

Automated Guided Vehicles Navigating Problem In Container Terminal

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The subject of the paper is navigating of the automated guided vehicles (AGV) problems. The authors' special attention was focused on the solutions dedicated for the container terminals. The paper is focused on the UGV (*Unmanned Ground Vehicle*) localization problem, trajectories planning, work space mapping and AGV control problem. Described methods and tools for control problems are connected with chosen artificial intelligence solutions dedicated for autonomous vehicles working in container terminal.

Keywords: automated guided vehicles, navigating, container terminals.

1. INTRODUCTION

Transport has always been a fundamental impulse for the development of civilization [26]. The transport device auto-localization ability, determining current location in the work space, constitutes the crucial issue of shaping the reliability [25] and safeties of material handling devices, extremely important in AGV vehicles [9].

For solving automatic navigation problems is required to define 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, 11] with simultaneous resources commit between a variety of possible tasks (*scheduling*) [15]. Finally it is necessary to insert a certain interactivity rank, enabling the information exchange between transport devices, environment and human factor (*Human Machine Interface System*) [28]. But the most important things in AGV navigation problem is the control task. Each AGV control system and their algorithms must be projected as a system enabling collisions avoiding and prevent against other dangerous events [12, 31].

2. AUTOMATED GUIDED VEHICLES NAVIGATION - A SURVEY

The first fully automatically controlled vehicles for industrial application (previously called driverless vehicles) was design in 1954 year [7]. The electric cart without the driver was produced by Barrett Electronics¹. One of the first industrial problems 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 first non-wire navigation system using laser target navigation system was develop. In this system reflective targets are mounted above the floor of facility. Additionally the facility work space was given by a XY coordinate system. The basic work space coordinates are loaded into onboard AGV's memory. Laser with rotating mirror was emitting the laser beam. With the laser light help was measured distance to the other object in the work space in automatic mode. The obtained data compared with onboard memory configuration

¹ Barrett Electronics Corporation, Northbrook, Illinois, USA.

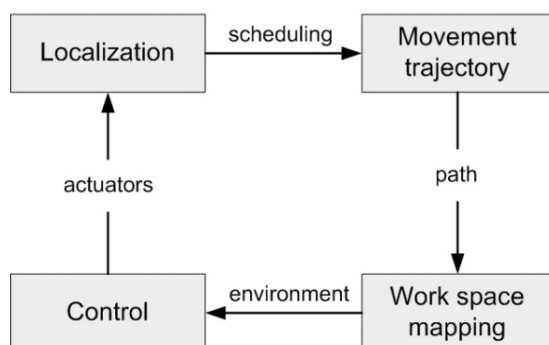
(after several AGV position preprocessing) gave actual vehicle position. After that, the AGV onboard computer can compare calculated position with a preplanned path. On the base path stored in the onboard memory another steering instructions can be sending to the AGV actuators.

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 estimated on the base of travel deviations. Additionally in the facility floor were installed magnet markers with unique X,Y coordinates. There markers were 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 corrected and additionally the signal from the nearest marker position was checked.

2.1. AUTOMATED GUIDED VEHICLE NAVIGATION PROBLEM

Contemporary 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 new kind of solution so-called e-systems was developed. E-systems contributed to development of a new kind of automated control vehicles - UGV. Unmanned Ground Vehicles are a whole family of vehicles that use modern tools with all power today available electronics for navigation task and decision making process on the basis of artificial intelligence (AI) algorithms. On the Fig. 1 a chart of UGV's navigation system was presented.

Fig. 1. UGV's navigation system mode



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, 10, 14, 26].

2.2. AGV LOCALIZATION

The need 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 flow 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 requires a high level of computing power.

In the navigation system designing phase (both in the global and local coordinates system) it is necessary to take a decision about passive or active localization mode. In the passive mode the transport unit can't make an extra move for the localization process. In active mode transport device has possibility to 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 expects sensors group designed for the purposes of getting the information about surrounding transport device. For this target the following issnes 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 sensors motion 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 accurate calculation of 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. It 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 work space save on the onboard memory with the pictures (or chosen pictures parameters) taken in real time mode.

