Cable-Driven Parallel Robot for Smart Farming

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Cable-driven parallel robot or CDPR is the robot that the actuation is transmitted through cables to the end-effector. Based on the specific qualification and the utility of cable transmission, the CDPR is become popular in this modern day. The purposes of this project are to construct the CDPR which can be operated in term of remote monitoring and irrigation process and to investigate the motion generation of robot during the transmission process. The small scale of CDPR has been constructed which consists of a mechanical structure, microcontroller, driver, computer for programming, and the end-effector that was attached with water nozzle and camera for irrigation and remote monitoring respectively. In this design, the pose of the end-effector is not completely controlled by the cables length and it will depend on the presence of gravity (under-constrained type). The performance of CDPR in term of the accuracy position of the end-effector in order of vertical, horizontal and curvilinear movement has been observed. However, there three factors that can be affected on the unbalancing of the end-effector such as actuators speed, mass of the end-effector and external load. Therefore, the ways to overcome the problems were developed. The speed of the actuators and the mass of the end-effector have been dropped by the reason to reduce the inertia and to avoid the sagging of cable during the transmission system. The unstable of the end-effector is caused by the presence of water tube (external load). Therefore, the center of mass balancing has been designed in the robot.

Index Terms— Cable-Driven System; End-Effector; Arduino; Bipolar Stepper Motor; Pulley Lifting.

I. Introduction

Cable-driven parallel robot (CDPR) is a type of parallel manipulators that is the end-effector is supported in parallel by multiple cables that are controlled by multiple tensioning actuators. The CDPR is a robot whose end-effector pose is controlled by winding and unwinding independent cables connecting the end effector to the fixed base [1].

The CDPRs have a large potential in various applications, such as agriculture irrigation, remote monitoring, clean-up of the dirty area, manipulation of heavy payloads, and rescue systems. There are consists of the end-effector which connected by multiple cables. Besides, the end-effector is operated by actuators which can extend or retract cables. Cable-driven manipulators are structurally that like the parallel ones and possess desirable characteristics, such as a large workspace, when compared to the workspace of the classical parallel manipulators.

Furthermore, CDPR is the robot that structure is light. This will be giving a good dynamic property, can hold the high load, can be used as a transport and etc. However, the robot have the limitation due to the main characteristic of the cables. The cables can only pull the end-effector but cannot push it. Therefore, the analysis and design of workspace are different from its which can be referred to parallel manipulators. The workspace is restricted by the requirement that having the positive tension in all cables. For example, Pinto et al. [2] proposed SPIDERobot, a 4 degree of freedom (DOF) robot, for architectures projects. However, the CDPR need for efficient tension distribution algorithms to improve the positioning accuracy. Such algorithms have been tested in simulations but remain to be used for the real-time control of a prototype [3].

II. Methodology

The performance of CDPR can be affected by their construction or model. The option of a relevant model such as full-constrained and under-constrained can predict the feature of a robot in term of moving platform positioning accuracy. The under-constrained cable robot has been chosen in this project. The pose of the end-effector of this robot is not completely determined by the system transmission from cable and they rely on the presence of gravity. CDPR for smart farming is composed of the major parts such as rigid frame, four pulleys lifting and actuators, cables, and the end- effector that attached with camera and water spray nozzle. The system of the robot will be controlled by the PC.

The construction robot in this project has been scaled down in terms of prototype and others relevant hardware and components. Furthermore, this robot was needed to attach the external load or water tube as an irrigation system that can lead to the unbalancing of the end-effector. Therefore, the design of the end-effector has the significant role to make the end-effector balancing during the irrigation process. However, the speed and mass of the end-effector also can affect the stability of the effector. Therefore, all these factors will be considered in this project. Furthermore, all hardware and components to construct the robot have been listed and their functional was explained. The block diagram, schematic diagram and 3D modeling have been designed to virtualize the mechanism of the robot.

A. Block Diagram and Flowchart

The block diagram of cable driven parallel robot for smart farming has been developed. As a control system, the program code has been created through the PC and uploaded to the microcontroller which acts as a brain of CDPR. At the same time, the data from microcontroller will be transferred to stepper driver to initialize the actuators. The transmission system has been designed as composed of lifting pulleys and cables to drive the end-effector from one position to another position. The below shown the block diagram of the CDPR.

