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MOTION PLANNING FOR AUTOMATED GUIDED VEHICLE

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Abstract: This paper deals with further development of an AGV (Automated Guided Vehicle) and its motion planning. The AGV can be found at the Logistic Institute at University of Miskolc. It was developed for a High–Tech Laboratory in 2011 by Gamma Digital Ltd. The system can perform delivering, picking and placing of materials. The AGV has a differential–drive with two caster wheels. A Mitsubishi 6–DoF industrial robot is mounted on it. A Wago PLC (Programmable Logic Controller) and a Linux–based PC handle the inputs and outputs. The PLC controls the lamps, switches and buttons. For safety reasons two SICK short range laser detectors were mounted on the front and rear side of the AGV. The navigation is performed by a SICK laser positioning sensor. The servomotors are controlled by Dugong servo drives, the signals for these drives are controlled by the PC. With the help of the PC both of the controllers are programmed to handle the navigation system and the safety sensors.
Keywords: mechatronics, mobile robot, Automated Guided Vehicle (AGV), navigation, motion planning

INTRODUCTION

Nowadays the number of automated industrial devices exponentially raises. These devices can increase the productivity, decrease the costs and human fault [1]. However, the automation of human controlled devices is not simple. The research and education of such problems inevitable are important. The vehicle engineering education has been started last year at University of Miskolc. The preparation of lecture notes is in progress. This paper is a contribution to this task.

The Automated Guided Vehicles (AGVs) have been used usually in logistics systems, e.g. in supply chain [2], since 1950s years [3]. Automating of these vehicles is a complex task, because several problems should be handled: sensing of the environment, movements of the vehicle, safety functions, and communications inside and outside of the vehicle.

An autonomous carrier vehicle can be regarded as mobile robot or AGV [4]. An AGV can be used for a lot of application, e.g. as service robot [15]. The AGVs can operate using the outside infrastructure, e.g. optical or magnetic paths, laser scanner, inductive sensing [5]–[7]. The technologies of guidance are written in [8], i.e., the navigation can use physical or virtual path. The mobile robots have to use only on–board devices, therefore other sensors e.g. visual camera [9]–[10] are needed to navigate.

This paper deals with motion planning of an AGV. This AGV can be found at laboratory of Logistic Institute at University Miskolc [11]–[12], which is a pathless carrier [3],[13]. The investigated system in this paper navigates with onboard laser scanner, similarly to [7].

Special mirrors, which can reflect the laser beam in same direction, were placed at the edges of laboratory. The safety sensors may operate with laser method, but it can be replaced by camera [9].

The PLC, PC, wireless router, main drives, safety sensors and navigation devices are connected in a network, such as it was published in [14]. A 6 DoF industrial robot, such as in [16], was mounted on AGV, which can pick and place different workpieces. The drives of the examined AGV are differential–drive, but it can have four wheel steering [17].

The motion along a straight line can be easily performed, but the vehicle often has to move along arch, when cornering or overtaking are taking place. However, the motion along arch may have more critical situation.

The solution of differential equation system is carried out by Runge–Kutta numerical method written in Scilab software system. The program can compute vehicle X, Y position, absolute yaw angle, yaw rate and the track of wheels and vehicle's center of gravity in time.

Examples of different maneuverings, including cornering, motion along arch, and straight motion between two given points in different cases will be shown in Section 2–4. These examples are very useful in engineering education. Finally, the last section summarizes the results.

THE MOTION OF AGV: CORNERING, WHEELS NO CONSIDERED

An AGV is shown in Figure 1, where the notations are given as follow:

- $\mathrm{v_{left}}$ or $\mathrm{v_L}$: velocity of left wheel,
- $\mathrm{v_{right}}$ or $\mathrm{v_R}$: velocity of right wheel,
- v: velocity of vehicle's center,
- φ: angle of AGV
- ω: angular velocity of AGV
- $\mathrm{r = 70mm}$: radius of the wheel
- $\mathrm{b = 250mm}$: distance between wheel and vehicle's AGV

