Moving Object Tracking and Avoidance Algorithm for Differential Driving AGV Based on Laser Measurement Technology

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Abstract*—This paper proposed an algorithm to track the obstacle position and avoid the moving objects for differential driving Automatic Guided Vehicles (AGV) system in industrial environment. This algorithm has several abilities such as: to detect the moving objects, to predict the velocity and direction of moving objects, to predict the collision possibility and to plan the avoidance maneuver. For sensing the local environment and positioning, the laser measurement system LMS-151 and laser navigation system NAV-200 are applied. Based on the measurement results of the sensors, the stationary and moving obstacles are detected and the collision possibility is calculated. The velocity and direction of the obstacle are predicted using Kalman filter algorithm. Collision possibility, time, and position can be calculated by comparing the AGV movement and obstacle prediction result obtained by Kalman filter. Finally the avoidance maneuver using the well known tangent Bug algorithm is decided based on the calculation data. The effectiveness of proposed algorithm is verified using simulation and experiment. Several examples of experiment conditions are presented using stationary obstacle, and moving obstacles. The simulation and experiment results show that the AGV can detect and avoid the obstacles successfully in all experimental condition.*

[Keywords— *Obstacle avoidance, AGV, differential drive, laser measurement system, laser navigation system]*.

I. Introduction

In factory environment, Automatic Guided Vehicles (AGV) is common equipment to transport the materials in production process. To guarantee the safety of workers while the AGV moves around inside the factory, the moving object tracking and avoiding algorithm should be applied on AGV. This algorithm works when objects suddenly pass in front of moving AGV and block the AGV's path. To avoid the collision condition the AGV should detect the moving object in time and make reasonable decision to avoid the obstacle.

There are two ways to deal with moving object in the obstacle avoiding process, the first one does not consider the motion of object, but improve the motion planning ability and responding ability of AGV such as Artificial Potential Field [1-2] and grid algorithm [3-4]. Those algorithms need computation time to replan the trajectory and only work in known environment. The second one is to forecast the relative motion of object to AGV, and then adapt reasonable avoiding policy according to the anticipated collision time and position such as in [5-7], which is more effective for quick motion of AGV and the object. Those algorithms don't consider the path planning but only track the given path. Therefore, the obstacle avoidance algorithm for stationary and moving obstacle that can works in unknown environment, and guarantee the reachablity of goal position is needed.

This paper proposes an algorithm based on the motion planning ability to avoid the moving obstacle using motion prediction while find the optimal path. The object tracking algorithm based on the laser measurement result can estimate the current state and future state of moving obstacle using accurate distance information. The data process and responding speed are quick. The obstacles are assumed as linear system and the system noise is fit as Gaussian distribution. Therefore, Kalman filter based tracking is suitable for this application. Based on the prediction velocity of obstacle, the collision possibility is calculated. For avoiding policy, the tangent Bug algorithm is proposed to avoid the obstacles and finds the shortest path to the goal position.

To verify the effectiveness of proposed algorithm, the simulation and experiment are done. Experiments and simulation are presented using stationary obstacle, and moving obstacles.

II. System Description

The AGV hardware configuration system used in this experiment is shown in Fig. 1. This AGV has dimension: width = 60 cm, length = 100 cm and height = 190 cm. This system uses differential drive system, powered by two 24V/300W/3000RPM BLDC motors on the left and right sides of AGV. Two castor wheels support the AGV on the front and back sides of AGV as shown in Fig. 2. The laser measurement system LMS-151 is used for measuring the environment condition. It has high sensitivity over the first 20 m, and is suitable for measuring contours and checking the projections of the obstacle. The laser navigation system NAV-200 is used for positioning the AGV. It is free maintenance, flexible and high precision. All of the sensors and actuator controlled by Industrial PC TANK-800. The wireless keyboard and mouse are used for the input for industrial PC. The touch screen monitor is used for monitoring the process and interface. This system is powered by 2 x 12 V 80 AH batteries.

