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Research Paper

DEVELOPMENT OF AN AUTOMATED GUIDED VEHICLES IN INDUSTRIAL ENVIRONMENT

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With the advancements of robotic technologies, the industrial environments are adopting more and more aspects of automation to enhance product quality and accuracy and to reduce product cost. One of these aspects is the use of Automated Guided Vehicle (AGV) which is gaining importance in industrial logistics and transportation systems. Automated Guided Vehicles are the essential parts of all automated factories. They are the pre-programmed vehicles, normally used to carry raw materials, in-process parts and assembly and finished items from one location to the other location inside the plant. No human intervention is required for its normal functioning during task-execution stage. In this paper, automated guided vehicle is interfaced with Programmable logic control, which is a new concept in the field of automation and replacement of traditional electro-mechanical control system. In steel plants, a lot of transporting is required inside the plant to help in production, such as, steel coils are transported from one location to another. For this purpose automated guided vehicle systems are very useful. For such a system in steel plant four different software with its logic diagram using PLC has been developed and presented. The software deals with the movement of the vehicles in four different states (Raise, Reverse, Lower and Forward movement of the vehicle). The use of such system is applicable for any cyclic process in an industry, enhance the productivity of any industry taking care of safety measures and will also ensure good quality of product.

Keywords: Automated guided vehicle, Programmable logic controller, Material handling system, Automation

INTRODUCTION

Automated Guided Vehicles (AGV) has been applied for the flexible manufacturing system. Many factories were adopted it into assembly line or production line such as automobile, food processing, wood working, and other factories. Many researchers developed and designed in order to suite with their applications which are related to the main problem of factory. Automatic Guided Vehicle (AGV) has firstly developed and conducted the research by Butdee and Suebsomran (2007 and 2006)

