Digital sensor and controller for two-rail electrically driven vehicles

M P Ursu
University of Oradea, Department of Computers and Information Technology, Faculty of Electrical Engineering and Information Technology, str.Universității nr.1, Oradea 410087, Romania

E-mail: mpursu@uoradea.ro

Abstract. Within factories, the transportation of components and of assembled parts to and from storage is very important. This paper presents an original idea of such transportation by means of two-rail electrical vehicles. The digital sensors and controllers can be connected into a wider digital network in order to ensure automation, efficiency and safety of the vehicles. The computerized central command station can learn the behaviour of the manufacturing chain and adapt the system operation parameters accordingly. The digital sensor and controller has two functions: it signals the presence of the vehicle in its controlled rail block, and it stops the vehicle if the block ahead is occupied or the operator issued a “stop” command, or lets it pass through if the block ahead is clear and the operator does not need it there. The vehicles are fitted with electrical motors which drive their wheels, and they collect low-voltage electricity from the two metal rails by means of wheel pick-up contacts. This system can be implemented in small or medium-size factories, and it can be extended and/or upgraded according to necessities. Due to the resemblance with the miniature railway systems, this idea can also be used in this field of activity.

1. Introduction
The efficiency of factories can be rated by several factors, such as accuracy, high quality of products, low percent of faults, high assembly speed, good use of energy input and so on. Among these, the efficient transportation means within the factory are very important, because this is how the components are sent to the operators, either humans or robots, and the assembled parts are sent to checking, packaging or other sectors. Some factories use conveyors (rubber, roller, gravity etc), manual or electric trucks, bigger or smaller cranes, elevators etc., each of them with its own advantages and disadvantages, according to their dimensions and amount of activity.

An interesting idea of transportation within small or medium-sized factories would be the use of a two-rail system with electrical driven vehicles, which pick up low-voltage electricity and specific commands from the powered rails. This system, somewhat similar to the well-known railways, includes stations where the vehicles will be halted if the operator issued a “STOP” command or if the line block ahead is occupied by another vehicle. Thus, if more components are needed or many assemblies are completed and take up space, the operator will issue a “STOP” command, and the next vehicle that holds components in one carriage and completed assemblies in the other carriage will stop in front of him/her. After unloading the components and/or loading the completed assemblies from/in the appropriate carriages of the vehicle, the operator will issue a “PASS” command, which will be
enabled if the block ahead is free or automatically disabled until so. The digital electronic sensor and controller device, presented in this paper, is able to signal the presence of such vehicle in its controlled section of track, and to ensure the safe travelling of the vehicles by automatically checking the status of the line ahead.

2. The digital sensor and controller

This proposed two-rail transportation system is similar to the common railway network system and to its smaller versions. The two metal rails will be mounted on insulating sleepers of hard wood or impact-resistant plastic, and they will be fed with low-voltage AC/DC electricity or DCC signals [1]. The vehicles will be fitted with low-voltage electric motors which will drive their metal wheels that feature pick-up current collectors. Usually, the motors will be connected directly to the wheels pick-up collectors. Also, if necessary, the vehicles may be fitted with digital decoders which are able to receive, decode and execute specific commands. In such cases, the wheel pick-up collectors will be connected to the input wires of the decoders (red and black), the motors will be connected to the motor outputs (orange and grey) and the headlights, if present, will be connected to the appropriate light outputs (blue, white and yellow).

The digital sensor and controller consists of an electronic device that has two functions: it signals the presence of the vehicle in its controlled rail block, and it stops the vehicle if the block ahead is occupied or the operator issued a “stop” command, or lets it pass through if the block ahead is clear and the operator does not need it there (figure 1, figure 2).

