cable - suspended robots," *Global Journal of Researches in Engineering (H)*, vol. XVII, no. I Version I, 2017.

Tai Duc Nguyen, lecturers and Head of project work Lab in An Giang Vocational College. He received the B.S degree in mechatronics from Nong Lam University, in 2011 and M.S degree in mechatronics from HCM University of Technology and Enducation, in 2019. His main research interests are agricultural Robotics, Mechatronics, IOT.

Thinh Truong Nguyen is Associate Professor of Mechatronics at Ho Chi Minh City University of Technology and Education (HCMUTE). He received his Ph.D in Mechanical Engineering at Chonnnam National University (Korea) in 2010 and obtained a positive evaluation as Associate Professor in 2012. His main research interests are Industrial Robotics, Service robotics, Mechatronics, Industrial Automation.

Phuc Thanh Phan received the B.S degree in mechatronic engineering from Industrial University of Ho Chi Minh, Ho chi minh city, Vietnam, in 2015 and the M.S degree in mechatronic engineering from Ho Chi Minh University of Technology and Education, Ho Chi Minh city, Vietnam, in 2018.

Currently, he is teaching at Central Transportation 6 College, Ho Chi Minh City, Vietnam.