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Enhancing Efficiency and Safety in Self-Guided Logistics Vehicles: A Comprehensive Analysis and Integration of Hardware and Control Systems

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Abstract

Self-guided logistics vehicles have become increasingly popular in various industries and warehouses for material lifting and transportation purposes. These automated systems have proven to be valuable in both small-scale production lines and large areas. However, challenges persist in the field of logistics, where industries and factories face difficulties in efficiently transporting materials. In response to these challenges, self-guided vehicles have been employed, but issues such as collisions with obstacles, material falls, and rigid path constraints have been observed. This project aims to address these challenges by implementing hardware safety precautions and incorporating routing and scheduling capabilities to enhance system automation. The article presents a comprehensive analysis of hardware safety precautions and highlights key features including sensors, actuators, and control systems, which contribute to the overall efficiency and smooth operation of the self-guided logistics vehicle system. By integrating these elements, the system can overcome obstacles, ensure material safety, and adapt to changing traffic conditions, thereby optimizing logistics operations in industries and warehouses.

Introduction

Automation is a word constructed from the Greek word “AUTO” means “self” and, MATOS means “moving” therefore, it is a mechanism for a system that “moves by itself”. Automation which is the use of electronics and computer controlled devices, the aim of the automation is to higher the efficiency and reliability. In most cases automation replaces labor. Nowadays many new technologies will significantly push the unemployment rate. While there are three types of automation in production it can differentiate (1) fixed automation (2) programmable automation (3) Flexible automation. In the United States of America, a total of over 1 million robots were used in factories in 2012. This number increased by 50% in the next two years.[1] Robots in the present day are growing more aware and can perform tasks which are difficult, with a great amount of skill. The costs that are involved in changing the manual manufacturing process into an automated one is getting lesser. Robots and automation is getting more and more feasible by the day. There is a lot of merits and demerits of automation. Automation producing at higher rates and increase productivity, better products quality, improve safety. The higher output and increased productivity have been two of the grand reasons in justifying the use of automation. However, this technology is very useful in automated industry such as in a warehouse or factory. AGV is basically a portable robot that follows tracks on the floor by using sensors, vision cameras, radio waves, magnets or lasers for navigation. AGV can rationalize manufacturing process in various scenarios such as conveyance between processes parts supply to production lines or cellular manufacturing lines. The benefits of this technology are that it reduces labor cost .it is flexible as well.as intelligent.

The motivation for an AGV of this type is to let AGVs be feasible and usable for industries in countries like Pakistan which cannot afford the standard AGVs, along with backup AGVs. It's also difficult to sustain such a system due to the common power outages. Due to all of these problems, we've come up with solutions that can help AGVs be a standard method of automation of material handling systems.

The thriving of international trade spurs, the elaboration of automated container terminals (ACTs) rigged with automated container transshipment system (which consists of automated container and AGV etc.). For the construction of an AGV system the four main consequences will occur in an Acts. The first issue is the guide-path design that defines possible ways in which vehicle can.travel. The second issue.is dispatching problem which means when and where vehicle should go to fulfill their task the third problem is the route of vehicle. The route should have good path for transportation of object. The last issue is the contest resolutions among the vehicle fleet and betwixt the vehicle and other container handling equipment. All these problems are related to each other as far as system performance is anxious; it is very difficult to put them all in an inclusive consideration.

We are offering a solution to the previously highlighted problems by firstly replacing the use of conventional magnetic tapes for AGV guidance with metallic strips. The second solution we are offering is to provide a more easily sustained AGV by replacing the need of electricity with solar energy. The third solution that we are offering is to provide an AGV that does not rely on a battery; this is critical for making the AGV feasible for small and medium enterprises.

This project seeks to improve upon the aspects of an AGV as a stand-alone machine; that is, a network of AGVs will not be tackled, so dispatching, dead-lock and inter-AGV collisions will not be addressed. The system is based around a simple manufacturing environment where machines can send signals to the AGV to pick up or deliver materials, and the AGV can do the task by tracking its current position and finding the shortest path. There will be some conventional methods used, such as RFID sensors, for the purposes of tracking work stations, as the system is ideal and does not require improvements.

Literature Review

P.J. Egbelu and J.M.A. Tanchoco, in their paper, simulated and presented a set of rules for the dispatching of an AGV. This was an optimization problem, which they solved by letting an AGV make a decision to assign different workstations as different priorities. Their research was vital in producing a manufacturing system that maintains an efficient autonomous system. [2]

We are assigning the similar task to our AGV according to the priority and requirement to carry load and dispatch it to the required workstation. This is the most advanced technique by which we can save time.
Our aim is to carry load up to 30 kg by which we can save number of delivery trips. Reorganizing the AGV to carry multiple loads is an attractive strategy to increase the number of single load AGV in just in time (JIT) system. When the system size becomes larger, we can perform multiple dispatching tasks at the same time according to required workstation.

