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Adaptive Steering Control for Self-Guided Air Cushion Transporters

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Abstract: The paper presents a method to implement an intelligent steering control system for self-guiding air cushion transporters. A particular sensors configuration, providing the necessary information to allow the self-guiding, an adaptive control algorithm and two possible hardware configurations of the control system are proposed. The control system uses digital magnetic sensors to obtain information about the position of the transporter, with respect to the ideal trajectory, and analog transducers to obtain information about the angular position of the wheels. The proposed control algorithm offers good results with both hardware configurations presented, a dedicated microcontroller based system and a general purpose PLC modular system.

Key-Words: Self-guiding, Intelligent control, Steerage control, Pneumatic systems, Microcontrollers, PLC.

1 Introduction

The air cushion transporter is an industrial vehicle used to move, usually indoor, different loads, from tens of kg to hundreds of tones. It offers the possibility to move large charges and to position them with high accuracy, on any layout [1].
Using air cushion transporters in assembly lines, for moving cars, buses, tramcars, railway wagons or airplanes, the area of the production facility can be reduced several times, with investment advantages. In order to efficiently use the limited space in an assembly hall, the movement must be precisely controlled, in speed, forward or backward, in direction, angle to right or to left, etc.
Because of the wide charge range, of the different movement and positioning necessities and accuracy, of the need to fit particular configurations, the transporter control must be accurate, adaptive and flexible.
For air cushion transport, the surface must be horizontal, smooth and continuous. The transporter uses at least 4 air cushions, for stability and at least 2 active wheels, for propulsion and steerage. When stopped, the air cushions have low pressure, so the transporter lies on wheels, with all weight. Before moving, the air cushions are pressured, so the transporter is elevated fractions of millimeters from the surface, because of the air wave [2].
The driving of an air cushion transporter can be realized manually or automatically.
In manual driving mode, the transporter is guided using joystick controls [3].
The automatic driving requires an intelligent control system which should be able to guide the transporter following a tape. The tape represents the ideal movement path for the transporter. The tape used may be painted, or metallic.
The metallic tape, if used, must be embedded into the floor, because the movement surface must be smooth and continuous for air cushion transporters.
For painted tape, the vehicle must use optical sensors to move, while in the case of metallic tape, the sensors must be magnetic. In both cases the sensors may be digital or analog.
In the implementation of the control algorithm presented in the paper, the magnetic solution was chosen, using magnetic threshold sensors with binary output.
The implementation of an automatic driver for steering air cushion transporters requires the following steps:

- choosing the sensors configuration to allow the automatic guiding of the transporter;
- designing an intelligent control algorithm that implements the adaptive steering;
- choosing the hardware configuration of the intelligent control system which will drive the transporter;
- implementing the software algorithm on the chosen hardware control system.

2 Sensors Configuration

The number of sensors used is essential. The goal is to establish a configuration of sensors able to provide both qualitative and quantitative information about the position of the vehicle at any moment.

In order to obtain accurate steerage, with fast corrections and avoiding oscillations around the ideal trajectory, the sensors configuration must provide information about the position of the transporter with a resolution of 5 steps or more, for each wheel.

2.1 Qualitative and Quantitative Information Necessity

The qualitative information is necessary to establish weather the transporter is in the right position with respect to the guiding tape or it has a deviation to the left or to the right. If this is the only information available to the automatic driving system, the transporter will oscillate around the guiding tape, because the system will apply the same correction, regardless the dimension of the deviation.
The quantitative information is important because, based on this information, the control system will be able to apply an adaptive correction depending on the deviation, avoiding oscillations around the ideal trajectory.

2.2 Sensor Configurations for Qualitative Information

If a single sensor is used, the information obtained would be binary (i.e. the sensor detects the guiding tape or not). This information is not enough to allow the guiding of the vehicle. When the sensor does not detect the tape it is impossible to decide whether the transporter is on the left side of the tape or on the right side of the tape. Thus, using a single sensor, the correction that must be applied to the vehicle cannot be decided.
More sensors have to be used to establish precisely the position of the moving wheel with respect to the ideal movement path. Therefore, a group of sensors must be used for each wheel.
If 2 sensors are used, the distance between them must be small enough to allow both sensors to detect the tape, when the transporter is centered on the guiding tape. When the transporter deviates from the guiding tape, only one sensor will detect the tape. So, this configuration provides qualitative information about the position of the vehicle and allows the automatic driving. But, in this case, because no quantitative information about the deviation is provided, the system will apply the same correction, regardless of the dimension of the deviation.
If a small correction is used, this will result in a longer correction time, which will lead to accurate steerage only for low movement speeds.
If a large correction is used, the correction time will decrease, but the system will oscillate around the ideal trajectory.
If 3 sensors are disposed on a bar, perpendicular on the transporter's longitudinal axis, and they are co-linear and equally spaced, they still do not provide quantitative information about the position of the transporter with respect to the guiding tape.