![Figure 1. The digital sensor and controller – internal structure.](image)

![Figure 2. The connection to the two-rail transportation system.](image)

The sensor continuously monitors the presence or absence of the motorized vehicle on the controlled stretch of line. When there isn’t any such vehicle on the rails of the controlled line, then
there is no voltage drop across the triac $T_1$ so all the three transistors $Q_{1,3}$ are blocked and the Trigger-Schmitt NAND gate $IC_{1c}$ receives 1L, thus its output named “Line_Status” is maintained at 0L, whether the triac is open or blocked. When a motorized vehicle enters the controlled line and the triac is opened, then a voltage drop of approximately 1V appears on the triac. If this voltage drop is positive, then the transistor $Q_1$ is opened, and if this voltage drop is negative, then the group $Q_{2,3}$ is opened. In both cases, the inputs of gate $IC_{1c}$ receive 0L, thus the “Line_Status” output is maintained at 1L. If the triac $T_1$ is blocked by a “STOP” command or because the line ahead is occupied, then the motorized vehicle is halted onto the controlled line, and the entire voltage of the other rail will be sensed through the motor by the three transistors $Q_{1,3}$ with the same result, output “Line_Status” at 1L. Thus, the sensor will yield a 0L signal when the controlled line is free and a 1L signal when the controlled line is occupied, whether the motorized vehicle is moving or halted.

The safety automation is fulfilled by bringing the line status signal from the next block to the “Next_Line” input. When the next block is occupied, then the corresponding signal is 1L, the inputs of Trigger-Schmitt NAND gate $IC_{1d}$ receive this signal through the $D_1$, $D_2$, $R_3$ OR wired circuit and its output yields 0L, thus the triac $T_1$ is blocked and any incoming vehicle will be halted, whether the operator has issued a “STOP” command or not. Also, if a motorized vehicle is present on the controlled line in this situation, the “PASS” command will not be able to open the triac $T_1$ until when the next block will be free, which will be reported as a 0L signal to the “Next_Line” input. Due to the controller function of this device, the operator is able to stop an approaching vehicle by pressing the “STOP” button. The flip-flop $IC_{1a}, IC_{1b}$ will activate the output of $IC_{1b}$, enabling the “Red” output and sending a 1L signal through the $D_1$, $D_2$, $R_3$ OR wired circuit to the inputs of gate $IC_{1d}$, grounding the gate of triac $T_1$ by the 0L issued by its output, thus disabling the voltage of the controlled track. In this situation, any approaching vehicle will halt after entering the controlled line. After finishing dealing with the halted vehicle, the operator pushes the “PASS” button. The flip-flop $IC_{1a},IC_{1b}$ will activate the “Green” output and will deactivate the output of $IC_{1b}$, sending a 0L through the $D_1$, $D_2$, $R_3$ OR wired circuit to the inputs of gate $IC_{1d}$. If the occupancy signal of the next line is set to 1L, then the inputs of gate $IC_{1d}$ will be held at 1L until the next line is cleared. Only then the gate $IC_{1d}$ will receive 0L and will yield 1L to the gate of $T_1$, and so the triac will open and will feed with electricity the controlled line, thus enabling the departure of the stationed vehicle. Of course, if the line ahead is free, then the vehicle will leave the station immediately after the operator has pressed the “PASS” button.

For safety reasons, when the entire two-rail system is started, the flip-flop $IC_{1a},IC_{1b}$ is automatically set to the state where the “Green” output is disabled and the “Red” output is enabled, by means of resistor $R_3$ and capacitor $C_1$. Then all the operators will press their respective “PASS” buttons to let the transport operations begin.

The chain of sensors & controllers is powered by a separate power supply of stabilized 15V, which enables the CD4093 CMOS quad Trigger Schmitt NAND gate to operate properly, with a large noise margin and fast response time [2]. The VSS terminal is connected to the railway rectified and not filtered power supply terminal which will feed the upper (left) rail by means of the triacs within the sensing and controlling devices. According to the standards of the analog miniature railways, the motorized vehicle will advance if it receives positive voltage at the right wheels and negative voltage at the left wheels. However, due to the capabilities of the triac, the rails may be fed with AC or even DCC voltage.

The PCB was made by means of conventional methods (figure 3) by company AR Elektronik from Cluj-Napoca, according to the project that the author has made with EAGLE software suite [3]. The material was FR4 TG135 / 1.6 mm with single-sided 35 μm copper layer, with green soldermask and white top legend writing. This device combines both analogical and digital components, such as conventional NPN and PNP transistors, diodes and one triac, and the CMOS quad Trigger-Schmitt gates CD4093 integrated circuit. The digital IC converts the analogical sloped signals of the sensor itself into crisp digital signals, and also it acts as a digital bistable circuit in order to convert the commands of the human operator into digital signals.
The experiments have been carried out using the miniature H0 (1:87) train collection of the author. Of course, this scale is way too small to be used for such applications, which require larger and sturdier vehicles, along with wider rail systems with thicker and stronger tracks. More suitable scales may be 0 (1:45) with 32 mm track gauge, 1 (1:32) with 45 mm track gauge and so on.

