3 Methodology of finding Centre of Friction of an Object

In order to push an object with a MR comfortably the object should make approximately equal reaction on the wheels on both sides of the robot. Hence the COF of the object should be kept on the Symmetrical plane of the MR. So there should be a method to find the COF of the object. If the shape of the object is arbitrary and the terrain where the object is being pushed is not even, finding of the COF is not an easy task. Centre of mass of an object with a known shape can be found by using an image processing technique if the mass distribution inside the object is even.

In this research only the servo motor driving PWM waveform and the encoder pulses are used to determine the COF of any shaped object.

3.1 Forces act on moving object

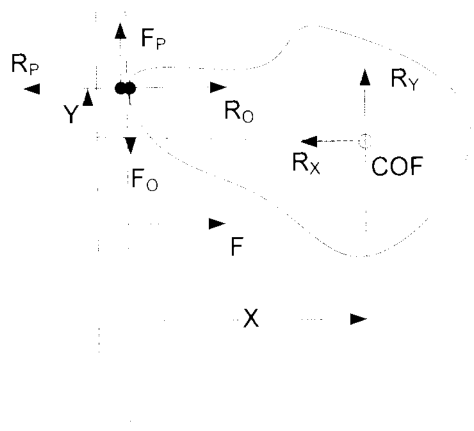

Figure 3-1 Forces act on pusher and the object

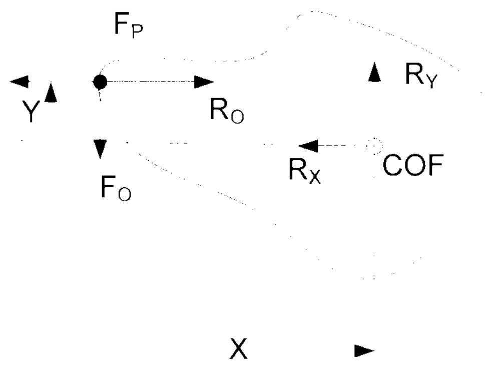

Figure 3-2 Forces act on the object

Where

R_x	Reaction on the object from the floor along x axis
R_Y	Reaction on the object from the floor along y axis
R_O	Reaction force on the object
F_O	Friction force on the object from the plate
R_P	Reaction force on the plate
F_P	Friction force on the plate from the object
X	Distance between COF and the plate perpendicular to R_O
Y	Distance between COF and touching point perpendicular to F_O
F	Force applied on the plate

If an object is being pushed by a plate as shown in figure 3.1 there are several reactions needed to be considered to predict the movement of the object. When the object and its touching point of the plate are considered,

$$R_O = R_P$$

$$F_O = F_P$$

If these forces are at equilibrium

$$R_O = R_P = R_X = F$$
$$F_O = F_p = R_Y$$

$$F_O * X = R_O * Y$$

$$F_O = \mu_{op} R_O$$

$$R_X^2 + R_Y^2 = \mu_f Mg$$

Where M is the mass of the object

g is the gravitational acceleration

μ_{op} is the friction coefficient between the plate and the object

μ_f is the friction coefficient between the floor and the object

When the force applied from the plate increased this equilibrium will break and object starts to move and rotate. If the F_O is greater than maximum possible static friction force the object tries to slip along the plate. Due to the torque created by $(F_O \hat{} X - R_O \hat{} Y)$ the object tries to rotate around the COF. Direction of this rotation depends on the magnitudes of F_O, R_O and the distance between the COF of the object and the plate. This rotation will stop when the object rotates to a position which creates zero torque around the COF of the object. At this stage the object might touch the plate from several points. Figure 3-3 shows such arrangement of an object. Here the R_{Oi} and

F_{Oi} are the reaction and friction forces on the object at the i[th] point of contact. Hence this arrangement can mathematically be represented as follows

$$\sum_{i=1}^{n} F_{Oi}{}^{\wedge} X_i - \sum_{i=1}^{n} R_{Oi}{}^{\wedge} Y_i = \text{Total torque on the object in clockwise direction}$$

Here the Xi and Yi are the distance from COF to F_{Oi} and R_{Oi} respectively and n is the number of touching points of object and the pusher. If this torque is zero then there is no rotation of the object.