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and Butdee *et al.* (2006) in the attempt to using at Jumbo Truck Manufacturing in Thailand. On the past of developed AGV, several papers was surveyed concerned to the design and control aspects as following. The different structures were proposed in several cases as (Sung *et al.*, 1989) proposed the architecture of AGV with two wheels driven by differential gear drive and parallel linkage steering, and the design and operation was also presented by Mentel and Landeweerd (1995). This paper stated that the track layout and the number of AGVs in transportation control on a job-shop and a flow-shop were determined by using the queuing network theory. For entire FMS system, Lee and DiCesare (1994) proposed the operation control method by using two AGVs system. They solved the problem in scheduling method of AGVs model based on Petri nets. The formulation and heuristic search were used by global search in order to seek the optimal operation of the entire FMS. The operations of AGVs choice of guided path selection problem in FMS system was proposed by Gourgand *et al.* (1995). They proposed an approach for material flow modeling based on mathematical optimization method. With this approach, they obtained the guide path layout design with wire guided vehicles. The objective of optimization model is the minimization of the total distance traveled by vehicles to transport the material handing system. The route planning of AGVs in FMS was proposed by Liu and Fu (1989) and Naiqi Wu and ZFou (2003 and 2004). Liu and Fu (1989) presented the new approach for dynamics route planning and scheduling problem of AGVs. They applied the search algorithm and some heuristic rules to solve the route assignment in dynamic situations. Naiqi Wu and ZFou (2003) also proposed the path planning strategy of AGV to navigation, collision avoidance and docking to the target. The path planning was implemented on-board computer in order to avoid the wire-guided path. Not only the AGV was moved along the path with collision avoidance, but also it should be navigated with no deadlock condition as done by Fanti and Turchiano (2001). They formulated the control algorithm by digraph method in real-time path assignment to the vehicles. The deadlock control of AGV was controlled by colored resource-oriented Petri net model method to deal with the conflict free in real-time control as shown Naiqi Wu and ZFou (2004). The AGV control approach was the important part for controlling the AGV actions. Ertugrul *et al.* (1995) applied the variable structure system techniques. The AGV was modeled by using kinematics and dynamic system. Sliding mode control by using Lyapunov design was applied for eliminating the chattering. They only implemented by simulation methods. The other paper proposed the control of AGV by using fuzzy logic control as shown in Senoo *et al.* (1989) and Dianyong and Hui (2003). The AGV was guided by photoelectric guide way. The designed controller was the self-adjustment of control parameter by fuzzy controller. Senoo *et al.* (1989) proposed the steering control of AGV using fuzzy control. The AGV was guided by guide tape. They showed the response and energy saving in case of step change of guide tape. Fuzzy controller was achieved the reduction of steering energy more than the PI controller. Kim and Hong (2004) was presented the tracking algorithm of AGV navigation in container terminal. The multiple model algorithm based on multiple sensor detection in order to detect obstacle or other AGVs. Unscented Kalman filter was used to localization of AGV. They verified the propose algorithm by simulation methods. The adaptive control of AGV is also proposed by Beji and Bestaoui (2005). The nonlinear of dynamic model was developed for motion generation. The propose control was based on Lyapunov concept to ensure the control of AGV even if the dynamic parameter was not perfect. The intelligent of AGV was also worked on several methods. The integrate sensor and vision was applied for control AGV. Fang and Xie (2004) studied the intelligent path following and control for vision-based automated guided vehicle. They presented the control 3 path following of AGV by vision control system, and multi-sensors was also applied in real time steering control. The hough transform algorithm was applied to detect the guideline of path as shown by Zhang *et al.* (2004). The guideline of path was recognized by optical sensor as proposed by Borges *et al.* (2000). This paper proposed the array of optical sensor with 14 infrared (IR) emitter-detector pairs arranged in two columns. The trajectory recognition was based on neural networks. Position and orientation of vehicle must keep the precise navigation and known its positioning at each place during travelling. To know and maintain its position, the currently the localization is the key of research on mobile vehicle. AGV is one of the significance of the present research trend. In industrial application, manufacturing factory is brought the mobile vehicle to incorporate working with other machine in order to being the automated manufacturing system. Many applications were adopted the AGV in different tasks such as material handling system, AS/RS system, transportation system, etc. Thus the research on the localization of mobile vehicle has increasingly researched in different aspects for improving the ability of vehicle. For reviewing the past research, several methods have been reported the localization of mobile vehicle such as Leonard and Durrant-Whyte (1991) and Anousaki and Kyriakopoulos (1999) was developed a system in which the basic localization algorithm is formalized as a vehicle-tracking problem, employing an Extended Kalman Filter (EKF) to match beacon observations to a navigation map to maintain an estimate of mobile robot location. Tong and Tang proposed the robot self-localization. They applied the sensor fusion algorithm, which is used ultrasonic and CCD sensors, to filter out unreliable the sensor data reading. Moreover Extend Discrete Kalman Filters (EDKF) used to design for raw sensor data fusion to obtain more reliable representation in environment perception procedures Song and Tang (1996). Modeling of ultrasonic range sensors was developed by Naiqi Wu and ZFou (2004), and they presented a probabilistic model of ultrasonic range sensors using back propagation neural networks trained on experimental data. Extend Kalman filter is used for update location from the prediction and observation matching as shown in Gutierrez-Osuna *et al.* (1998) and Tsai (1998). Self-localization techniques by using probabilistic for mobile robot that based on the maximum-likelihood estimation were also done by Olson (2000). For outdoor navigation problem of mobile robot, Bonnifait and Garcia (1998) reported the localization with 2-D mobile robot localization based on observability analysis in order to determine the undergo difficulties. They developed the localization algorithm called Multisensor Localization System (MLS). Due to nonlinear system model obtained in statespace description, Extend Kalman Filter is applied for estimate the state X which is done in two steps, prediction and filtering, respectively. The use of GPS and inertial plate sensor for outdoor navigation also is presented by Panzieri *et al.* (2002). They presented the localization algorithm based on Kalman filtering that tries to fuse information coming from an inexpensive single GPS with inertial data and map-based data. And also Georgiev and Allen (2004) developed a localization system that employs two methods. The first method uses odometry, a compass and tile sensor, and Global Position Sensor (GPS). An Extended Kalman filter integrates the sensor data and keeps track of uncertainty associated with it. The second method is based on camera pose estimation. Another localization method was implemented and based on vision sensor. As reported by Lee *et al.* (2003), they proposed a new approach for determining the location of a mobile robot using image of a moving object. This scheme combines data from the observed position, using dead-reckoning sensors, and the estimated position, using images of moving objects captured by a fix camera to determine the location of a mobile robot. The proposed methods utilizes the error between the observed and estimated image coordinates to localize the mobile robot, and the Kalman filtering scheme is used for the estimation of mobile robot location. Wolf *et al.* (2005) applied the vision based localization, and used Monte Carlo for extracting each image in the database a set of possible viewpoints using a two-dimension map of the environment, but Se *et al.* (2005) used vision sensor to localize and build simultaneous three-dimensional map in global 4 localization. Multiple robot formation is done by Huang *et al.* (2006) to localize the group of mobile robots, a leader and follower control.