3. Applications of the digital sensor and controller
As mentioned before, this device monitors the presence of a motorized vehicle onto its respective line block, and is able to control its motion according to the commands of the operator and to the occupancy of the next line block.

Due to the use of the Trigger-Schmitt NAND gates, the signals yielded and accepted by the sensor & controller devices are digital, either 0L or 1L, which makes possible to use them to gather data about the motion of the vehicles by a central processing unit (CPU). Also, these devices may be upgraded with optical readers for the bar-codes that can be printed on the sides of the vehicles for identification. The data can be sent to the CPU directly by wires or by means of optocouplers or even by more modern means, such as Bluetooth connections or wireless communication.

In case of longer distances between two adjacent manufacturing posts, the intermediate line blocks will be automatically operated by such devices with their “PASS” inputs permanently hard-wired to VSS, so that they will simply observe the occupancy of the line blocks ahead, halting the moving vehicles only when necessary.

Figure 3. The digital sensor and controller – PCB (left), assembled (right).

Figure 4. The digital sensor and controller, adapted for DCC operation.
If necessary, the motorized vehicles can be fitted with DCC digital decoders, which make them able to perform additional tasks and to be controlled much more efficiently by the CPU. The rectangular alternative DCC signal can be properly handled by this sensing and controlling device, except for the fact that the signal is entirely cut off when the vehicles must stop. This disadvantage can be eliminated by adapting the digital sensor and controller according to figure 4. The DCC decoders, when adequately programmed, are able to perform automatic braking and stopping if they detect a slight asymmetry in the DCC signal. Thus, the triac is replaced with a group of anti-parallel diodes $D_3 - D_7$, of which $D_5 - D_7$ are short-circuited by the normal-closed contacts of a miniature electromagnetic relay. When the motorized vehicle must stop, either because the line ahead is blocked or because the operator issued a “STOP” command, the inputs of gate $IC_{1D}$ receive 1L and its output yields 0L, which opens the transistor $Q_4$ and, in turn, powers the coil of the relay. The normal-closed contact opens and removes the short-circuit from diodes $D_5 - D_7$. Now the different number of diodes causes a small asymmetry between the “positive” and “negative” alternations of the DCC signal, and any present motorized vehicle with digital decoder will automatically brake and stop, without losing the DCC signal, which is very important and useful. When the line ahead is free and the operator issues a “PASS” command, then the inputs of gate $IC_{1D}$ receive 0L and its output yields 1L, which closes the transistor $Q_4$. The coil of the relay loses power and its normal-closed contact returns to the closed position, which short-circuits the diodes $D_5 - D_7$ again. Now only the anti-parallel diodes $D_5$ and $D_7$ remain in series with the DCC signal, which passes to the controlled line symmetrically and any digital motorized vehicle will travel along the controlled line. Unfortunately, this DCC version of the digital sensor and controller is not compatible with the analogical system previously described, so the potential users must know with certainty from the very beginning which system will they use for transportation. In both cases, the information yielded by the digital sensor and controller is digital and has the same meanings.

The entire two-rail transportation system will be fitted with protection devices against overload and short-circuits, which may occur in case of too many vehicles and/or derailments. According to the local conditions, the system may be fitted with passing loops, so that vehicles with higher priority will be able to overpass the other vehicles. The turnouts will be fitted with electric actuators, which will be automatically driven by the CPU or manually by the respective operators if necessary.

4. Optimization of the two-rail transportation system

By means of optimization algorithms, the CPU will be able to adjust the number of the vehicles and their speed according to the current requirements, conditions and possibilities. The software can be based on neural networks, fuzzy logic [4, 5, 6] or even Just-in-Time or Kaizen [7] concepts, so that the transportation system would be able to adjust optimally to the present conditions in real time. For example, too few vehicles on the two-rail system would lead to overloading of the carriages and to supply disruptions, and too many vehicles would lead to congestion because of too many occupied sectors of track which would automatically stop the incoming vehicles too often.