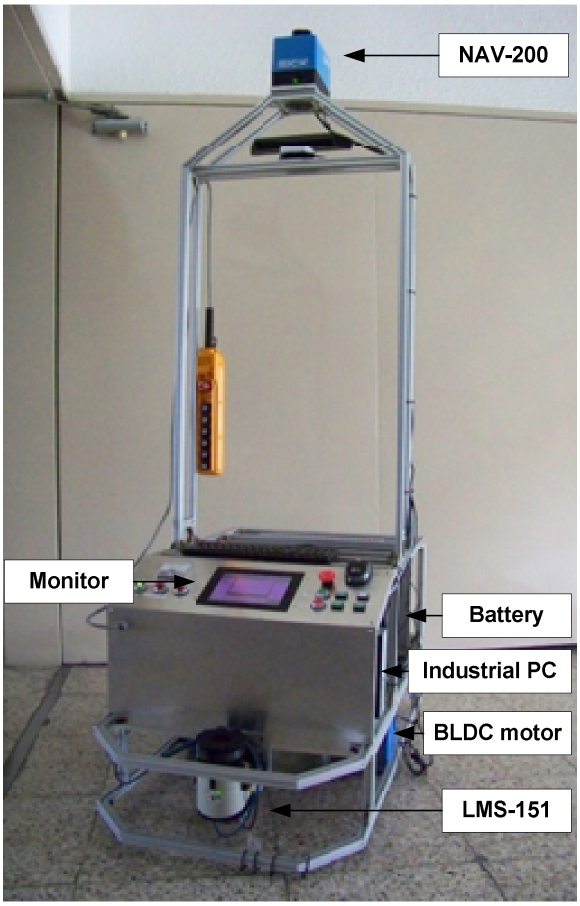

Fig. 1 AGV system

The configuration of the system is shown in Fig. 2.

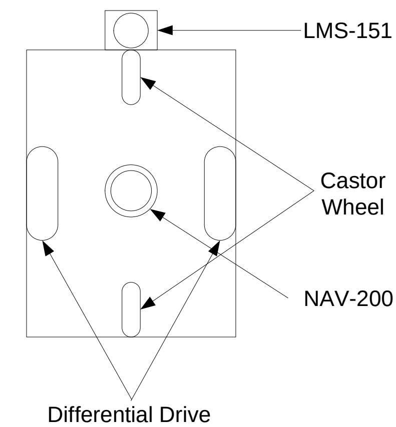

Fig. 2 Configuration of AGV system

III. Obstacle Avoidance Algorithm

A. Obstacle Detector

To detect the local environment, the laser measurement system LMS-151 is applied to AGV as shown in Fig. 2. This sensor scans the environment by transmitting and receiving the laser signal over desired area. The definition of this area W (R, α, β) is given by R=20m, α=0°, β=180° where R is the radius of scanning area, α the start angle, and β the end angle. The resolution of laser scanning is 0.5° and scanning frequency is 50 Hz.

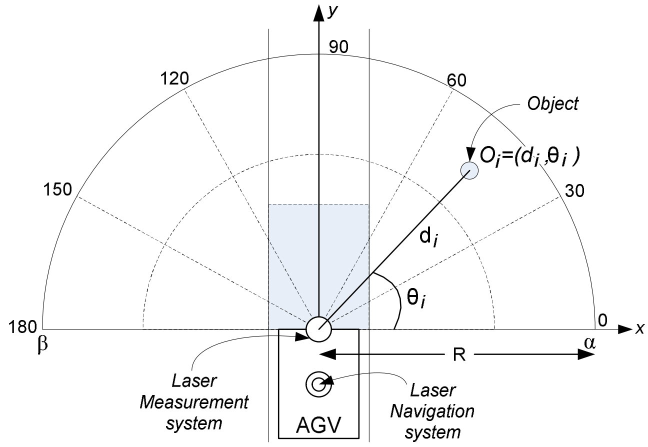

Fig. 2 LMS-151 scanning area

where y is the center of laser scanner, θ_i is the angle between the object O_i and x horizontal axis. The detected object can be expressed with polar coordinate as (d_i, θ_i), or with Cartesian coordinates as:

$$O_i = (d_i \cos\theta_i, d_i \sin\theta_i) \text{ for } i = 1,...n \quad (1)$$

The positioning method using NAV-200 is shown in Fig. 3.

