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AUTOMATED GUIDED VEHICLES – THE SURVEY

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Abstract

Transport has always been a fundamental impulse for the development of civilization. The first fully automatically controlled vehicles for industrial application (previously called driverless vehicles) was design in 1954 year. This has been achieved more than 60 years ago. Unmanned Ground Vehicles are a whole family of autonomous vehicles use modern tools with all power today available electronics for navigation task and decision making process on the base artificial intelligence and (AI) algorithms. At present time a problem of the realization a fully reconfiguration navigation system working in real time mode for UGV vehicles is the subject of the research for many scientific units of the entire scientific world. The object of the statement constitute AGV short historical outline with actual trends marking. The special authors' attention was focused on the solutions dedicated for so-called e-tools functionalities implementing in modern AGV vehicles. The main purpose of the article was focused on the set of issues involving the most problems in the whole material handling (MHD) family devices with any autonomous factor. The article is focused on the localization problem, trajectories founding, path planning, scheduling, workspace with environment mapping and AGV control issues. Described methods and tools are connected with chosen artificial intelligence solutions dedicated or adapted for autonomous vehicles' needs.

Keywords*: AGV, navigation, patch planning, scheduling, workspace mapping, control, telematics*

1. Introduction

Transport has always been a fundamental impulse for the development of civilization [21]. The transport device auto-localization ability, determining current location in the workspace, constitutes the crucial issue of shaping the reliability and safeties of material handling devices (MHD), extremely important in AGV vehicles [8]. For solving automatic navigation problems is required defining the boundary conditions enabling formalize the description, connected with coordinate system, the transport devices environment feature, selecting the optimum route trajectory (routing) and paths [1, 10] with simultaneous resources commit between a variety of possible tasks (scheduling) [13]. Finally is necessary insert a certain interactivity rank, enabling the information exchange between transport devices, environment and human factor, so called HMI (*Human Machine Interface*). However, the most important things in AGV navigation problem are the control task. Each AGV control system and their algorithms avoiding and prevent against other dangerous events [11, 25]. It has to be projected as a system enabling collisions

2. The short historical outline

The first fully automatically controlled vehicles for industrial application (previously called driverless vehicles) was design in 1954 year [6]. The electric cart without the driver was produced by Barrett Electronics. One of the first industrial problem solve by DLV's was moving cargo in the warehouse in the South Carolina state. The navigation of DLV vehicles was very easy. In the concreted floor was mounted the group of the wires. The device following by the signal emitting by wires entrenched in concrete floors. In the middle of last century was develop first non-wire navigation system using laser target navigation system. In this system, reflective targets are mounted above the floor of facility. Additionally the facility workspace was given by an X, Y coordinate system. The basic workspace coordinates are loaded into on-board AGV's memory. Laser with rotating mirror was emitting the laser beam. With the laser, light help was measure distance to the other object in the workspace in automatic mode. The obtained data compared with on-board memory configuration (after several AGV position preprocessing) gave actual vehicle position. After that, the AGV on-board computer can compares calculated position with a preplanned path. On the base path stored in the on-board memory another steering instructions can be sending to the AGV actuators. A new form of non-wire navigation was introduced in the middle 1990's. This technology was called a gyro navigation. In this solution, each AGV was equipped with a solid-state gyroscope. The actual AGV location was estimate on the base travel deviations. Additionally in the facility floor was installed magnet markers with unique X, Y coordinates. This marker was used as reference points to correct any slight error accumulated over the distance from point to point travel with the gyro navigation help. When gyro detects change in travel direction (with the actual stored travel path). The course was correct and additionally was check the signal from the nearest marker position. All this functionalities has been achieved more than 60 years ago.

3. Unmanned Ground Vehicles

Contemporary unmanned transport systems, improved by modern integrated solutions especially telematics contributed to the development of new methods and the navigation tools for AGV vehicles. For the navigation need was develop new kind of solution so-called e-systems. E-systems contributed to develop new kind of automated control vehicles – UGV. Unmanned Ground Vehicles are a whole family of vehicles use modern tools with all power today available electronics for navigation task and decision making process on the base artificial intelligence (AI) algorithms. At present time a problem of the realization a fully reconfiguration navigation system working in real time mode for AGV vehicles is the subject of the research for many scientific units of the entire scientific world [2, 3, 9, 12, 21]. To achieve a success in AGV field not only the electronic tools implementation are crucial but their modular construction too. Reconfiguration of the construction for the actual transport task adaptation for potential changes is key to obtain the final success. In the Fig. 1 was presented AGV designed as modular project.

