Electric Powered Wheelchair Trajectory Planning on Artificial Potential Field Method

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Abstract. An addendum of People with Disabilities (PWDs) worldwide quite worries the World Health Organization in which they are consist of people that incapability of doing their own daily routine without the aid of a third party. The third party may consist of a person or a specific equipment or tools that could aid for their daily mobility. This paper tends to help PWDs with their daily routine by introducing a path planning method that recognize the trajectory of the route by using the Artificial Potential Field Method (APF) that will act as an algorithm in a control system of an Electric Powered Wheelchair (EPW). The EPW will be modelled into the MATLAB and Simulink according to the parameters such as inductance, resistance, and driving torque that is exactly as an actual model. Artificial Potential Field Method (APF) are consist of two main force field, Repulsive Force Field (RFF) and Attractive Force Field (AFF). The Repulsive Force Field (RFF) is designated as obstacle on a path whereas influencing the EPW to navigate away from the obstacle. While the Attractive Force Field (AFF) act as goal or the destination that designated for the EPW in which the EPW will be navigated in a way by approaching towards the AFF. The RFF consists of spacing headway that defines the distance from the obstacle to the EPW and while the limit distance is the maximum distance for the EPW to navigate away from the obstacle before the EPW collides with the obstacle. The strategy is to control the trajectory of the EPW during the obstacle avoidance with yaw angular velocity of the EPW. With spacing headway, limit distance and yaw angular velocity results, the trajectory of the EPW during the obstacle avoidance could be determined.
1. Introduction

The rapid increment of population leads to increase of People with Disabilities (PWDs) worldwide. Researchers tirelessly developing the all sorts of device to improve the daily life of the PWDs. The Electroencephalogram-based brain–computer interfaces (BCIs) is a machine interactive technology that allows the user to interact with the wheelchair without using the peripheral muscles[1]. Moreover, researchers nowadays have actively developed numerous system that could aid the PWDs. The researcher also tends to build the smart wheelchair from the conventional wheelchair [2] that allows the system to be in customized condition suits with the type of impairment of the PWDs faced. Integrating head gesture navigation is also another approach that help PWDs for mobility. The user only uses the head gesture as the control input to navigate the wheelchair that comes with various speed for different direction depends on the head gesture applied. [3]

The development of autonomous wheelchair is also actively developed among the researcher. Some of the breakthrough is the semi-autonomous wheelchair that uses hand motor imagery (MI) and jaw clench to navigate the wheelchair[4]. The selection of control system in order to navigate the wheelchair is also important in which [5] uses the MPC control scheme to address the motion problems of an autonomous wheelchair in realistic environment. The problem arises with autonomous system is the path planning for the wheelchair. For recent years, the most used approaches to solve the path planning are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Artificial Potential Field (APF), and Ant Colony Optimization [6]. This method of path planning is widely used among the researchers to solve the path planning problems. The most used path planning is GA compared to the others. GA is able to find a valid and feasible path between two positions while avoiding obstacle and could optimize the route and providing the optimal path for the mobile robot [7].

Particle Swarm Optimization is a method used to search an optimum path to the target or goal of the destination. This method is taken into another step in which using the Self-Adaptive Learning Particle Swarm Optimization (SLPSO) in order to search more feasible path for the mobile robot [8]. Ant Colony Optimization (ACO) is also an another method to search an optimal path for the mobile robot. This method uses pheromone trail laying and following the real behaviour of ants[9]. In order to achieve the optimum ACO, improvement has been made to the ACO such as implementation of fuzzy logic with the ACO in minimizing the iterative learning error [10]. Another improvement made for the ACO is based on research from [11] which increase the accuracy of the and accelerate the convergence speed and to enlarge the search space.

The Artificial Potential Field (APF) uses the concept of potential field that consist repulsive and attractive field. Commonly researchers tend to choose this method due to the simple algorithm structure, the concise mathematical description and convenience for real time control [12]. The issues faced for utilizing the APF method is that the subject influenced by the local minima and affecting the trajectory of the mobile robot or the subject. Some researchers developed an improved version of APF to avoid the local minima by changing the repulsive potential function [13]. Method that also being used to avoid the local minima us route planning based on [13]. The main idea for the APF is mobile robot or vehicle is being surrounded with charged potential field that makes the mobile robot either attracted or repelled away [14].
The development of the wheelchair is crucial to help the PWDs facing their daily life and selection of the path planning method is based on the criteria that of the research itself.

