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A review of the automated guided vehicle systems: dispatching systems and navigation concept

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Abstract. Problem. *As one of the three key elements of flexible manufacturing systems (FMS), automated guided vehicles (AGVs) play a significant role in material handling systems. They've been around for more than a decade, primarily in Europe. AGVs were formerly utilized mostly in production lines, but due to recent industrial development, they now play a vital role in a variety of different applications and domains, including warehouses, port facilities, transportation systems, and even the medical sector.* ***Goal.*** *The purpose of the work is to analyze two methods of AGV control and the paths that the AGV should follow during transport operations, taking into account safety and limitations for heavy loads that need to be transported in difficult conditions.* ***Methodology****. We attempted to provide a summary of the two existing AGV control methods, centralized and decentralized control offered by major manufacturers in this study. Almost all function in a centralized manner, with a single central controller controlling the whole fleet of AGVs. The author sees a tendency toward decentralized systems in which AGVs make individual decisions in favor of transportation flexibility, robustness, and adaptability. A brief explanation of well-known and mature navigation technologies used by AGVs in the industry is also provided, along with both physical and virtual paths to be followed by the AGV during transportation operations, since these technologies get to be a key issue given the safety constraints, particularly for heavy loads to be transported in challenging environments.* ***Results.*** *This paper covers one of the key tasks that must be completed in order to control an AGV system for a central and decentral architecture, for which we have already given a broad overview, as well as the differences between the architectures and their benefits and drawbacks.* ***Originality.*** *The author sees that the merging of various techniques we have will lead to more and new challenges as well as innovations, however, that practical application of distributed control still requires further research and studies and has a way to go in terms of taking other sections such as safety and sustainability into account.* ***Practical value.*** *The primary benefits and drawbacks of various technologies are discussed, as well as how we might improve the efficiency of some of them.*

Key words: *Automated guided vehicles; control techniques; localization; centralized; decentralized*

Introduction

Today, autonomous load transportation is critical for timely providing and disposing of operational units such as machines, plants, and workspaces. Material holdup or lack of supply can occur when the material flows [1]. The AGV, which is a driverless material handling device used for horizontal material transportation, performs these activities rapidly and safely. AGVs were first used in 1955 [2]. Since their inception, the utilization of AGVs has increased dramatically [3]. Around 20,000 AGVs were employed in industrial applications [3], according to [4]. Although many of their features, real AGV systems are still severely limited in terms of adaptability, reconfigurability, and scalability. This study addresses two key reasons for these limitations: centralized control structure and vehicle motion confinement to a network of predetermined paths (guide path).

Analysis of publications

Online dispatching systems are classified into two types: decentralized and centralized. Existing AGV systems typically have a centralized control architecture in which a single central unit performs many complicated tasks like mission scheduling, path planning, and motion coordination as shown in Figure 1. The central unit connects with each vehicle in the system, monitors their positions, generates motion plans, and sends control commands to them. Centralized control approaches are often characterized as coupled or decoupled based on the quantity of information utilized during the planning process [5]. Coupled techniques [5,6] consider the entire system to be a composite system where traditional single-vehicle motion planning algorithms are utilized. These techniques are quite resource-intensive in regard to computation, despite having certain desired characteristics like completeness and the ability to calculate optimal motion plans. Decoupled techniques tackle the coordination problem by splitting it into two independent phases: path planning as well as motion coordination; This reduces computational complexity. Prioritized planning and path coordination are standard methods for decoupling coordination [5, 7, 8]. Prioritized planning entails calculating courses sequentially in priority order while taking higher priority vehicles' motion through their calculated path into account as moving impediments that must be avoided. On the contrary hand, path coordination techniques determine each vehicle's individual trajectories first, without taking into account other vehicles, and instead, modify each vehicle's velocity profile to prevent collisions. When compared to coupled planners, decoupled planners are typically orders of magnitude faster but at the cost of incompleteness and poor performance. Other centralized coordination techniques that fall under the category of being decoupled include zone control techniques [9], time windows [10], and multiagent systems [11].