In this paper, automated guided vehicle is interfaced with Programmable logic control, which is a new concept in the field of automation and replacement of traditional electro-mechanical control system. In steel plants, a lot of transporting is required inside the plant to help in production, such as, steel coils are transported from one location to another. For this purpose automated guided vehicle systems are very useful. For such a system in steel plant four different software with its logic diagram using PLC has been developed and presented. The software deals with the movement of the vehicles in four different states. (Raise, Reverse, Lower and Forward movement of the vehicle.)

PROGRAMMABLE LOGIC CONTROLLER (PLC)

Use of electromechanical relays were much in vogue in electrical control circuits for achieving drive control, process interlocking, industrial safety etc. till recent past. In this system contacts and coils of the relays had to be interconnected with wires with a view to achieve control and interlocks. This system had disadvantages of large space requirements, large number of process wings, contact problems, etc., which may cause reliability problem in process. Any modification or alteration was not possible without change in wiring. Satisfactory working of the system needed constant supervision and maintenance. The problem of large number of contacts was over-come by introducing contactless solid state logic system. In both the above cases the system logic has to be designed first and then it has to be manufactured and wired accordingly which will definitely increase the load time.

These difficulties are overcome by developing standard units which can be programmed as per requirement and put to work within a short time. These standard units are known as Programmable Logic Controller which when programmed for particular interlocking sequence and control and kept in its memory can do the job very efficiently without much maintenance. As the programs can be changed by a stroke of key it is very easy to change the sequential logic and schemes.

Basic Principle

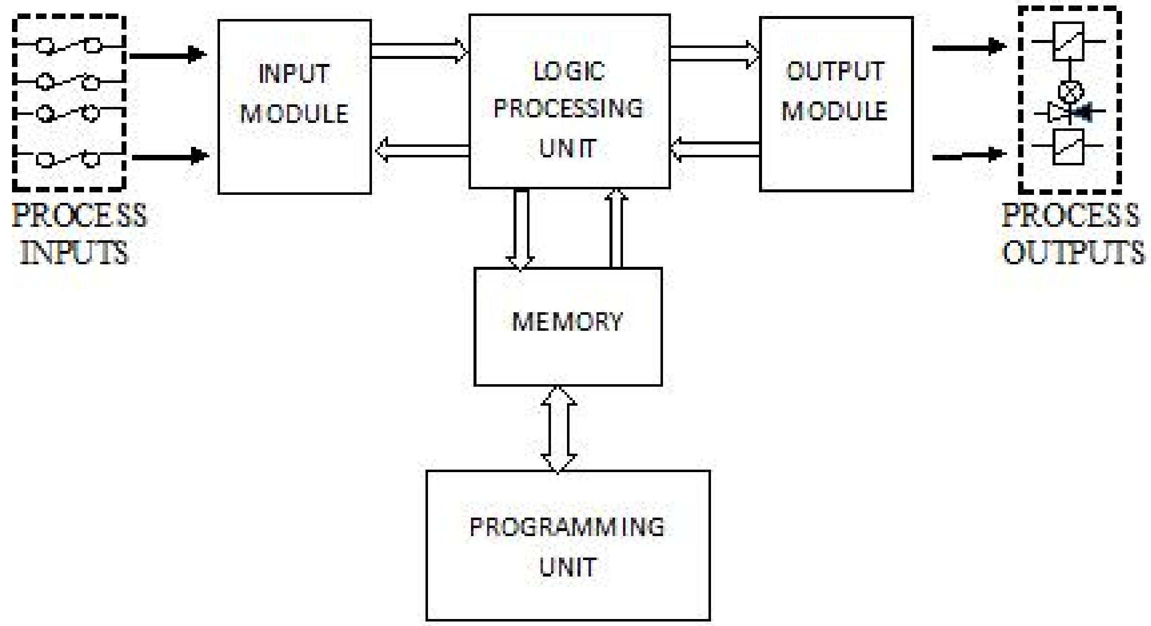
Basically most of the sequential operations and process interlocking operate on inputs from binary elements such as push buttons, limit switches, photo elastic switches, electro contact thermometers, pressure gauges etc. If the contacts of these elements are closed then some input say 24 V or 48 V which is called signal "I" reaches PLC, otherwise no input will be there if the contact is open. In that case it is said to be signal "O". The basic principle of operation in a stored program of logic involving inputs/outputs is scanned at a high speed under the direction of program statements stored in the memory.