2. Methodology

This paper purposely to implement the Artificial Potential Field Method (APF) on the Electric Powered Wheelchair. The application of APF on the EPW is due to the simplicity of equation APF itself. Below shows the specification of the EPW that being used for the simulation purpose. The modelling of the EPW in MatLab and Simulink is based on the specification provided.

2.1. Electric Powered Wheelchair Specification

The list of authors should be indented 25 mm to match the abstract. The style for the names is initials then surname, with a comma after all but the last two names, which are separated by ‘and’. Initials should not have full stops—for example A J Smith and not A. J. Smith. First names in full may be used if desired. If an author has additional information to appear as a footnote, such as a permanent address or to indicate that they are the corresponding author, the footnote should be entered after the surname.

Figure 1. The commercial Electric Power Wheelchair used in the experiment with the measurements.

The EPW installed with the two free rolling wheel or castor wheels in front of the EPW. The wheel could rotate in 360 degrees to ease the mobility and maneuvering the EPW. The wheelchair is driven with the DC motors installed along with the wheels (in the middle).

Figure 2. The castor wheel equipped along with the Electric Power Wheelchair.
Figure 3. The joystick on the EPW where the user can justify the speed of the wheelchair.

Table 1. The specifications of the EPW [15]

| Specifications       | Capabilities             |
|----------------------|--------------------------|
| Motor Power          | 250W per motor           |
| Climbing Ability     | <13 Degree               |
| Battery              | 24V,12A                  |
| Battery Endurance    | 10-15 Km                 |
| Speed Mode           | 6 Speed Adjustment       |
| Brand                | Jikang                   |
| Model                | Tw100                    |
| Wheel Size           | 10 Inch (Front), 22Inch (Rear) |
| Weight               | 34 Kg (Without Battery)  |
| User                 | Elder and Disables       |

All of the specifications from the tables and figures are directly from the manufacturer. For the experiment some modification has been made on the EPW in order to ease the installation of the sensors that will attached to the EPW.

2.2. DC Motor in EPW

This section will discuss on the equations involve for the EPW. These equations will be utilized in the Matlab and Simulink for modelling and simulation. Generally, the torque of the EPW generated from the DC motor. The DC motor equation can be seen as follows [16].

\[ T_m = K_t i \]  

(1)

The motor torque, \( T_m \) produced from the DC motor, constant factor, \( K_t \) and the armature current of the DC motor, \( i \). The motor torque is directly proportional with the armature current by constant factor.
The back Electromotive Force (EMF), \(e_b\) is directly proportional to the angular velocity \(\dot{\theta}\) of the shaft by the constant factor, \(K_e\).

\[ e_b = K_e \dot{\theta} \]  

The back EMF constant, \(K_e\) and motor torque constant, \(K_t\) are considered equal thus it will denoted as, \(K\).

\[ K_t = K_e = K \]  

From the equation (1), (2) and (3), the equations can be derived to formulate Newton’s Second Law accordingly;

\[ J \ddot{\theta} + b \dot{\theta} = Ki \]  

The above equation follows the Newton’s Second Law where moment of inertia is, \(J\) angular acceleration denoted as \(\dot{\theta}\) and motor bearing is denoted as \(b\).

The Kirchhoff’s Voltage Law is also applied in order to be implemented into the Matlab and Simulink. The Kirchhoff’s Voltage Law can be seen as follows;

\[ L \frac{di}{dt} + Ri = V - K \dot{\theta} \]  

\(L\) indicates the inductance, \(R\) as the resistance in the motor and \(V\) represents the voltage of the motor. The above equations will be implemented for modelling the EPW model.