Roger B. and Tsai H. discussed the many different procedures that are involved in the docking of an autonomous vehicle. Their research was fundamental in outlining the process that must be followed when an AGV loads materials from one station and unloads them onto other stations. This must be a precise process as any minutiae deviation can cause materials to be improperly placed, thus resulting in a catastrophic failure of the manufacturing.[3]

We are also following the docking process but we are using guides for this purpose with the help of RFID sensor. Zhang J. and Peng Y. conducted their research on hybrid I/O automata model, based on Autmata Theory. They constructed a simulated model of the AGV based on a hybridized model of continuous and discrete variables. They modeled the AGV as a system of hybrid automata with five different parts: the chassis, the left and right wheels, the sensor and the controller. By assigning differential equations to these models, they were able to define the constraints for each part of the system. [4]

In 2011, Q. Li and A. C. A Adriaansen conducted a case study in their research on Automated Guided Vehicle Systems. They designed an AGV along with a road network, which they programmed with a routing algorithm to minimize the travel distance between their workstations. Their system was designed to work in an automated container terminal. With a 10mx4m vehicle, and a top speed of 7m/s, they discussed four different layouts for their roads. Their result which proved their zone control system as a solution to AGV systems provided crucial information.[5]

We designed our AGV according to the priority and requirement of workstation by minimizing the traveling distance. We will be assigned a shortest path to AGV. The algorithm which will use for this purpose is A*.
Ferreira and Gorlach (2016) worked on the development of an AGV controller to be implemented into an industrial environment. Their system was simulated and then fabricated with the capacity to tow up to 200kg of material at any given time. Their research also outlined that the majority of the costs associated with a manual manufacturing process is credited to the labor. If this cost is invested into an AGV system instead, a more efficient manufacturing system can be implemented. Their system was designed to work with multiple AGVs and work-stations, and could be reconfigured according to different environments. [6] .We are also working on an AGV for an industrial environment however our capacity is 30kg.our system requires only one AGV this results in lower cost so it is cheaper than labor.

Parikh et al. (2018) worked with his team on a simulation to drive an Automated Guided Vehicle at a uniform speed. By using a closed system and a PID fuzzy logic controller they were able to produce results that would reduce settling time, steady state errors and overshooting. They compared a normal PID controller with a fuzzy PID controller, and used the Ziegler-Nichols algorithm to find the ideal values for the PID controller. Their primary tool was the MATLAB Simulink and the fuzzy tool box. Their final result had small oscillations which were not present in the PID controller. However, all other parameters had significant improvements. [7]. Our instrument will be Raspberry Pi which will be in the ROS environment. Our algorithm will be the A* Shortest Path Algorithm and we will be using a simple PID controller for tracking of the metallic strip. Modular Automation Corp. was assigned an early patent in 1985 for Automated Guided Vehicle Systems. They worked on an AGV that used two methods for their pathing. The first method was to use electromagnetic signals generated by wires that were buried under the concrete. The second method was to use digitally coded patterns on the path, and convert them into a digital signal using a microcomputer. Typically, these patterns are made of black and white lines. They also used a selection of other sensors to enable the AGV to execute special commands independent of the guide tracks. [8]

Methodology

The automated guided vehicle that we designed had to accomplish the objectives we set for ourselves. Of these, the first goal we kept in mind was to be able to bear a load of at least 30 kilograms. Thus, our hardware design began with bearing the fact that we had to divide the AGV into two parts; the car and the load cage. The car itself would be the major compartment which would hold all the electronics, and would have the mechanism for producing motion within it. The cage would be designed using trusses to ensure a cart which could bear at least a load of 30kg on a long term basis.Thus, the figure below shows the design that we produced.

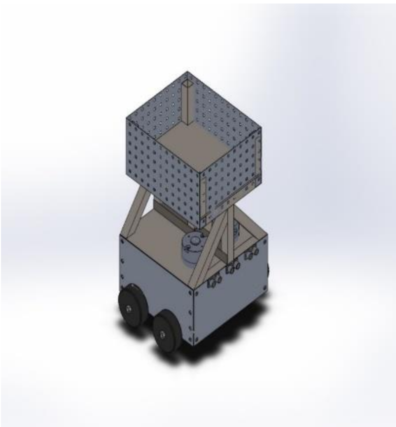

Figure 1 CAD Model of the AGV

The mass of which came out to be approximately 30kg, include of all the materials and equipment that were attached on the AGV.We proceeded to conduct a stress analysis on two core components of the AGV. Firstly, the AGV cage that would hold the load would be the first critical point of the AGV. This would have to hold the initial load of 30kg.

The second critical component would be the shaft that attached the wheels to the motors. This would have to hold up to 60kg load, that would include 30kg of the AGV itself and 30kg of the load that the AGV would carry. The results of the stress analysis are as follows:

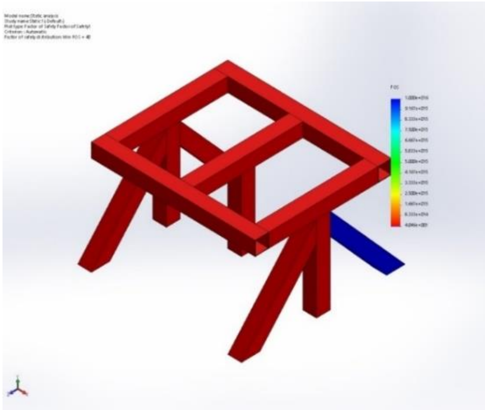

Figure 2. The Factor of Safety of the AGV Cage Structure

This figure tells us that the minimum factor of safety that is observed is around 40.