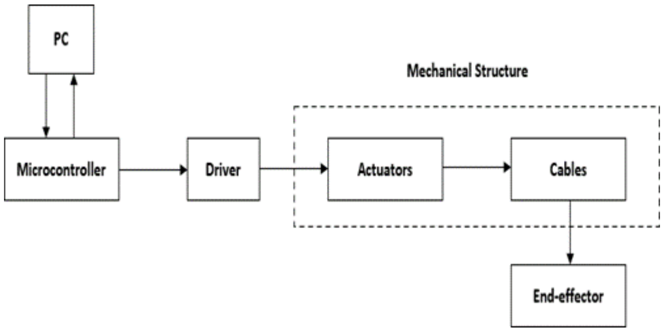


Figure 1: Block Diagram of CDPR

For the beginning of the system, the microcontroller, IP camera and water nozzle are switched on. The IP camera will record and display the image through the PC. When the water pump is opened, the water will flow through the water nozzle and start for irrigation process. The signal from microcontroller will be sent via the stepper drivers to each the stepper motors. Then, the stepper motors will release or pull the cables based on the preset program. The end-effector start moving for implement the irrigation and remote monitoring system. The Figure 2 show the flowchart of the CDPR for smart farming.

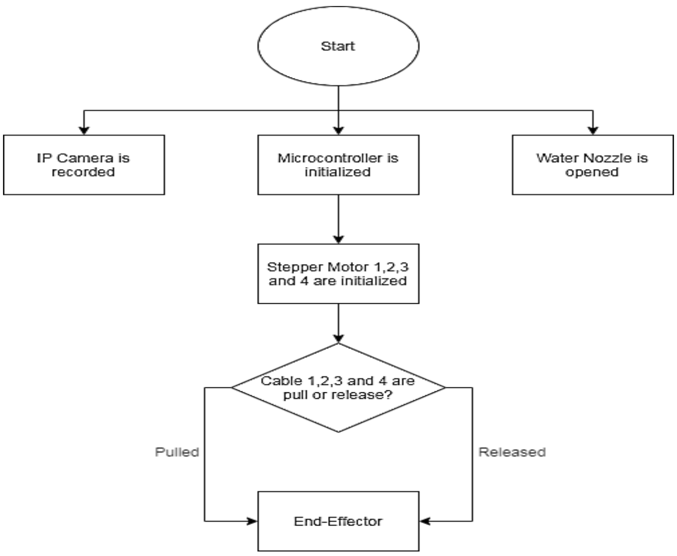


Figure 2: Flowchart of CDPR

B. Schematic Diagram and Pin Connection

This section explained the methods of the circuit connection of this project. The hardware and components for wiring are composed of Arduino Mega, NEMA 17 stepper motor, A4988 driver, resistors, capacitors and power source. The voltage supply to the stepper motor is 12v. The 10000kΩ resistors have been used to avoid the floating input of stepper driver. Furthermore, the100uF capacitors have been used to protect the driver board from voltage spikes. The Figure 3 and Table 1 shown the schematic diagram and their pin connection respectively.

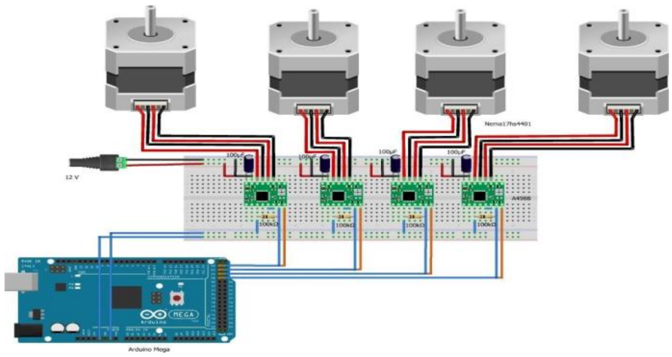


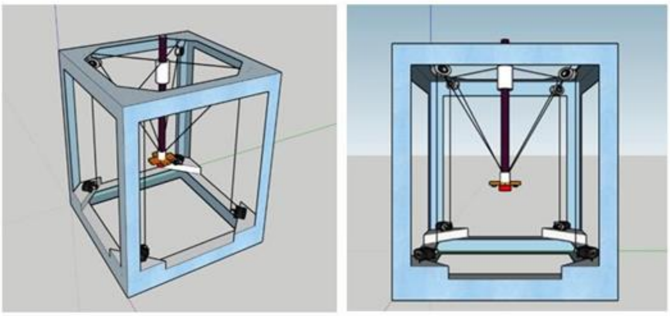
Figure 3: Schematic Diagram of CDPR

Table 1: Pin Connection [4]