Statements stored in the memory are fetched one by one in serial order and based upon the instructions in the statement, the necessary task is carried out. Sequential fetching of statements is controlled through high speed clock pulses. The process of sequential execution of each statement is called memory scanning. Status of the input flags etc. are scanned as per the above principle, and different outputs, and flags are set. These outputs may energise a contactor to drive a motor or a solenoid valve to drive hydraulically operated drive or give signal by energising lamps, or may be used as input to other systems (Figure 1).

Operation of PLC

As far as PLC user is concerned, the program steps defined by the ladder logic diagram are executed simultaneously and continuously. In truth, a certain amount of time is required for the PLC processor to step through the program and execute any changes in outputs. First, the inputs to PLC are sampled by the processor and the contents are stored in the memory. Next, the control program is executed. The input values stored in memory are used in the control logic calculations to determine the values of the outputs. Finally, the outputs are updated to agree with the calculated values. This cycle, consisting of reading the inputs, executing the control program, and revising the outputs, is referred to as scan. The time to perform the scan is called the scan time, and this depends on the number and complexity of control functions to be performed each cycles. Stating this another way, the scan time depends upon the number of rungs in the ladder diagram and the complexity of the logic operations to be carried out on each rung. These time typically vary between 1 and 100 ms.

Figure 1: Block Diagram of PLC

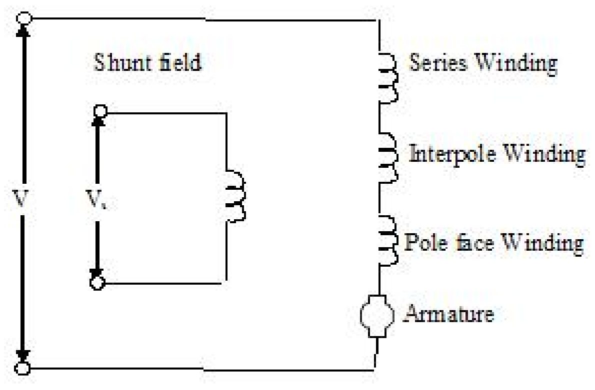


Power Converter Controls Using PLCs

Speed Control

Speed control is possible in automated guided vehicles, driven by d.c. motor by changing the speed of drive. Changing the speed of drive is possible through variation in the armature current or field current of d.c. motor. This is possible by using inverter-converter control of d.c. power by varying the firing-angle of converter according to the required d.c. voltage. The d.c. motor is operated in drive systems with the shunt field supplied separately. The field current may be maintained constant or varied to some extent to supplement the speed range. The shunt field reacts with the armature current to produce torque. The shunt field also reacts with the moving armature conductor to produce back e.m.f. Series winding alters the speed drop characteristics and to achieve higher starting torque. Pole face winding reduces the armature inductance and prevent the armature current from distorting the main magnetic field produced by the shunt field. Interpole winding is provided to help commutation (Figure 2).