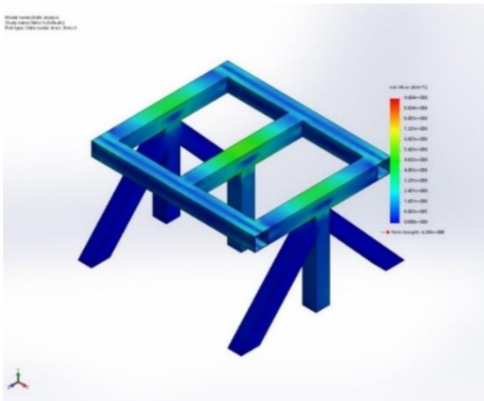

Figure 3. Stress Distribution of the AGV Cage Structure

This figure shows that the maximum stress on the structure is around 40 times less than the yield strength of the steel.

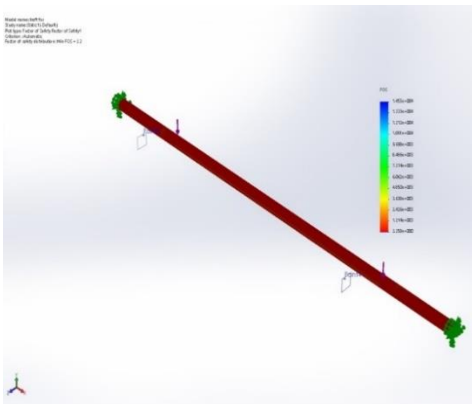

Figure 4. Factor of Safety Plot of the Connecting Rod

From this figure, we can observe the minimum factor of safety of 2 on the rod.

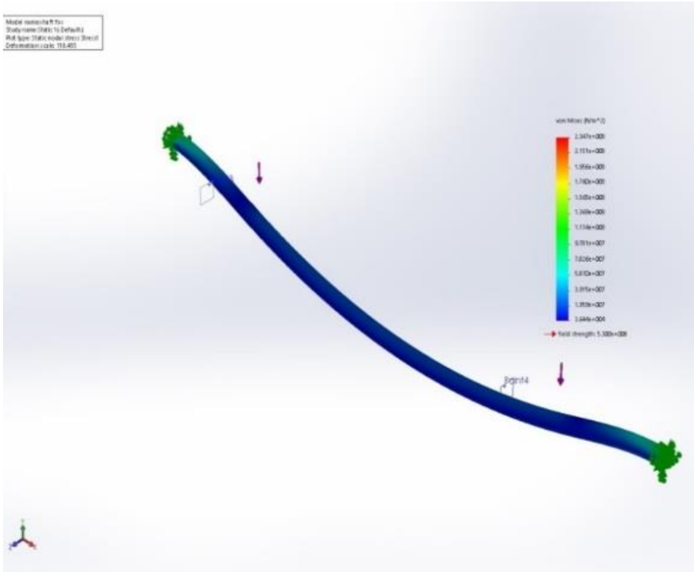

Figure 5. This Figure Shows the Stress Distribution along the AGV Rod

From the results, we can see that the structure has a factor of safety of around 40, which means the structure is well designed to hold more than the maximum load. However, from the connecting rod, we see a factor of safety of 2. Hence, this is the most critical component of the entire AGV. The maximum load that the rod can bear is 120kg; which is well over our limit of 60kg. Design of the Control Systems.

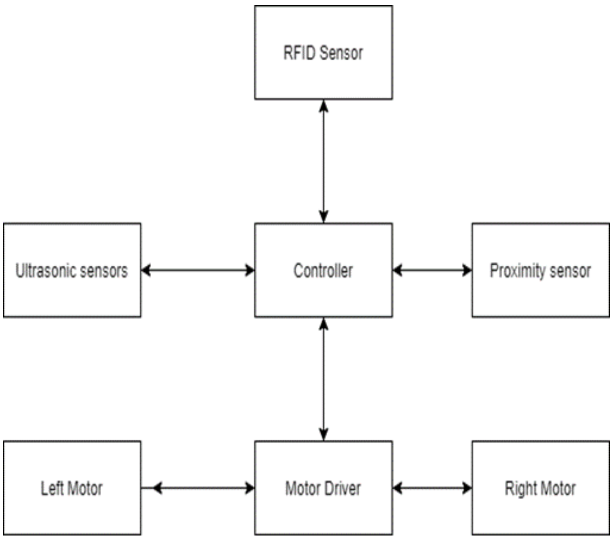

Figure 6. The Basic Block Diagram of the Systems Involved.

The above block diagram shows the basic model of the system, which includes three sensors and two motors being controlled by our microprocessor, Raspberry Pi. In short, each of the system would use feedback to implement a control mechanism to allow the AGV to make decisions and function effectively. These blocks are further expanded upon in the following figure.

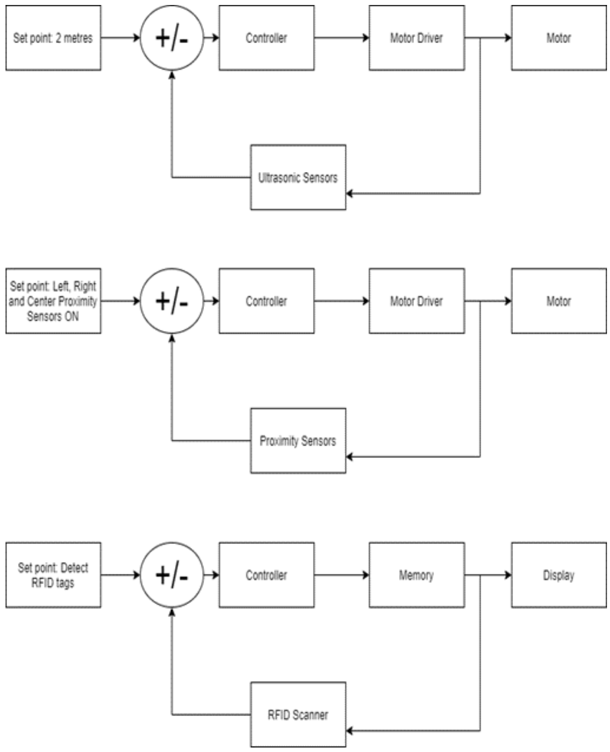

Figure 7. The Control Systems that have to be Put in Place.