Fig. 1. The AGV modular construction type

3.1. Localization problem

The needed of establishing the position of each transport device require to define a reference frame. The reference frame is necessary to determine ambiguous the mobile robot position. In the local reference frame, the position tracking is relatively easy. However, the local reference frame position tracking enables location only in small area and requires the knowledge of the start point position. Inconvenience of the small area localization possibility preliminary a reference frame in global mode. In this mode, the device position is estimating without the knowledge of the start point. Additionally global mode gave possibility the transport device localization after system shot down or the localization signal clutter. The crucial flaw of the global location mode is a complexity of computational procedures. Realization algorithms for global location in real time mode for a fleet of material handling devices require a high level of computing power.

In the navigation system, designing phase (both in the global and local coordinates system) is necessary to take a decision about passive or active localization mode. In the passive mode, the transport unit cannot make an extra move for the localization process. In active mode transport device has possibility make an additional move for the eliminating ambiguity of vehicle location. The active location is useful especially, when for localization is use a set of vision system, because picture taken from device cameras can be similar in type or some kind of parameters and an extra move is necessary to eliminate this problem.

Automatic localization task expect a sensors group designed for the purposes of getting the information about surrounding transport device. For this target are dedicated:

- odometry navigation. This type of navigation system collect data from moving sensors to estimate (not determine) the position over the period of time,
- inertial navigation. It is so called dead reckoning type of navigation system that computes position on the motion sensors base. When the initial latitude and longitude is established, the system receives impulses from motion detectors that measure the acceleration along three or more axes enabling accurately calculate the current latitude and longitude,
- trilateration. Methods of this type involve the determination of absolute or relative locations of points by measurement of distances, using the geometry of spheres or triangles (e.g.: Global Positioning System, Assisted GPS and Differential GPS systems),
- triangulation. Is the process of determining the location of a point by measuring angles to it from known fixed points or baseline,
- defining positions with the help of artificial markers located in the area of the working space,
- vision methods. They compare digital model of the workspace save on the on-board memory with the pictures (or chosen pictures parameters) taken in real time mode.

To sum up the key points of this chapter the great expectation is connected with Galileo global satellite navigation system constructed by the European Union and ESA (European Space Agency). The system was expected to become fully operational by 2012, but that final date has been repeatedly moved back. Today, initial signal is expected around 2014 and the full completion is expected by 2019. In further when the Galileo was complete, the localization of AGV units should be more precisely and accurate. Galileo program contain five types of services. The first one is the "free to air" service for mass market but the second service promise to be interesting most of all. The encrypted Commercial Service (CS) will be available for a fee and will offer accuracy better than 1 m. With the help ground stations, the final accuracy should be less than 10 cm. By contrast, today GPS-NAVSTAR satellite positioning system, offers CEP (radius of a circle centred on the true value) accuracy ratings with disabled SA (*Selective Ability*) approximately: <4 m horizontally and <10 m vertically.

3.2. Trajectory, path planning and scheduling

Main rule of design trajectory for the AGV vehicle consist on the preplanned the path of the further movement. The path must conduct the transport device from the start point (start task point) to destination point (end task point) considering device configuration, construction and the cargo dimension. Additionally the path has to be planned with a special optimizing criterion with defined goal function. All optimizing criterion in the trajectory design process can be express by three basic criterion:

- route criterion (minimization of the length of a journey),
- time criterion (the shortest time of the task completion),

– energy criterion (minimization of the energy expense associated with the action completion).