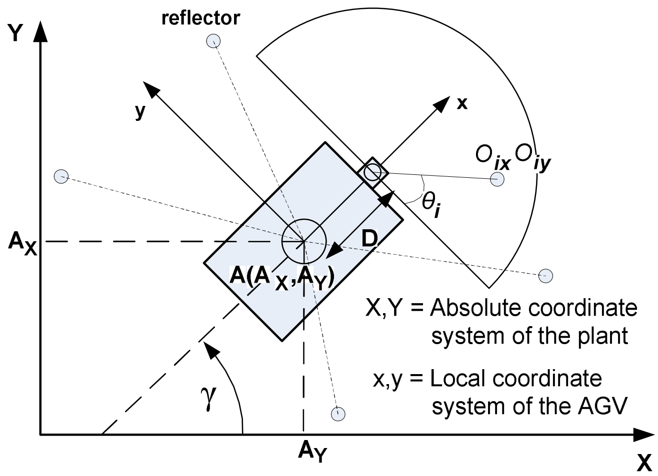

Fig. 3 Positioning using NAV-200

The reflector positions in absolute coordinate system of the plant are saved inside the AGV's memory. By comparing the reflector scanning result and the reflector coordinate in AGV's memory, the absolute coordinate and orientation of AGV are obtained.

Using coordinate transformation, the absolute position of obstacle O_i is obtained:

$$\begin{bmatrix} O_{iX} \\ O_{iY} \end{bmatrix} = \begin{bmatrix} A_X \\ A_Y \end{bmatrix} + \begin{bmatrix} \cos\gamma & -\sin\gamma \\ \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} O_{ix} \\ O_{iy} \end{bmatrix} + D \begin{bmatrix} \cos\gamma \\ \sin\gamma \end{bmatrix} \quad (2)$$

where A is the absolute position of AGV, and D is distance between NAV-200 and LMS-151.

B. Moving Object Tracking Based on Kalman Filter

In factory environment, the moving objects are mainly persons that their accelerations change slowly. Therefore, an uniform motion model can be set up with acceleration as white Gaussian noise. The state vector of the object is defined as $\mathbf{X}=[x \ \ v_x \ \ y \ \ v_y]^T$ and the observation vector is $Y=[x \ \ y]^T$ where *x, y* are position of the obstacle, and v_x, v_y is obstacle velocities in directions of x, y, respectively.

The state equation of moving object is given as follows:

$$\mathbf{X}(k)=\mathbf{A}\mathbf{X}(k-1)+\mathbf{W}(k-1) \quad (3)$$

and measurement equation is:

$$\mathbf{Y}(k)=\mathbf{C}\mathbf{X}(k)+\mathbf{V}(k) \quad (4)$$

where **W** is Gaussian process noise and **V** is Gaussian measurement noise.

The state parameters for dead reckoning can be given as:

$$\mathbf{A}=\begin{bmatrix}1 & T & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & T\\ 0 & 0 & 0 & 1\end{bmatrix}, \mathbf{C}=\begin{bmatrix}0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

Since measurement parameters are distance and directional angle, the real measurement equation can be expressed as:

$$\mathbf{Y}(k)=\begin{bmatrix}x(k)\\ y(k)\end{bmatrix}=\begin{bmatrix}d_i\cos\theta_i\\ d_i\sin\theta_i\end{bmatrix}+\mathbf{V}(k) \quad (5)$$