Figure 7 shows how the sensors would be used to control the AGV. In each case, the result of each individual control system would be stored within the controller, and the AGV would be able to execute commands using the inputs. For the distance control system, the ultrasonic sensors would detect whenever the AGV is facing an object that is less than 2 meters away from the AGV. To avoid confusion between an obstacle and the AGV guides, the AGV would slow down and continue motion until the distance becomes 4 inches, which is the minimum distance between the AGV and the guides. From here, the AGV would have enough room to execute a turn; which will be the case if the AGV is facing a guide. If not, the AGV will come to a complete stop, as the AGV is now facing an obstacle and not a guide.

As for the proximity sensors, there would be three sensors placed on the front end of the AGV. The sensors would be fixed above the center of the steel strip, and on either side of the strip. If the left sensor turns off, it means the AGV has steered too far to the left, and must be turned right. If the right sensor turns off, it means the AGV is too far to the right, and must be steered left. Finally, the RFID tags would be used to identify and store in memory the current workstation that the AGV is at; this would be used to find the distance between the current workstation and all the other workstations.

Selection of Material for Electrical Transmission

Most AGVs that were previously fabricated used batteries that would need to be recharged. Batteries were not suitable for industries where work hours are limited and the downtime due to recharging of batteries could hurt losses. Thus, an additional AGV would be required. Our idea is to replace batteries from solar panels. For the sake of this idea we need to choose a material for electrical transmission by which AGV can use solar energy.

For this purpose we have tested some materials (copper, steel, brass). Results are given below for the experimental resistance of the samples of the materials that we acquired. To keep testing as accurate as possible, all the samples were 1m in length, 2.54cm in width and 1mm in thickness, of rectangular shape. All of the samples were given equal voltages.

Table 1. The Results of the Electrical Testing

Material	Voltage Applied (mV)	Current Measured (A)	Resistance Calculated (Ohm)
Brass	101.6	0.24	0.423
Copper	101.6	0.32	0.3175
Steel	101.6	0.17	0.598

On the basis of these results we selected copper as the best material because of its properties. Copper has an excellent heat conductivity, high corrosion resistance, is non-magnetic and has good machinability.

Motor Selection

For the purpose of selecting motors, we firstly had to calculate the overall torque that the wheels would bear due to the combined load of the weight of the AGV and the weight of the load that the AGV would have to carry. Thus, we used the equations below to accomplish this.

$$T_w=F_t.r_w \tag{1}$$

where
rw = mean wheel effective radius
Ft = total force exerted
And, by measuring diameter of the wheels,
$r_w=3.75in=0.09525m$
And

$$F_t=F_(r+) F_g+F_d+F_ie \tag{2}$$

Where
Fr = Tire rolling resistance (can be in the form of μrN - simplified and treated as independent of velocity)
Fg = forces due to gradient (depending on slope angle, can be positive of negative)
Fd = aerodynamics drag (as a function of air density, drag coefficient, vehicle cross sectional area, and squared of vehicle velocity)
Fie = equivalent inertial force (during acceleration) - (including linear and rotational inertias, due to vehicle mass and rotating component of gear train and wheels)

$$F_r=\mu N \tag{3}$$

Where μ = coefficient of friction between the wheel and ground and

N = normal force exerted on the wheel by the ground

$=0.7 \times 60 \times 9.81=412N$

$F_g=0$

$F_d=C_d \times A \times V^2$

$F_d=2 \times 0.0628 \times 0.2^2=0.005N$

$F_{ie}=0.2 \times 60=12N$

$a= (v_2-v_1)/t=(0.2-0)/1=0.2m/s^2$

$T_w=0.09525(412+0.005+12)=40.39Nm$

Hence, the overall torque produced by the AGV and its load is 40.39Nm. This would be divided into half, due to the load being distributed on two different sides. As such, our motors of selection can provide up to 39.6Nm of torque each. This gives us a factor of safety of approximately 2, as our motors have the capacity to hold double the load.