It is possible to express all other existing criterions, through combinations criterions expressed above. The essential problem of planning the path consists on the seeking the geometrical curve of pass between the initial and defined goal. Additionally the sought curve must consider restrictions associated with obstacles (the movement cannot cause the collision) and must consider structural restrictions of the AGV vehicle. From the AGV vehicles group it is possible to divide vehicles with holonomic (see Fig. 2a) and nonholonomic kinematic structure (see Fig. 2b) [18]. Manoeuvrability possibilities of the AGV vehicles with nonholonomic kinematic structure can be compare with the traditional car construction (characteristic by turning circled with end value). The second group of AGV vehicles has holonomic kinematic structure. The independently motor-operated wheels enhanced the possibilities of manoeuvring through revolve around own axis and in some cases ride over the diagonal. At present, AGV structures with holonomic kinematic structure are more willingly implement inside the container terminal for the limited space reason and limited space for the domestic container terminal route.

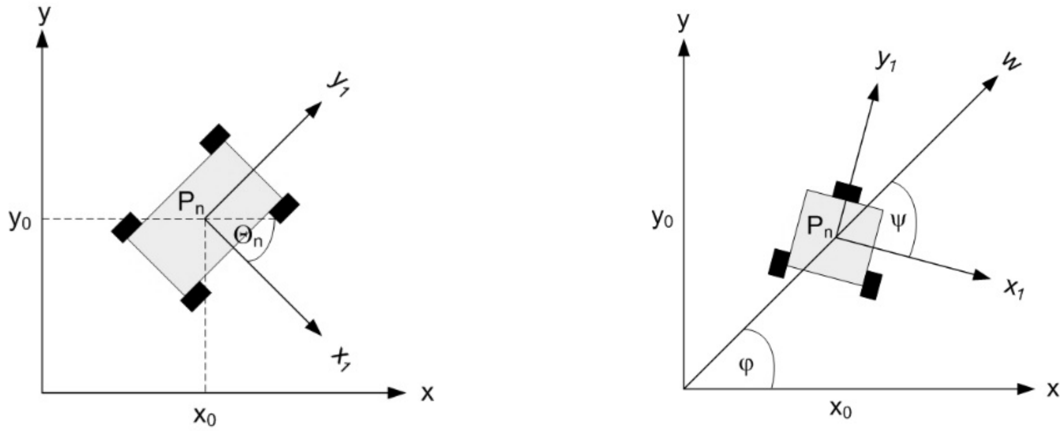

Fig. 2. From the left: nonholonomic kinematic structure (Fig. 2a), with holonomic kinematic structure (Fig. 2b)

Other issue associated with path designing for UGV vehicles is a possibility of obstacles avoiding. The container terminal architecture excludes problems with domestic route surface problem, but in this field is possible to use teramechanics theory (vehicles wheels cooperation with ground surface). This problem is important because AGV wheels stress is proportional for the cargo weight and ground surface kind.

a) Trajectory planning – an algorithms

Majority of the solution appearing in scientific literature for automated transport devices trajectories design, based on methods implementing artificial intelligence science e.g.: fuzzy logic [4, 14], heuristic algorithms [16] and hybrid tools assembling fuzzy logic with neural network [1, 15]. For solving the trajectory design problem are use also often genetic algorithms [2]. Container terminals as specific place with fast workspace rebuilt, implement a trajectory planning methods from a UGV vehicle –APF's methods. Artificial Potential Field method consist on the realization two independent superior operation: pull the target and push the obstacle. Between start and finish, vehicle point was realized an action directly connected with effect of; *follow to* and *avoid from* linking with optimization function. The APF method can be realized as a classic method (the main optimization criterion is the vehicle speed) or generalized method (the main optimization criterions are vehicle speed and position) [26]. Another methods use for trajectory design in container terminal is A*Star algorithm with all family of derivatives like a: D*, Field D*, IDA*, Fringe Saving A* (FSA*), Generalized Adaptive A* (GAA*), Lifelong Planning A* (LPA*), Theta* methods [11].