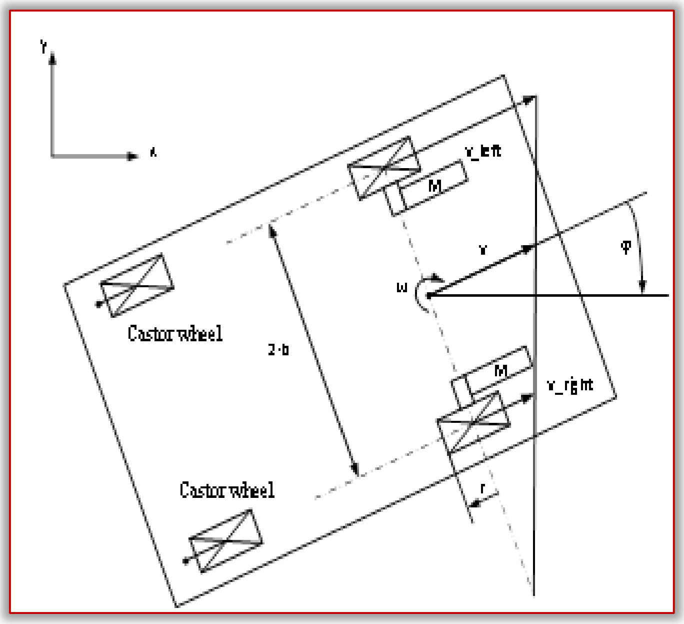

Figure 1. Kinematic model of the AGV

A differential equation system should be written for the motion. The state vector is necessary for the differential equation system as follows:

$$\underline{\mathbf{x}} = \begin{bmatrix} \mathbf{x_1} \\ \mathbf{x_2} \\ \mathbf{x_3} \\ \mathbf{x_4} \\ \mathbf{x_5} \end{bmatrix} = \begin{bmatrix} \mathbf{x} \\ \mathbf{y} \\ \boldsymbol{\varphi} \\ \mathbf{v} \\ \boldsymbol{\omega} \end{bmatrix} \tag{1}$$

where $\mathbf{x}$ and $\mathbf{y}$ are the position of AGV in absolute coordinate system.

The derivate of the state vector gives the differential equation system:

$$\underline{\dot{\mathbf{x}}} = \begin{bmatrix} \dot{\mathbf{x}} \\ \dot{\mathbf{y}} \\ \dot{\boldsymbol{\varphi}} \\ \dot{\mathbf{v}} \\ \dot{\boldsymbol{\omega}} \end{bmatrix} = \begin{bmatrix} (\mathbf{v} + \mathbf{r} \cdot \boldsymbol{\omega}) \cdot \mathbf{cos\varphi} \\ (\mathbf{v} + \mathbf{r} \cdot \boldsymbol{\omega}) \cdot -\mathbf{sin\varphi} \\ \boldsymbol{\omega} \\ \mathbf{a} \\ \boldsymbol{\varepsilon} \end{bmatrix} \tag{2}$$

where the $\mathbf{a}$ is the acceleration of the vehicle's center and $\boldsymbol{\varepsilon}$ is the angular acceleration. Here only the center of AGV is considered.

All the parameters are zero by initial time. The illustration of motion is shown on Figure 2.

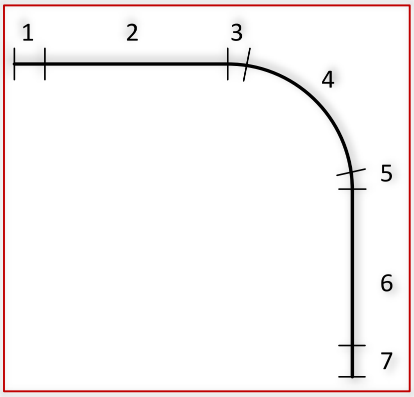

Figure 2. Illustration of path of the AGV during cornering

The acceleration and angular acceleration are changing during the motion as follows:

- Acceleration in straight line, $\mathbf{a} = \mathbf{300}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$, $\mathbf{v_2} = \mathbf{150}\,\frac{\mathbf{mm}}{\mathbf{s}}$, time can be calculated $\mathbf{t_{1-2}} = \frac{\mathbf{v_2 - v_1}}{\mathbf{a}} = \mathbf{0.5\ s}$
- Straight line motion without acceleration, $\mathbf{t_{2-3}} = \mathbf{2\ s}$
- Arch deceleration, $\mathbf{a} = -\mathbf{300}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$, the rotation acceleration can be calculate $\boldsymbol{\varepsilon} = \frac{\mathbf{a_0}}{\mathbf{b}} = \mathbf{1.2}\,\frac{\mathbf{rad}}{\mathbf{s^2}}$, $\mathbf{v_4} == \frac{\mathbf{150+75}}{\mathbf{2}}\,\frac{\mathbf{mm}}{\mathbf{s}} = \mathbf{112.5}\,\frac{\mathbf{mm}}{\mathbf{s}}$, the time can be calculate $\mathbf{t_{3-4}} = \frac{\mathbf{v_4 - v_3}}{\mathbf{a}} = \mathbf{0.125\ s}$
- Arch motion without acceleration, $\boldsymbol{\omega} = \frac{\mathbf{v_4}}{\mathbf{3b}} = \mathbf{0.5}\,\frac{\mathbf{rad}}{\mathbf{s}}$, time can be calculated by angle and angular velocity: $\mathbf{t_{4-5}} = \frac{\boldsymbol{\varphi}_{\mathbf{4-5}}}{\boldsymbol{\omega}} = \mathbf{10.347\ s}$, where $\boldsymbol{\varphi}_{\mathbf{4-5}} = \mathbf{1.5502}$
- Arch acceleration, $\mathbf{a} = \mathbf{300}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$ $\boldsymbol{\varepsilon} = \frac{\mathbf{a_0}}{\mathbf{b}} = \mathbf{1.2}\,\frac{\mathbf{rad}}{\mathbf{s^2}}$, $\mathbf{v_6} = \mathbf{150}\,\frac{\mathbf{mm}}{\mathbf{s}}$, $\mathbf{t_{5-6}} = \frac{\mathbf{v_6 - v_5}}{\mathbf{a}} = \mathbf{0.125\ s}$
- Straight line motion without acceleration, $\mathbf{t_{6-7}} = \mathbf{2\ s}$
- Deceleration in straight line, $\mathbf{a} = -\mathbf{300}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$, $\mathbf{v_8} = \mathbf{0}\,\frac{\mathbf{mm}}{\mathbf{s}}$, $\mathbf{t_{7-8}} = \frac{\mathbf{v_8 - v_7}}{\mathbf{a}} = \mathbf{0.5\ s}$

The summarized motion time is: $\mathbf{t_{1-8}} = \sum_{\mathbf{i=1}}^{\mathbf{8}} \mathbf{t_i} = \mathbf{15.597s}$

The differential equation system was solved in Scilab software system with Runge–Kutta method. The results of this cornering, i.e., X position, Y position, angle, angular velocity, and velocity of AGV during cornering are shown from Figure 3 to Figure 7, respectively.