To summed 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 CEP² accuracy ratings (with disabled SA³) approximately: <4m horizontally and <10m vertically.

² CEP is defined as the radius of a circle centered on the true value that contains 50% of the actual GPS measurements. So a receiver with 1 meter CEP accuracy will be within one meter of the true measurement 50% of the time. The other 50% of the time the measurement will be in error by more than one meter.

³ Selective Availability (SA) was an intentional degradation of public GPS signals implemented for USA national security reasons. At the direction of the Bill

3. TRAJECTORY AND PATH PLANNING FOR AGV VEHICLES

The main rule of design trajectory for the AGV vehicle consists of the preplanned the path of 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 must be planed with special optimizing criteria with defined goal function. All optimizing criterion in the trajectory design process can be expressed by three basic criteria:

- 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 criteria, through combinations criteria expressed above. The essential problem of planning the path consists of seeking the geometrical curve of pass between the initial and defined goal. Additionally the sought curve must consider restrictions associated with obstacles (the movement can't cause the collision) and must consider structural restrictions of the AGV vehicle. From the AGV vehicles group it is possible to single out vehicles with holonomic (see Fig. 2) and nonholonomic kinematic structure (see Fig. 3).

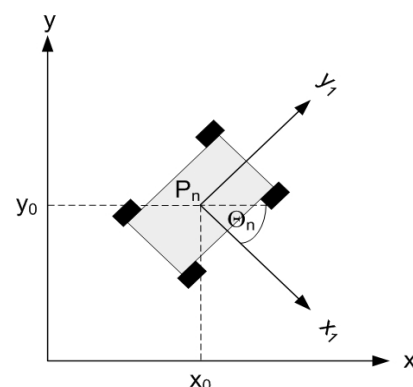


Fig. 2. Vehicle with nonholonomic kinematic structure

Clinton, SA was discontinued in May 2000, to make GPS more responsive to civil and commercial users.

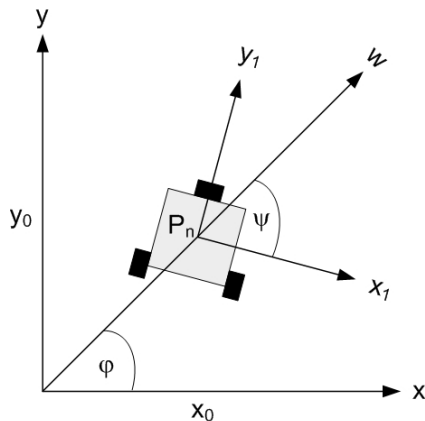


Fig 3. Vehicle with holonomic kinematic structure

Maneuverability possibilities of the AGV vehicles with nonholonomic kinematic structure can be compared 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 maneuvering through revolve around own axis and in some cases ride over the diagonal. At present, AGV structures with holonomic kinematic structure are more willingly implemented inside the container terminal for the limited space reason and limited space for the domestic container terminal route.

Other issue associated with path designing for UGV vehicles is a possibility of obstacles avoidance. The container terminal architecture exclude problems with domestic route surface problem, but in this field is possible to use terramechanics theory⁴ (vehicles wheels cooperation with ground surface). This problem is important because AGV wheels stress is proportional for container with the cargo weight and ground surface kind.

3.1. METHODS FOR TRAJECTORY PLANNING – A SURVEY

The majority of the solution appearing in scientific literature for automated transport devices

⁴ Terramechanics theory author's is a Polish scientist Mieczysław Bekker. The articles entitled: *Theory of land locomotion* (1956), *Off the road locomotion* (1960) and *Introduction to terrain vehicle* (1969) are the first and pioneer on this field.

trajectories design, based on methods implementing artificial intelligence science e.g.: fuzzy logic [4, 16, 17], heuristic algorithms [19] and hybrid tools assembling fuzzy logic with neural network [1, 18]. For solving the trajectory design problem are used also often genetic algorithms [2, 6].

