Navigation possibilities for Autonomous Guided Vehicles

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***Abstract*— Autonomous Guided vehicles are commonly used in industrial automatization. Smart manufacturing contains many AGV solutions for every type of industrial activities and the navigation methods of these vehicles are cardinal points of their applicability. This paper introduces the common navigation techniques and their industrial appearences.**

Keywords— navigation, AGV, forklift

I. INTRODUCTION

Autonomous Guided Vehicles or Automated Guided Vehicles (AGVs) consist of two main parts namely the vehicle and the controlling system. Navigation is an important part of this system which means exact positioning and path tracking. The navigation method depends on the industrial environment type, inner and outer application need different approaches and techniques. Each technique has advantages and disadvantages and the optimal solution depends on the exact knowledge of parameters.

The main navigation methods are:

- Natural navigation
- RFID based localization
- Machine vision based navigation
- Inductive fixed guideline
- Magnetic tape guidance
- Light coding
- Laser navigation system

II. NAVIGATION TECHNICS

Natural navigation

The essence of natural navigation is that there is no need to install any driving paths or markers on the wall and the existing paths and boundaries can be removed. The AGV navigates freely and reacts in a very short time due to its sensors. Object detection happens in less than 60 milliseconds which is faster than human beings' reaction time.

The factory's area is mapped and stored in system memory and only some reference points are needed for precise navigation as the system navigates by laser sensors using the existing environment.
Natural navigation is originated from NDC Concept Team at Kollmorgen.

Fig. 1. Natural navigation[1]

Raw data is collected by laser sensors then a map of the plant or warehouse is created. The baseline map is editable and any part of the map can be removed or new parts can be added if necessary. During navigation the real environment and the baseline map is compared by the algorithm. Natural environment navigation is an optimal solution for controlled environments and for specific applications like deep lane storage systems.
One of the main advantages of this system is flexible, there is no need to install any signals or markers thus the implementation time is very short and the installation costs are relatively low. If an expansion is needed in plants or warehouses using this solution there will not be any restrictions for widening the system, the only necessary step is a new mapping. The natural navigation system continuously scans its environment and can intervene when necessary. This navigation type has been being available for 2-3 years.

RFID based localisation

Radio frequency identification (RFID) based location is commonly used in industrial environment. This technology uses wireless radio waves for tracking and is very flexible with an excellent accuracy. During navigation RFID technology generates a great amount of data thus valuable data filtering is necessary for effective navigation.
In industrial plants and warehouses the RFID transponders are implanted into the floor and are covered with resin. The RFID system uses electromagnetic field to identify and distinguish RFID tags which are embedded into different objects. RFID tags contain coded information which can be decoded by RFID readers. The two-way-communication readers are called interrogators as they send signals to the RFID tags and hear their responses. There are two types of tags: one is the passive RFID tag which has no extra power source and is readable from short distances and the other one is the active RFID tag which has a local power supply and can be used from greater distances (even 15 metres or more). Although the RFID tag is often not visible it can be used in both cases, too.
During navigation the fixed RFID tags have a special interrogation area which tell them apart from the other RFID tags. When an AVG forklift uses this local identification method these zones can be easily identified. The RFID tags and readers can use a wide frequency range from 120kHz to 10 GHz depending on the field of usage.
Using RFID navigation, antennas play an important role in positioning. The size and the position installation of the antenna determinate the read range thus the precision of navigation. Placing the tags horizontally or vertically also influences navigation [2].

Machine vision based navigation

Machine vision is a digital image based technology which is very suitable for process automation and automated or autonomous guidance. Machine vision includes hardware elements and sensors, software background and integrated systems, too. The machine vision process consists of the following elements: image capturing, image processing and any kind of use of the output results.
AGVs navigation is not the only interest area of machine vision techniques, it can be used in automated inspections, quality controlling, code reading, etc.
Image capture is the first step made by different types of cameras, lenses and sensors. Smart cameras and other sensors can be connected to the central unit via wired or wireless connectors. Sensors can be laser diode, etc.
In machine vision systems there are different sorts of captured images: 2D or 3D, visible light, multi- or hyperspectral images, x-ray or infrared images, etc. Visible light images can be monochromatic or real coloured. The camera/image resolution is an important issue in machine vision based systems when moving objects or objects by moving sensors must be captured without quality loss. The image type depends on the field of usage; industry needs different images than human navigation methods or self-storage systems.
Image processing type depends on the further objectives of machine vision based systems. There are many image processing methods and only the main types are enumerated: image segmentation, pattern or shape recognition, edge detection, pixel counting and deep learning process. Image processing gives output information for the AGV navigation.
The output of machine vision image process in AGVs systems is the exact position and steering/orientation of the AGV and the decision making possibility for the future.
There are some problems with machine vision based systems. The relatively long period of image capturing/acquisition and image processing limits the velocity of the AGV. The other problem is the limited capability of navigation accuracy which can be improved by using other sensor parallel.

