New AGV Capabilities are Safety Driven

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Automated guided vehicles (AGVs) transporting material usually travel along a two-way street. More specifically, they work in single or dual opposing-direction lanes along known paths near workers. We polled AGV manufacturers, and several representatives said this is ideal for safe AGV operation. However, when an AGV halts for an obstacle in its path, it serially stops the flow of other AGVs behind it until the obstacle moves out of the way (e.g., a person walks across the AGV path) or is removed by an AGV supervisor (e.g., picking up a piece of broken pallet dropped in the lane). This can slow production rates and may require more or faster vehicles to achieve the continuous material flow rates desired by the facility owner.

An alternative to stopping and waiting for obstacles to be cleared from the AGV path is to implement obstacle detection and avoidance (ODA) [1], a concept that is well known to the mobile robot research community, but is not as familiar to the AGV world. In our research we found two videos of AGV companies demonstrating their vehicles detecting and avoiding obstacles. These involve a unit load vehicle [2] and a floor cleaning vehicle [3]. Further research also uncovered another floor cleaning robot manufacturer that provided similar capability [4].

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One of the AGV companies that demonstrated ODA stated that "autonomous navigation provides increased responsiveness, operational flexibility, and improved material flow." So, there appears to be both points of view in the AGV industry.

Facility Adaptation

Seeing the potential benefit of ODA to the AGV industry, the National Institute of Standards and Technology (NIST) is performing research in this area. Moreover, in the Smart Manufacturing Program, NIST looks beyond ODA technology towards the future when AGVs can expand to small and medium size manufacturers where the AGV would be required to more or less adapt to the facility using unstructured environment navigation. Also, these areas may include humans working in close proximity to vehicles and AGVs may be used to carry advanced onboard equipment such as robotic arms.

NIST has been researching both mobile robot and AGV control for understanding what capabilities are possible and developing safety and performance test methods for several years [5, 6, 7]. NIST mobile autonomous vehicle research has investigated performance of obstacle detection algorithms and sensors with respect to standard test pieces, human forms and overhanging obstacles to foster more intelligently

controlled AGVs. Past AGV controls research was enabled through open-source controls and algorithms developed by NIST, for example, to navigate between waypoints on its own and then using non-contact sensors (e.g., active RFID [radio frequency identification]), LADAR/LIDAR (laser/light detection and ranging), and stereo vision to detect doorways, turns and obstacles to continue navigation to the destination without stopping.

Recently, NIST procured an industrial AGV with stock controls for developing performance metrics and test methods for mobile robots within smart manufacturing facilities. Using existing technology to conduct this research dramatically reduces the risk of using ODA or other technologies for current AGV users and manufacturers. The 2025 Material Handling and Logistics Roadmap suggests that "as confidence in algorithms increases, many routine and even complex decisions will be turned over and automated" and "real-time optimization algorithms for dynamic control of logistics systems should be developed and widely used." [8]

Where AGVs are Headed

Detecting and avoiding obstacles may be considered complex for some in the industry, but it is also directing them toward future unstructured environment navigation—even with their current AGV systems.

NIST is investigating whether current, commercial off-the-shelf AGVs, having closed-source proprietary controls, could be controlled to perform with greater flexibility, such as adapting to changing environments, and if so, how well they perform. Hence, NIST also worked with ASTM International to begin a new AGV performance standard. Should the AGV adapt appropriately, overall factory performance would benefit, for example, through enabling parallel material handling AGV flow, where a stopped AGV or obstacle could be passed by other AGVs in buffer zones or adjacent lanes.

Having buffer zones is perhaps not new to the industry, although performing passing or ODA operations in other areas is new—requiring sensor integration and algorithm development. The NIST algorithm uses an externally generated spline which the stock controller calls when approaching the segment with obstacles.

In the test case, two facility-based line scanners detected the obstacle positions and shared their positions with the planner algorithm. Facility-based scanners limit the passing location to the detection area but are a good place to begin algorithm development and testing, as well as providing obstacle views from multiple positions making one-time path planning possible. However, future use of onboard scanners appears ideal for full unstructured facility navigation since the sensors are already used to detect obstacles, although from only the AGV travel direction.

Three-dimensional (3-D) scanners would be ideal for obstacle detection. NIST hopes to continue developing this concept too. The onboard sensors simply require raw scan data to be accessible to the controller and some of the current sensors already provide this capability. Using this feature would require simultaneous AGV position and relative obstacle position be communicated to the AGV from the onboard line scanners and a filter to only detect obstacles in the AGV path.

