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## Kinematic Motion Control for Robot Mobile Manipulators as Fire Fighters

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## Kinematic Motion Control for Robot Mobile Manipulators as Fire Fighters

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**Abstract.** The purpose of this research is to make mobile manipulator robot as firefighting, to derivate kinematical formulation for mobile robot manipulator system, beside that is to make control system of such robot. The design and experiments were conducted in a mobile manipulator study as a firefighter. The result of this unmanned robot design can still carry the appropriate the standard sprinkle of firefighting system. The design of mobile manipulator mechanism is done by using 3 SolidWorks 2010 design software design. The process of making robot begins with mobile robot as base frame and then installed the robot manipulator. Direct control method was done in this research by using arduino mega as interface system. The conclusion of this research is that robot can move with direct control and autonavigation for tracking trajectory case as firefighting system.

Keywords: Firefighting, direct control, Arduino, Control System

### 1. Introduction

A team of firefighters with a fast response system both natural and artificial system is increasingly needed [1]. Infact that, in the fire disaster there are two things those are dangerous fire and smoke hazard [2]. Furthermore, a fire disaster is a fire that is not controlled, not desired because it can cause harm to both property and fatalities.

Furthermore, fire can be happened if there is a balance of three elements consisting of fuel, oxygen, and heat. The relationship of these three components is usually called a fire triangle, so that if one of the elements is removed then the fire will be extinguished. Based on the theory of fire triangle then the principle of extinguishing technique is to damage the balance of mixing the three elements, for stopping the combustion process by breaking the chain reaction.

This principle can be done for firefighters with the following techniques [3]:

1. Cooling Method; fires can be extinguished by cooling the surface of a burning material using a water spray until the temperature below the flash point. But, in the case for fuels with low flash point such as gasoline, for cooling by water is not effective. Usually cooling is used to extinguishing fires involving fuel with high flash point.
2. Smothering method; a fire is limited by disconnecting the fuel with oxygen or air required for the combustion process. Covering a fire with CO<sub>2</sub> or foam will stop the air supply for fire.
3. Starvation method; this method of extinguishing the fire by separating the combustible material by closing the flow of fuel into the fire or stop the fuel supply.



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4. Breaking the chemical chain reaction; the combustion process combines by three elements to produce other gases such as H<sub>2</sub>S, NH<sub>3</sub>, HCN (according to a burning object). An important reaction is a free atom of O and H known as the radical atoms that make up OH and rupture into H<sub>2</sub> and O. The radical O atom can form a larger flame. So that the way this outage is to break the chain of combustion reaction with fire extinguishers that work chemically.

Firefighting is a very dangerous task but it is still often done by human operators [3]. The need for rescue robot action planning was identified over 25 years ago by Professor Satoshi Tadokoro's group, he also proposed the Rescue Robo Cup5 competition framework. Then, According to Robin R. Murphy, 2001, rescue robots can be grouped into four major types as follows[4]:

- a. Unmanned Ground Vehicles (UGVs) - UGV is working on the ground and can help rescue teams find and interact with trapped victims, in areas that are dangerous and difficult for rescue workers to enter the area.
- b. Unmanned Surface Vehicles (USVs)- USVs floats on the surface of the water, and as searching robot then can help rescue teams to the right locate for preparing equipment to the victims.
- c. Unmanned Underwater Vehicles (UUVs)- UUVs has the ability to search through water and identify fatalities, subject or hazardous materials.
- d. The UAV works without contact with the ground surface and can assist in transporting medical assistance to the victim and to present a rough scenario of the crash site

The science of robotics is very often used in hazardous industries to undertake dangerous technological processes [5].



Figure 1. Mobile manipulator robot as firefighting robot

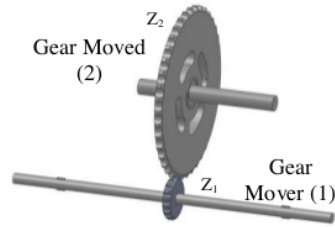
## 2. Design of Firefighting Rescue Robot

### 2.1. Design of rescue robot

The initial stage of planning is to calculate the load will be handled by mobile robot manipulator as a fire extinguisher system. After that, determine the type of motor that will be used. So that obtained the selected motor data. The authors already done an example manipulator robot applied to another system at [6]. Power obtained from torque and motor rotation. Power P (kw) must be transmitted and rotation spindle (rpm) is given. In this case it is necessary to check the power P is. If P is the required average power it shall be divided by the mechanical efficiency  $\eta$  of the transmission system to obtain the necessary initial driving force. Great power may be needed at startup. Thus it is often necessary to correct the required average power by using correction factors in the planning.