Inductive fixed guideline

Inductive guidance or wire guidance of AGVs is a traditional navigation method and needs more preparatory work in contrast with other available guidance techniques as the factory's floor must be cut and the guidance wire have to be built in the floor. In this system there is a frequency generator as a current and frequency driver for the guide wire. The steering antenna is located on the AGV together with the sensors which are implemented into the moving AGVs and these sensors navigate on the continuous embedded path.
The advantage of this technology is a high reliability and high accuracy in positioning. This kind of navigation is not influenced by environmental conditions such as snow outside or dirt by the wheels' abbreviation, etc. A massive disadvantage of these systems is the inflexibility as the path cannot be changed easily when necessary. In industrial environment metal installations in the ground also influence navigation and may cause positioning mistakes. Additional sensors are recommended to increase the preciseness of this method (see sensor fusion). The installation of the wire system is not feasible financially.

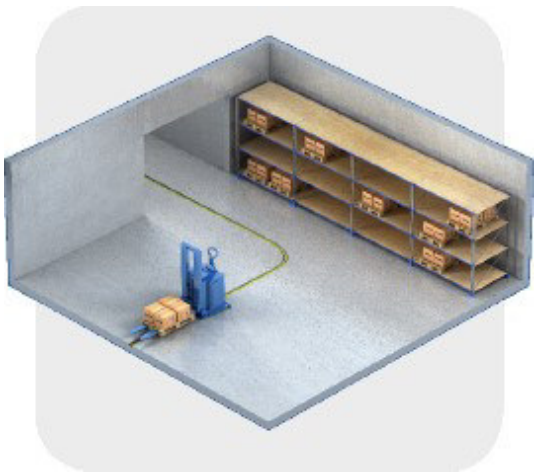

Fig. 2. Inductive navigation [1]

Magnetic tape guidance

Magnetic tape guidance technique in AGV navigation starts with the implementation of the guidance tape which is placed and fixed on the surface of the plant's ground. The width of the adhesive tape depends on the different technologies but at all events is between 20 and 50 millimetres. The tape can be laid in any kind of shapes as it is necessary for routing. Some manufacturers offer heavy load resistant durable magnetic tapes that can be built into the surface by carving.
The sensor, similar to the inductive guidance technique is implemented on the guided vehicle. The other similarity to the inductive method is that the guidance tape is continuous but in contrast with the mentioned system it is visible. The path can be changed easily as it is removed and a new tape is fixed on another route. This guidance system is mainly recommended for automatic guided carts (AGCs).
Magnet sensor like HG G-19600ZA detects the magnetic tape's magnetic field both in vertical and horizontal directions and continuously calculates the deviation from the path.

Light coding

Light coding technique can be regarded as the previous evolutional step of structured light technology. Structured light technique uses light source when cameras measure reflections. This method uses structured light source as the emitted visible light is modified and structured during radiation. The structured light is similar to a zebra or a black and white pattern. Because of the triggered light source, the measurement must be very strict and precise in timing to enrich acceptable results. Recently new techniques use blue light source instead of white light and generate 3D-point-cloud and reach higher resolution and more accurate measurements.

Light coding technique is the next step of structured light where laser source emits near infrared (NIR) light constantly and a filter transforms it into a dotted pattern. This dotted pattern is detected by an IR camera and the distance of the dots are estimated considering the distortion and other parameters of the dot cloud. The commonly known manifestation of this sensor appears in Microsoft Kinect [3].

Laser navigation system

The introduction of AGV system started in the mid 1970's at Tetra Pak manufacturing and warehouse facilities in Sweden. They wanted to improve their effectiveness and safety while moving huge paper rolls around. The speed limit of AGVs was 1m/s and it was guided by a wired floor network. In the 1980's they began testing with laser navigation and in 1991 laser navigation was implemented [1].
Laser navigation system is based on the triangulation method. Laser emits signals from the AGV and if at least three reflections come back the position and heading of the AGV can be calculated from the directions of the reflected laser beams [4].

Laser navigation systems sometimes have some disadvantages like slow response and low accuracy.