2.3 Sensor Configurations for Qualitative and Quantitative Information

With 5 co-linear and equally spaced sensors, the quantitative information is available – in 5 steps resolution – together with the qualitative information. As the number of sensors is increased, the resolution of the quantitative information increases too.
The proposed solution, with a particular pattern of 3 sensors, offers the same 5 steps resolution provided by the above described 5 sensors configuration.
The proposed sensor configuration used in experiments consists, for each wheel, of 3 digital sensors, grouped in a triangle, placed central on a bar. The bar is disposed perpendicularly on the transporter's longitudinal axis. The purpose of the 3 sensors is to provide gradual information about the position of the vehicle with respect to the guiding tape.

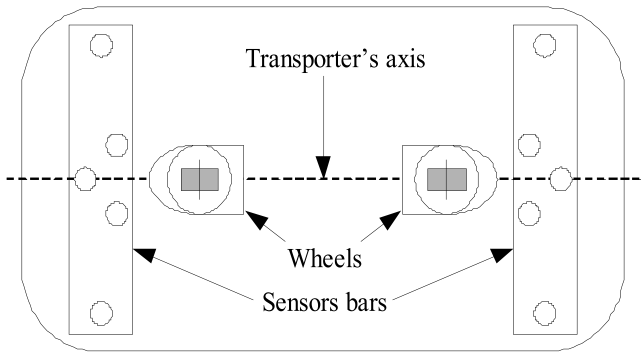
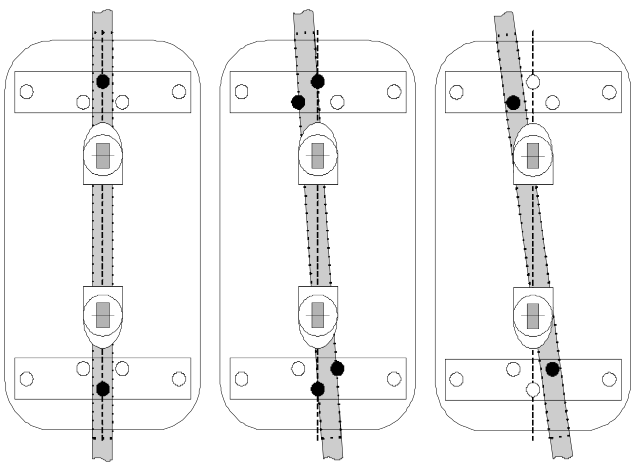


Fig. 1. Digital sensors configuration.



a) no deviation b) small deviation c) big deviation

Fig. 2. Sensors detecting the guiding tape.

Two additional sensors are disposed on the 2 ends of the bar, but these sensors are not used for guiding purposes. Their purpose is to detect special codes, like STOP, LATERAL MOVEMENT, etc. [2].
For convenience, in this paper, the term of "lateral sensors" will refer to the 2 sensors form the central triangle, which are disposed on the left and the right side of the transporter's longitudinal axis. The 2 sensors disposed at the end of the bar will be referenced as "end sensors".
If the 3 central sensors are disposed in the corners of an isosceles triangle, as shown in figure 1, they can provide quantitative information too. In this case the 3 sensors are disposed so as in normal functionality, at most 2 of them will detect the tape.
When the transporter is in the right position with respect to the guiding tape – figure 2.a) – only the central sensor will detect the tape. If the transporter has a small deviation from the ideal trajectory – figure 2.b) – the central sensor and one of the lateral sensors will detect the tape together. If the transporter has a larger deviation from the ideal trajectory – figure 2.c) – only one of the lateral sensors will detect the tape. Table 1 shows a more detailed description of the way the sensors information is decoded.
Therefore, the proposed configuration allows not only a qualitative detection of deviations from the trajectory (left or right), but also a quantitative evaluation of these deviations, as shown in table 1.

Table 1. Sensor information decoding.