For the human motion, the covariance matrix of process noise can be determined by the following [6]

$$\mathbf{W}(k)=\begin{bmatrix}\frac{T^3}{3} & \frac{T^2}{2} & 0 & 0\\ \frac{T^2}{2} & T & 0 & 0\\ 0 & 0 & \frac{T^3}{3} & \frac{T^2}{2}\\ 0 & 0 & \frac{T^2}{2} & T\end{bmatrix}\times a \quad (6)$$

where a is factor determined by acceleration, and T is observation period. The covariance matrix of direct observation is:

$$\mathbf{V}(k)=\begin{bmatrix}\sigma_\rho^2 & 0\\ 0 & \sigma_\theta^2\end{bmatrix} \quad (7)$$

Then following the Kalman filter equations the next step motion state of object can be estimated using prediction and update laws as following.

Prediction:

$$\hat{X}(k\,|\,k-1)=A(k-1)X(k-1\,|\,k-1) \quad (8)$$

$$P(k\,|\,k-1)=A(k-1)P(k-1\,|\,k-1)A^T+Q(k-1)(k-1) \quad (9)$$

Update:

$$\hat{X}(k\,|\,k)=\hat{X}(k\,|\,k-1)+K(k)[Z(k)-C(k)\hat{X}(k\,|\,k-1)] \quad (10)$$

$$K(k)=P(k\,|\,k-1)C^T(k)\,[C(k)P(k\,|\,k-1)C^T(k)+R(k)]^{-1} \quad (11)$$

$$P(k\,|\,k)=[I-K(k)C(k)]P(k\,|\,k-1) \quad (12)$$

C. Collision Possibility Prediction

Based on the obstacle movement prediction by Kalman filter, the collision possibility is predicted. When the AGV velocity is V_A, and the predicted obstacle velocity is V_O, the relative velocity between the obstacle and the AGV is:

$$V_{OA}=V_O-V_A \quad (13)$$

The collision condition estimates by projecting the obstacle to the AGV dimension. To simplify the calculation, only the edges of obstacle and the nearest point from the obstacle to AGV are calculated.

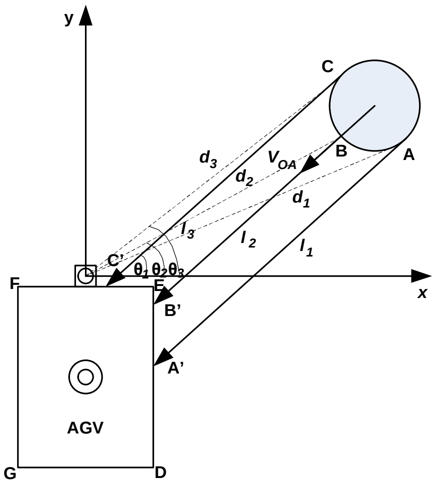

Fig. 4 Obstacle projection

The obstacle line projection equation is obtained by:

$$y=\frac{V_{OAy}}{V_{OAx}}(x-d_i\cos\theta_i)+d_i\sin\theta_i \quad (14)$$

for $i=1,2,3,...$

If one of three line projections intersects with one of AGV dimension line (DE, EF, FG, GD), the collision possibility is high. The shortest distance between AGV and obstacle is:

$$l_{\min}=\min(l_1,l_2,l_3) \quad (15)$$

The anticipated collision time is:

$$t_c=\frac{l_{\min}}{|V_{OA}|} \quad (16)$$

and anticipated collision position is:

$$P_c=(V_{Ax}\cdot t_c, V_{Ay}\cdot t_c) \quad (17)$$

D. Obstacle Avoidance Policy

Based on the collision possibility calculation, the obstacle avoidance policy is generated. To avoid the obstacle and find the shortest path to the goal, the tangent bug algorithm is applied. This algorithm is suitable for AGV using laser measurement system and also it guarantees the AGV so as to reach the goal position. Only based on the start position and goal position information, the AGV can find the path and avoid the obstacles efficiently. In Fig. 5 when the AGV finds the stationary obstacle, the algorithm calculates the distance between the point O_i and q_{goal} . The AGV then goes to the shortest point to get the optimal path.