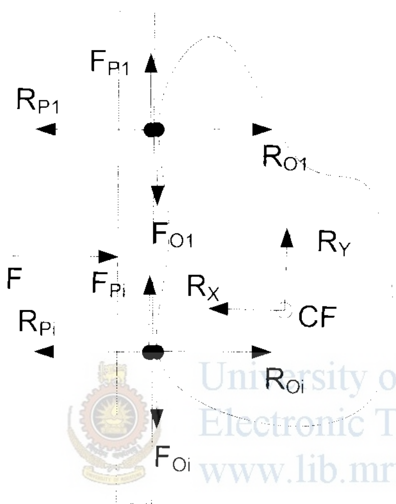

Figure 3-3. Several points of contact between plate and the object

Similarly if the $R_X^2 + R_Y^2$ is greater than the maximum allowable static friction force between the object and the floor, the object tends to moveto the direction of the applied force. If the force applies on the object changes its direction there is a possibility of passing the applied force through the COF of the object. At that instance the object will only move towards the direction of the applied force without any rotation.

When an object is being pushing, we need to keep COF of the object closer to the centre of the pushing bar. Then equal torque applies to both motors. So the object needs to be pushed to the centre of the pusher if it is in a side of the pusher. Since the pusher creates both rotational motion around the COF of the object and perpendicular motion along the COF of the object when pushing with higher force by turning the angle between the pusher and the object the object can be moved towards the centre of the pusher. This action need to be done by both sides of the pusher. Then the robot tends to move in a zigzag pattern. This zigzag pattern can be implemented by turning one wheel of the MR at a time.

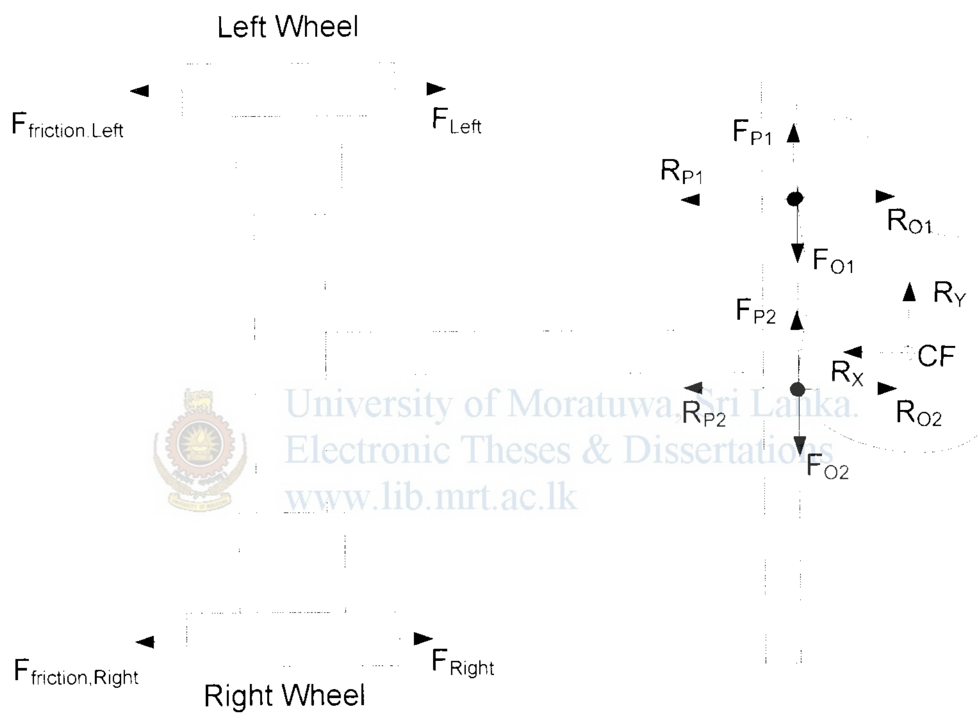

Figure 3-4 Forces applied on Mobile robot

If an object is being pushed by a plate as shown in figure 3-4 there are several reactions needed to be considered to predict the movement of the object. When the object and the touching point of the plate are considered, a reaction force creates due to friction on the object. The magnitude of this force mainly depends on the weight of the object and the frictional force created on the object.