End	Guiding triangle			End	Decoding
Left	Left	Center	Right	Righ	
0	1	0	0	0	Big deviation right
0	1	1	0	0	Small deviation right
0	0	1	0	0	No deviation
0	0	1	1	0	Small deviation left
0	0	0	1	0	Big deviation left
x	0	0	0	x	Guiding tape missing
1	x	x	x	1	End of line
0	1	x	1	0	Error codes
0	1	x	1	1	
1	1	x	1	0	

The resolution obtained with this configuration of 3 sensors is equivalent to the resolution obtained with the configuration of 5 co-linear, equally spaced sensors.

3 Adaptive Control Algorithm

The proposed control algorithm is presented in figure 3. The minimization of trajectory deviations can be achieved by taking into account the following considerations:

- the sensor system provides information on the size of the deviation,
- the correction angle is chosen according to the size of the deviation,
- the correction speed is chosen according to the angular distance to the target position; in order to allow the wheel to stop, with good precision, at the target position [3].

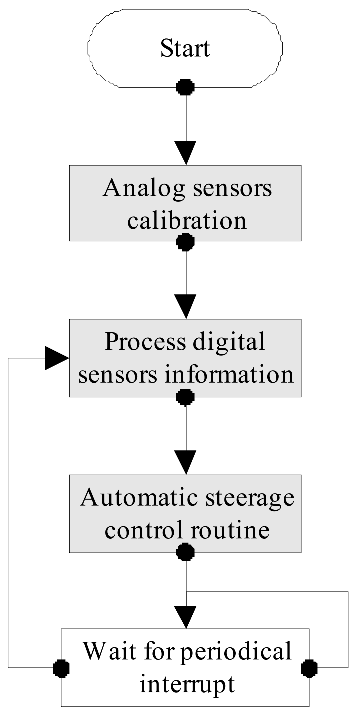


Fig. 3. Automatic drive algorithm.

The main steps of the algorithm are:

- calibration of analog sensors (wheels angular position),
- read and processing of the information from the digital sensors,
- adaptive steerage.

The direction command block will drive the left-right steering engine of each wheel according to the deviations detected. For adaptive direction control, each wheel is provided with angular position transducers. The position transducers are calibrated initially in order to allow the control system to read and store the voltage levels corresponding to the 0°, respectively 90° angles.

The calibration of the analog sensors is performed only once, when the control system is started and may be skipped if no change in the analog sensors configuration occurred since the last utilization. This operation is necessary in order to establish an accurate correspondence between the voltage values read from the analog sensors and the angles the wheels will make with the longitudinal axis of the transporter.

The next 2 steps are executed periodically, triggered by an interrupt. First, the information from the digital sensors is read and processed. This step is detailed in figure 4 and consists of the following operations:

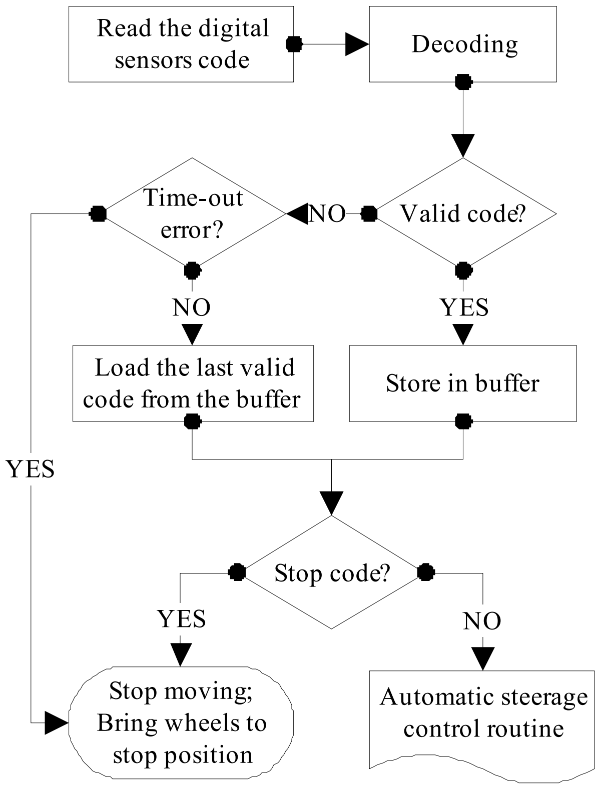


Fig. 4. Digital sensors information processing

- read of digital sensors,
- decoding of the information obtained from the sensors,
- validation of the information obtained from the sensors,
- if an invalid code is read, it is ignored once, and is considered error if repeated,
- go to the steerage control routine if a valid code was obtained or stop moving if not.