### 2.2. Gears transmission

2.2.1. Gears straight. The gears are defined as the power transmission wheel, the wheels that transmit motion from the drive to the actuated. The use of gears as a transmission is commonly in industry, for example in small and meticulous measuring instruments such as watches, to reducing gears on large turbines that are powered by tens of mega-watts, machine tools, motor vehicles, lifting machines, transportation machinery etc . An example of straight gears can be found at Figure 2.



**Figure 2.** Direct Gear Transmission

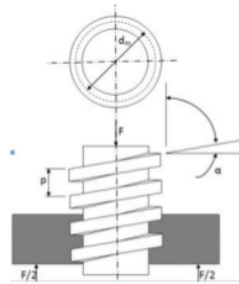
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If  $Z_1$  is the number of gears on the motor shaft gear,  $Z_2$  is the number of gears on the output shaft  $T_1$  is the torque on the motor shaft, and  $T_2$  is the torque on the output shaft. The output torque can be calculated by the formula,

$$T_2 = \frac{Z_2}{Z_1} T_1 \quad (1)$$

The direction of rotation of the shaft in the direct connection gear transmission is always opposite for each serial connection. To get the same rotation direction as on the motor shaft the gear must be arranged with an odd number.

Torque that occurs on the thread:



**Figure 3.** The direction of force on the pair of thread and nut



**Figure 4.** The force equilibrium on the thread (a. up, b. Down)

The force balance of forces acting on, when raising the load, is found:

$$\begin{aligned} \Sigma F_x = 0, \quad P - N \sin \alpha - \mu N \cos \alpha &= 0 & (2) \\ \Sigma F_y = 0, \quad P + \mu N \sin \alpha - N \cos \alpha &= 0 & (3) \end{aligned}$$

While the balance of force of forces that work, when lowering the load, is obtained:

$$\Sigma F_x = 0, \quad P - N \sin \alpha + \mu N \cos \alpha = 0 \quad (4)$$

$$\Sigma F_y = 0, \quad F - \mu N \sin \alpha - N \cos \alpha = 0 \quad (5)$$

From the equation (1) and (2), it is found:

$$P = \frac{F (\sin \alpha + \mu \cos \alpha)}{\cos \alpha - \mu \sin \alpha} \quad (6)$$

Then, with the same path, equation (3) and (4), can be define:

$$P = \frac{F (\mu \cos \alpha + \sin \alpha)}{\cos \alpha - \mu \sin \alpha} \quad (7)$$

Also, from the equation (5) and (6), multiply by  $1/\cos \alpha$  and  $\tan \alpha = 1/\pi dm$ , so that, force P to raise and lower the load:

$$P_n = \frac{F [(1/\pi dm) + \mu]}{1 - [\mu(1/\pi dm)]} \quad (8)$$

$$P_t = \frac{F [\mu - (1/\pi dm)]}{1 + [\mu(1/\pi dm)]} \quad (9)$$

So that the torque acts on the driving thread:

$$Mt = P \frac{d_m}{2} \quad (10)$$

When equation (7) and (8), substitute to equation (9), it was found:

$$Mt_n = \frac{F dm (1 + \pi \mu dm)}{2 (\pi dm - \mu l)} \quad (11)$$

$$Mt_t = \frac{F dm (\pi \mu dm - 1)}{2 (\pi dm + \mu l)} \quad (12)$$

**2.2.2. Belt Transmission.** This transmission is a power transmission / torque system from one shaft to the other through a circular belt on a pulley attached to the axes. The belt friction character and the pulley surface greatly affect the transmission capability. So the amount of tension in the belt determines the amount of torque that can be transmitted.

The belt can transfer the power elastically, so no elastic coupling is required. And it is not noisy and can accept and reduce shock loads, also easy and cheap in the manufacture and requires little maintenance

### 3. Research Method

The research method used is design and experiment. Details of the method used are shown below.

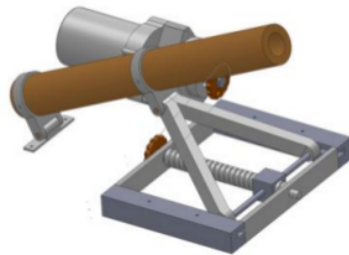
#### 3.1. Mechanics System Design

The design of the mechanical system we created in the making of robot consists of 2 (two) units, namely: mechanical system of mobile axle driving wheel, mechanical system manipulator as sprinkle mechanism, as follow:

*3.1.1. Design of Mechanical System of Robot Drive Wheel.* The design of mechanical systems of the robot drive wheel is based on the environmental conditions that will be passed by the robot.

Tracking trajectory that will be traversed by the robot is a trajectory that is essentially uneven and made of soil used for wheel berbentu chain. Nonholonomic mobile robot is design in this robot. The number of chain wheels used are two (2) pieces each driven by a motor.