Power Calculation

Our motors are rated at 24V 17A each as their maximum load. Continuous operation at our given load would draw approximately 12A total, at 24V each. However, assuming maximum current draw for the motor starting current, at 24V, 34A of current would be drawn by the motor. Approximately 5A of current would be drawn at 5V by the electronic components such as sensors and controllers. This amounts to a total power usage of 841W. This means the power that reaches the AGV must be at least 841W. Thus, we select solar panels that come up to a total of 1000W to allow for a 16% margin of error in calculations. Figure 8.The block diagram for the power transmission. However, we also calculate that the energy loss to the copper electrical tracks is 0.3175 Ohm/meter. For our total length of copper that is 12.4m, the total resistance comes out to be 3.94Ohm. For a current of 39A to be passing through this copper, this could lead to losses of up to 6000W. However, by transmitting at 220Vac these losses could be reduced to 60W. Hence, we could use a DC to AC converter, and step up the voltage from the solar panels to 220Vac. A smaller transformer on the AGV could step it down to 24V. Design of AGV Arena

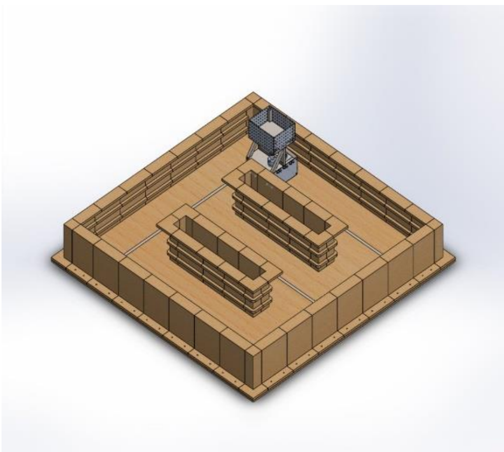

Figure 9.The Arena and the Wooden Guides

One of the concerns was that transmission of power at 220Vac could prove to be a safety hazard for the employees around the working environment. To address this issue, we decided that insulating guides of a height of 18 inches would be placed along the path of the AGV. On the sides, there is space for the copper tracks, while the steel strips that go in the center would serve as the tracking mechanism.

There would be carbon brushes coming out the sides that would receive the electrical signal, and feed it to the smaller transformer that is within the AGV. The combination of the steel strips, the copper tracks, and the wooden guides was called the AGV Arena; a prototype workplace environment where the AGV could be tested.

Simulation

Simulation of Shortest Path Algorithm

The simulation of the A* shortest path algorithm was done in the ROS Turtlebot3 simulator using Gazebo.
The ROS Gazebo simulator can be interfaced with a robot in real time using sensor plugins that allows sensor interaction between the simulated robot with real sensors. We implemented the design of our arena using the TurtleBot3 simulator to test the algorithm for shortest path navigation and obstacle avoidance.

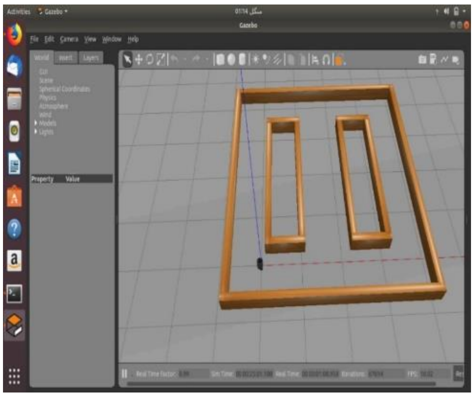

Figure 10. Gazebo Layout of Our AGV Arena

Simulation of FLEXSIM

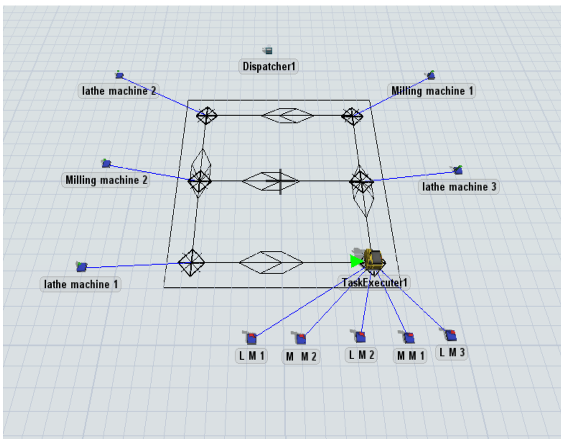

Figure 11. The Simulation Setup of the AGV in Stand-By Mode.

The concept of this simulation depends on six different work stations, all of which generate different tasks, which are to be deposited at the common sink node which the executer starts off at. Whenever a task is generated from any work station, the AGV finds the shortest path to the respective work station, picks up the part and drops it off at the deposit zone.

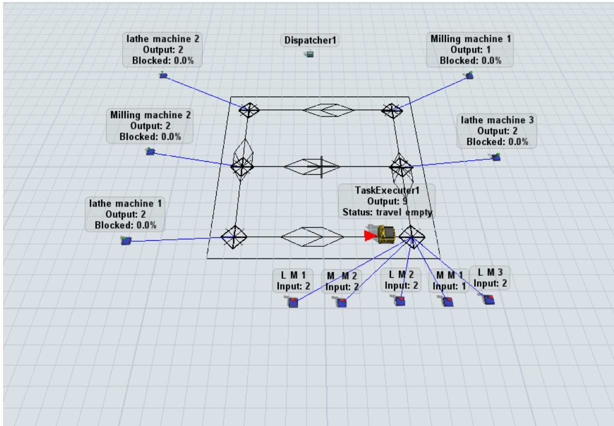

Figure 12. The Simulation Setup of the AGV Once Tasks Are Generated.

When the AGV picks up some material, it deposits it to the deposit zone where the manufactured parts are scheduled for further processing.