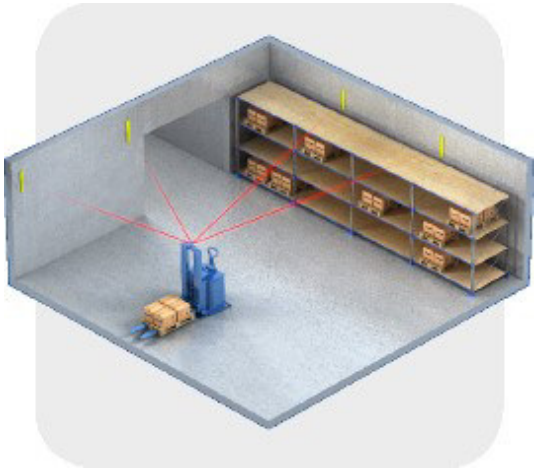

Fig. 3. Laser navigation

III. Main AGV producers and their solutions

Dematic uses four types of navigation system in their AGVs: laser navigation, magnetic tape guidance, natural navigation and wire (inductive fixed) navigation. All these navigation methods are available separately or in combination (see sensor fusion). Dematic offers software solution, too. The company uses lead acid and hydrogen fuel cell batteries and the batteries can be changed manually or automatically or can be charged without removing them from the AGV. Dematic has different types of AGV solution:

•compact AGVs – ultra compact AGVs for tight places, there are three types: Compact Tugger, Compact CB Fork, Straddle Fork

•standard AGVs – commercial standard solutions with forklift, chassis, etc.

•Hybrid AGVs – traditional forklift ruled by driver or works as an AGV

•Custom E'gv – special needs can be solved as asked by consumers (i.e. 180-degree cheese rotation during maturation)

•E'tow systems – rail in the floor guides the transport system, the in-floor chain conveyors are good for large transportation

Since 1960 Crown company has been dealing with forklifts and material handling equipment. They have 19 facilities and are present all around the world. They produce AGVs systems for warehouse automation, too.

For the navigation Crown has wire and rail guidance for minimal aisle width but AGV can become a man guided forklift on any occasion. They have solutions for low level order picking and for very narrow-aisle automation. There is an auto fence function available for TPS series. These machines are operated by lithium ion batteries with 48 or 72/80 volts depending on the series.

IKV Robot Nanchang company is located in China. Their work is based on German technique and their field of interest covers AGVs, industrial automation, intelligent warehousing and industrial controllers.

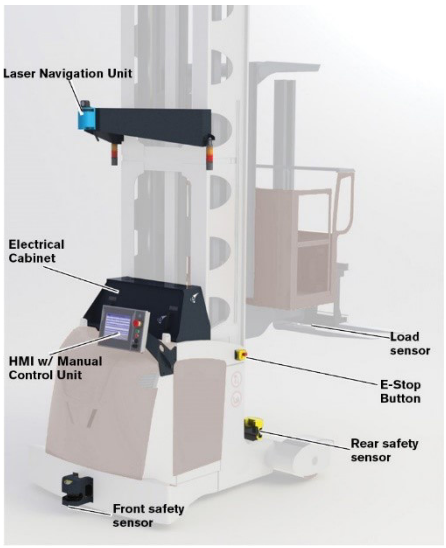

Fig. 4. Hybrid AGV [5]

The IKV Robot has the following AGVs:

•Bidirectional Roller AGV – navigates by magnetic tape guidance, photoelectric or laser guidance and it carries maximum 1000 kilograms

•Laser guided forklift – it has a 24V lead acid battery and can carry up to 1000 kilograms

•One way lurking AGV – this AGV navigates under the car or pallet and transports it. It navigates by magnetic tape-, light electrical or laser guidance and can carry up to 1000 kilograms.

•Backpack AGV – this AGV works with magnetic tape guidance system and has a 24V lead acid battery.

•Magnetic guidance forklift AGV – versatile system equipped with hydraulic lifting system and it can carry up to 2000 kilograms.

•Heavy Burden Carriers AGV – this AGV was planned for large coil and plate transport and for large assembly. This AGV navigates by magnetic tape guidance, photoelectric or laser guidance and it carries maximum 1000 kilograms.

Toyota corporation is one of the leading forklift producers of the world as they manufactured more than 500 000 forklifts just in the USA. These products are available for warehouses, manufacturing plants and retail storefront. In AGV solutions Toyota offers two systems:

•BT Staxio SAE160 AGV Autopilot Stacker – its load capacity is 2 tons and can lift up things up to 5 metres. It navigates with laser technology/natural navigation technique and has a manual mode, too.