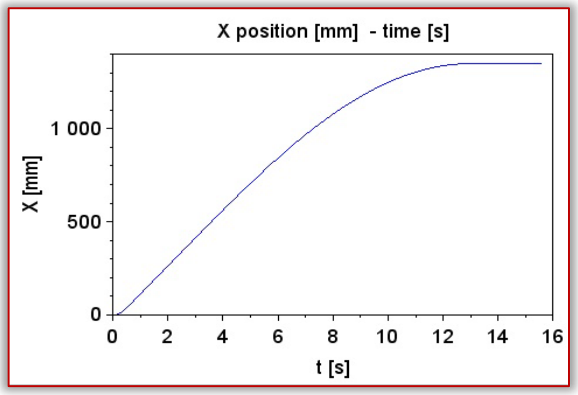

Figure 3. X position of the AGV during cornering

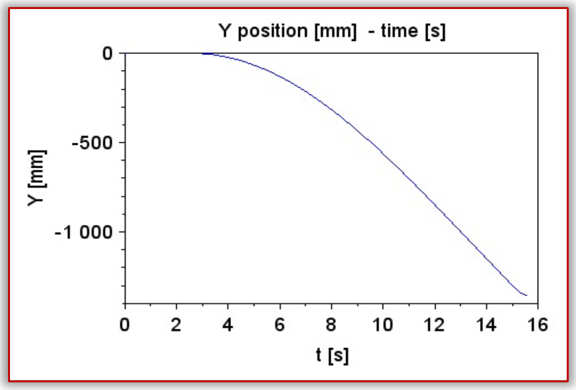

Figure 4. Y position of the AGV during cornering

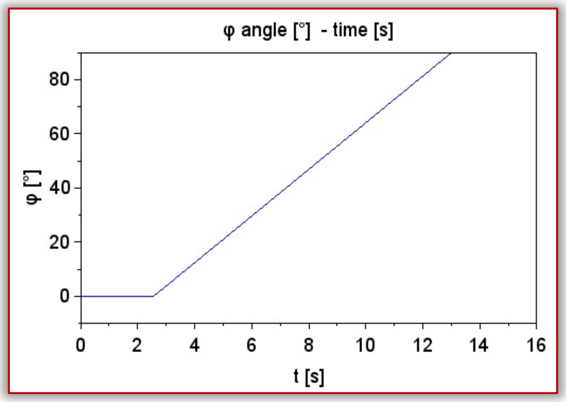

Figure 5. Angle of the AGV during cornering

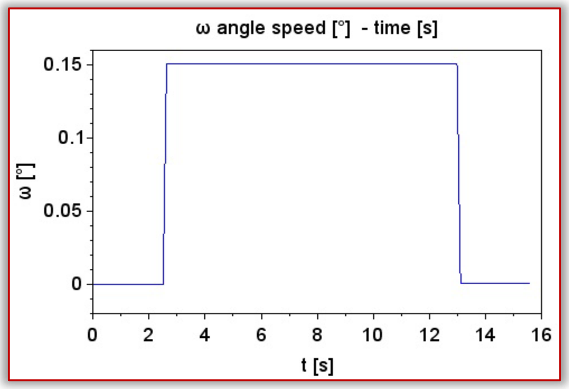

Figure 6. Angular velocity of the AGV during cornering

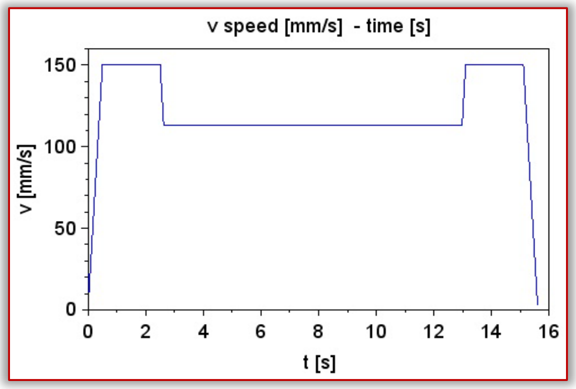

Figure 7. Velocity of the AGV during cornering

The path of the vehicle can be seen on Figure 8. The value of final X and Y position are same in absolute values.

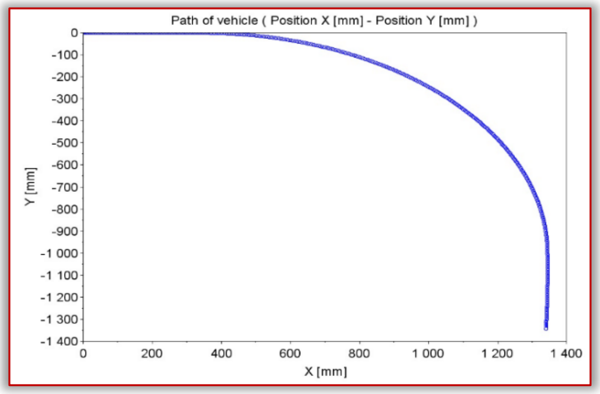

Figure 8. Path of the AGV during cornering

THE MOTION OF AGV: ARCH LINE, WHEELS CONSIDERED

The wheels are considered in this section. A differential equation system should be changed considering of the wheels. The state vector changes as follows:

$$\underline{\mathbf{x}} = [\mathbf{x_R}, \mathbf{y_R}, \mathbf{x_L}, \mathbf{y_L}, \mathbf{x}, \mathbf{y}, \mathbf{v_R}, \mathbf{v_L}, \mathbf{v}, \boldsymbol{\varphi}, \boldsymbol{\omega}]^{\mathbf{T}} \qquad (3)$$

