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CYBER PHYSICAL SYSTEM IMPLEMENTATION FOR MATERIAL HANDLING IN SMES

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Abstract:
Digital transformation in manufacturing and related industrial sectors forms the crux of Industry 4.0 that encompasses automation and data exchange in manufacturing expertise. It thus facilitates the availability of right information to concerned staff in real time with minimal or no delay leading to improved decision making, system efficiency and yield. Cyber Physical System (CPS) in Industry 4.0 assists in creating smart factories with autonomous systems for carrying out various manufacturing activities, material handling, being one of them. CPS in the form of an Automated Guided Vehicle (AGV) was developed for handling multiple components particularly in Small and Medium Enterprises (SMEs) to offer flexible and smart customized material manoeuvre solution. The paper talks about a working prototype and involved sub-systems of an AGV built for moving diverse components across workstations in pre-defined sequence. It further presents the results of comparison of manual and automated handling times adopting line follower and computer vision navigation methods signifying one of the benefits of CPS in terms of time saving.
Keywords: *Automated Guided Vehicle, Computer Vision, Cyber Physical System, Line Follower, Material Handling, Small and Medium Enterprises*

1. Introduction:

The unavailing time of machines owing to non-availability or amassing of materials at various workstations can be lessened through methodic material handling by providing an appropriate quantity of required material to the exact workstation. The effective transferring of materials at various stages is crucial as it involves about 25% of all staff, 55% of available workspace and 70% of manufacturing cost and time and hence calls for a cautious selection of material handling equipment.[1] The labor intensive SMEs due to restricted resource availability for automation depended on manual operations including material handling activity despite high modularity required to transfer wide variety of components satisfactorily to the customers.[2] Hence there is high research potential for automating material handling activities in SMEs.

The material handling device choice is usually done on the basis of category and model. The norms for category based selection were material, distance and path, control, available facilities and human factor while the model based decision was made considering factors like safety and maintainability, speed, weight and capacity, cost, supplier, ergonomics and environment, etc.[3] Based on above criteria, a Unit load AGV was proposed with a view

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to integrate physical structure for handling components with suitable network and application elements. The work stations in the industry communicate with each other and exchange the relevant data in real time with the cloud storage through networking thus making AGV an application of cyber physical system for material movement.[4]

CPS is the key module of Industry 4.0 that involve physical systems combined with networks for data transmission and cyber space. The physical component represents the devices to be controlled while cyber element signifies the state-of-art data infrastructure with an appropriate networking for establishing communication between them.[5] The paper describes framework of an AGV and associated subsystems as important CPS layers built for handling three distinct cylindrical components and includes results of comparison between line follower and computer vision navigation methods in terms of handling times.

This paper is organized in five sections. This section talks about the importance of material handling in manufacturing industry and the need of adopting Industry 4.0. Section II describes the layers of CPS, AGV components and correlation between them. Section III represents the detailed comparison between line follower and computer vision navigation methods while the results in terms of contrast of manual and automated handling times in both techniques are illustrated in Section IV. Section V presents the concluding remarks about AGV compatibility in material handling operation through handling time evaluation.

2. Materials and Methods:

2.1. Layers of CPS:

CPS is the Industry 4.0 domain where essential data is acquired, supervised and coordinated between physical environment and cyber space. The amalgamation of CPS with manufacturing and logistics would result in enhanced productivity, safety, quality and hence the profits. CPS being a budding technology its implementation calls for detailed understanding of CPS framework or layers.[6]

CPS consists of three main layers. Perception or physical layer also known as recognition layer comprises of sensors, actuators, embedded systems and hardware system gathers the real time data for further computation. It forms the lowermost layer of the architecture. Network or transmission layer forms the next layer that transmits the data received from perception layer to the topmost Application layer which on processing sensor data triggers the physical devices through decision making.[7][8]

2.2. AGV Components:

AGVs have tendency to become accustomed to the working environments soon with reduced human intervention their use has been extended in diverse domains gradually overcoming traditional counterpart. An autonomous mobile vehicle or AGV primarily comprises of vehicle structure collaborated with navigation, control and networking systems as illustrated in Figure 1.[9] The vehicle structure contains the components to be handled and can be built as per the size, shape, quantity, form and weight of the material to be handled. The navigation system guides AGV across desired locations and networking module transfers data to and from AGV and application system while this hardware and software integration is controlled using suitable controller.