Figure 2: "Armature and Field Windings in a DC Motor



Speed is expressed as, $N = V\text{-}IaRa/K\varnothing$, where Ia, Ra, K, $\varnothing$ are constant, i.e., N will directly depend upon V, i.e., speed is directly proportional to voltage,

where,

N = Speed

V = Supply voltage

Ia = Armature current

Ra = Armature circuit resistance

K = Constant = (ZP/60A) × 10^{-8}

Ø = Magnetic flux in maxwells

Z = No. of active conductors in the armature windings

P = No. of pole pairs in the motor

A = No. of parallel path pairs in the armature winding

The above equation indicates that the speed of the motor can be controlled in three ways. (a) By varying the armature circuit voltage V which is nearly proportional to speed. (b) By varying the armature circuit resistance Ra which is proportional to speed drop but increases the armature loss. (c) By varying the magnetic field which is inversely proportional to speed.

Speed is directly dependent on d.c. voltage across the armature. Therefore the d.c. voltage output from the converter can be changed by changing the firing angle of the thyristor in the converters. The firing circuits of the thyrister in the converter can be pre-programmed by using the logics in the PLC. As the firing circuit in the (Figure 3.4) converter, are connected to the output lines of PLC and the input lines of the PLC are connected to the speed sensor transducer, a suitable program for maintaining the constant speed for varying outputs of the transducer and corresponding change in the firing angle has to be determined through the close study of the control circuit.

Direction Control

Direction control is normally done in non-automated guided vehicle through steering wheels which moves the wheel according to the desired direction. In Automated guided vehicles, where direction control is pre-programmed according to the path of movement of the vehicle.

Starting

The d.c. motor in the beginning has to be given uniform increase of d.c. voltage to the armature starting from zero until the voltage reaches to the required value of the running speed.

Stopping

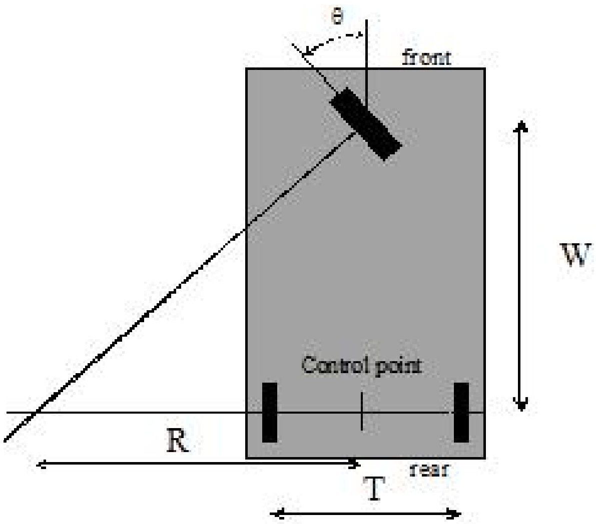
The stopping of vehicle is possible by two means; (a) by applying brake to the wheels whose movement can be controlled through PLC, (b) the braking can also be implemented by using the method of “Forced Commutation” to bring the d.c. voltage of the converter abruptly to zero. In this method there will be a jerk.

SYSTEM ARCHEITECTURE

The AGV prototype design is based on existing JUMBO industrial truck as shown Figure 3. It is a three wheels vehicle as shown in Figure 4. The front wheel is used for driving and steering the AGV and the two rear wheels are free. The steering and driving are DC motor. Two encoders are individually attached on the two rear wheels in order to measure the vehicle displacement and then calculate its real time position and orientation. The choice of positioning the encoders on the free wheels provides to the vehicle an accurate measurement of its progression. A Programmable Logic Control (PLC) is used for motion control.