b) Trajectory planning – the methods type

Depending on the availability of the information about surroundings and transport means kind, it is possible to divide methods of trajectory planning at three groups: global, local and hybrid methods. In global methods are usually used idealized model of transport devices and the workspace is constant in time or every taken action is registered. However the algorithm for trajectory planning has, an access to database with data refer workspace changes. Global methods flexibility level is very low, additionally for realize it is need a lot of computational power. Global methods are goods only in off-line mode and its primary target is trajectory preselecting. Local methods constitute the opposite for the global methods. They can be used in the online mode. In the local methods, the path of the further move was created on the current vehicle location base and obstacle configuration. Generated trajectory is usually non-optimal, but this inconvenience was compensated by adaptation possibility to work space with dynamic changes (e.g. container terminal). The last group of methods for trajectory planning constitute hybrid combination linking global and local methods solution. With the help hybrid methods a trajectory, planning is more efficiency and more interact. The transport device in automatic mode has a possibility comparing the currently prevailing workspace conditions with workspace digital model. In the case of detecting disagreements, the pre planed trajectory is corrected. The trajectory is changing only in segment were the further move could cause collisions with other transport device or object. Sum up, the hybrid methods join advantage of local and global trajectory methods planning with simultaneous eliminating a majority weak points. Other manner of methods for trajectory planning distribution includes only an environment model. In this division, we can list topology and raster methods. Topological methods converting the primal model of transport device environment to the graph outlining all possible paths. The raster methods base on the geometrical methods for trajectory planning. An example illustrating the discussed issue is a "taboo search" algorithm [2, 5]. The TS method is used for solving Traveling Salesman Problem in container terminals. The essential idea of this application consists on searching all possible combination of paths (also prohibited) generated on the base functional container terminal model. In the next step the generated patch on the functional model base are converted to a graph for estimating the better solution. Raster methods consist in the division the workspace with the grid. The grid elementary cell can has regular or irregular shape. After the cell distribution, including obstacles and the inaccessible places for the AGV unit the trajectory can be preplanned. One of regular raster method algorithm is so called quad tree method [23]. In the method the entire space work is divided into four square fields which the assign attributing like a: empty, fully and mixed. The mixed fields are divided into smaller square and the attributing potential procedure was repeated. Another division enables construction the kind of tree, of which every top is a point of graph determined to search. The next step determines that the cells are adjacent to themselves. When the cells are adjacent, it is possible to planning the grade-separated trajectory of the further move [12].

3.3. Work space and environment mapping

The workspace maps are used to determine a location within an environment and to depict the dynamic changes an environment for planning trajectory [7]. They support the assessment of actual location by recording information obtained with the help electronic devices. The benefit of a poses workspace digital map in aiding the assessment of an obstacle location and increases the precision of automatic transport devices moves. However, workspace maps generally represent the state at the time when the map was drawn. The main scientific problem is develop solutions supporting methods and tools capable to upgrade or acquire information about workspace in real time mode. Workspace mapping is a set of various operation undertaken for one purpose: collect the information about material handling devices surroundings. Therefore, the workspace mapping is a representation preserving properties of bijection type. In order to increase a number of AGV vehicles operating at container terminal is necessary eliminate hazardous situation. In this purpose several types of workspace systems and concepts have been develop. One of them is SLAM system [3, 9]. Simultaneous localization and mapping is a technique used by autonomous vehicles to build up a map within an unknown environment (without a priori knowledge) or to update a map within a known environment (with a priori knowledge from a given map) while at the same time keeping trajectory of their current location. AGV vehicles equipped with complexes of sensors of the SLAM type search for characteristic points of workspace and on their base generated an actual workspace model. For supporting workspace mapping the new methods was develop, deliver a tools for precision workspace mapping, dedicated for automated control transport devices. With the help 3D laser scanner [19] is possible to build a system for precise workspace mapping. Additionally is possible use other solution e.g. Vision technique [20] for obtaining information linking mapping model with information gathered in real time mode [19]. The answer for this challenge is CV. As a scientific discipline, CV (*Computer Vision*) is focused for building artificial systems with the ability to obtain information from images. The processed data in CV can take many forms: from single image, via views from multiple cameras, till to video sequence. Computer vision can be also described as a complement (but not necessarily the opposite) of biological vision. One of few vision systems dedicated for AGV's devices based on CV systems for workspace mapping is stereovision [20] with dense disparity map calculation.

3.4 Control and monitoring issue

The problem of improving dependability of existing AGV control system are under investigation through research and development centres of whole world [10, 13]. At present novel control, systems [9] are dedicated for so-called Flexible Manufacturing Systems. The FMS is a production system in which a set of machines and flexible material handling system are controlled by a central supervisory control [20]. FMS's expansion is linked with the decentralized system structure of MAS type [22]. The decentralized control system scheme was presented in the Fig. 3. In presented model, the low (local) control layer is responsible for AGV's movements, the higher control layer is responsible for the trajectory planning and scheduling. The supervisory control has additionally possibility use a kind of database with social behaviour with rules support control process.