The derivate of the state vector gives the differential equation system of motion:

$$\dot{\underline{\mathbf{x}}} = \begin{bmatrix} \dot{x}_R \\ \dot{y}_R \\ \dot{x}_L \\ \dot{y}_L \\ \dot{x} \\ \dot{y} \\ \dot{v}_R \\ \dot{v}_L \\ \dot{v} \\ \dot{\varphi} \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} v_R \cdot \cos\varphi \\ v_R \cdot \sin\varphi \\ v_L \cdot \cos\varphi \\ v_L \cdot \sin\varphi \\ \frac{v_R+v_L}{2} \cdot \cos\varphi \\ \frac{v_R+v_L}{2} \cdot \sin\varphi \\ a_R \\ a_L \\ a \\ \frac{v_R-v_L}{2\cdot r} \\ \frac{a_R-a_L}{2\cdot r} \end{bmatrix} \qquad (4)$$

where $\mathbf{a_L}$ and $\mathbf{a_R}$ are the tangential acceleration of left and right wheels, respectively.

All the parameters are zero by initial time, except $\mathbf{y_R} = -\mathbf{150mm}$, $\mathbf{y_L} = +\mathbf{150mm}$. The illustration of motion is shown on Figure 9.

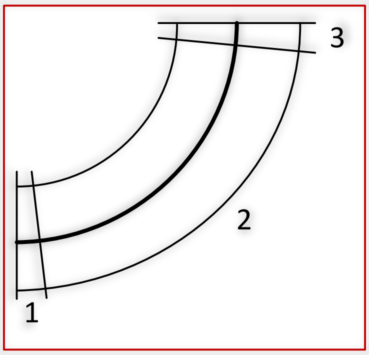

Figure 9. Illustration of path of the AGV during arch motion

The acceleration and angular acceleration are changing during the motion as follows:

- Arch acceleration, $\mathbf{a_R} = \mathbf{300}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$, $\mathbf{a_L} = \mathbf{150}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$, $\mathbf{v_2} = \frac{\mathbf{150+75}}{\mathbf{2}}\frac{\mathbf{mm}}{\mathbf{s}} = \mathbf{112.5}\,\frac{\mathbf{m}}{\mathbf{s}}$, the time can be calculate $\mathbf{t_{1-2}} = \frac{\mathbf{v_2-v_1}}{\mathbf{a}} = \mathbf{0.5\ s}$, where the $\mathbf{a}$ is the average acceleration of wheels
- Arch motion without acceleration, $\boldsymbol{\omega} = \frac{\mathbf{v_4}}{\mathbf{3b}} = \mathbf{0.5}\,\frac{\mathbf{rad}}{\mathbf{s}}$;: $\mathbf{t_{2-3}} = \mathbf{2\ s}$
- Arch deceleration, $\mathbf{a_R} = -\mathbf{300}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$, $\mathbf{a_L} = -\mathbf{150}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$, the time can be calculate $\mathbf{t_{3-4}} = \frac{\mathbf{v_4-v_3}}{\mathbf{a}} = \mathbf{0.5\ s}$

The summarized motion time is: $\mathbf{t_{1-4}} = \sum_{i=1}^{4} \mathbf{t_i} = \mathbf{3s}$

The results of this arch motion, i.e., X position, Y position, angle, angular velocity, and velocity of AGV during cornering are shown from Figure 10 to Figure 14, respectively.