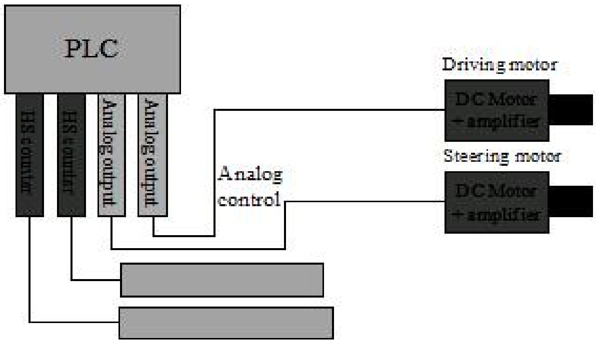
Figure 3: Photo of the AGV Prototype

Figure 4: AGV Prototype Architecture



The parameters of the motion are driving speed and steering angle which determine the evolution of the position and orientation of the AGV. The input and output signal are interfaced with PLC module. The inputs are the encoder signal from left and right rear wheels. The driving speed and steering angle are calculated form these inputs and the digital output is converted to analog signal to drive amplifier of the driving motor and steering motor on front wheel as shown in Figure 5.

Figure 5: AGV Prototype Command Architecture



SOFTWARE DEVELOPMENT

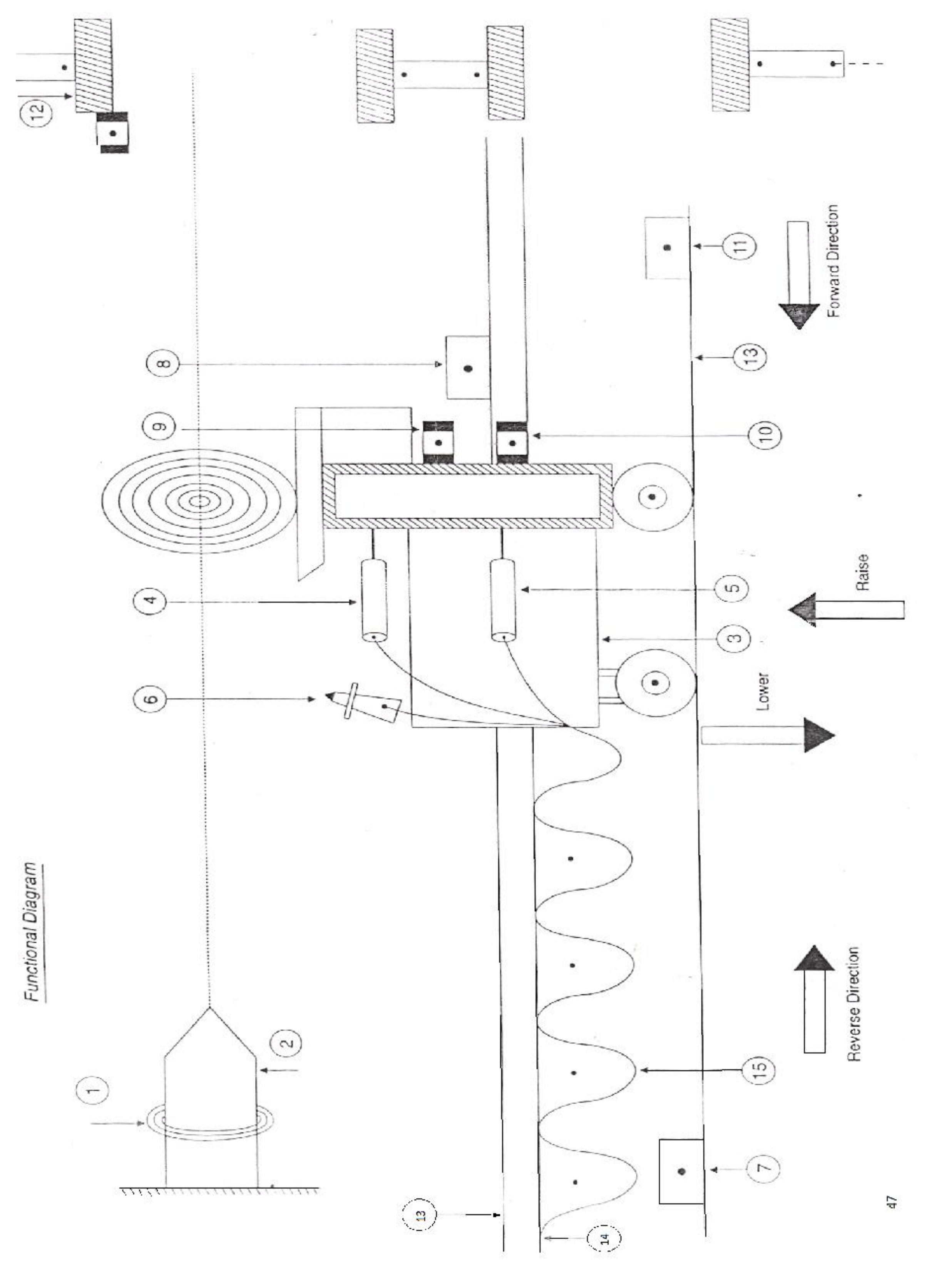
In steel plants, a lot of transporting is required inside the plant to help in production, such as, steel coils are transported from one location to another. For this purpose automated guided vehicle systems are very useful. Sometimes the systems is also called automated coil car which is used for transporting steel coils. For such a system in steel plant four different software with its logic diagram has been developed and presented. The system is based on Programmable Logic Controller (PLC). The software deals with the movement of the vehicles in four different states (Raise, Reverse, Lower and Forward movement of the vehicle). The objective of this automated guided vehicle is to remove the ready coil from the uncoiler and to place it on the conveyor. The functional diagram for the operation is shown in Figure 6.

