SAFETY AND PERFORMANCE STANDARD DEVELOPMENTS FOR AUTOMATED GUIDED VEHICLES

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The American National Standards Institute/Industrial Truck Standards Development Foundation (ANSI/ITSDF) B56.5 Safety Standard committee for safety of automated guided vehicles (AGVs) recently considered proposals for changes to improve the to make AGVs safer. The potential changes include new bumper force test methods and revisions to address sudden obstacle appearance in the AGV path. Also, the committee discussed the addition of full human form test pieces to the three current geometric obstacle test pieces. Beyond these changes to the safety standard, the National Institute of Standards and Technology (NIST) has suggested a new AGV Performance Standard be established through ASTM International to provide AGV users and manufacturers with non-safety test methods to relate measured vehicle performance to required tasks. The ASTM AGV Performance standard has been approved. Both the suggested safety standard improvements, and the proposed new performance standard, are described and/or referenced in this paper including illustrative laboratory measurement data and analysis to foster and support discussion.

1. Introduction

The American National Standards Institute/Industrial Truck Standards Development Foundation (ANSI/ITSDF) B56.5 Safety Standard for automatic guided vehicles (AGVs) and manned vehicles with automated functions* was modified in 2012 to include several additions, one of which was the non-contact safety sensing test method. The standard now states that if noncontact sensing devices are used "as the primary sensing device," as opposed to contact bumpers, the sensor "shall be fail-safe in its operation and mounting, and when sensing people or an object in the path of the vehicle at a distance no less than

* ANSI/ITSDF B56.5 Safety Standard for AGVs and manned vehicles with automated functions

the leading edge of the sensing field in the main direction of travel shall cause a safety stop of the vehicle prior to contact between the vehicle structure and the people or objects." Additionally, test pieces are to be placed at specific locations and orientations, with specific dimensions and coatings, and sensed by the noncontact sensors while the vehicle is static or moving at half or full speeds towards the test pieces. Test pieces mandated in ANSI/ITSDF B56.5 and BS EN1525† are 70 mm diameter x 400 mm long and 200 mm diameter x 600 mm long cylinders. B56.5 also includes a 0.5 m square flat panel. Figure 1 shows the test piece placement for the noncontact sensing as defined in the standard. Test pieces are a step forward but as stated in B56.5, "when sensing people" the enhanced standard may still fall short of establishing requirements to ensure people near vehicles are properly detected and safe.

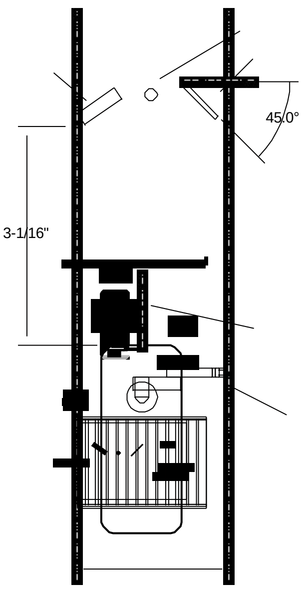

Figure 1 – Figure from ANSI/ITSDF B56.5 showing the (a) test method and (b) sensing areas required of noncontact sensors on AGVs.

To address these issues, the NIST Intelligent Systems Division's new Robotic Systems for Smart Manufacturing Program is reviewing AGV standards to consider new performance and updated safety test methods for current (e.g., bumpers) and future industrial vehicle technology (e.g., mobile manipulators or collaborative AGVs operating with workers). Standards have never included test methods for AGV bumpers to guarantee that manufacturers all use the same procedures to assess performance of their bumper measurements. Hence, bumper test methods are being formally proposed by NIST to the B56.5 committee. Additionally, no test methods are currently defined in any AGV standards for when objects suddenly enter the area needed to stop the AGV upon detecting obstacles in the path. A solution to this "exception," as it is termed in the standard, is also being formally proposed

† British Standard EN 1525:1997 Driverless industrial trucks and their systems.

by NIST to the B56.5 committee where the AGV system performance is measured and AGV braking results reported. These two formal proposals are further described in this paper.