The parameters for the DC motor of the EPW that being applied in the simulation is based on the real model of the EPW itself.
### Table 2. The parameters of DC motor

| Parameters | Value      |
|------------|------------|
| $K$        | 2.8842     |
| $J$        | 0.175 kg/m²|
| $b$        | 0.1 Nms    |
| $L$        | 0.0002 H   |
| $R$        | 3.116 Ohm  |
| $V$        | 12V        |

#### 2.3. Potential Field Method

As being aware, the Potential Field Method is another approach in path planning method. This research is mainly focused on the obstacle in a static condition and the path is pre-determined. The idea is to implement the artificial potential field in the environment enabling the EPW move toward the goal or destination and navigates away before reaching the obstacle. The EPW is represented as a particle under a scalar potential field.

**a. Attractive Field and Force**

The attractive field is under one of Artificial Potential Field Method. The attractive field will be drawing the EPW towards the goal or the destination for the EPW.

$$U_{Att} = \frac{1}{2} \varphi x^2$$  \hspace{1cm} (6)

Above shows the attraction potential field equation. Where, $\varphi$ is an adjustable constant. The attraction force be shown by the equation below.

$$F_{Att}(x) = -\nabla U_{Att} = -\varphi |x_{EPW} - x_{Att}|$$  \hspace{1cm} (7)

Where, $\varphi$ is an adjustable constant, $x_{EPW}$ is the current position of the EPW. $x_{ATT}$, is the position of an attraction point.
b. Repulsive Field and Force

Repulsive field or force is another scalar potential field under Artificial Potential Field Method. The repulsive field or force is applied on the obstacle to ensure the EPW navigates away upon approaching the obstacle.

\[
U_{Rep} = \begin{cases} 
\frac{1}{2} \eta \left( \frac{1}{x} - \frac{1}{x_o} \right)^2, & \text{if } x \leq x_o \\
0, & \text{if } x > x_o 
\end{cases}
\]  

(8)

The above shows the equation for repulsive field. Where, \( \eta \) is the adjustable constant.

\[
F_{Rep} = \begin{cases} 
\frac{1}{2} \eta \left( \frac{1}{x} - \frac{1}{x_o} \right) \left( \frac{x_{EPW} - x_o}{x} \right), & \text{if } x \leq x_o \\
0, & \text{if } x > x_o 
\end{cases}
\]  

(10)

Equation above shows the repulsive force, Where;

\[
x = |x_{EPW} - x_o|
\]  

(11)

\( x_{EPW} \), is the current position of the EPW. \( x_{Att} \), is the position of an attraction point.

These equations will be applied into the simulation in order to map the trajectory of the Electric Powered Wheelchair (EPW). The repulsive force will act as the input for the EPW to change the direction for navigating away from the obstacle.

c. Repulsive Force as Input.

The next step is to take the repulsive force value as input for navigating control of the EPW. The idea is to take the highest value of the repulsive force.
Figure 4: Repulsive Force Map on a Longitudinal Axis.

Figure: 4 shows the preliminary result gained from the repulsive force. The peak value of the repulsive force will be applied into the EPW control system for the EPW navigate away from the obstacle.

The idea is to assume the EPW equipped with distance sensors that would detect the obstacle. The obstacle will have the artificial repulsive force surrounding the obstacle. The sensors will detect the obstacle and assuming the force field around the obstacle also will be detected. The simulation will be conducted to study the effect of distance towards the repulsive force around the obstacle.

As in the theory, the repulsive force will be higher when approaching the obstacle or near the obstacle and become lower as move away from the obstacle. But the idea for this system is the distance that required to be activated is depends on the EPW sensors. The repulsive force value as the input will be varied but the output value will be kept constant. The output will be the differential drive motor of the EPW.

3. Results and Discussion

The results shown below are based on the simulation in the Matlab and Simulink.
3.1. Repulsive Force Response

The above Figure 5 shows the repulsive force response at different activation distance. The value of this response will be used as the control input for the EPW. This activation distances mainly to observe the trajectory of the EPW.