Components of Coil Car / Automated Guided Vehicles

The main components of this proposed vehicles is shown in Figure 6 of the functional diagram.

1. Ready coil to be removed
2. Uncoiler

Figure 6: Functional Diagram of Automated Coli Car



3. Coil-car
4. Traverse motor
5. Hydraulic motor
6. Raise/Lower solenoid valve
7. Under coiler (mandrel) limit switch
8. Manipulating position limit switch
9. Conveyer height adjust limit switch
10. Car extreme lower limit switch
11. Under conveyer limit switch
12. Conveyor position limit switch
13. Rail (Track)
14. Beam with jockey
15. Trailing cable

System Description

The operation of the proposed system is as shown in the functional diagram is described in the following steps given below.

- Initially the coil car will remain under coiler in LOWERMOST position.
- First to remove the coil the, the hydraulic motor is started.
- Coil car is RAISED such that it touches the outer layer of the ready coil.
- Selection is kept in AUTO and the gripper which supports the coil is extended, the car removes the coil and starts moving in REVERSE direction but it stops at manipulating position with the help of manipulating limit switch.
- At the manipulating position, it starts going DOWN – UP to a height of high saddle conveyor.
- With AUTO start command, vehicle further moves in REVERSE direction but at that time the conveyor must be in position with the position limit switch operated.
- The car enters into the conveyor and stops with under conveyor L/S and starts going DOWN. It stops with extreme down L/S and places the coil on conveyor.
- The moment the extreme down L/S operating the coil-car starts moving in forward direction and it goes UP to the coiler.
- Similarly, next cycle starts as above.

Action Plan

The action plan for the proposed system is stated as follows.

- Use of PLC for Automation.
- Logic diagram is prepared for Automatic movement of the coiler.
- Based on the logic diagram, software of the PLC is developed.

PROGRAMMING INSTRUCTIONS

Basic advantage of PLC lies in the fact that the interlocking sequence is achieved by loading the program into the memory. The program can easily be developed by using either Boolean equation or ladder diagram or logic diagrams. Software details of PLC can be described under the following heads.

- Memory organisation
- Input/Output organisation
- Instruction repertoire
- Instruction coding

Memory Organisation

Each instruction consisting of 8 bits is stored in the memory in a specified location. There are 16,384 memory locations which are loaded in OCTAL code. Memory is organised in 8 EPROM chips, each having 2048 locations. Address of memory locations ranges from 00000 to 37777 as per the following distribution of chips.