Purpose and Tasks

The purpose of the work is to analyze two methods of AGV control and the paths that the AGV should follow during transport operations, taking into account safety and limitations for heavy loads that need to be transported in difficult conditions.

Centralized and decentralized control structure

Given the above-mentioned computational restrictions of centralized control methods, as well as their high communication requirements and limited level of tolerance to fault requirements, there is an immense practical request for developing effective decentralized control techniques [5]. This is one of the key features of the Industry 4.0 approach [12], and much research has already been done on decentralized algorithms and methodologies to coordinate multiple processes [9]. Studies on the advantages of this architecture in comparison to present central and hierarchical arrangements have been conducted. Distributed computation and now a high degree of vehicle autonomy define decentralized techniques. Decentralized control systems may easily scale to applications with a high number of vehicles and are more robust since they don't have a single point of failure because the vehicles automatically plan their pathways and decide how to move, a simple model is presented in Figure 1.

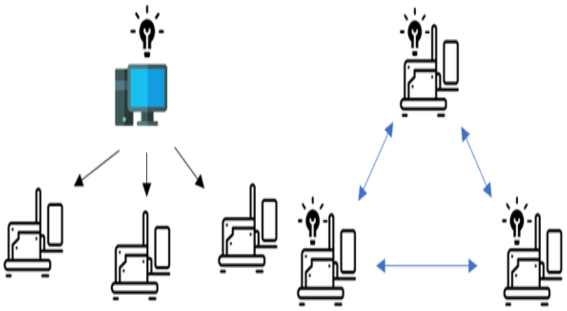

Fig. 1. Centralized and decentralized control structure

Many scholars [10, 13] note the necessity for decentralization in the future, acknowledging the limitations of the present central architectures as unsuitable for managing flexible manufacturing, custom products, and complex product specifications. Meissner et al. [14] compare the current central and decentralized control systems in manufacturing and make it clear that centralized and hierarchical structures are incompatible with the requirements of new systems and that decentralization is the most likely path to take to deal with the current circumstances. According to them, decentralized control works well in dynamic contexts because it may alter quickly. Nevertheless, they clearly outline the negatives of such a decentralized architecture.

The fundamental disadvantage of decentralized control is really the extra work required to coordinate all of those autonomous entities as they compete for attention. This won't always result in the system's overall global optimum. The optimality and adaptability of decentralized control structures in manufacturing processes will always be compromised. Although less ideal than a centralized architecture for little systems, decentralized techniques can nonetheless ensure greater robustness and flexibility. For larger systems, however, this will still be far from ideal due to the limits of the central architecture, whereas decentralized techniques can still ensure robustness and adaptability even in very large systems. A small comparison is presented in Table 1. Over the past few years, various methods for integrating decentralization into a control architecture have been created.

Table 1. Comparison between the two structures [12]

Centralized approaches	Decentralized approaches
Deeply rooted in the industry	Hardly implemented in the industry
Well-known algorithms	Well-known algorithms
Access to global information	Access to local information
Global optimum	Sub-optimal
Small scaled systems	Large scaled systems
Simple systems	Complex systems
Not robust in dynamic situations	Robust in dynamic situations

These methods are offered for use in standard manufacturing but can also be applied in more specialized fields such as autonomous guided vehicles, self-driving autos, and unmanned air vehicles (Drones).