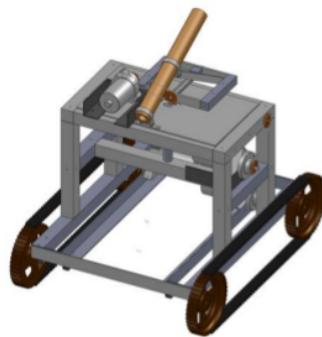
*3.1.2. Design sprinkle mechanism as manipulator robot.* Sprinkler system is considered as a robot manipulator. Sprinkle is one component of the robot that serves to direct the liquid fluid during the blackout process takes place. The sprinkler is directed according to the position of the heat source that needs spraying. At the time of the blackout process, sprinkler direction control requires a large force due to the pressure of the liquid fluid through the sprinkler hole and the momentum occurring at the sprinkler ends due to fluid backflow that slid out of the sprinkler. The driving source of the sprinkler motion control mechanism uses a DC motor. To ensure that the sprinkler moves well in the desired direction, a mechanical system design of the sprinkler drive is shown in FIG. 4.



**Figure 5.** Design of the Sprinkler Motion Control mechanism.

#### **4. Result and Discussion**

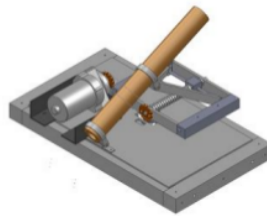
The result of the research is design of robot control which able to overcome the blackout process with various position of height of heat source.



**Figure 6.** Model Fire Fighting Robot

##### *4.1. Sprinkler Motion Control System*

Sprinkler is one part of the firefighting robot. The drive mechanism of the sprinkler can be seen in Figure. 11.



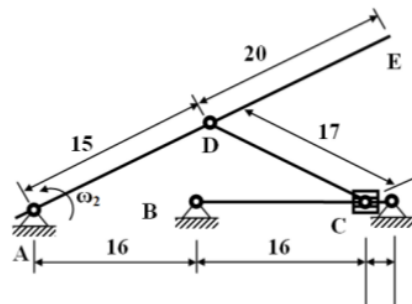
**Figure 7.** Sprinkler system as manipulator robot

Using a DC motor connected by several components forming a finite kinematic circuit, including: motor shaft, gear drive, chain, gear actuated, threaded shaft, driving nut, drive shaft, and sprinkler holder. When the motor is rotating, the driving gear moves another gear through a chain.

The specification of DC motor data and sprinkler mechanical systems are used:

**3** Table 1. Specification of DC Motor

Torque ( $T_m$ )	100 kg.cm
Rotation ( $n$ )	500 rpm
Threaded Pitch ( $p$ )	1,6 mm
Volt (V)	12 Volt
Current (I)	4 ampere
Shaft Diameter (d)	1,5 cm
Length of motor (L)	12,5 cm
Diameter of motor (dm)	5 cm
Mass (m)	930 gram
Threaded angle ( $\alpha$ )	4°

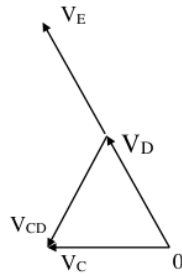


**Figure 8.** Free-body diagram of mechanical system of sprinkler motion controller

Polygon of Speed Movement System Mechanical Control of Sprinkler Motion

Table 2 Polygon Speed of Sprinkle Mechanism

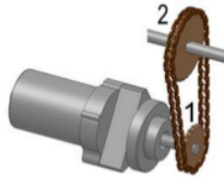
Point	Distance
A-D	15 cm
D-E	20 cm
D-C	17 cm
A-B	16 cm
B-C	16 cm



**Figure 9.** Polygon velocity of sprinkler system as a robot manipulator.

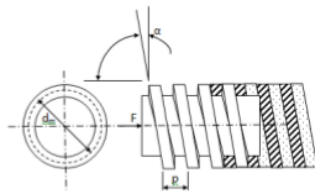
#### 4.2. Force on Sprinkler system

Using the equation (1) The force that occurs in the driving gear ( $F_1$ ) and ( $F_2$ ) is 50 kg.



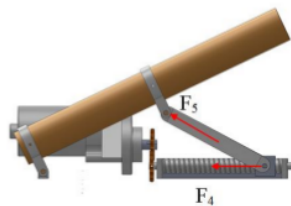
**Figure 10.** Transmission of gear 1 to gear 2

The force transfer system used from the gear 2 ( $F_2$ ) to the screw nut of the steering wheel ( $F_3$ ) is by using the principle of screw pairs of bolts and nut [3]. The magnitude of the screw angle is inversely proportional to the magnitude of the forwarded force. For more details, the principle can be seen in the following figure:



**Figure 11.** Transmission System to a shaft (Syam, 2018)

Using the equation (10) The force occurring in the threaded stem  $F_3 = 100\text{kg}$ . Force that occur during thread ( $F_4$ ):



**Figure 12.** The force on the nut screw ( $F_4$ ) and the connecting rod ( $F_5$ ) as a nozzle

By using the equilibrium equation of force then it obtained  $F_4 = 299\text{ kg}$ . Given the force ( $F_4$ ) on the threaded stem it will produce a force ( $F_4$ ) reaction on the nut screw in the opposite direction.