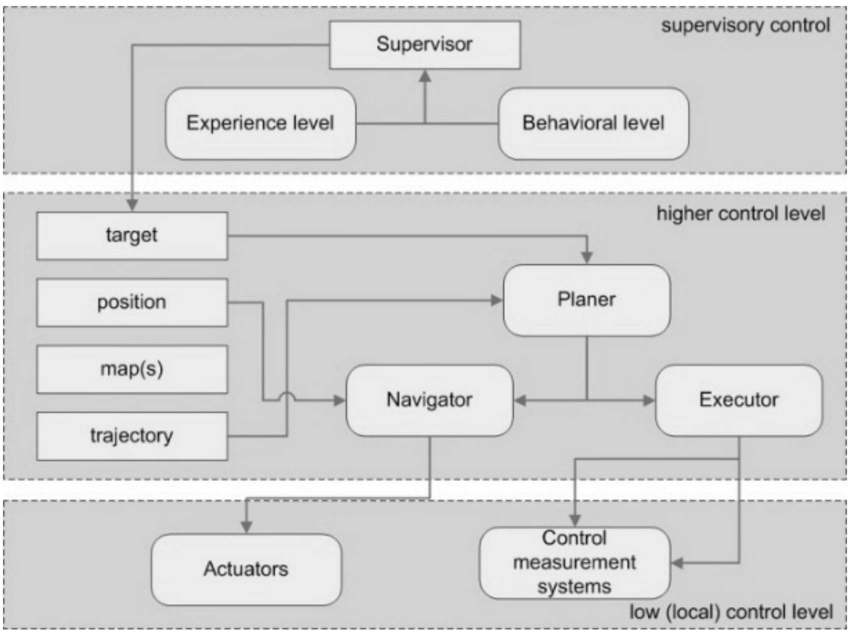

Fig. 3. The decentralized control system dedicated for AGV vehicles [18]

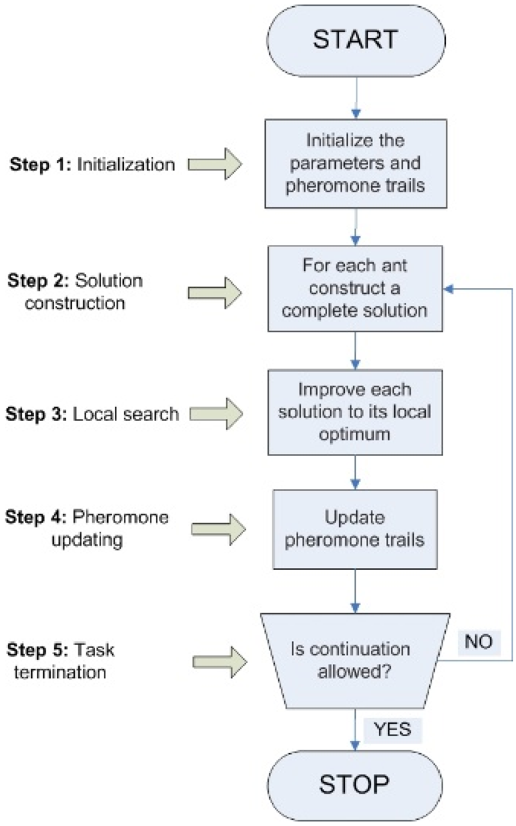

Fig. 4. The general Multi Agent System algorithm

The main idea of MAS (*Multi Agent System*) is modelling social behaviour of life form implementing in various transport system especially material handling systems. The one of first MAS system was built on the base ant's colony [17]. In this work was presented a decentralized algorithm of MAS type for AGV's vehicles. The main algorithm rules were design on the social insects' behaviour base, e.g. ants (see Fig. 4). In the presented algorithm, a complete finding path solution (routing) based on the ant social behaviour. In the real ants life a path from the nest to the food source is the optimization problem of TSP (*Travel Salesman Problem*) type, similar to the taboo search algorithm (TS). In step 4 in ant algorithm is a „pheromone updating" point. In real life, ants deposit on the selected track a specific substance called pheromone. With this substance help, other ants acquire information about specific path frequency use. It is very helpful and got possibility implementing some kind of TS method. This behaviour for AGV's vehicle can be model with the GPS, local GPS technique or other markers technique help.