Once planned, a new path can be sent to the AGV controller to execute. Should a detected obstacle move within, or a new obstacle appear within, the new spline path, the AGV safety sensors simply stop the AGV normally until the obstacle is removed. Therefore, safe operation is unchanged.

The NIST algorithm also provides a feature called "exclusive tracks" to prevent AGVs from approaching each other from different directions, sensing each other and going into emergency stop mode. With this

option, one AGV is given priority. The path that it sweeps out adds boundaries that will be considered in planning the path of the other AGV.

After a series of tests, a laser tracker measurement system was used to detect how closely the AGV followed the new spline path. In only a handfull of runs, worst case distance to spline generated waypoints along the straightaways were approximately 60 mm. Measurement of the curves showed they were further away, although analysis did not consider a mathematical spline-based comparison. In summary, the spline generator algorithm that was adapted to a current AGV controller performed as expected. Tolerances to force the AGV to traverse closer to waypoints is also achievable if necessary.

Other AGV advancements, namely AGV performance and mobile manipulator performance and safety, require similar measurements to understand how useful these systems can be to manufacturers and other industries, especially for small- to medium-sized companies who might question adaptability of automated systems to their facilities or processes.

Besides the obstacle detection and avoidance testing, NIST has been measuring the performance of AGVs towards test methods potentially useful to the new ASTM F45 Driverless Automatic Guided Industrial Vehicles standard. Driving vehicles along simple geometric shaped paths (e.g., circles and squares) will help determine if the AGVs and their trackers (interval position recording), as compared to ground truth measurement system trackers, provide the AGV navigation accuracy and repeatability that AGV users need. Especially when adding onboard equipment, such as a robot arm, that requires the AGV to position and move the robot base along a path with precision.

A new performance test apparatus for mobile manipulators is being developed at NIST to test how accurately the robot accesses part or assembly locations. The reconfigurable apparatus can be assembled into various flat, convex and concave patterns and includes curved, circular, square and triangular patterns of points for the mobile manipulator to access via adjustable-angle reflector positioners and collimated cylinders to ensure directional alignment and to maximize test patterns that generically model robot pose requirements needed for manufacturing.

NIST has also been working on collaborative robot research within the Smart Manufacturing Program. Early tests of a lightweight manipulator integrated onto the NIST AGV already uncovered potential control methods and safety interlock possibilities for future safety standards to consider. There are still gaps that need to be addressed, however, between the AGV and the robot arm safety standards.

This article is based on research by Roger Bostelman, Will Shackleford and Geraldine Cheok of the National Institute of Standards and Technology. Bostelman is a member of MH&L's Editorial Advisory Board.

[1]"Obstacle Detection and Avoidance from an Automated Guided Vehicle," by Bostelman, Shackleford and Cheok, to be presented at the 6th Workshop on Planning, Perception and Navigation for Intelligent Vehicles, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014) in Chicago, Ill., September 14, 2014.

[2] Video of obstacle avoidance, http://youtube.com/JVigBUcvA-c, consulted October 2013.

[3] Video of autonomous floor cleaning robot avoids obstacles, http://www.youtube.com/watch?v=4GJ0oEBbBfQ, consulted October 2013.

[4] Wikipedia, search on "mobile robot," June 21, 2014.

[5]Roger Bostelman, Will Shackleford, Geraldine Cheok, Richard Norcross, "Standard Test Procedures and Metrics Development for Automated Guided Vehicle Safety Standards," Performance Metrics for Intelligent Systems (PerMIS'12) Workshop, College Park, MD, March 2012.

[6] Roger Bostelman, Will Shackleford, Geraldine Cheok, Kamel Saidi, "Safe Control of Manufacturing Vehicles Research Towards Standard Test Methods, International Material Handling Research Colloquium (IMHRC) 2012, Gardanne, France, June 2012.

[7] Roger Bostelman, Richard Norcrossa, Joe Falco, Jeremy Marvel, "Development of Standard Test Methods for Unmanned and Manned Industrial Vehicles Used Near Humans, SPIE Defense, Security, and Sensing 2013, Baltimore, MD, May 2013.

[8] Material Handling and Logistics U.S. Roadmap, http://www.mhlroadmap.org/,2014.

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