The fastest feasible fulfillment of transportation requests while preventing AGV conflicts is one of the control policy's primary goals. Therefore, a controller of the network must carry out several tasks [15]: Task allocation, Path planning, Localization, and Motion planning…, but in this study, We will only look at localization as a navigation concept. The AGV's ability to successfully traverse its surroundings is crucial. Therefore, localization is one of the crucial core AGV tasks as well. An AGV may not be able to follow the shortest path determined by the path planning algorithm without encountering difficulties. The path might be blocked by an unexpected object or person, or other AGVs might require a part of the path at the same time. Localization is among the most important responsibilities to take into account for any vehicle going inside, including AGV controls. Contrary to the other activities, this one is already largely decentralized because all the necessary software and hardware for localization are already present. A central computer or nearby devices may receive information about the location on the environment’s 2D map for the purpose of additional control. We won't go through whether each localization solution is appropriate for a specific control architecture because this basic task comes independently of the control architecture. But in order to make the paper comprehensive, we will discuss the current localization techniques and evaluate their robustness and adaptability. The localization systems have undergone significant development during the past few decades [16,17]. Some traditional methods are still in use, while others are more recent and will receive greater focus in the future. Among the most established, antiquated methods are:

1. Physical path localization;
2. Virtual path localization.

Physical path localization

Wire or inductive localization: First-generation AGVs employ this kind of localization as a primary technique [18,19]. The wheels of wire/inductive guided vehicles are controlled by an onboard sensor that is made up of coils that pick up the magnetic flux produced by the wire that is embedded in the floor and powered by electricity. This sensor allows a controller to adjust the speed of the wheels. A frequency generator is built on each floor of a building, and guide wires are placed in a loop in the ground there.

This approach offers several advantages, such as:

1. It is quite durable;
2. It can track paths with a very high degree of accuracy (3 mm);
3. It has emergency stop mechanisms built into it;
4. It has been around for more than 60 years.

This method has been shown to work, especially in narrow aisles, to maintain accuracy. It is acknowledged that this method's capacity to handle route alterations is severely constrained. Access to the facilities and rerouting of wires buried in the facility floor would be necessary for this [12,20].

Optical localization: In this kind of localization, a colored tape or painted line that contrasts sharply with the color of the floor is placed there [21].

The AGV is equipped with an optical sensor that performs the same function as inductive guidance and offers the same advantages. Just a few improvements over before, such as [20]:

1. It is built on a physical pathway that is independent of a power source;
2. Since it does not necessitate rerouting wires and the channels where the wires flow, it is relatively adaptable to accommodate path changes.

The negative point in this situation is that when the AGV runs continuously on top of painted or taped lines, the tape may get unclean, scratched, or damaged. The lines may therefore need to be periodically repaired, replaced, or protected with a cover. But compared to the above wire technique, it is simpler to adapt. Due to the tape and the single usage of an optical sensor, this approach is also economical [12,20].

Magnetic tape guidance: On top of the floor is placed an adhesive magnetic tape. Sensors on board are able to detect the tape's invisible magnetic field. Both dirt and lighting conditions have no effect on this approach. In addition to providing the path for the AGV to follow, it may also have floor markers affixed to direct the vehicle to change lanes, accelerate, decelerate, or stop. As opposed to the wire, which necessitates energizing the medium, this technology is passive. It is simple to lay and change the tape.

However, track switching at intersections is more challenging compared to the wire, inductive, or optical guidance approaches. The magnetic tape will eventually need to be replaced because of the continuous AGV operation's degradation of it [20].

Virtual path localization

Magnetic-gyro grid navigation: Between the line guiding and the free-roaming techniques, there is a group of navigational methodologies with similar fundamentals. On the one hand, they don't have any physical path established at the floor level, while on the other, they depend on dead-reckoning and inertial measurement sensors to estimate absolute localization (The practice of establishing an object's current position by projecting trajectories and speeds from known historical positions, as well as predicting future positions by projecting the current trajectory and speed, is known as dead-reckoning). Because of accumulated inaccuracies, dead-reckoning, as well as inertial measuring methods need periodic correction during a normal day. This can be achieved by sensors or devices installed on the floor, typically in a grid pattern [20].

On particular (x, y) coordinates on the area map, a structure or line of points is indented into the ground. The points may be transponders or passive permanent magnets [22]. The vehicle has a magnetic sensor inside that can find the points.