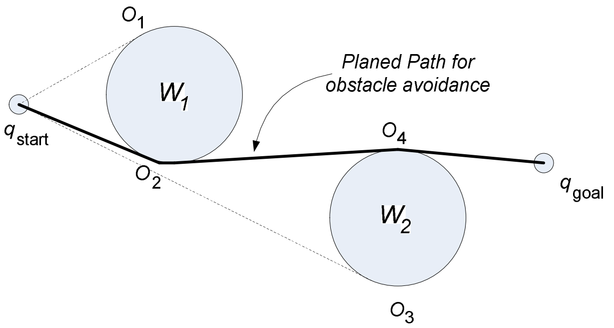

Fig. 5 Tangent Bug algorithm

When the moving obstacle is detected, the AGV reduces or increases the speed. The increasing speed policy is adopted if the following condition

$$(V_{A\max} - V_{Anow})\, t_c > AC + \Delta L \qquad (18)$$

where $V_{A\max}$ is AGV's maximum velocity, V_{Anow} is AGV's current velocity, t_c collision time, AC obstacle size, and ΔL save distance. When this condition is not satisfied, the AGV stops to avoid the collision condition.

IV. Simulation and Experimental Result

A. Simulation Results

The simulation environment of obstacle avoidance using stationary obstacle and moving obstacle are shown in Fig. 6.

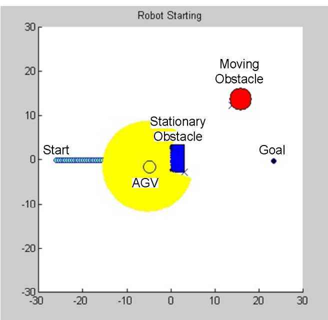

Fig. 6 Simulation environment

Fig. 7 shows the simulation results using stationary and moving obstacles when the AGV reaches the goal position.

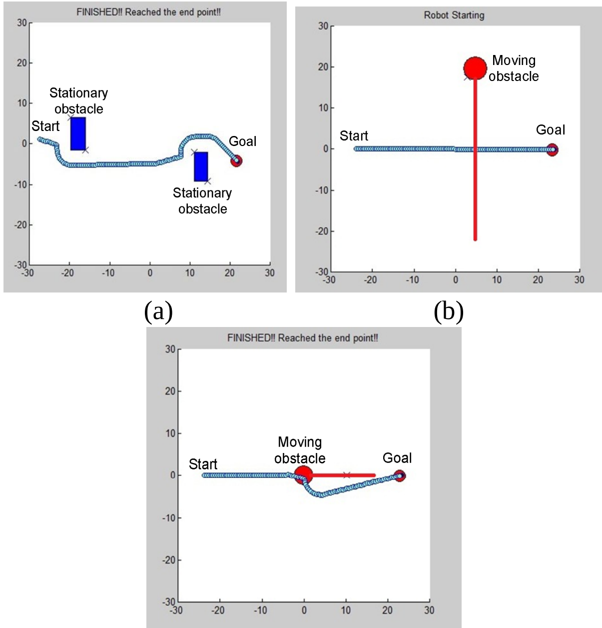

Fig. 7 simulation results for stationary and moving obstacles

Fig. 7 (a) shows the simulation result using 2 static obstacles. Fig. 7 (b) shows the result using moving obstacle with transversal direction. Fig. 7 (c) shows the result using moving obstacle with longitudinal direction.

B. Experimental Results

This experiment is given to demonstrate the algorithm in real factory environment. The stationary obstacle experiment is shown in Fig. 8. Fig. 8(a) shows that the AGV detects the obstacle and decides the next point. In Fig. 8(b) the AGV goes to the next shortest point to goal. In Fig. 8(c) the AGV passes the obstacle and goes to the goal position.