Container terminals as specific places with fast workspace rebuilt, implement a trajectory planning methods from a UGV vehicle –APF's methods. Artificial Potential Field method consists of the realization of two independent superior operations: pull the target and push the obstacle. Between start and finish vehicle point was realized the 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) [32].

Another methods used for trajectory design in container terminal are 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 [12].

3.2. CHARACTERISTICS OF THE TRAJECTORY PLANNING METHODS

Depending on the availability of the information about surroundings and transport means kind, it is possible to divide methods of trajectory planning into three groups: global, local and hybrid methods.

In global methods are usually used idealized model of transport devices and the work space is constant in time or every taken action is registered. However the algorithm for trajectory planning has an access to data base with data that refer work space changes. Global methods flexibility level is very low, additionally in order to realize it a lot of computational power is needed. Global methods are good only in off-line mode and its primary target is trajectory preselecting. Local methods constitute the opposite for the global methods and can be used in 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 of hybrid methods for trajectory planning it is more efficient and more interactive. The transport device in automatic mode has a possibility of comparing the currently prevailing work space conditions with work space digital model. In the case of detecting disagreements, the pre planned trajectory is corrected. The trajectory is changing only in segment where the further move could cause collisions with other transport device or object. To sum up, the hybrid methods join advantage of local and global trajectory methods planning with simultaneous eliminating of majority of weak points.

Other manner of methods for trajectory planning distribution include only 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 outline all possible paths. The raster methods base on the geometrical methods for trajectory planning. An example illustrating the discussed issue is a "tabu search" algorithm [2, 5]. The TS method is used for solving Traveling Salesman Problem in container terminals. The essential idea of this application, consists of searching all possible combination of paths (also prohibited) generated on the base functional container terminal model (see Fig. 4). In the next step the generated path on the functional model base (see Fig. 5) is converted into a graph (see Fig. 6) for estimating a better solution.

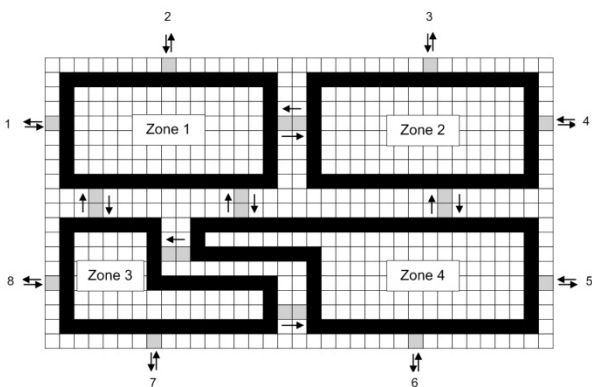


Fig. 4. Functional model of container terminal [22]

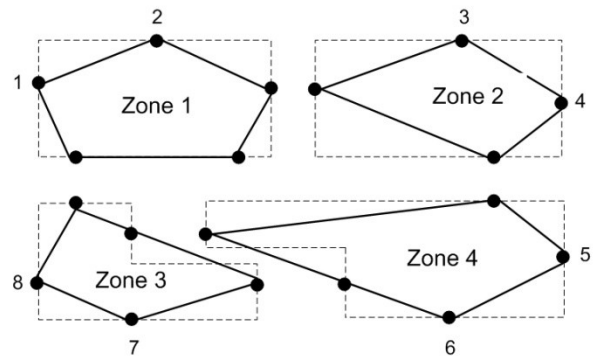


Fig. 5. Functional model converted into path graph

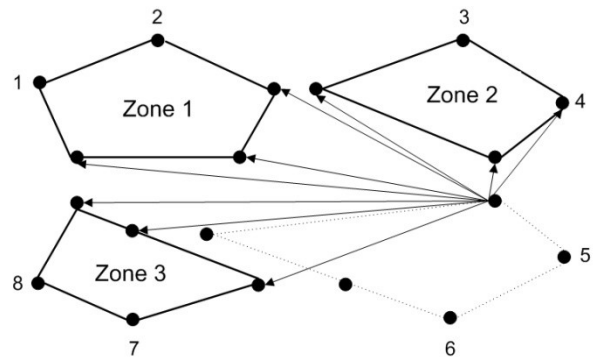


Fig. 6. Graf preparation for the TS algorithm

Raster methods consist in the division of the work space with the grid. The grid elementary cell can have regular or irregular shape (see Fig. 7). After the cell distribution including obstacles and the inaccessible places for the AGV unit the trajectory can be replanned.