Figure 2 represents model of AGV developed for handling three different components where NA denotes Nut Assembly, SP denotes Spindle and VA denotes Valve Assembly as shown in Figure 3. With this working prototype each component was assumed to be weighing between 80-100 gm and having length of 80 mm with acceptable tolerance of +0.1. 25 components of each type were handled in three M.S. trays containing holes for holding the components during AGV travel. The red colored rejection bin and blue colored rework bin were provided on either sides of AGV for sorting out the questionable components and handling only the acceptable ones making it one of the unique features of the system.

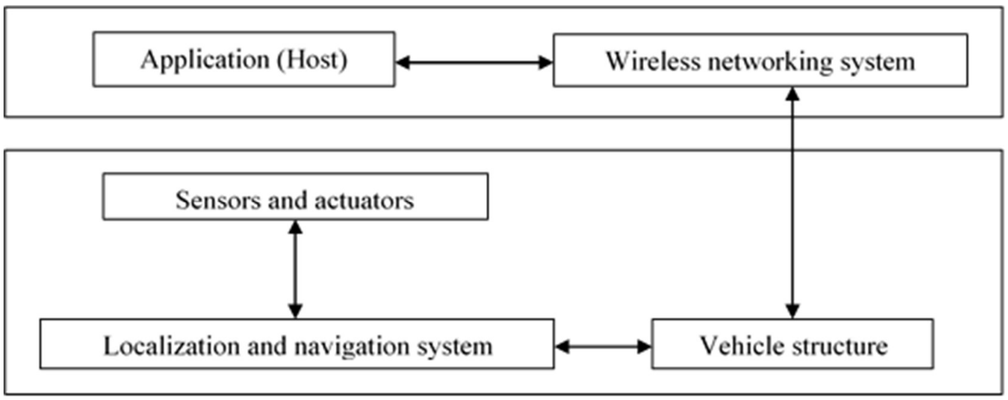


Fig.1. Major AGV components

Fig.2. Actual model of AGV

Fig.3. Actual components handled

2.3. Correlation between AGV components and CPS layers:

As the components of AGV and layers of CPS are known a correlation between them should be established to represent the AGV as CPS application in logistics and have better understanding of the AGV operation. The correlation is explained with reference to AGV modules following two navigation techniques i.e. guidance with lines and guidance without path or lines. The fixed guidance methods included line follower, electromagnetic, wire guided and magnetic tape methods but the later changes in path are difficult. The later three methods required modifications on the shop floor and hence line follower was selected where black and white colored strips were pasted on the floor. Guidance without path or lines method included LiDAR, laser, inertial and visual or vision types. These techniques though costly offered high path flexibility making it suitable for industries involving versatile operations and outputs. Vision method was chosen for the study as earlier technologies required environmental compatibilities for efficient results.[10]

The line follower method involved 8 arrays of Infra Red (IR) sensor pairs for detecting black and white strips laid on the floor for decision making related to straight or turning motions. An ultrasonic sensor was attached to AGV base for spotting and bypassing the obstructions in the route using the signals received by the sensor receiver. The ultrasonic sensor was retained in computer vision method too whereas the input for AGV travel was obtained through monocular camera on the top of AGV. The Logitech C270 plug and play HD 720p camera offered 60° field of view with maximum resolution of 720p and 30fps and captured station numbers on the shop floor. The servo motor supplied required rotations to camera for image grabbing.

The essential motion to AGV wheels for its accurate travel towards various workstations was obtained using prime mover. The line follower method used DC geared motor but due to jerky and less precise motions during turns it was replaced by stepper motor in vision method. In the case of controller, Arduino ATMega2560 was used for controlling motors during transit. As the vision method involved station image grabbing and extensive processing more advanced Raspberry Pi 4 was deployed while Arduino UNO handled motor control with the two configured as Master and Slave respectively. The sensors, actuators and controllers discussed here form the physical layer of CPS.