The AGV can identify its precise location on the map by identifying the points. The encoders attached to the wheels collect relative positions from the locations between the spots to calculate the distance traveled (odometry). This is a fairly precise strategy since it combines absolute and relative localization [12].

The following are this option's key drawbacks:

1. The position and heading mistakes are accumulated, i.e. the size of the error grows along the trajectory [20];
2. It takes a long time to install and for modifying [12].

Some new techniques which are rapidly gaining attention are:

1. Laser localization: This remote sensing technique illuminates a target with a laser and examines the reflected light to determine the target's distance and reflectivity. Laser-based localization is frequently used in the industry, where vehicles are equipped with on-board lasers and passive reflecting markers are placed on the walls. To be able to navigate, at least three points must be visible because the localization is determined using triangulation [12,20]. Off-board lasers positioned within the immediate environment can be used in the same way as laser technology. They pick up passive markers placed in precisely defined AGV locations. AGV localization is approximated in the on-board computing unit with on-board lasers. Obstacle detection can also be done using these sensors. The data collecting is carried out off-board thanks to lasers positioned in the surrounding area for AGV localization [5]. The collected data is transmitted via a connected system to the control center, where the data from several laser sensors is combined to determine the AGV's localization. The AGV receives the motion commands from the off-board controller

in the control center via the wireless communications system. Complete localization of the AGV can be made possible by laser technology, either on-board or off-board, with an updating rate of 0.1s and an accuracy of about 2 cm. Accuracy is increased by combining localization data with information from the AGV wheels' odometers. Lasers have a good range (about 80 m) that is appropriate for large buildings. Path tracking in either virtual path, predetermined or not, is supported by laser-based navigation. This method may therefore fully support any kind of motion needed for rescue operations. Off-board lasers are capable of supporting operations with any other sort of vehicle, such as rescue vehicles, as well as the various AGV typologies that have already been taken into consideration. Remotely testing and calibrating off-board lasers is simple and doesn't require involving any people in the process. In contrast to wire guiding, which is more established, laser guidance is more recent. Despite this, it is nonetheless well-known and widely utilized in industry, and many AGV systems today employ it as a standard [20,23].

2. GPS localization: In this localization technique, satellites that have been assigned known positions on the world map release signals that the GPS receiver picks up [21]. Then this receiver can calculate the separation between each satellite. Trilateration is employed using this information to establish the receiver's precise location. For navigation to be possible, a minimum of four satellites must be visible. It is necessary to have a clear sight line to the sky for this approach. In industrial and commercial applications, it is challenging to get this. Instead of satellites, a Local Positioning Radar (LPR) in the workplace could be utilized. The issue with the LPR is the precision range of 10 cm, which is not particularly accurate but might be enhanced by sensor fusion.

3. Natural localization: This method of localization scans the entire area around the vehicle with a Light Detection and Ranging (LiDAR) sensor [21]. There is no need for permanent landmarks like reflectors. The AGV navigates by utilizing elements of the current environment. This eliminates the need for additional infrastructure, which makes this kind of localization incredibly flexible. Unfortunately, because of reflections and drift, the method is not very accurate and reliable. The vehicle may create a 2D map of its environment by using the scanned map of the area, including any readily visible elements like walls, barriers, and pillars. The robot may use Synchronous Localization and Mapping (SLAM) to determine its location on the map by comparing this local map with the factory's map [24]. The robot uses SLAM to investigate the surroundings while updating a local 2D map using laser scans, making the system much more adaptable in dynamic environments. The pricey sensors and the inability of some transparent materials to be detected by lasers are the drawbacks. Sonar sensors, for example, can be utilized as an alternative.