**Table 3.** The peak value of Repulsive Force based on the activation distance.

| Distance, (m) | Repulsive Force \((10^{-5}), (\text{Kgm}^2/\text{s}^2)\) |
|---------------|-----------------------------------------------|
| 3             | 27.43                                         |
| 3.1           | 24.86                                         |
| 3.2           | 22.61                                         |
| 3.3           | 20.61                                         |
| 3.4           | 18.85                                         |
| 3.5           | 17.28                                         |
| 3.6           | 15.88                                         |
| 3.7           | 14.62                                         |
| 3.8           | 13.5                                          |
| 3.9           | 12.49                                         |
| 4             | 11.57                                         |

The Table 3 shows the results of the repulsive force when the EPW approaching the obstacle. The values that taken are the peak or the maximum value of the repulsive force. It is based on the distance activation
that measured assumedly by the distance sensor of the EPW. The distance activation of the repulsive force is set by the user and not controlled by any algorithm or artificial intelligence.

3.2. EPW Trajectory

Below shows the trajectory of the EPW based on the repulsive force response.

![EPW Trajectory Based on Repulsive Force Response](image)

**Figure 6.** EPW Trajectory Based on Repulsive Force Response.

Figure: 5 shows the trajectory of the EPW based on the response of the repulsive force. The voltage ratio of each tire before the activation distance of repulsive force are 1:1 and that is 12V for each tire. Upon reaching the obstacle or the activation distance is activated, the ratio for the right and left tire is changed to 2:1.

From the figure, the EPW changes its direction before reaching 6m. It is due to the fact of the position of the obstacle is assumed to be at 6m but the activation distance for repulsive force is before reaching 6m. From the trajectory, it could assume that all the trajectories manage to avoid the obstacle but width of the EPW also must be considered in order the EPW to avoid the obstacle successfully.

This simulation conducted to study the most optimum activation distance of the repulsive force that can be take as the input for the EPW to navigate away from the obstacle. By considering the width of the EPW, the most optimum activation distance of the repulsive force is on 3.2m.
3.3. *EPW Trajectory Response with Repulsive Force for Obstacle Avoidance*

Result below shows the effect of full repulsive force towards EPW response.

![EPW Trajectory](image)

**Figure 7.** The Trajectory of EPW

Figure 7 shows the trajectory of the EPW that affected by the repulsive force. The trajectory of the EPW is based on the repulsive force that artificially applied on the obstacle. The detail input voltage for the wheelchair as shown below;

| Conditions affecting the input voltage | Right Voltage Input, (V) | Left Voltage Input, (V) |
|---------------------------------------|--------------------------|------------------------|
| Straight line                         | 12                       | 12                     |
| Obstacle Avoidance                   | 10                       | 3.6                    |
| Path Correction                      | 3.6                      | 10                     |

Table 4 shows the voltage input for right and left for the EPW. Each condition gives the different trajectory response for the EPW. During straight line, the input voltage for right and left are same from starting point until the activation distance for repulsive force (approximately between 4 to 4.5 meter).

For the obstacle avoidance, the voltage input for left and right of the EPW as shown in the table above. The input voltage also influencing the trajectory of the EPW. If the input voltage is to high or
low, the trajectory of the EPW will be affected either the EPW will be too closed with obstacle or too far from the obstacle. The path correction is another condition which is the EPW will correct the path towards its original path as shown on figure above.

The trajectory above gained from the optimum voltage of right and left tire of EPW. As being mentioned earlier, the obstacle is assumed to be on 6 meters from the starting point and the width and length of the obstacle is assumed to be 1 meter. From the simulations, the trajectory of the EPW shows that it is able to avoid the obstacle successfully with the repulsive force as the input response for the sensor on EPW.

4. CONCLUSIONS

From this research, the idea was to control the trajectory of the EPW based on the value of the repulsive force. From the simulation conducted, the highest value of the repulsive force is taken as the input for the EPW to navigate away from the obstacle.

This method has been proven could be applied to control the trajectory of the EPW with the value from the repulsive force by selecting the right value of activation distance of the repulsive force. It is important to select the precise sensor to detect the obstacle in order for the EPW to mitigate the obstacle. Even though the result is based on the simulation, the application of the system could be implemented in the real situation.

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