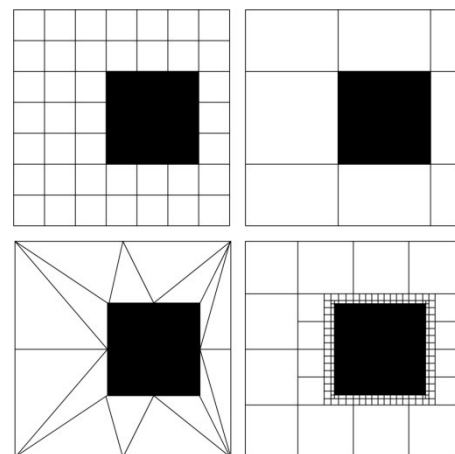


Fig. 7. Elementary grid cell for raster trajectory planning methods

One of regular raster method algorithm is so called quad tree method [29]. In this 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. The another divisions enables construction the kind of tree (see Fig. 8), of which every top is a point of graph determined to search. The next step determine that the cells are adjacent to themselves. When the cells are adjacent, it is possible to plan the grade-separated trajectory of the further move [14].

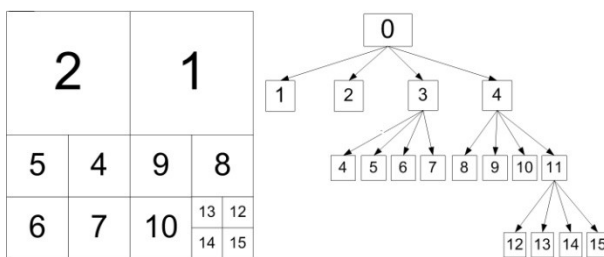


Fig. 8. Quad-tree division with the graph

4. WORK SPACE MAPPING

The work space maps are used to determine a location within an environment and to depict the dynamic changes of environment for trajectory planning [8]. They support the assessment of actual location by recording information obtained with the help of electronic devices. The benefit of a poses work space digital map in aiding the assessment of a obstacle location and increases the precision of automatic transport devices moves. However, work space 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 work space in real time mode [13]. Work space mapping is a set of various operation undertaken for one purpose: collect the information about material handling devices surroundings. So, the work space mapping is a representation preserving properties of bijection type.

In order to increase the number of AGV vehicles operating at container terminal it is necessary to eliminate hazardous situation. For this purpose several types of work space systems and concepts have been developed. One of them is

SLAM system [3, 10]. 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 work space and on their base a actual work space model is generated.

For supporting work space mapping the new methods was developed, deliver a tools for precision work space mapping, dedicated for automated control transport devices. With the help of 3D laser scanner [21] it is possible to built a system for precise work space mapping (see Fig. 9).

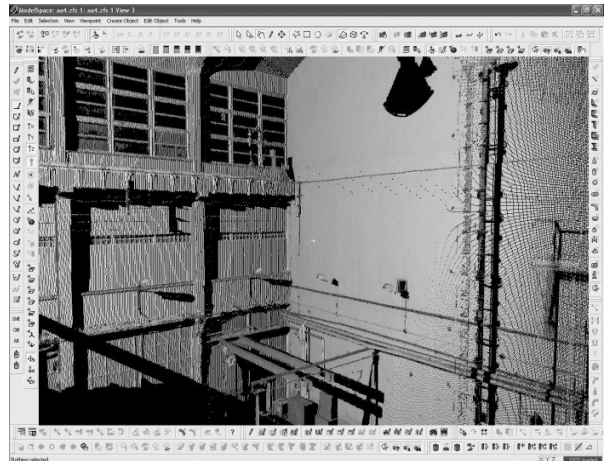


Fig. 9. The model of bridge crane work space generated on the cloud of point 3D scan data base

Additionally it is possible to use other solutions e.g. Vision technique [23] for obtaining information linking mapping model with information gathered in real time mode [21]. The answer for this challenge is CV. As a scientific discipline CV (Computer Vision) is focused on 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 work space

mapping is stereovision [23] with dense disparity map calculation.