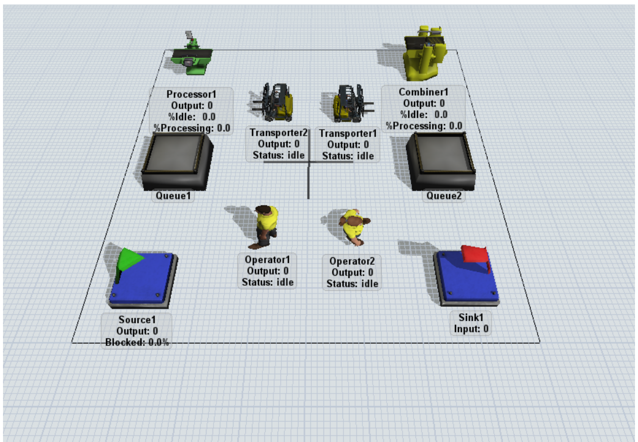

Figure 13. The Simulation Setup of the Manual Labor System in Standby Mode.

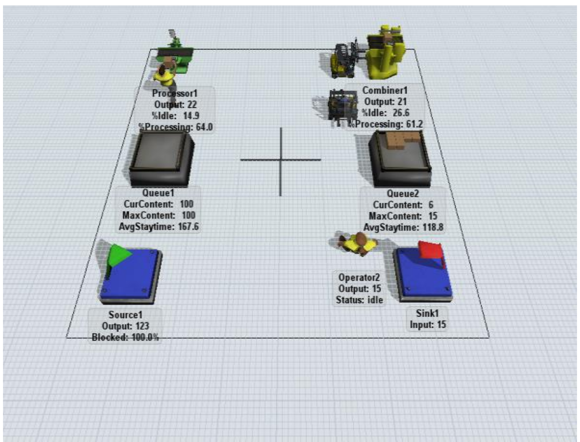

Figure 14. The Simulation Setup of the Manual Labor When Tasks Are Generated.

For comparison on the same scenario, two operators are hired for transporting the parts from a source to a queue and from queue to a sink. There are also two transporters to transport the parts to further processing points. Such a manual labor system is compared with the AGV system.

When tasks are generated from Source 1, an operator takes the material from the source to the queue, where a transporter or an operator keeps feeding it to the processor whenever the processor is free. From here, the transporter takes the part to the combiner. At the end of this process, the part is taken to the second queue, and then to the sink as the output.

Analysis

Outputs of Simulations

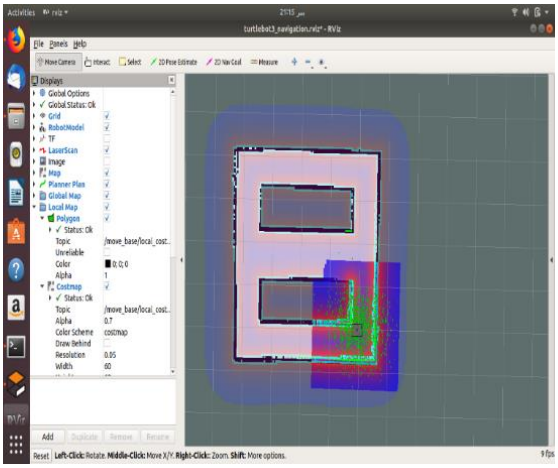

Figure 15. The Map Given to the TurtleBot3

Initially for the shortest path algorithm, a map has to be generated and given to the TurtleBot3 or to any robot that is employing a shortest path algorithm. This was the map of our arena generated by the TurtleBot3 using the simulation package to drive around the arena and read the map autonomously.

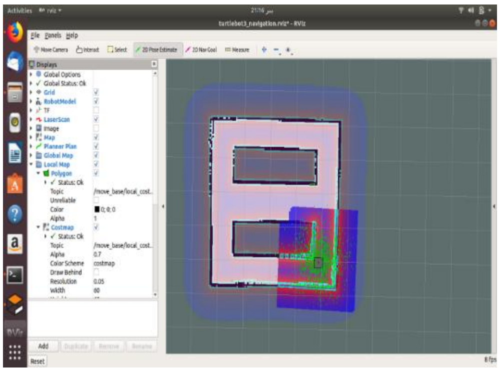

Figure 16. Giving an Estimate of the Robot's Position

Initially when starting the simulation, an initial position estimate has to be given to the robot that will allow it to figure out its current location, so it can make all future decisions based on this position.

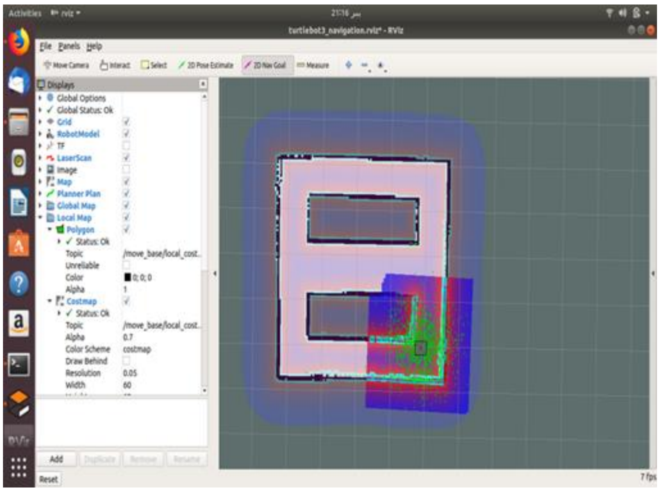

Figure 17. Giving a Destination Goal to the AGV

When you give a 2D navigation goal to the AGV/robot, it calculates the shortest path based on the type of shortest path algorithm it's using.