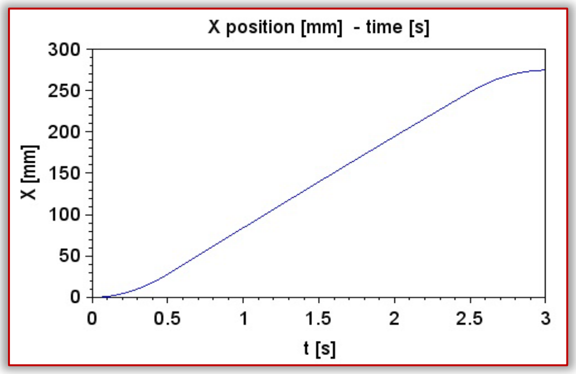

Figure 10. X position of the AGV during arch motion

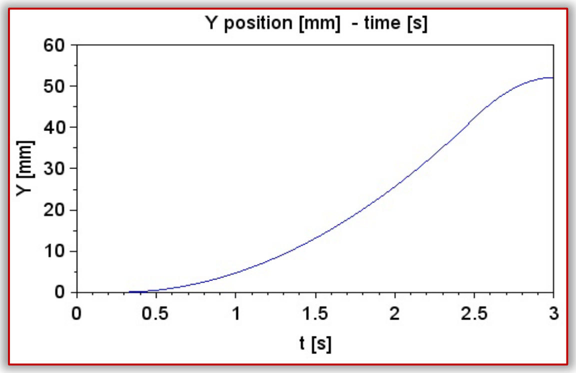

Figure 11. Y position of the AGV during arch motion

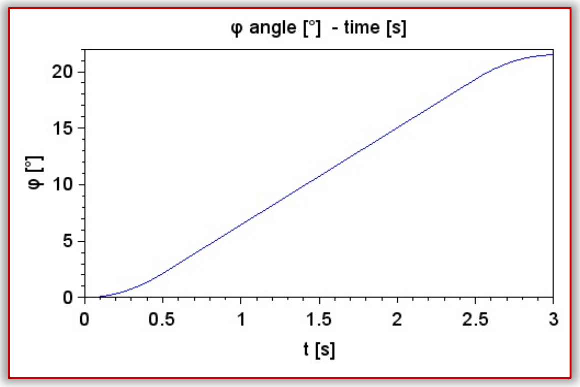

Figure 12. Angle of the AGV during arch motion

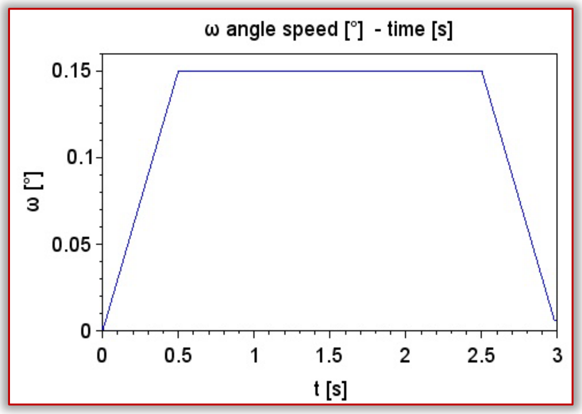

Figure 13. Angular velocity of the AGV during arch motion

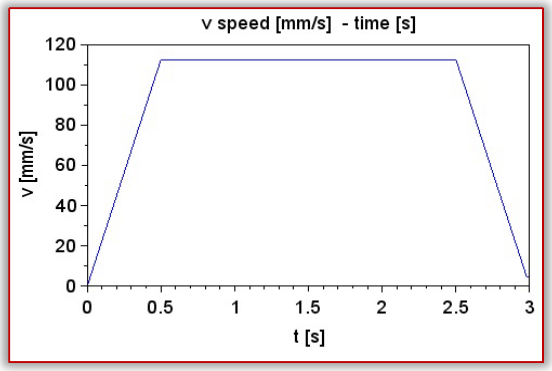

Figure 14. Velocity of the AGV during arch motion

The path of the vehicle can be seen on Figure 15. Alternatively the acceleration or deceleration of the left wheel can be zero ($\mathbf{a_L} = \mathbf{0}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$), only the right wheel accelerates or decelerates ($\mathbf{a_R} = \pm\mathbf{300}\,\frac{\mathbf{mm}}{\mathbf{s^2}}$). The velocity of left wheel is zero during motion ($\mathbf{v_L} = \mathbf{0}\,\frac{\mathbf{mm}}{\mathbf{s}}$). The path of the vehicle with this small changing can be seen on Figure 16.