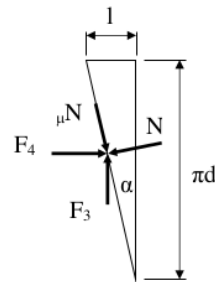


Figure 13. Freebody diagram ( $F_3$ )

The force on the connecting rod to the sprinkler holder of magnitude changes according to the angular change between the threaded axis of the rod and the sprinkler connecting rod. If the angle formed between the threaded rod and with the sprinkle connecting rod is  $30^\circ$ , then the lift force on the sprinkler holder can be calculated with the result  $F_5 = F_4 \cdot \cos 30^\circ$ .

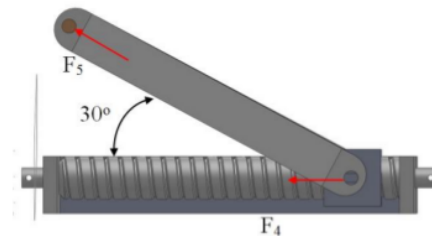


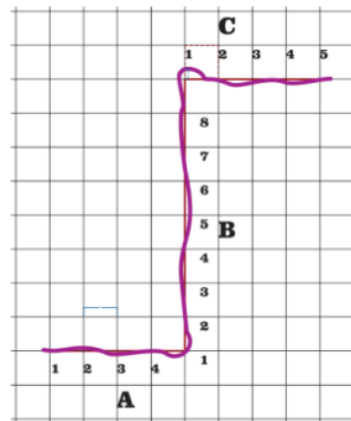
Figure 14. The angle between the screw axis with the connecting rod

The result of sprinkler vertical motion is used to control the altitude of the blackout direction during the process. As it happens that the blackout targets constantly change according to the position of the heat source. From the test results with at some position of the heat source, it is seen that sprinkler movement control able to steer well the blackout path after the previous position of the robot to take the right position.

#### 4.3. Experiment of tracking trajectory problem of firefighting robot

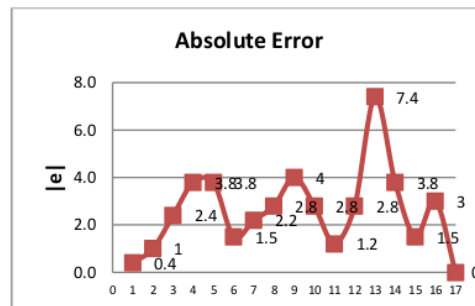
GPS tracking method is done in this experiment. This experiment used GPS tracking trajectory method for mobile manipulator robot as firefighting system. The trajectory of the robot can be found at Fig. 15. The mobile robot follows the trajectory then the effectiveness shown on Figure152. On this path there are 17 waypoints starting at -5.2306 LS, 119.5024 LB to -5.2307 LS, 119.5024 LB, then -5.2306 LS, 119.5024 LB and end-point -5.2307 LS, 199.5024 LB.. The result of this experiment can be found at Figure 40. The mean waypoint distance is 25 cm with the total length of 4 meters.

In Figure 15. Visible cross passing by mobile robot. There are 3 stages: Stage A, B and C. Turns 90 degrees from A to B. The amount of mobile robot deviation as a fire extinguisher during the trial can be seen in Figure 47.



**Figure 15.** Error history of tracking Trajectory Mobile robot rescue as a fire fighting

Sometime after the mobile robot goes there are some deviations. Trajectory tracking experiments during the first trajectory occur several deviations on the axes  $X_a$ ,  $Y_b$ , and  $X_c$  but the farthest extent of the waypoint is on the  $X_c$  axis at waypoint 1 with a distance of 7.43 cm apart and deviate at the coordinate point -5.2307 South Latitude, 199.5024 Longitude.



**Figure 16.** Error history during tracking trajectory

Root mean square error, RMS Error method is used to calculate tracking trajectory error in this experiment. The Error total of all trajectories is 0.1757 m, as shown in figure 16.

## 5. Conclusions

It was found some conclusions:

1. Experiment of tracking trajectory with direct control method succeeded by using RMS error method.
2. The rotary motion of the driving DC motor is transformed into linear motion by the actuation mechanism and the threaded rod.
3. Torque of DC motor is 100 kg.cm can be converted into lift force on the sprinkler holder by a connecting rod of 149 kg.

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