•BT Optio OAE 120CB AGV Autopilot Order Picker – it can load 1.2 tons, lift up things to 4.1 metres and suitable for order picking purposes. ERP system and barcode scanner are integrated on-board.

•BT Reflex RAE250 AGV Autopilot Reach Truck – its load capacity is 2.5 tons and lift height is 10 metres. ERP system and barcode scanning are integrated on-board.

•BT Movit TAE500 – AGV Autopilot Tow Truck – this AGV can tow up to 5 tons, navigated by natural navigation technique and ERP system is integrated on-board.

•Tug-cart mouse AGV – this AGV can navigate in narrow aisles and is powered with 24V. It can carry about 1350 kilograms.

•L-cart AGV – this AGV is powered by 24V lead acid battery. It can carry up to 1550 kilograms and can be variously built up as necessary.

Atab is a Swedish company dealing with AGVs for 30 years. Not only the hardware but the whole solution is available for consumers. They produce forklifts, carriers and assembly AGVs. The product name of their solution is MAXAGV. Their products are categorised into three groups: FX means forklift, CX means carrier and AX means assembly. In this paper I am trying to present only the FX series.

•FX10 – there are three versions of FX10 where the difference is in lifting height and in maximum weight.

•FX15 – this forklift AGV is designed for pallets and stillages. There are also three versions of it considering the maximum lift height and the maximum weight. Battery operates this AGV for 16 hours.

•FX30 – this model is similar to FX15 but it has higher load and battery capacity.

•FX40 – this model can load pallets and racks. It has a wide massive chassis.

Rocla is a Finnish company dealing with intelligent material handling systems. The company has been dealing with automation intelligence since 1983 and since 2007 a fully modular serially manufactured AGV has been being manufactured here (AWT). This company manufactures warehouse trucks and forklifts and around 8000 AGVs have been being shipped to their partners since then. The Rocla AGVs use three types of navigations namely laser triangulation, magnetic spots and floor wire system. The AGV solutions are:

•Low lift AGV – this AGV is called ATX16 and has 2m/s driving speed, 1600 kilograms' load weight, 150 millimetres lifting height.

•Fork over lift AGV – this AGV is called ATX12, its lifting height is 1.7 metres. Automated navigation is mixed with manual picking of loads.

•Straddle AGV – its lifting height is 0.86 metres and the load weight is 2500 kilograms.

•Counterbalance AGV – this AGV is a good solution for gravity-flow racks with its 0.84 metres lifting height and 2500 kilograms' load weight.

EK Automation is a German company existing since the 1980's. This company delivered around 9000 AGVs for 1000 industrial plants. EK AGVs navigates with different methods such as natural-, optical-, laser guidance and hybrid systems are also available for special tasks. The AGVs' controller system is PLC and PC based.

Beewatec systems is a German company dealing with AGVs among others. Low cost modular systems and lean processes are the main factors of their AGVs.

•Bee spurmeisse straddle forklift transporter – this is a versatile AGV system with different load weight capacity from 1000 to 2000 kilograms.

•Bee mini – there are three subtypes in this AGV group namely Carry transporter, Pickup transporter and Underride transporter.

•Bee Truck transporter – this transporter is a compact tractor and pulls up to 4000 kilograms.

Savant company supplies AGVs and AGCs for industry, commercial and medical fields. Savant AGVs practice inertial navigation techniques and can carry maximum 20 tons. Fork AGVs can carry 2 tons. These AGVs use 'Virtual path' navigation.

•DF40 – this forklift AGV can carry around 1800 kilograms of weight and has a 600 AH battery with 8 hours working time capacity.

•DT-100 – this AGV can carry more than 20 tons and is powered by 1100 AH battery which is 2 tons.

•DC-60 – this AGV carries about 3 tons and use a 48V power system.

•DL-40 – it carries 2 tons and has a 630 AH battery.

Axter is a French company with more than 25 years' experience in mobile robotics. Their AGVs operate mainly with laser guided and natural navigation methods but sensor fusion solutions are also available depending on the need of consumers. There are three types of Axter AGVs:

•Intelligent AGC – these AGVs carry small pallets.

•Special carriers – extra needs resulted in special solutions. Size, weight or nature of products influence the shape of the AGVs.

•Standard vehicles – these AGVs include pallet trucks, stackers, tractors and reach tracks. Their maximum load weight can be up to 3.5 tons.

Sesto robotics is dealing with industrial automation and the headquarters are located in Singapore. They have AGVs and IMRs (Intelligent Mobile Robots). The company manufacture the following AGVs which use laser based navigation.