3.2 Zigzag movement of the robot and detection of the COF of the object

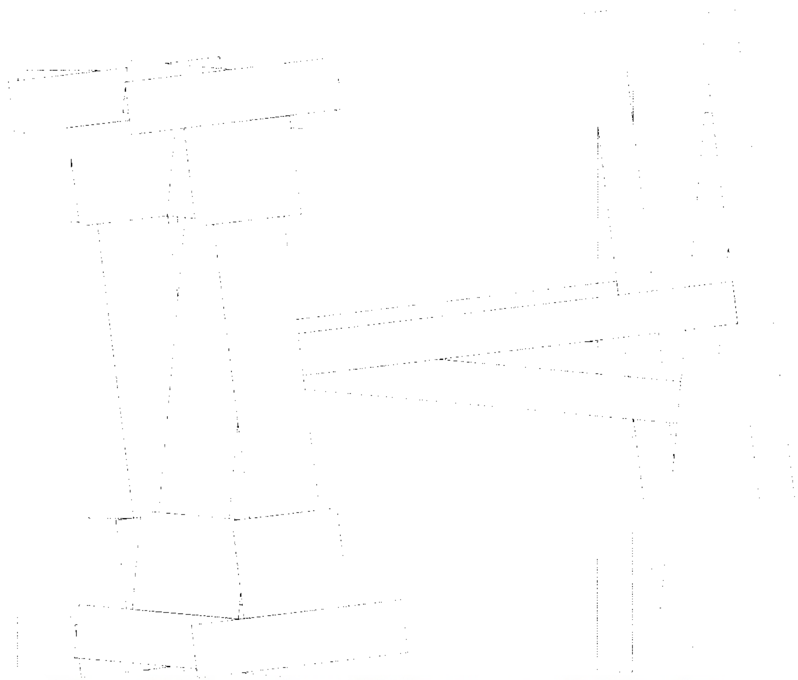

Figure 3-5 Zigzag Motion of the Mobile Robot

As shown in the figure 3-5 the robot moves turning one wheel at a time. The wheel speed is increased from its neutral position by changing the pulse width of the DC servo motor input. This is done while monitoring the encoder pulses produced by the encoder attached to the rotating wheel. In every 20ms the positive width of the PWM signal is increased by 4us and this will create more and more force on the motor. When the motor torque is sufficient to move the MR the robot will start to turn. Still the PWM positive width increment is going on. When the pusher attached to the MR touches an object the speed of the MR get slower. If it touches close to the driving motor side edge of the pusher the motor needs more power to drive it. Hence motor speed gets much slower. Then it needs more time to rotate the wheel until it produces the required number of pulses. But the object moves more towards the centre. When the required number of encoder pulses are obtained the motor stops it's rotation and will record the maximum positive pulse width used to drive the motor. After that the

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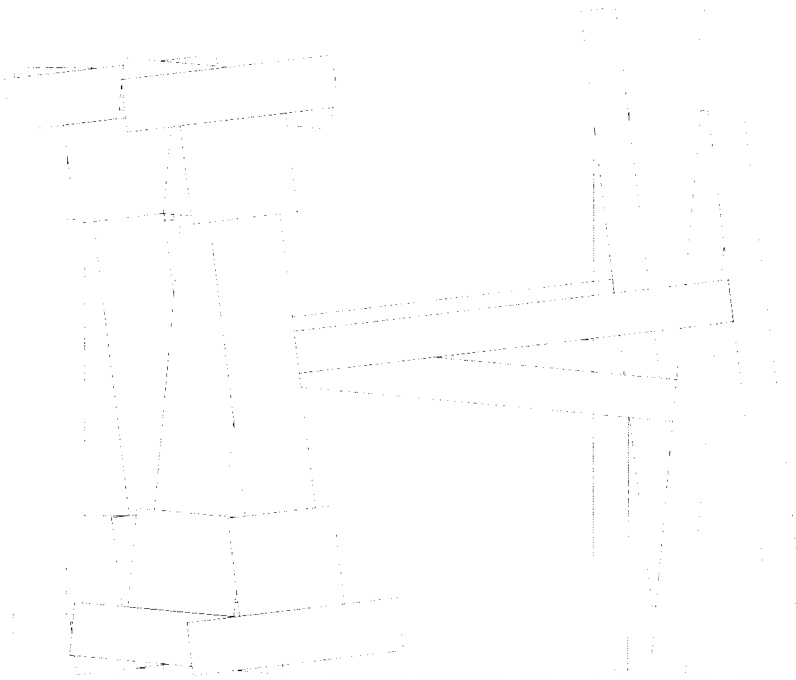

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