4. Vision-guided localization: This approach resembles contour localization. A stereo camera is applied to create images out of which 3D point clouds can be constructed rather than LiDAR. The camera's pixels are translated into points in 3D space that are placed in front of the camera. This 3D point cloud is made up of points that represent the various features seen by the camera. It is then possible to project this point cloud onto a 2D point cloud, which is a 2D translation of these features. The local environment map can be represented using an occupancy grid scheme [25]. A cell-decomposed depiction of the environment is an occupancy grid. A grid of tiny squares divides the entire region. Each square is labeled as 'Unoccupied', 'Occupied', or 'Unvisited'. The likelihood of occupation can also be used. The camera-observed features are converted into occupied cells by reflecting the 2D-point cloud of the previously seen features onto the occupancy grid. Moving around while continually projecting the visible 2D point cloud onto the occupied grid allows for the construction of an environment map. Similar to natural localization, a person utilizing SLAM to explore the entire area will need to create an initial map of the robot's surroundings. The fact that this approach is susceptible to light conditions, which are frequently present in real-world settings, is a negative point.

Also still there are two other localization methods: Motion capture systems and Inertial navigation, but we're not going to speak on them because they are not usable and still need more development to be suitable for being implemented and challenging the previously discussed techniques in several fields.

Research methodology

The paper's main objective is to evaluate prior research and studies on AGV systems, including their integration with the industry 4.0 paradigm, impact on various industrial sectors, and extension into new fields, including health care and human services. Research resources like Google Scholar and Science Direct have been used with the help of manufacturers' websites to find journal articles, book chapters, and relevant information on the topic to provide more understanding.

Results and discussion

In this paper, we clearly want to take some steps towards the two available controlling approaches: Centralized and decentralized systems, in addition to one of the indispensable tasks during the AGV control.

Beginning with the most common control architecture, centralized control, it cannot handle the increasing AGV numbers, the complexity of the structures, and upcoming applications and innovations due to its memory, communication, and computation limitations. Decentralized control, on the other hand, is capable of meeting all of these challenges. It can ensure sturdiness, adaptability, and flexibility. Because overcoming, the prior drawbacks of centralized authority and adapting to the conditions and problems of the present world are likely to be accomplished through decentralization. The decentralized control is appropriate for dynamic situations since it swiftly adjusts to changes and is necessary for the future, according to a number of studies conducted by [26–28]. Meissner et al. [14] contrast the central and decentralized control structures used in production today and explain that decentralization is the future because centralized and hierarchical structures are incompatible with the requirements of future systems. Decentralization, however, can ensure more robustness and flexibility while being less effective than a centralized architecture for small systems.

By moving to the localization work, which has two primary sections and is widely decentralized. Despite the benefits it provides, physical path localization has begun to fade and eventually disappear because the demands of future flexible systems cannot be met by physically rigid circuits. Virtual localization techniques are frequently used because of the adaptability of the circuit. The disadvantage of these latter methods is that they are not very precise and susceptible to disturbance, particularly from the surrounding elements like vibrations, and ambient light in addition to the uncertainties in measurements.

Finally, in order to resolve the above problems more effectively, new research and inventions are required. The optimum course of action should be a gradual shift that can go from a central to a more hybrid and ultimately to a distributed design. The same is true for localization techniques, combining them could be the best approach to get over their current limitations and downsides. For example, the future of AGV localization may involve combining vision-guided and natural methods with extremely precise and reliable laser localization.

Conclusions

This paper covers one of the key tasks that must be completed in order to control an AGV system for a central and decentral architecture, for which we have already given a broad overview, as well as the differences between the architectures and their benefits and drawbacks. There are many central and decentralized algorithms and methodologies for controlling an AGV fleet that is described in the literature. More adaptable techniques that don't rely on actually specified circuits are preferred for the localization challenge. In decentralized systems, virtual path localization techniques will be applied more frequently. The authors see that the future of localization will be a combination of extremely precise laser localization and adaptable and data-rich contour or vision-based localization.