5. AGV CONTROL MODE

The problem of improving dependability of existing AGV control system is under investigation through research and development centre [11, 15, 24, 28]. At present novel control systems [9] are dedicated for 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 computer [20].

FMS's expansion is linked with the decentralized system structure of MAS type [27]. The decentralized control system scheme was presented on the Fig. 10

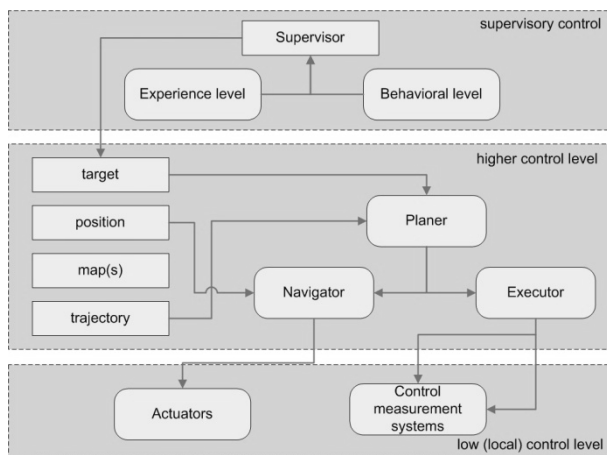


Fig. 10. Decentralized multi-agent system

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 to use a kind of data base with social behavior with rules support control process.

The main idea of MAS (Multi Agent System) is modeling social behavior of life form implementing in various transport system especially material handling systems. The One of the first MAS systems was built on the base ants colony [20]. In this work a decentralized algorithm of MAS type for AGV's vehicles was presented. The main algorithm rules was designed on the social insects behavior base, e.g. ants (see Fig. 11).

In the presented algorithm a complete path finding solution (routing) is based on the ant social behavior. In the real ants life a path from the

nest to the food source is the optimization problem of TSP type, similar to the tabu search algorithm.

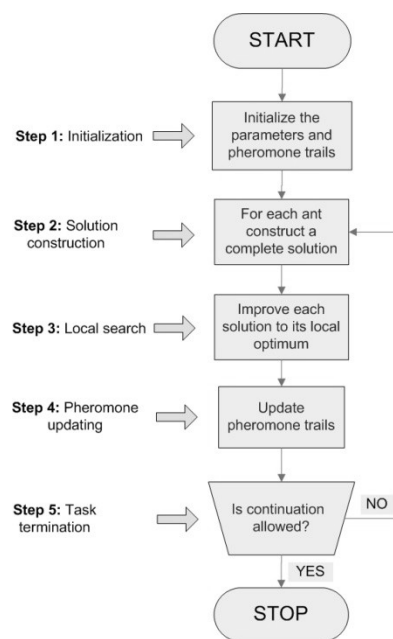


Fig. 11. The ant algorithm main steps

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 behavior 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 to notice attempts to modify existing control methods through enriching e.g. PID regulator with new elements. The hybrid tool linking Proportional-Integral-Derivative controller with self-adjusting model excreted from immune system⁵ (see Fig. 12).

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

⁵ An immune system is a system of biological structures and processes within an organism that protects against disease by identifying and killing pathogens and tumor cells.

the immune response, T_h helps the other parts, and T_k destroys pathogenic material.