Too low transportation speed would lead also to overloading of the carriages, congestion of the system and supply disruptions, and too high transportation speed would increase the derailment risk, and the increased stopping distances due to the inertia of the moving vehicles may lead to sector overtaking and collisions with the vehicles ahead. As the speed of the analogical vehicles is controlled by the voltage supplied to the rails, a smaller voltage leads to smaller speeds but also to smaller traction power, and the moving vehicles may stop uncontrollably because of load, slopes, curves and frictions. A greater rail voltage would lead to greater speed and traction power, but also increases the risk of electrical overload and higher accidental short-circuit currents.

The DCC system feeds the tracks with rectangular alternative voltage of fixed amplitude, which carries not only electricity, but also other binary-coded specific commands. By means of this system, the speed of the motorized vehicles can be modified without altering the amplitude of the DCC signal and without losing the traction power, which is a great advantage in comparison to the analogical system, and other specific tasks can be executed by the digital hardware of the vehicles.
The fuzzy sets systems do not operate with strict values as “YES” and “NO”, as the well-known binary digital systems, but with shaded values such as “large negative”, “medium negative”, “small negative”, “zero”, “small positive”, “medium positive” and “large positive” [4, 5, 6]. These systems are able to balance the antagonistic input parameters in order to attain optimal values of the output parameters. Thus, according to the dynamics of the manufacturing chain, given by the rates of “STOP” and “PASS” commands, the time extensions and frequency of the automatic and required halts etc, the system will be able to adjust the speed of the vehicles and their number in order to achieve the maximum possible efficiency and safety of the manufacturing process.

As mentioned earlier, this system can be further developed and improved by adding more devices and functions, such as barcode readers, turnouts and passing loops, intercom applications, safety devices etc. Of course, the rail system and vehicles will be large enough and well balanced in order to ensure safe motion and transportation, and the tracks will be designed with moderate slopes and large curves. The lengths of the controlled stretches of track will be set according to the sizes and speeds of the vehicles, so that they will not be overrun because of inertia.

5. Conclusions
The two-rail transportation system, which is similar to the well-known railways, both real and reduced to scale, may be suitable for small or medium manufacturing facilities. Compared to conveyors, for example, it is less complicated, less demanding and more flexible. Track extensions, stations, turnouts and passing loops can be easily installed if/when/where necessary. The particular profiles of the wheels ensure safe travelling on the rails, provided that the vehicles are driven with reasonable speed and there are no obstacles on the track.

The low-voltage powered rails are able to feed the motorized vehicles with electricity and supplementary commands, and a custom-made CPU is perfectly able to control all traffic on the entire transportation system, due to the digital signals yielded by the chain of digital sensors and controllers that are placed along the insulated rail blocks.

Very similar applications have been already used in some public restaurants, where large scale miniature trains are used to bring the ordered foods and drinks to the customers. Also, this system can be used to update any existing analog or even digital miniature model railway system, in order to add automation and safety to their operation.

6. References
[1] https://www.nmra.org/dcc-rps-standards
[2] http://www.ti.com/lit/ds/symlink/cd4093b.pdf
[3] https://www.autodesk.com/products/eagle/overview
[4] https://en.wikipedia.org/wiki/Fuzzy_control_system
[5] Stănășel I, Blaga F and Hule V 2010 Decision System Based On Fuzzy Sets For Aided Design Of Technological Processes, Proceedings of the 14th International Conference on Modern Technologies, Quality and Innovation (ModTech 2010), pp 559-562, https://goo.gl/gMHfo6
[6] Blaga F, Stănășel I, Hule V and Ursu M P 2011 Study For Total Cost Of Design Activity Based On Fuzzy Sets, Proceedings of the 15th International Conference of Modern Technologies, Quality and Innovation, pp 93-96, May 25-27, https://goo.gl/qaitg2
[7] Bungău C, Blaga F and Gherghea C 2014 Kaizen Implementation For Cost Reduction In Manufacturing Process Product “Driver Control Board, International Conference on Production Research - Regional Conference Africa, Europe and the Middle East (ICPR-AEM) / 3rd International Conference on Quality and Innovation in Engineering and Management (QIEM), pp 55-58, July 01-05, Cluj-Napoca, https://goo.gl/nyLFPY