Appropriate wireless communication technique was quintessential for effective communication between AGV hardware and software elements. AGVs could minimize the overall cost and defects with enhancement in productivity if exact data is transferred instantly achieving fast decision making and control. The communication method offering high reliability should be thus preferred over others. Range, cost, network interference, number of users sharing network, etc. are some of the other deciding factors.[11]

Global Positioning System (GPS) was extensively used for outdoor applications but had environmental restrictions for its effective use in terms of interruptions offered by buildings, subway, etc. Receiver Signal Strength (RSS) sorted this problem but its scanning output was affected by ratio of atmosphere parameters where RSS scanner and AGV have been implemented. Bluetooth had limitations in terms of less bandwidth, frequency, range and number of users while Zigbee has low data transmission rate and high channel noise. Hence it was proposed to opt for Wi-fi network for data transmission forming the network layer.[12][13]

A webpage was designed for client server interface that permitted user to choose the model of component to be machined through web interface AGV movement through work stations in the predefined sequence for each component type. The data related to AGV location tracking, revising the quantity of each component type processed and dispatched per shift or day and obstacle detection in AGV path with an alarm in real time was presented on the interactive webpage. This cloud based webpage formed the application layer of the CPS depicting the material handling activity in the industry. Table 1 provides an idea about the correlation between CPS layers and AGV components employed.

Table 1: Correlation between CPS layers and AGV components

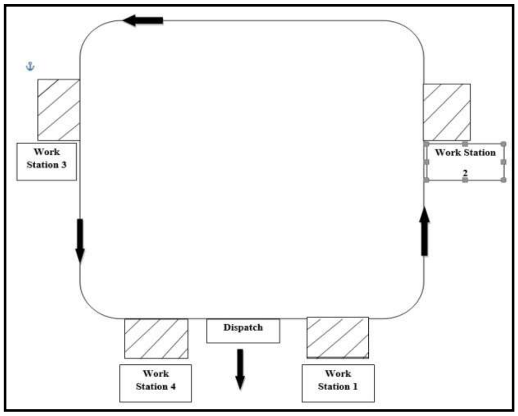
CPS Layers	AGV Components
Application Layer ⟷	Interactive webpage
Transmission Layer ⟷	Wireless Technology (Wi-fi)
Perception Layer ⟷	Sensors - InfraRed sensor, Ultrasonic sensor, Camera Actuator – DC gear motor, Stepper motor, Servo motor Controller – Raspberry Pi, Arduino

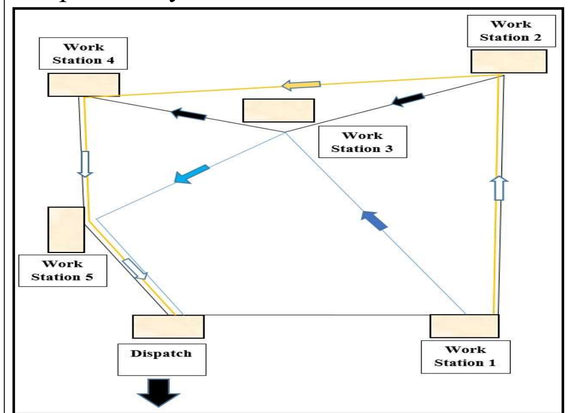
3. Comparison between line follower and computer vision navigation methods:

Most of the industrial AGVs follow predefined or fixed paths posing constraints on the flexibility and hence are suitable where the product mix for handling is restricted. Designing a path on floor in electromagnetic and wired navigation is difficult while magnetic tape guidance is affected by the ferromagnetic material presence in the vicinity. Hence line follower method using black and white strip was selected. The mobile vehicles moving without any guided paths usually require some sensing devices to fetch information about location and existing environment. These devices include Global Positioning System (GPS), camera, Light Detection and Ranging (LiDAR), laser, etc. These techniques despite high cost and environmental constraints are preferred in various guiding applications due to high reliability and accuracy and vision guidance using camera was selected in the study.[14][15] This section compares the two navigation methods opted from various aspects and is illustrated in Table 2.