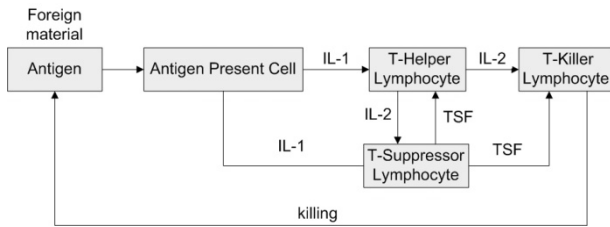


Fig. 12. The immune response system regulation mechanism

The PID control system enrich in the immune system rules was designed for the needs of unmanned container transporter (UCT). This UTC was operated in a harbor to transport containers. Generally, various sensors (magnetic, ultrasonic, infrared and other) are used to detect the path trajectory or recognize obstacles. The authors [30] chose vision system with a CCD camera attached in front of UTC vehicles for vision data acquisition. The paths are composed of a black surface and yellow guide lines. To recognize UTC's positions it was necessary appropriate data collected filtering process. System was designed for the needs of 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 of an interference.

From the set of technique predestinate to UGV's control methods with artificial intelligence perform a fuzzy logic control (see Fig. 13) [4]. Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory⁶.

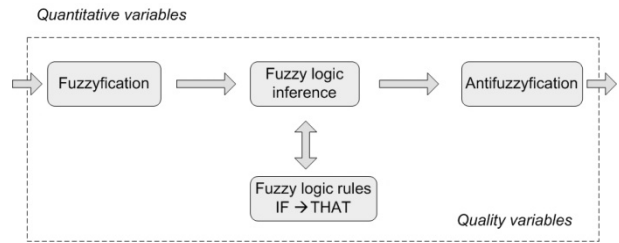


Fig. 13 The block scheme of fuzzy logic control

Fuzzy logic variables may have a truth value that ranges between 0 and 1 (see Fig. 14). The control process with fuzzy logic set theories usage (for AGV's vehicles or other material handling devices) constitutes important complement of existing methods and tools for syntheses nonlinear autonomous systems.

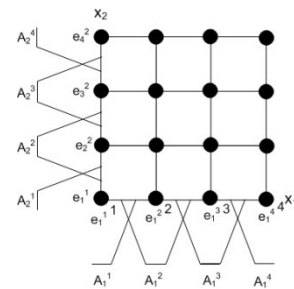


Fig. 14. The fuzzy logic example set for the purposes of AGV vehicles control

The main advantages of fuzzy logic control are possibilities of obtaining simple and independent form of disruptions solution in a wide range of parameters, no much sensitive to the inaccuracy of control system model.

6. THE SUMMARY

In this paper, authors have discussed most key issues related to AGV's navigation problem. The quantitative and qualitative analysis was done for described AGV's qualities and limitations.

The navigation system has a strategic role in AGV's design and control. In this paper navigation system was divided into four categories (see Fig. 1): localization, movement trajectory, control and work space mapping. Each of presented categories was detailed described with literature review and present trends talk over. After reviewing publications of the navigation field of AGV's devices, authors found some blank places which need to be studied more deeply. However this gaps suggest the directions for future research:

⁶ Fuzzy logic theory father is a Lotfali Askar Zadeh, better known as Lotfi A. Zadeh, mathematician, electrical engineer, computer scientist, and a professor of computer science at the University of California, Berkeley, USA.

- The significance of UTC's operated in a harbor (for container transport) are dramatically growth. However, more studies are still needed to improve these agents advanced capabilities such as self-learning or use more AI technique for autonomous task realization a decision making process,
- Specialized vehicles are expensive in use especially a family of ALV vehicles (Automatic Lifting Vehicle). These vehicles are predestinate to work in the container terminal. They don't need a assist other lifting vehicle to unload/load the cargo. There is still lack of studies which develop efficient scheduling and dispatching algorithms for economic ALV's use,
- In future it is important to possess tools for estimating the required number of vehicles and limit vehicle empty travel,
- AGV's system must be flexible. For example today obtaining an optimal guide-path system is crucial but in future, the flexibility of whole system and adaptation skill might be more important,
- It is important to still improve the navigation methods for AGV vehicles, the navigation dependability is one of the crucial requirements for the whole system performance.

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