In the worldwide scientific literature it is possible notice an attempts modify an existing control methods through enrich e.g. PID regulator with new elements. The hybrid tool linking Proportional-Integral-Derivative controller with self-adjusting model excreted from immune system (see Fig. 5).

The main role of the immune response system is stimulates macrophages and T-cells to kill external invaders. A T-cell consists of three parts (T_s, T_h, and T_k lymphocyte cell), where T_s controls the immune response, T_h helps the other parts, and T_k destroys pathogenic material. The PID control system enrich in the immune system rules was designed for the needs unmanned container transporter (UCT). This UTC was operated in a harbour to transport containers. Generally, various sensors (magnetic, ultrasonic, infrared and other) are used to detect the path trajectory or recognize obstacles. The authors [24] chose vision system with a CCD camera attached in front of UTC vehicles for vision data acquire. The paths are composed of a black surface and yellow guidelines. To recognize UTC's positions was necessary appropriate data collected filtering process. System was design for the needs path planning and lines marker locate with great adaptability and flexibility ability. The PID controller enrich in the HIA module (*Humour Immune Algorithm*) enable disruptions selection with assigning the status: disruption/obstacle and chose task type realization: new trajectory planning or use the standard planned trajectory if detected „obstacle" is some kind an interference. From the set of technique predestinate to UGV's control methods with artificial intelligence perform a fuzzy logic control [4]. Fuzzy logic is a form of multi-valued logic derived from fuzzy sets and rules theory. Fuzzy logic variables may have a truth-value that ranges between 0 and 1. The control process with fuzzy logic set theories use (for AGV's vehicles or other material handling devices) constitutes important complement of existing methods and tools for syntheses nonlinear autonomous systems. The main advantages of fuzzy logic control are possibilities of obtaining simple and independent form disruptions solution in a wide range of parameters, no much sensitive on the inaccuracy of control system model.

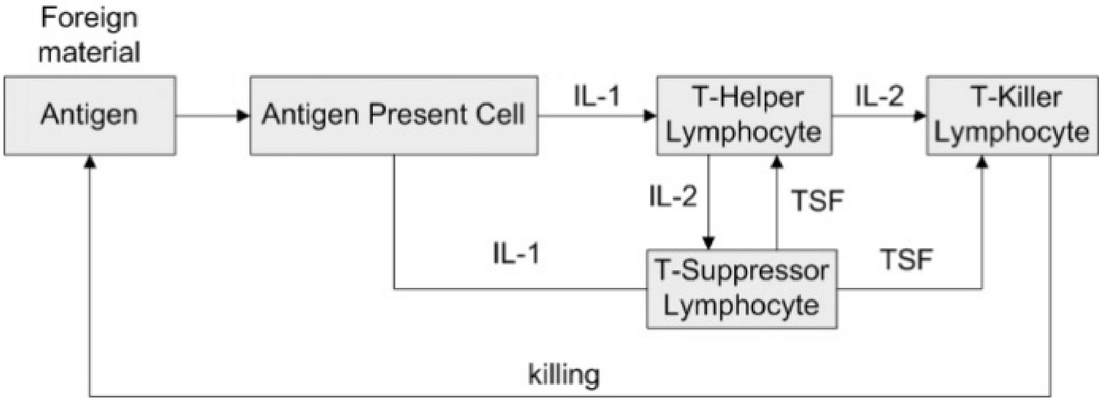

Fig. 5. The modern immune response system regulation mechanism based on PID controller

4. The summary

In this article, authors have discussed most key issues related to AGV's problem. The quantitative and qualitative analysis was done for described AGV's qualities and limitations. In the article, the authors talk over four factors, which play a strategic role in today AGV's modern design:

- localization problem,
- trajectory, path planning and scheduling,
- work space and environment mapping,
- control and monitoring issue.

Each of presented categories was detailed described with literature review and present trends talk over.

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