If a valid code from the digital sensors is active, the program will advance to the steerage routine, which is detailed in figure 5 and consists of the following operations:

- computing the target positions (correction angles) for each wheel,
- computing the angular distances from the actual position to the target position,
- choosing the proper correction speed,
- steering the wheels.

The correction speed can be changed using PWM control for the steering engines. Different correction speeds can be obtained using different widths for the command pulses.

After the automatic steerage routine is completed by driving the wheels, the system goes to a wait state. The wait state is exited when the periodical interrupt occurs, and the algorithm restarts with the reading and processing of information from the digital sensors.

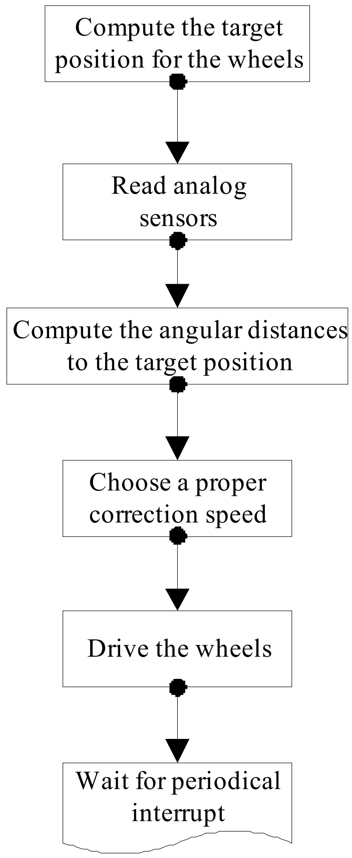


Fig. 5. Automatic steerage routine.

4 Hardware Configuration

The paper analysis 2 possible solutions for the hardware system used to drive the transporter. The first solution is to design a dedicated control system based on a general purpose microcontroller. The second solution is to use a PLC modular system.

4.1 Dedicated Microcontroller Based System

In this case, the hardware control system must be designed and implemented using a general purpose microcontroller that integrates on the same chip with the CPU multiple modules, as: memory, A/D converters, timers, PWM modules and so on. A block diagram of such a system is presented in figure 6.

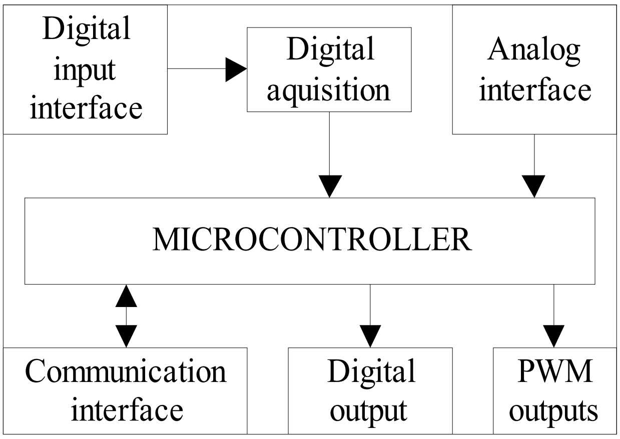


Fig. 6. Block diagram of microcontroller based system.

4.2 General Purpose PLC Modular System

A PLC system consists of a core module which contains the CPU and a various number of digital inputs and outputs, and is also able to connect at least 8 extension modules.

Various types of extension modules are available on the market, as well as the core modules. An extension module contains either a number of digital inputs and/or digital outputs either analog inputs and/or analog outputs. There are no limitations concerning the number of extension modules of a specific type that can be added to the core system. The only limitation concerns the total number of extension modules connected to the core module, which should not exceed the maximum number of extension modules indicated in the core module's specifications.

The architecture of the PLC modular system, used in experiments, is presented in figure 7.