Table 2: Comparison of Line follower and Computer Vision Methods

Sr. No.	Line Follower	Computer Vision
1.	Fixed guidance with station numbers marked on the floor on the laid path making it more rigid.	Flexible guidance with movable station number boards offering multiple station locations and paths.
2.	Infrared ray (IR) sensors were used for AGV position determination.	Camera was used as sensor for AGV position determination.
3.	Arduino AT mega2560 was used for AGV process control.	Raspberry Pi and Arduino UNO were used for process control in Master-Slave configuration.
4.	DC Gear motors were employed for AGV wheel motion	Stepper motors were employed for precise AGV wheel motion and avoiding jerks as in line follower method.

<table>
<tr><td>5.</td><td>Proposed Layout and Work Stations –


Work Station 1 – Lathe
Work Station 2 – Milling
Work Station 3 – Grinding
Work Station 4 – Assembly
Dispatch</td><td>Proposed Layout and Work Stations–


Work Station 1 – Lathe
Work Station 2 – Milling
Work Station 3 – Grinding
Work Station 4 – Threading
Work Station 5 – Assembly
Dispatch</td></tr>
<tr><td>6.</td><td>Operational Sequence for Components –<table><tr><th>Component</th><th>Sequence</th></tr><tr><td>NA</td><td>1 – 2 – 3 – 4 – Dispatch</td></tr><tr><td>SP</td><td>1 - 2 – 4 – Dispatch</td></tr><tr><td>VA</td><td>1 - 3 – Dispatch</td></tr></table></td><td>Operational Paths for Components –<table><tr><th>Component</th><th>Sequence</th></tr><tr><td>NA</td><td>1 – 2 – 4 – 5 – Dispatch</td></tr><tr><td>SP</td><td>1 - 2 – 3 – 4 - 5 – Dispatch</td></tr><tr><td>VA</td><td>1 - 3 - 5– Dispatch</td></tr></table></td></tr>
<tr><td>7.</td><td>No machine learning technique was employed.</td><td>Machine learning algorithm Convolutional Neural Network (CNN) was used for station number image detection providing more accurate results.</td></tr>
<tr><td>8.</td><td>Simple to use and economical.</td><td>High complexity in terms of programming and expensive technique.</td></tr>
<tr><td>9.</td><td>Less reliability and accuracy affected by environmental constraints.</td><td>The high cost can be compensated for high reliability, accuracy and flexibility offered.</td></tr>
<tr><td>10.</td><td>The colored strip may get dirty or tampered hence needed to be laid down periodically to avoid discontinuities.</td><td>Sufficient lighting on shop floor and highly trained CNN model is required for better image recognition and detection.</td></tr>
</table>

4. Results:

The trials on AGV handling components were carried out opting two methods i.e. line follower offering fixed path and computer vision with flexible paths possible. In both the methods the handling times were computed and the time savings were noted. Table 3 gives the manual and automated handling times for the three components for line follower method.

Table 3: Manual and Automated Handling Times for Line Follower Method

Type	Manual Material Handling Time (sec)	Automated Material Handling Time (sec)	Difference in Manual and Automated Handling Times	Total time saving (%)
NA	54.26	46.25	8.01	14.76
SP	53.45	43.15	11.09	21.47
VA	45.23	42.19	3.04	6.72

The total time saving in handling times was evaluated using the following equation –

Total time saving = [(Manual handling time – Automated handling time) / Manual handling time] * 100

For NA, Total time saving (%) = [(54.26 – 46.25) / (54.26)] * 100 = 14.76 %

Similarly other handling times were calculated.

