ADVANCED NAVIGATION OF AUTOMATED VEHICLES IN SMART MANUFACTURING

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Abstract: Smart manufacturing or also known as Industry 4.0 is the current trend in automated manufacturing. It includes IoT, cloud technologies, super-flexible automation and cooperative human-robot interaction to name a few aspects. Utilization of Autonomous Guided Vehicles is crucial in successful smart manufacturing. The paper reviews the most widely applied navigation strategies and current research directions related to AGV control.

Keywords: *smart manufacturing, intralogistics, AGV*

I. INTRODUCTION

Autonomous Guided Vehicles or Automated Guided Vehicles (AGVs) have an important logistics role in smart manufacturing [1]-[3]. 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.

Generally, only one sensor is used but sometimes more sensors are needed for a more precise positioning. More sensors can be used one after another or simultaneously depending on the environment. When more sensors are used simultaneously and the parameters ensure more information it is called sensor fusion. Using sensor fusion not only more but better quality information can be gained.

Laser navigation system is based on the triangulation method. The 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].

Path determination and path tracking are crucial points of AGV systems. Path abrasion can be decreased by using a freer moving path. It is also important to define the extent of preparatory works for path defining and navigation (such as marks, beacons, cords, etc.). The main goal is the collision-free routing using the optimal navigation method. Navigation can be different considering the circumstances.

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. 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.

Figure 1. Natural navigation[5]

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.

III. 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 [6].

Not only the antenna positioning influences the system effectiveness but the density of RFID tags. The denser the network the more precise the navigation is but there are limitations. The denser the network the more data is available but the slower the data procession is. The other aspect is the cost – benefit ratio as the denser the network the more expensive the implementation is.

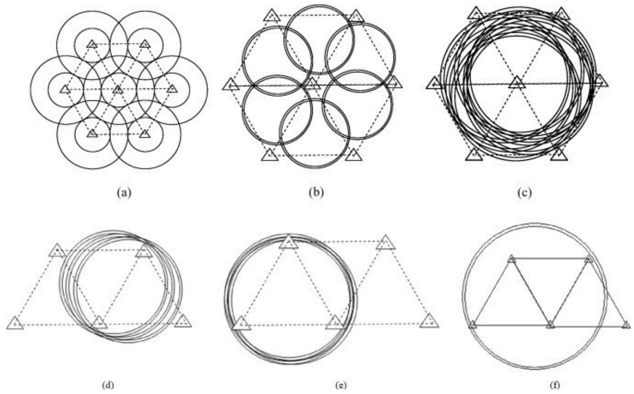

Figure 2. RFID reading [7]

IV. 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 (see sensor fusion).

Machine vision based AGVs system can be used with fiduciary markers which guide the AGV. Hue and saturation information can be used for optimal image. Character recognition based localization and positional relation between markers and sensor are calculated. This system reached almost 99 percent of character recognition rate by using ten characters and four directional signals [8].

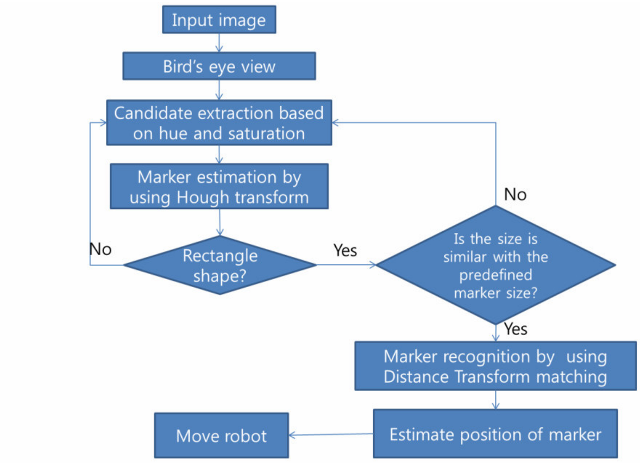

Figure 3. Marker detection and robot control [8]

V. 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.

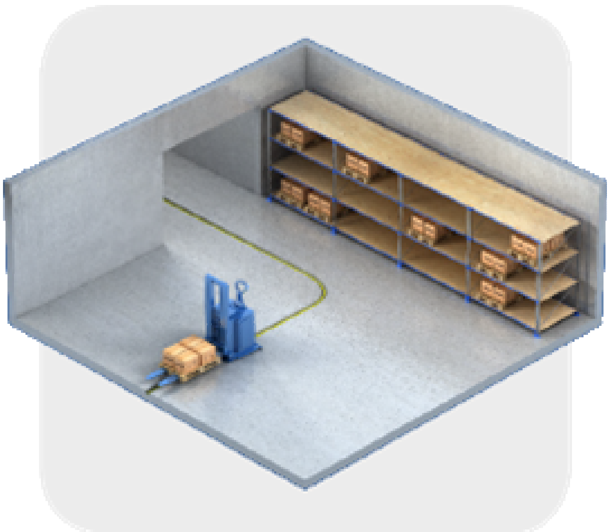
Figure 4. Inductive navigation [5]