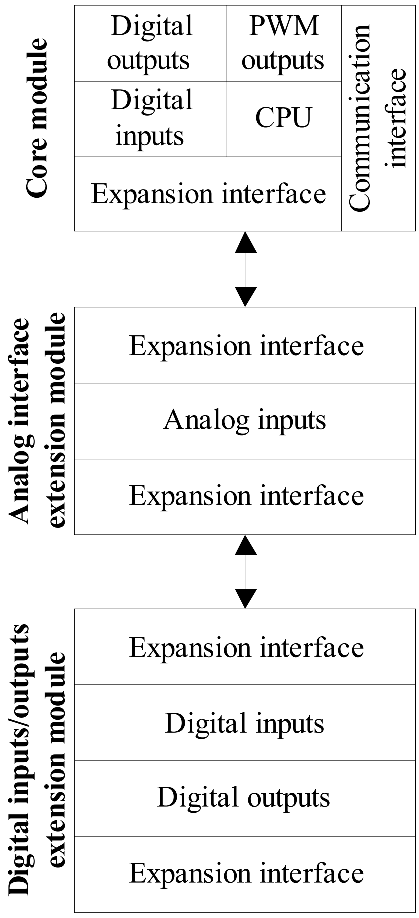


Fig. 7. Block diagram of PLC modular system

This solution requires electronic hardware design and implementation, increasing the cost of the system [2]. On the other hand, considering that most of the microcontrollers, available today on the market, offer protection against firmware piracy, this solution protects the product against unauthorized reproduction and distribution.

The general purpose PLC system used for implementation of the algorithm consisted of a core module from the family SIMATIC S7-200, produced by Siemens, and two compatible extension modules – one for analog inputs and a second for additional digital inputs and digital outputs [5].

This solution offers a great flexibility in the design of the control system, with no need of any electronic hardware design and implementation. This results in a considerable reduced implementation time. Another advantage is the friendly "Ladder" programming language, which allows easy implementation of software algorithms.

But there are also disadvantages of this solution, as the vulnerability to software piracy and the higher cost of the modules.

Table 2 shows a comparison between the two solutions.

5 Implementation of the Control Algorithm

The control algorithm was implemented and tested on both hardware solutions.

For the dedicated microcontroller based system, the PIC16F873 microcontroller from Microchip was chosen and the software algorithm was developed in assembler, using MPLAB [4].

Table 2. Microcontroller dedicated system vs. general purpose PLC system.

	Microcontrolle r system	PLC system
Complexity and price	Medium	High
Total implementatio n time	Long	Short
Piracy protection	Good	Poor
Future development possibilities	Yes	Yes

6 Test results

In order to appreciate the efficiency of the proposed algorithm, it was tested with both hardware configurations on various test trajectories. Figure 8 presents some of the test trajectories used: Fig.8.a) – no curves; Fig.8.b) – 45° curve; Fig.8.c) – 90° curve. The results obtained were compared with those of non-adaptive control algorithms.

With non-adaptive algorithms (single correction angle, rigid control, etc.), large errors and oscillations occur when higher movement speed is used.

With the proposed algorithm (adaptive PWM control) the transporter is able to follow the guiding tape even at high movement speeds and with very small errors. Further, it allows the transporter to recover from any expected deviation with very small, short-term oscillations.

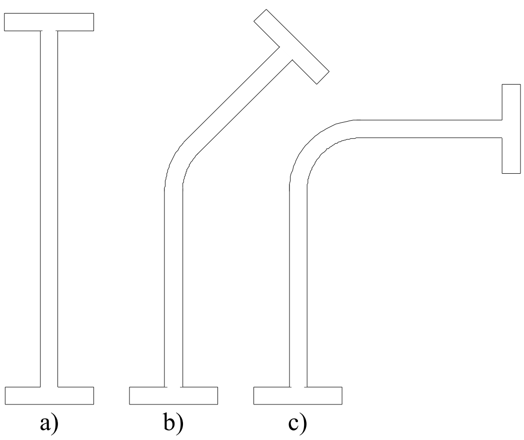


Fig. 8. Test trajectories

7 Conclusions

The paper proposes an efficient control method for self-guiding air-cushion transporters. All information, necessary for accurate steerage, is obtained using only 3 digital guiding sensors and one angular position transducer for each wheel.

The information provided by the proposed configuration with 3 digital sensors has a resolution of 5 steps, allowing the control algorithm to steer the wheels with different correction angles, for small and large deviations. Based on the information about the wheels angular position, delivered by the analog transducers, existing on each transporter, the control algorithm uses different correction speeds, depending on the angular distance to the target position.

The control algorithm was implemented and tested, with good results, on two hardware configurations, for an air cushion transporter with 2 wheels, used for propulsion and steerage. The dedicated microcontroller solution is better in terms of complexity, price and protection against firmware piracy, while the general purpose PLC modular system is indicated when short development time is imposed and piracy protection is not critical.

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