INPUT/OUTPUT	ARDUINO MEGA PIN	CONNECTION
Output from Arduino Mega to Stepper Driver	Digital Pin 22 & 23 Digital Pin 24 & 25 Digital Pin 26 & 27 Digital Pin 28 & 29	DIR & STEP Pin on Driver 1 DIR & STEP Pin on Driver 2 DIR & STEP Pin on Driver 3 DIR & STEP Pin on Driver 4
Input power from Arduino Mega to Stepper Driver	5V Pin GND Pin	VDD Pin on Driver 1,2,3&4 GND Pin on Driver 1,2,3&4
INPUT/OUTPUT	**NEMA 17 STEPPER MOTOR**	**CONNECTION**
Output from NEMA 17 Stepper Motor to Stepper Driver	Motor1 Pin 2B, 2A, 1A & 1B Motor2 Pin 2B, 2A, 1A & 1B Motor3 Pin 2B, 2A, 1A & 1B Motor4 Pin 2B, 2A, 1A & 1B	2B, 2A, 1A & 1B Pin on Driver 1 2B, 2A, 1A & 1B Pin on Driver 2 2B, 2A, 1A & 1B Pin on Driver 3 2B, 2A, 1A & 1B Pin on Driver 4
INPUT/OUTPUT	**A4988 STEPPER DRIVER**	**CONNECTION**
Output from Stepper Driver to Resistor	Diver 1,2,3&4 STEP Pin	100kΩ from Driver 1, 2, 3 & 4 to GND
Output from Stepper Driver to Capacitor	Diver 1,2,3&4 VMOT Pin Diver 1,2,3&4 GND Pin	100µF Positive Pin 100µF Negative Pin
RST & SLP from Stepper Driver	Diver 1,2,3&4 RST & SLP Pin	RST to SLP Pin
INPUT/OUTPUT	**POWER SUPPLY**	**CONNECTION**
Input from Power Supply to Stepper Driver	12V GND	VMOT Pin from Driver 1,2,3&4 GND Pin from Driver 1,2,3&4

C. 3D Modeling

The main goal of this work is to design the cable-driven parallel robot for smart farming. In this design, the four cables are needed to suspend the end-effector in which to swing the water nozzle and camera that located at the end-effector to the target position. There were several parts that attached on the end-effector such as water nozzle, camera, load, and water tube. The 3D modeling has been drawn to virtualize the construction of CDPR. This drawing has been considered the system balancing of the end-effector during the transmission process. The Figure 4 shown the 3D modeling of CDPR: (a) Three-Dimensional View, (b) Front View.



(a) (b)

Figure 4: The 3D modeling of CDPR

D. System Dimensional Optimization

Modeling CDPR required the knowledge of several key system parameters such as width, depth, density, height and mass. The robot for smart farming has been scaled down in term of prototype. The figure below shown the dimensions of frame and the end-effector. The full scale of CDPR's frame was 1:1.

The dimensional of each part of robot should be considered based the capability or power of the actuators to suspend the load. In this design, the end-effector was attached with external load by the reason for balancing during the motion generation. Table 2 shown the full-scale system parameters of CDPR for smart farming.

Table 2: Full-scaled Parameter of CDPR

Parameters	Dimensions
Field width	1m
Field depth	0.8
Tower height	1m
Cable density	0.15 g/m
End-effector height	0.8
End-effector mass	300g

E. Motion Test

The motion test of the end-effector has been implemented after the robot has been built and all hardware and components were setup. The end-effector can be moved fast without the presence of camera for remote monitoring and water tube for irrigation process. However, when the camera and water tube were attached, the end effector was loss the stability during the transmission process. Therefore, the factors that affected to the unbalancing of the end-effector have been listed: 1) Speed of the actuators, 2) Mass of the end- effector, and 3) External load (water tube).

Based on this observation, the ways to overcome the problems were developed. The speed of the actuators and the mass of the end-effector have been dropped by the reason to reduce the inertia and to avoid the sagging of cable during the transmission system. However, the unbalancing of the end-effector can be caused by the presence of water tube. Therefore, the center of mass balancing has been designed in this project.

III. RESULT & DISCUSSION

The CDPR for smart farming was completely developed after the troubleshooting. This section will be focused on the outcomes of CDPR for smart farming based on the methodology or experiment setup. The overall design of robot will be shown as well as their explanation of the design. The system of robot was demonstrated by inserted some plants inside the CDPR. The motion generation have been analyzed.

A. Overall Design

The CDPR for smart farming has been demonstrated after the completely of troubleshooting. Some plants were put inside the CDPR for implementing the irrigation process and remote monitoring system. The Figure 5 shown the overall design of CDPR for smart farming.

(a) (b)

Figure 5: The overall design of CDPR for smart farming

B. Motion Generation

The performance of CDPR in term of the accuracy position of the end-effector during the transmission process were recorded. The end-effector was able to follow the preset program (vertical, horizontal and curvilinear movement). Based on the robot design, the end-effector was able to move on the x, y and z-plane as well. The Figure 6 shown the direction of the end-effector to the target location.