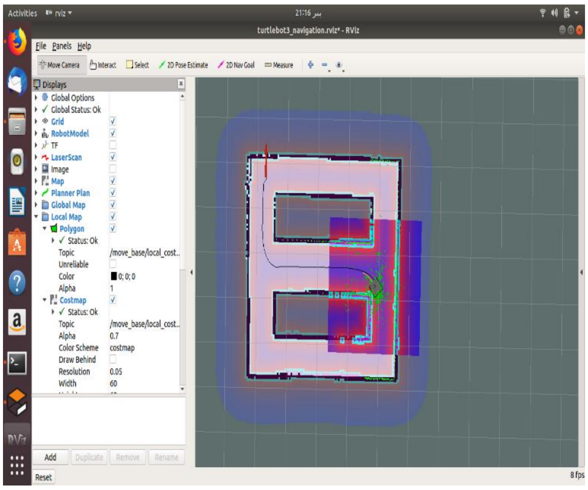

Figure 18. The AGV Navigating to the Destination Using the Shortest Path.

The robot displays the path it has calculated to reach the shortest path, without running into any obstacles.

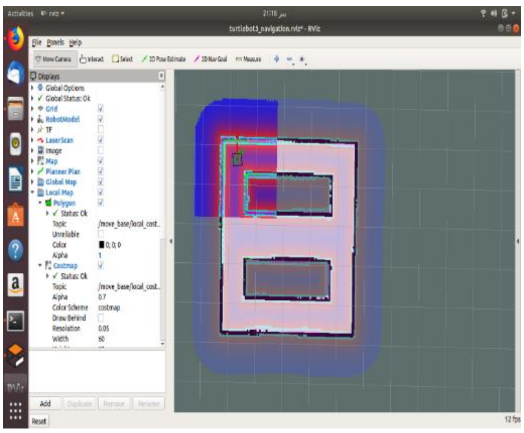

Figure 19. The AGV Reaches Its Destination.

When the robot reaches its destination, it comes to a stop until the next instruction is received.

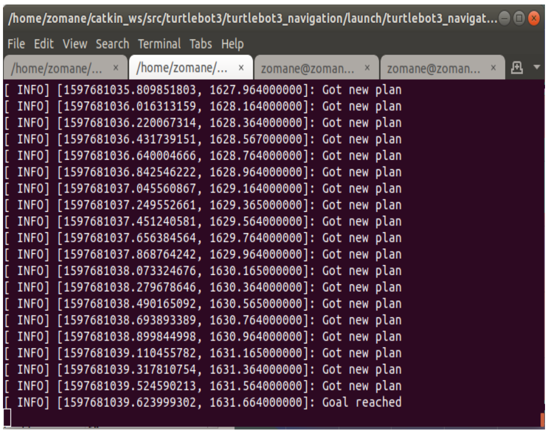

Figure 20. The Status of the AGV Being Monitored

Whenever the AGV receives a new instruction, it can be seen on the terminal above.

Results

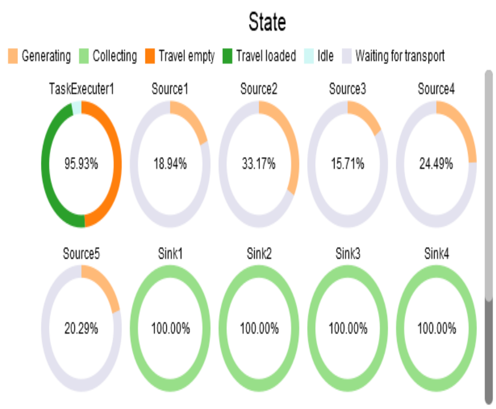

Figure 23. The Status of All Nodes Present in the AGV System during Task Generation

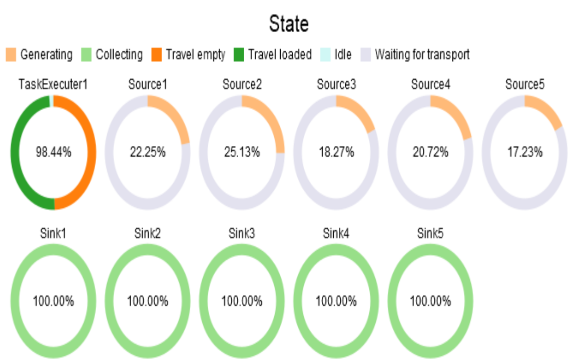

Figure 24. The Status of All the Nodes after Task Generation

The above pie charts show the status of all the nodes present in the system that is using the AGV, in figure 71.

The sinks are always ready to accept data, as expected. The sources are almost always waiting for a transport, which is to be expected in a linear AGV which is incapable of carrying multiple loads at once, which is different from our AGV of design.

When all the nodes have generated a task, the sources have nothing much to do so they spend most of their time idle. This also leads to the executer not having any delays in work, only travelling to sources to pick up objects, and travelling to sinks to drop off objects. The time spent between a sink and source is when the AGV is empty.