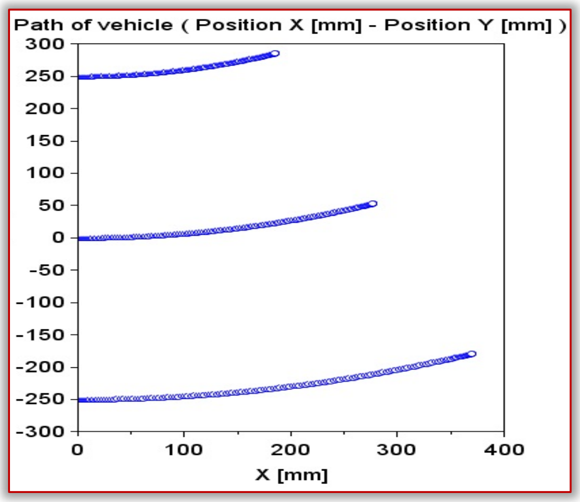

Figure 15. Path of the wheels and AGV during arch motion

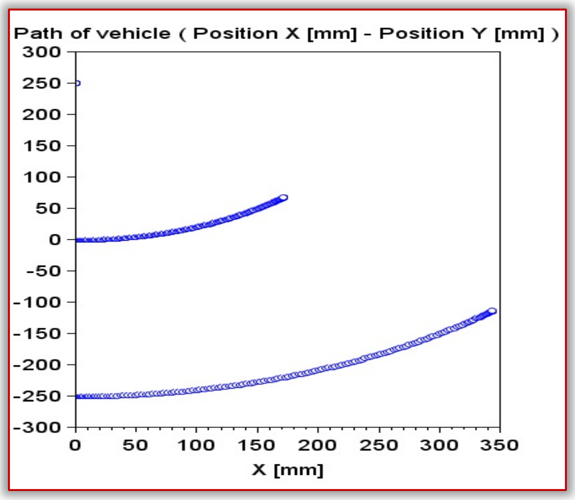

Figure 16. Path of the wheels and AGV during arch motion (only right wheel moves)

THE MOTION OF AGV: STRAIGTH LINE, BETWEEN TWO POINTS, WHEELS CONSIDERED

The wheels are also considered and the differential equation system is same as in Section 3. In the previous section the X and Y positions are calculated from the given time values. However for the motion planning the time values should be generated automatically from X and Y positions. For this calculating a new calculating method should be performed.

In this section the goal is a straight line motion from $\mathbf{x} = \mathbf{0mm}$ to exactly $\mathbf{x} = \mathbf{1000mm}$ position.

All the parameters are zero by initial time. , except $\mathbf{y_R} = \mathbf{-150mm}$, $\mathbf{y_L} = \mathbf{+150mm}$. The illustration of motion is shown on Figure 17.

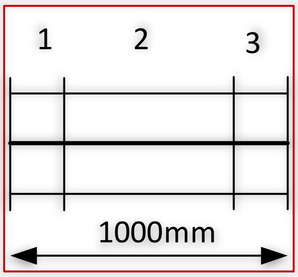

Figure 17. Illustration of path of the AGV during arch motion

The acceleration is changing during the motion as follows:

- Acceleration, $\mathbf{a_R} = \mathbf{300\frac{mm}{s^2}}$, $\mathbf{a_L} = \mathbf{300\frac{mm}{s^2}}$, $\mathbf{v_2} = \mathbf{150\frac{mm}{s}}$, the X position can be calculated $\mathbf{X_{1-2}} = \mathbf{a} \cdot \frac{\mathbf{t_{1-2}^2}}{\mathbf{2}} = \mathbf{37.5mm}$, where $\mathbf{t_{1-2}} = \mathbf{0.5s}$
- Straight line motion without acceleration, the X position can be calculated using the data of further step: $\mathbf{X_{2-3}} = \mathbf{1000mm} - \mathbf{X_{3-4}} - \mathbf{X_{1-2}} = \mathbf{925mm}$, the time: $\mathbf{t_{2-3}} = \frac{\mathbf{X_{2-3}}}{\mathbf{v_2}} = \frac{\mathbf{925mm}}{\mathbf{150\frac{mm}{s}}} = \mathbf{6.1667s}$
- Deceleration, $\mathbf{a_R} = \mathbf{-300\frac{mm}{s^2}}$, $\mathbf{a_L} = \mathbf{-300\frac{mm}{s^2}}$, $\mathbf{v_2} = \mathbf{0\frac{mm}{s}}$, the X position can be calculated $\mathbf{X_{3-4}} = \mathbf{v_2} \cdot \mathbf{t_{3-4}} - \mathbf{a} \cdot \frac{\mathbf{t_{3-4}^2}}{\mathbf{2}} = \mathbf{37.5mm}$, where $\mathbf{t_{3-4}} = \mathbf{0.5s}$