Figure 6: The direction of the end-effector to the target location

1) *Speed of Actuator and End-Effector*

The stepper motor that has been used as the actuator is a hybrid stepping motor with a 1.8 step angle or 200 steps per revolution. However, the type of stepper driver A4998 that has been used was set to quarter which mean the stepper motor need 800 steps for one revolution. Furthermore, each movement of the end-effector from one position to another position having 500 microsecond delays to avoid the cable sagging and reduce the inertia of the end-effector.

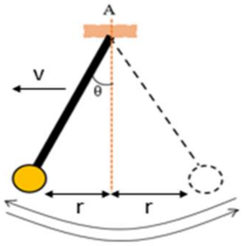


Figure 7: Curvilinear translational motion

In this section, the speed of actuator and the end-effector have been calculated as shown as below.

800 steps = 1 rev, for 2.47 seconds

Steps per second = 800/2.47 = 323.89 ≈ 324

Speed of actuator, $n = \frac{Steps\ per\ second}{Steps\ per\ revolution} \times 60 = \frac{324}{800} \times 60$

$= 24.3$ RPM

Linear distance (in a second), r = 7.2 cm = 0.072 m

The linear velocity of end-effector, $v = r \times n \times \frac{2\pi}{60}$

$v = 0.072 \times 24.3 \times \frac{2\pi}{60} =$ **0.18 m/s**

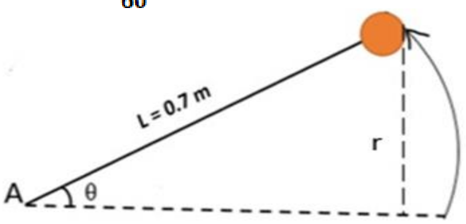


Figure 8: Rotation about a fixed axis

Angular velocity of the end-effector, $\omega = \frac{v}{L} = \frac{0.18}{0.7}$

= **0.26rad/s**

2) Association between cable lengths and speed

In this section, the length of each cable has been recorded as shown in the Table 3 while the end effector was moved from one position to another position as shown in the Figure 9. The graph of cables length versus times have been plotted and the observation were recorded.

Based on the graph that shown in the Figure 10, the rising and falling point are not constant which caused from the time delay in the preset program. The control system of robot was set with the time delay to reduce inertia and avoid the cable sagging during the motion generation of the end-effector.

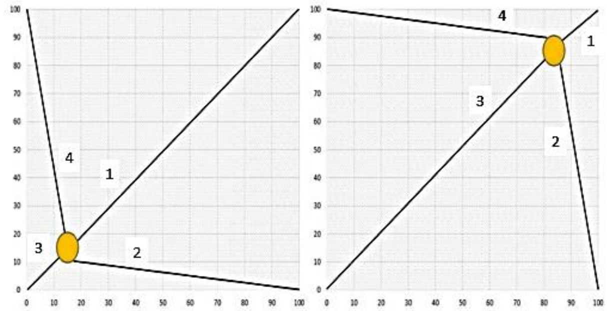


Figure 9: The movement of the end-effector

Table 3: The measurement of time and cable length during the transmission

Cable 1		Cable 2		Cable 3		Cable 4	
Time (s)	Length (cm)	Time (s)	Length (cm)	Time (s)	Length (cm)	Time (s)	Length (cm)
0	112	0	78	0	25	0	78
1	108	1	75	1	30	1	76
2	82	2	60	2	50	2	73
3	56	3	48	3	78	3	82
4	38	4	50	4	91	4	94
5	30	5	52	5	98	5	98

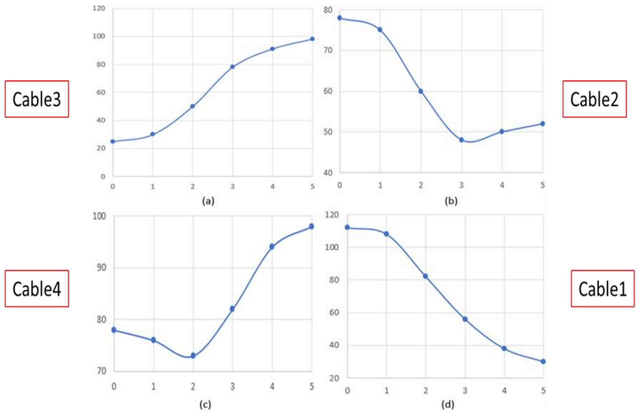


Figure 10: Graph of Cable Length (cm) Versus Time (s)

IV. CONCLUSION

In conclusion, the objectives of this project were achieved. The cable driven parallel robot for smart farming has been constructed. The irrigation process and remote monitoring have been demonstrated and the results of robot performance were recorded. The motion generation of the robot have been analyzed including the speed of the actuators, linear and angular velocity of the end-effector and the association between the motion of the end-effector and cables length. Lastly, the remote monitoring was operated as well during the irrigation process.

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