Table 1: Memory Organisation

Chips	Address of Memory Locations
1	00000 to 03777
2	04000 to 07777
3	10000 to 13777
4	14000 to 17777
5	20000 to 23777
6	24000 to 27777
7	30000 to 33777
8	34000 to 37777

Thus all eight memory chips can be loaded separately one at a time by keeping them at first position but a chip once put in a particular location on memory can assumes corresponding address, i.e., for example on EPROM chip programmed by keeping it in the first position will assume address of 00000 to 03777 but if it is plugged into IC3 memory chip socket the corresponding address of the instructions will be 10000 to 13777.

Input/Output Organisation

Organisation of inputs and outputs of PLC is done in the form of banks. Each PLC has maximum four banks. Each bank contains up to a total of 120 users available inputs and outputs in which output can be maximum of 60. If more than 60 inputs are required to be used in the same bank, the following combination of I/O's can be done suitably replacing one or two or three output cards as per need.

Table 2: Input and Output of PLC Banks

S. No.	Inputs	Outputs
1.	60	60
2.	75	45
3.	90	30
4.	105	15

There are four banks numbered as 1, 2, 3 and 4. Each input or output instruction has to be preceded by a bank instruction (SB1, SB2, SB3 and SB4). However, if all inputs and outputs of one program block are in the same bank then only one select bank instruction before the entire program block is necessary. Thus, unless the other bank instruction is given in the program, the input/output channels are treated as belonging to the bank mentioned in the immediate previous bank instruction. Input and output channels are to be addressed in OCTAL while writing the program. Input bank channels are addressed from 000 to 077 (077 in octal is equal to 63 in decimal) and output channels range from 100 to 177. However, when input card replaces output card in output bin, address of the channel remains unaltered. The following table gives the octal addresses for each channel corresponding to the S.N of the channels given on input modules.

For output bank channels '000' will become '100'.Thus output bank channels will start from '100' and end up with '177'. Every input/output channel address (in OCTAL) should be preceded by its bank number.

Instruction Repertoire

Instruction used in PROGICON – 480 PLC are described below in the Table 4.

Table 3: Octal Address of PLC Banks

Channel No. in Decimal	Octal Card No. 1	Octal Card No. 2	Octal Card No. 3	Octal Card No. 4
1	000	020	040	060
2	001	021	041	061
3	002	022	042	062
4	003	023	043	063
5	004	024	044	064
6	005	025	045	065
7	006	026	046	066
8	007	027	047	067
9	010	030	050	070
10	011	031	051	071
11	012	032	052	072
12	013	033	053	073
13	014	034	054	074
14	015	035	055	075
15	016	036	056	076
16	017	037	057	077

Table 4: Instruction Repertoire of Progicon – 480 PLC

Instruction	Channel No.	Function
READ	000 to 177	To scan the input or output and read the closed or open status of contact.
SET	100 to 177 (for 60 outputs in a bank	To energise a particular output depending on the result of the logic operation.
AND	–	To perform logical AND between two variables.
OR	–	To perform logical OR between two variables.
NOT	–	To invert the desired input data.
NOP	–	No operation.
SB-1	–	The inputs and outputs that are READ or SET are to be selected from bank – 1.
SB-2	–	The inputs and outputs that are READ or SET are to be selected from bank – 2.
SB-3	–	The inputs and outputs that are READ or SET are to be selected from bank – 3.
SB-4	–	The inputs and outputs that are READ or SET are to be selected from bank – 4.

IMPLEMENTATION

A general software program along with its logic diagram for operation and control of vehicle on a particular linear track from operation control centre has been developed for endless period and has not been included in the present text. However the program was validated for one cycle. The full detail of the program for endless period can be found in reference (Kumar, 1999).

CONCLUSION

- The above system is applicable for any cyclic operation in an industry.
- It is a fail proof system with the use of PLC.
- It will also help to enhance the productivity of any industry taking care of safety measures.
- The automation will ensure the good quality of product.

COMMENT

The utility and extension of this automated guided vehicle which is widely applicable in steel industries and a slight modification in the mechanical system can result into automated material transport vehicle on a fixed linear track. In all these vehicles, the speed vary linearly according to the scheduled program with provision for braking at the two ends. Any speed variation in the vehicle according to the desired program or route can be taken up with little modification in the system where the drive motor control is being done.

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