The summarized motion time is: $\mathbf{t_{1-4}} = \sum_{i=1}^{4} \mathbf{t_i} = \mathbf{7.167s}$

The results of this straight line motion, i.e., angular velocity, and velocity of AGV during cornering are shown from Figure 18 to Figure 19, respectively.

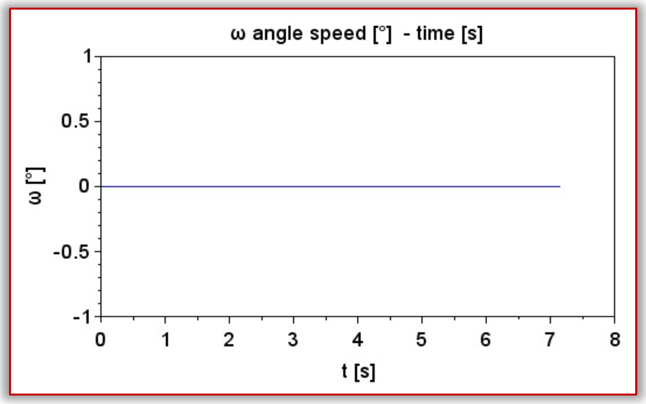

Figure 18. Angular velocity of the AGV during motion between two points

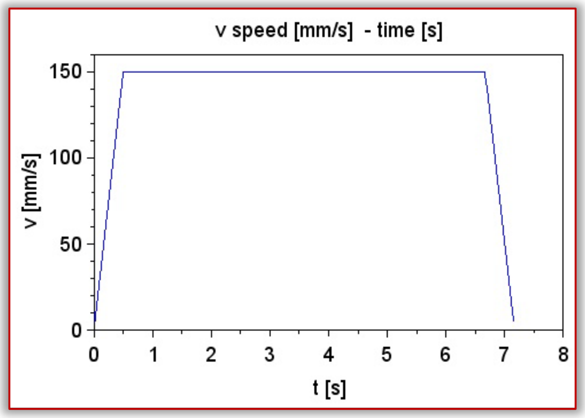

Figure 19. Velocity of the AGV during motion between two points

The path of the vehicle can be seen on Figure 20.

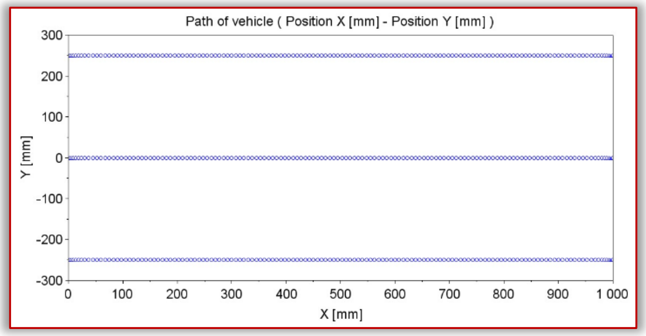

Figure 20. Path of the AGV during motion between two points

CONCLUSIONS

A motion of AGV has been investigated in this paper. The vehicle can be controlled by prescribing the acceleration and the angular acceleration. The solution of the model provides the vehicle X and Y position, the vehicle angle, the vehicle angular velocity, the vehicle velocity and the path.

Three maneuvering problems have been examined. In the first one a cornering was shown. In the second problem the wheels were considered, and the vehicle performed arch motion. In the last section a straight line motion was carried out between two points. In later stability of the maneuver will be experienced.

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