(a) (b) (c)

Fig. 8 Stationary obstacle avoidance

Fig. 9 shows the moving obstacle experiment in transversal direction. Fig. 9 (a) shows when the obstacle approaches, the adopted Bug algorithm calculates the velocity and decides the avoidance maneuver. The AGV decides to stop until the obstacle disappears as in Fig. 9 (b). Then AGV is moving continuously to goal position as in Fig. 9 (c).

(a) (b) (c)

Fig. 9 Moving obstacle avoidance in transversal direction

Fig. 10 shows the moving obstacle experiment in longitudinal direction. Fig. 10(a) shows when the obstacle approaches, the algorithm calculates the velocity and decides the avoidance maneuver. The algorithm decides to avoid the obstacle as in Fig. 10(b). Then AGV is moving continuously to goal position as in Fig. 10(c).

(a) (b) (c)

Fig. 10 Moving obstacle avoidance in longitudinal direction

Figs. 11-13 show the trajectory of the AGV after reaching the goal position using simulation and experimental data.

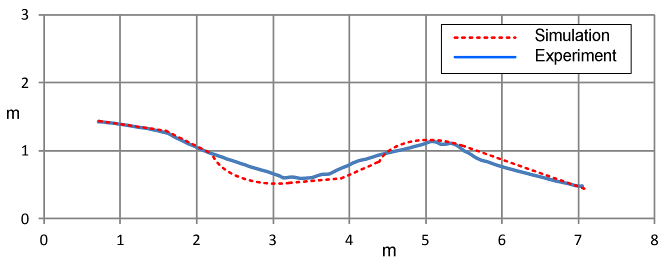

Fig. 11 Simulation and experiment trajectories for stationary obstacle avoidance

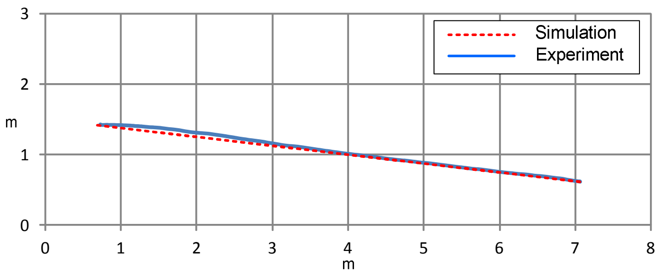

Fig. 12 Simulation and experiment trajectories for moving obstacle in transversal direction

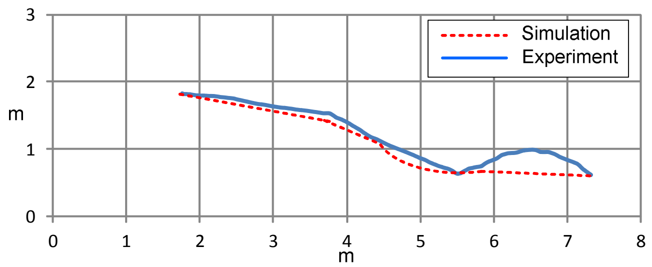

Fig. 13 Simulation and experiment trajectories for moving obstacle in longitudinal direction

Figs. 11-13 show that the simulation and experimental results are similar. The proposed algorithm can get successfully the right decision to avoid the obstacle. The reaction is fast enough to prevent the collision condition.

V. Conclusions

This paper proposed an algorithm to detect the environment quickly and reasonably to avoid the stationary and moving obstacles in factory environment such as human moving for differential AGV system. The Cartesian coordinate of obstacle in absolute coordinate system is obtained from laser scanner LMS-151 measurement data. The Kalman filter based object tracking method was considered for the prediction of the AGV and obstacle speeds, which can improves the accuracy and obstacle avoidance ability. Based on object tracking algorithm, the collision possibility, collision time and position were estimated. Finally, based on the obstacle avoiding policy, the obstacle avoidance maneuver was generated. The simulation and experiment results show that the AGV can get successfully the right decision to avoid the obstacle. The reaction is fast enough to prevent the collision condition.

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