VI. 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.

VII. 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 [9].

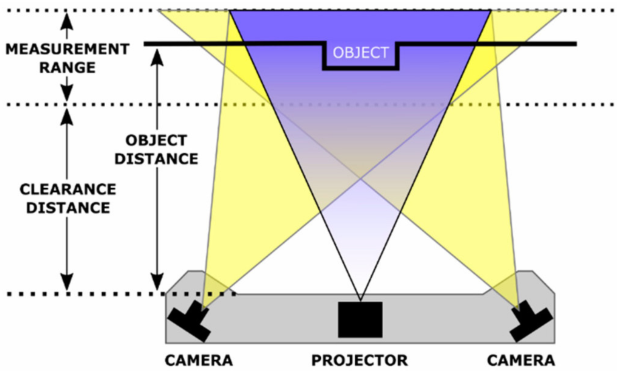

Figure 5. Light coding [9]

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 [9].

VIII. 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 [5].

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.

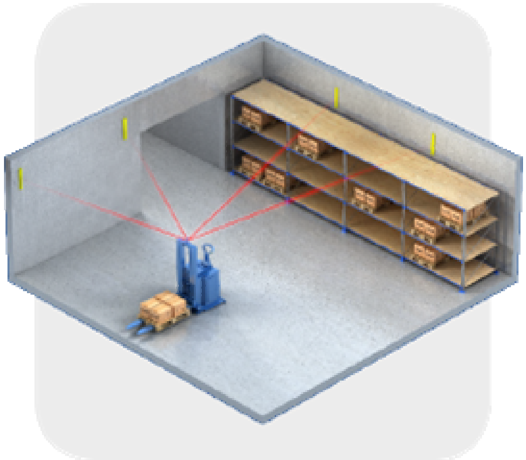

Figure 6. Laser navigation [5]

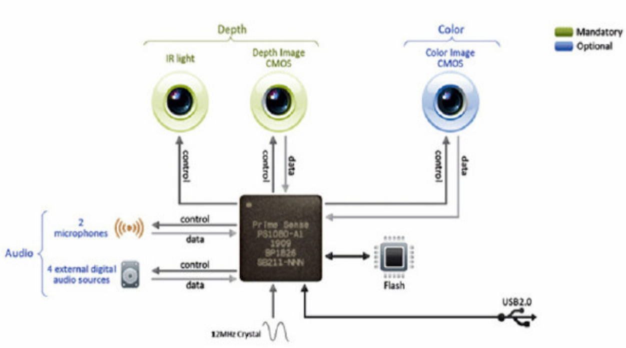

Figure 7. PrimeSense reference design [10]

IX. SENSOR FUSION

Recently, new techniques use blue light source instead of white light to generate 3D-point-cloud. As a result, a higher resolution is achieved and thus, the measurements can be more accurate [5].

Sensor fusion techniques have long been used to enhance the accuracy of positioning. One of the sensor fusion solutions can be the following approach that combines the Ultra-Wideband indoor positioning system and an Inertial Navigation System. The sensor fusion algorithm consists of two different parts: the first one is the delay compensation block which compensates the delay in positioning calculation coming from the indoor positioning system and the other block is an extended Kalman Filter (EKF) which combines the dynamic models of movement from the indoor positioning system with the inertial navigation system measurement data. This sensor fusion approach delivers 1kHz position update rate in real time operation with 3,7 centimeters error in linear movements and 1.7 degrees in rotation movement [11].

Another solution is the sensor fusion method when laser navigation system is combined with gyro sensor and they are fused by the unscented Kalman Filter and Fuzzy interference system. By using sensor fusion, we could get the navigation accuracy improved. [12]

X. CONCLUSION

Our paper is a general overview survey that introduces the role of AGV's in intralogistics and the navigation and positioning possibilities of these machines. The AGV's are parts of Industry 4.0 and this paper supports education.

We can conclude, that the navigation techniques are in continuous development, during navigation process fewer structured 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 the one hand and on the other hand it can be used for an environment where both inner and outside navigation is necessary.

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