In the real life, we observe that practically all of the AGV systems currently in use operate entirely centrally, but we also notice a definite interest in decentralization as a component to satisfy future requirements like flexibility, openness, scalability, and robustness. The world's industry is in continuous growth and development with trying to be more efficient than before, now we have the industry 4.0 paradigm which is one of the big industrial and efficient revolutions in this century that will force AGV manufacturers to consider decentralization as a key component to meet these requirements as systems get larger and more complex.

The author sees that the merging of various techniques we have will lead to more and new challenges as well as innovations why not, however, that practical application of distributed control still requires further research and studies and has a way to go in terms of taking other sections such as safety and sustainability into account.

Limitations and study forward

This paper didn't cover some other tasks that complemented the localization task, in addition, to flow path layout, either virtual or physical path localization. The AGV moving along the facility is done by tracking a guide path. Aisles are used in flow path design to connect equipment, processing hubs, stations, and other fixed structures. A directed network that includes aisles, intersections, pickup, and delivery sites as nodes typically depicts this arrangement. The effectiveness of the system is directly impacted by the flow path design.

Another thing is guidance, which is one of the three main elements that support the AGV's proper motion together with navigation and control. For the AGV-allocated tasks, guidance entails creating the best possible routes and velocity profiles while taking into account the limitations of the navigational environment.

The splitting of the system into several parts makes it easy to distribute each task or section for the actual suitable controlling architecture. This process is the faster way to get the transmission from centralization to decentralization control, which is our goal.

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Огляд автоматизованих керованих транспортних систем: системи диспетчеризації та концепція навігації

Анотація. Проблема. *Будучи одним із трьох ключових елементів гнучких виробничих систем (FMS), автоматизовані керовані транспортні засоби (AGV) відіграють значну роль у системах обробки матеріалів. Вони існують вже більше десяти років, переважно в Європі. Раніше AGV використовувалися здебільшого на виробничих лініях, але завдяки недавньому розвитку промисловості вони тепер відіграють життєво важливу роль у різноманітних сферах застосування та сферах, включаючи склади,* *портові споруди, транспортні системи та навіть медичний сектор.* ***Мета.*** *Метою роботи є аналіз двох методів контролю AGV та шляхів, якими AGV повинен йти під час транспортних операцій, враховуючи безпеку та обмеження для важких вантажів, які необхідно транспортувати в складних умовах.* ***Методологія****. У цьому дослідженні ми спробували надати підсумок двох існуючих методів контролю AGV, централізованого та децентралізованого керування, які пропонують основні виробники. Майже всі функціонують централізовано, з єдиним центральним контролером, який контролює весь парк AGV. Автор бачить тенденцію до децентралізованих систем, у яких AGV приймають індивідуальні рішення на користь транспортної гнучкості, надійності та адаптивності. Також надається стисле пояснення добре відомих і зрілих навігаційних технологій, які використовуються AGV у галузі, разом із фізичними та віртуальними шляхами, якими має слідувати AGV під час транспортних операцій, оскільки ці технології стають ключовим питанням з огляду на безпеку обмеження, особливо для важких вантажів, які потрібно транспортувати в складних умовах.* ***Результат.*** *Цей документ охоплює одне з ключових завдань, яке необхідно виконати для керування системою AGV для центральної та децентралізованої архітектури, для якої ми вже надали широкий огляд, а також відмінності між архітектурами та їхні переваги та недоліки.* ***Оригінальність.*** *Автор бачить, що об'єднання різних технік, які застосовуються сьогодення, призведе до нових викликів, а також до інновацій, проте практичне застосування розподіленого керування все ще вимагає подальших досліджень та напрацювань, які базуватимуться на безпеці та екологічності.* ***Практичне значення.*** *Обговорені основні переваги та недоліки різних технологій дозволять в майбутньому підвищити ефективність використання AGV.*

Ключові слова: *автоматизовані керовані транспортні засоби; техніка контролю; локалізація; централізація; децентралізація.*

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