•S200 – V2 version of this AGV is a compact and can carry about 200 kilograms

•S300 – this AGV is a trolley transporter which can carry 300 kilograms

•S500 - biggest AGV of Sesto with the 500 kilograms' payload capacity.

Fig. 5. Sesto 59S500 [6]

Aerocom is an English company since 2000 and is dealing with AGVs and pneumatic tube systems in warehouses. Their AGVs are not off-the-shelf but can be adapted to the requirements. Their AGVs are the followings:

•Phoenix series – these AGVs include high-lift guided fork trucks, high shift stackers, etc.

•Caesar series – these AGVs include drive-under tractors, platform trucks with roller conveyor, heavy-duty transporters and outdoor vehicles which operate down to -20 degree Celsius.

•Mayesto series – this group consists of high-rack stackers

•Motormouse series – these AGVs are supplied with different load handling components

Jungheinrich is a German manufacturer which has been dealing with industrial and warehouse intralogistics since the 1960's. In their AGV systems the company uses laser based navigation. These AGVs are based on a serial manufactured machines which are equipped with special techniques. The automated solutions are the followings:

•ERC215a – this stacker truck AGV lift up height up to 4 metres and can carry 1.5 tons

•ERE225a - this stacker truck AGV lift up height up to 2.4 metres and can carry 2.5 tons

•EZS350a - this AGV can tow up to 5 tons and can be used in narrow aisles

•EKS215a – this AGV can lift loads up to 6 metres and the maximum payload is 1.5 tons

Linde is a material handling company with around 13000 people worldwide. The company was founded in 1904. Linde is a leading company in forklift truck manufacturing with 80 series and 20 model variants.

Linde AGVs determinate their location by natural navigation. The Linde Matic range are the followings:

•P-Matic tow tractor – this AGV can carry 5 tons and its battery operates with 24V 375Ah

•L-Matic pallet stacker – this AGV can lift up weight up to 1.9 metres and the payload capacity is 1200 kilograms.

•L-Matic AC counterbalanced pallet stacker – this AGV can lift up weight up to 1.9 metres and the payload capacity is 1200 kilograms.

•T-Matic pallet truck – this AGV can lift up 3 tons up to 1.2 metres.

•K-Matic narrow aisle truck - this AGV can lift up 1 ton up to 7.2 metres.

SEW was founded in 1931 in Germany. The company started with electric motors and gearmotors. The company is the market leader in drive automation industry and also dealing with AGV solutions.

•The Maxolution up to 500 kilograms transporting vehicle can carry up to 500 kilograms and it can navigate considering the local requirements: RFID, inductive fixed guideline, magnetic tape guidance or SLAM (simultaneous localisation and mapping).

•The Maxolution up to 1500 kilograms transporting vehicle can carry up to 1500 kilograms. With additional componenets it can accept pallets, boxes or frames and can navigate with the maximum tolerance of 10 milimetres.

Agilox is an Austrian company dealing with supply chain management and intralogistics. The company was founded in 2008. They manufacture intelligent guided vehicles. The Agilox system is a wireless LAN based service.

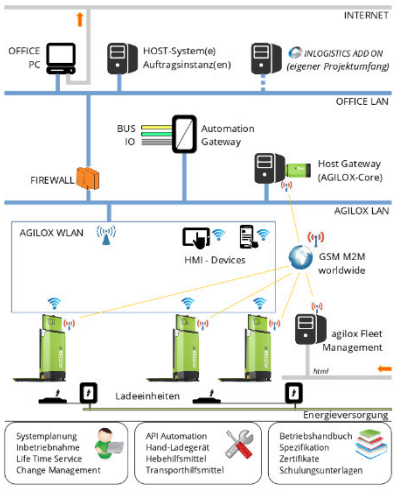

Fig. 6. Agilox navigation system [7]

IV. Conclusion

This paper was to show the autonomous guided vehicles, their navigation possibilities and techniques and the main AGV manufacturers and their solutions.

As a conclusion we can summarize that the navigation techniques are in continuous development, during navigation process less signals and markers or guides are used and the recognition of the environment by sensors come more and more into view.

Some special industrial applications or warehouse solutions require wired path installation to the floor but generally these techniques are not up-to-date, not flexible at all and cost a lot.

Sensor fusion can improve navigation accuracy on one hand and on the other hand it can be used for an environment where both inner and outside navigation are necessary.

Main AGV providers and their solutions are also introduced in this paper. There are many AGVs and navigation possibilities available on the market and most of the AVG manufacturers offer not only the machines and guidance systems but the software background as a complete solution, too.

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