The computer vision method had flexible locations for the work stations and hence before conducting the trials design of experiment was carried out to establish the optimum location of all the work stations offering the shortest path and hence the lower handling times. For these trials four factors representing each workstation number (Station 1 being fixed and same as the location of Station 1 in line follower method for reference) at three levels indicating positions were considered and hence L9 orthogonal array was selected. Figure 4 indicates Gray Relational Grade (GRG) for the trials conducted.

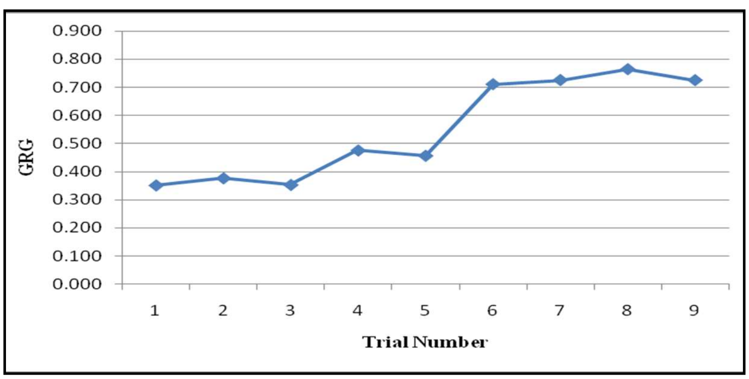


Fig. 4. GRG values for DOE trials

The initial GRG value was 0.765 while the predicted value was 0.92. The trial that yielded an experimental value of GRG as 0.82 was selected as it offered optimum path. The manual and automated handling times for the three components are as presented in Table 4.

Table 4: Manual and Automated Handling Times for Computer Vision Method

Type	Manual Material Handling Time (sec)	Automated Material Handling Time (sec)	Difference in Manual and Automated Handling Times	Total time saving (%)
NA	42.26	31.21	11.05	26.15
SP	47.39	34.23	13.16	27.80
VA	36.58	29.45	7.13	19.49

The total time saving for the components was calculated in way similar to that of line follower method. The total time savings in handling NA, SP and VA components opting line follower and computer vision methods were compared and the results are illustrated in Figure 5.

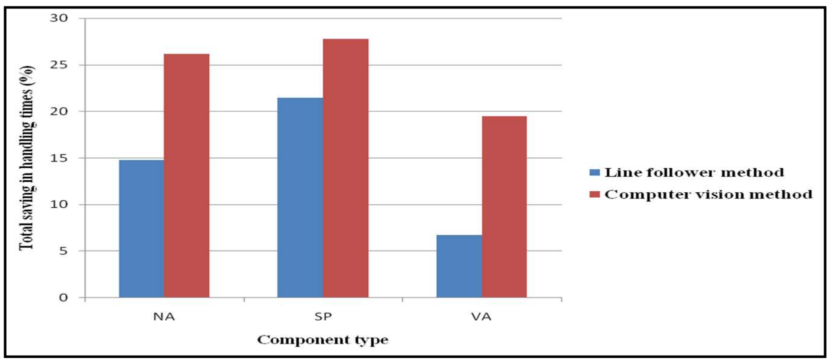


Fig. 5. Total handling times saving (%) comparison of line follower and computer vision methods

5. Conclusion:

The working prototype of AGV built for material handling encompassed physical structure with embedded systems thus making it a Cyber Physical System application in logistics. The implementations of such automated device face hindrances due to high initial cost and technology under development with unskilled manpower for operation. However the safety and flexibility obtained are compelling SMEs to adopt it but still there is scope for research and awareness creation in advanced logistics.

The major benefit of such automated mobile vehicles is considerable time saving thus improving the utilization of these devices as expected in a smart factory. The handling time obtained with AGV was lesser than its manual counterpart in both the navigation methods. Nevertheless total time saving offered by computer vision system was higher as compared to that of line follower method despite an additional work station. The lack of vision and distorting illumination in line follower method affected its accuracy while in computer vision method CNN offered better results due to image training even in case of reduced illumination hence computer vision method was chosen. Cyber Physical System in the form of AGV based on communication, computation and control was thus successfully built but its actual implementation on shop floor may require subsequent modifications in the AGV and surrounding environment.

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