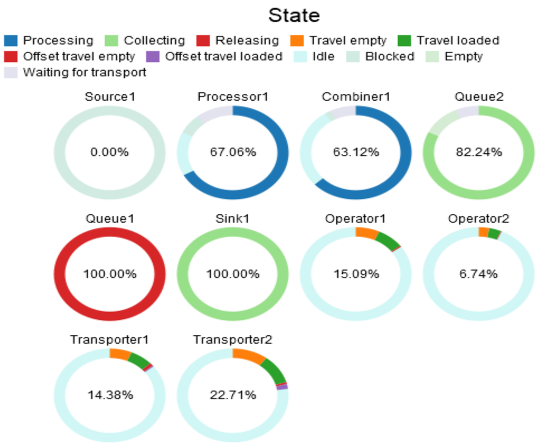

Figure 25. The Status of the Manual Labor System during Task Generation

We can see quite a large difference between the two systems by comparing Fig 24 with Fig 25, when both systems have not generated a task. As visible, the source is even more idle than in the AGV. This is mostly due to the entire system remaining busy due to being choked out.

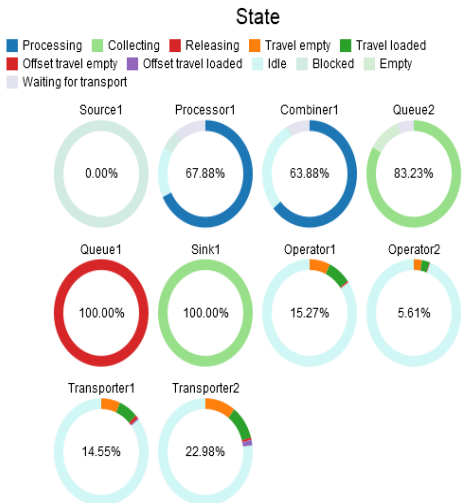

Figure 26. The Status of the Manual Labor System after Task Generation

When the task has been generated, the source becomes blocked and can no longer function well enough. Visibly, the AGV system, when optimized, can make the system more efficient than a manual labor system.

Table 2. Comparison of the efficiency of AGV and Manual Labor

State %	AGV		Manual Labor	
	Before Task Generation	After Task Generation	Before Task Generation	After Task Generation
In use	59	64	47	47
Idle	41	36	53	53

The table above shows us that the AGV shows a significant change in performance before and after the task is generated. This means that, at full capacity, the AGV is 64% efficient in handling 6 work stations while the manual labor system shows no improvement before and after task generation.The manual labor system had to often wait due to the long queue times as the labor could not process multiple nodes at once.The AGV, while also not processing multiple nodes at once, was significantly more efficient due to the fact that a single AGV was covering six work stations while four different units of labor were covering a single processing line. This shows us that, localized AGVs show an almost 20 percent more efficient result when compared to manual labor in a single production line.

Conclusion

The results state that the comparison between an AGV and manual labor display a difference of around 20% when it comes to efficiency in a production line. Furthermore the results also display the difference between the two states of the AGV line and the manual production line; the AGV, when transitioning from idle to working, improves efficiency by 5% while the manual labor is as efficient when idle, as it is when in use.
The work that could not be completed for this project include the removal of the battery components and including copper tracks on either side of the arena, connected by copper brushes to include the connection to the solar panels to make the project sustainable.

Furthermore, the solid integration of the A* shortest path algorithm couldn't be implemented into the physical AGV itself due to COVID-19 which placed severe restraints on acquisition of some of the electronic components. The project was executed well, especially the design phase, and thus, could be commercialized in the near future as an emerging technology to revolutionize automated guided vehicles for small and medium enterprises.
This is especially useful for hazardous material handling such as that in nuclear reactors. The elimination of the need for any spare AGVs or batteries cuts down in costs for the benefit of any enterprise owner, and serves to help produce localized workspaces where the entire manufacturing process can be automate

References

Allan S. MacKinnonDonald J. WillemsenDavid T. Hamilton. (1985). Automated guided vehicle system (Issue 4530056A).

Bostelman, R. V, & Hong, T. H. (2016). Review of Research for Docking Automatic Guided Vehicles and Mobile Robots.

Egbelu, P. J., & Tanchoco, J. M. A. (1984). Characterization of automatic guided vehicle dispatching rules. International Journal of Production Research, 22(3), 359–374. https://doi.org/10.1080/00207548408942459

Ferreira, T., & Gorlach, I. A. (2016). Development of an automated guided vehicle controller using a model-based systems engineering approach. South African Journal of Industrial Engineering, 27(2), 206–217. https://doi.org/10.7166/27-2-1327

Li, Q., Adriaansen, A. C., Udding, J. T., & Pogromsky, A. Y. (2011). Design and control of automated guided vehicle systems: A case study. IFAC Proceedings Volumes (IFAC-PapersOnline), 44(1 PART 1), 13852–13857. https://doi.org/10.3182/20110828-6-IT-1002.01232

Parikh, P., Sheth, S., Vasani, R., & Gohil, J. K. (2018). Implementing Fuzzy Logic Controller and PID Controller to a DC Encoder Motor—"a case of an Automated Guided Vehicle". Procedia Manufacturing, 20, 219–226. https://doi.org/10.1016/j.promfg.2018.02.032

What is automation? - Definition and examples—Market Business News. (n.d.). Retrieved April 18, 2020, from https://marketbusinessnews.com/financial-glossary/automation-definition-meaning/

Zhang, J., Peng, Y., Hung, W. N. N., Li, X., Tan, J., & Shi, Z. (2014). A case study on formal analysis of an automated guided vehicle system. Journal of Applied Mathematics, 2014. https://doi.org/10.1155/2014/327465

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