In addition, improvements of non-contact test procedures are needed to address detection of human shapes, instead of just human-representative geometric test pieces, so as to more fully and consistently find actual human presence. In a 2012 AGV accident, an "employee was discovered pinned between a laser-guided AGV and a metal racking unit."[‡] No detailed information has been released describing the reason for the incident, but inadequacies in safety procedures and sensor systems tied to AGV controls are possibilities. For example, in order for AGVs to access loads or move in confined areas, sensor systems are sometimes turned off. Standards to reduce the possibility of failing to detect a person in these spaces and elsewhere, as well as smarter, more capable, and always-on sensing systems and algorithms are required. This paper will detail an informal proposal for the B56.5 committee to consider for sensing people near AGVs. The proposed test method is supported by lab experiments measuring the performance of three dimensional (3D) advanced sensor systems detecting mannequins in mock scenarios of manufacturing or distribution facility workers and materials.

2. Bumper Force Test Methods

The original obstacle detection device, still in use today on many AGVs, is the collapsible contact bumper. These bumpers are instrumented to trigger a safety rated stop if they collide with an obstacle. Although performance measures are specified in AGV safety standards, there are no test methods specified to accompany them. Allowable forces exerted by an AGV bumper on a standard test piece, vary between B56.5 and the European standard. NIST does not set the force limits and instead develops and verifies test methods so that any mandated force limit can be tested the same way. A bumper force test method formally proposed to B56.5 is:

Test Method for Vertical Test Piece Bumper Force Measurement[§]

1. *Two force sensors, for example: load cells, strain gages, spring scales, etc., shall be calibrated prior to testing and able to accurately (within 1 N) measure the force applied to the test piece from the bumper.*

[‡] Tom Andel, "Death by AGV is a Tragic Surprise," Material Handling and Logistics Magazine, August 2012.

[§] Richard Norcross, Roger Bostelman, Joe Falco, "Automated Guided Vehicle Bumper Test Method Development," unpublished NIST report, available upon request, September 26, 2013.

2. *Mount the standard vertical test piece, as shown in Figure 2, to the bumper force measurement apparatus. Test pieces used must be rigid so that no applied force on the test piece causes test piece deflection. The test piece shall be mounted vertically as measured using a leveling device.*

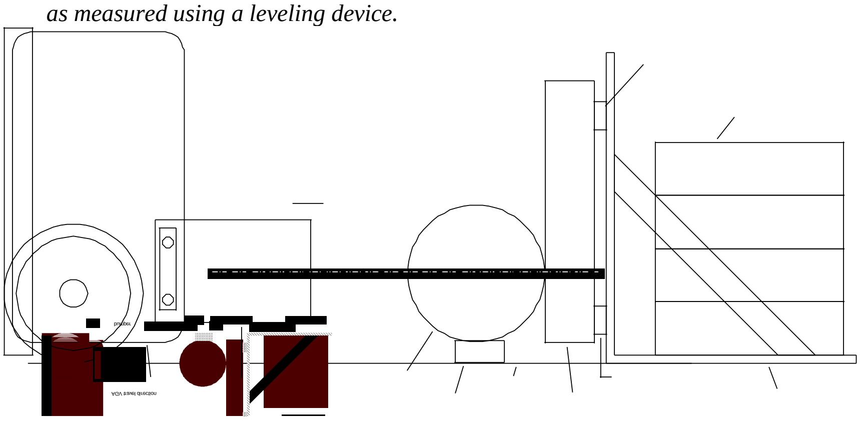

Figure 2: AGV bumper contacting the standard vertical test piece mounted to the bumper force apparatus. Shown in dashed lines is the horizontal test piece placed for that test.

3. *Support the vertical test piece from both ends to the bumper force test apparatus to only allow motion along the applied-force axis.*
4. *Two force measurement devices shall be mounted, between and in contact with the test piece and the apparatus, such that one is above and one is below the applied force.*
5. *The apparatus shall be weighted or fastened to the ground or other fixture so that it does not move during testing or such that the apparatus breaks away from ground friction or fastening to not harm the AGV or other equipment in case of unexpected forces.*
6. *Test the bumper striking the test piece as the bumper moves at varying approach angles and velocities to the test piece to include all maximum forces, including bumper-to-vehicle mount transitions, and ensuring all approach angles trigger safety stops.*
7. *Force data for initial impact force (the maximum force when the bumper first strikes the test piece) and clamping force (the maximum sustained force after impacting the test piece) shall be logged. Resulting impact forces and clamping forces from the two measurement devices (i.e., two data points for each force type) shall be summed and compared to be below the standard maximum bumper forces.*

A similar test method is proposed for the horizontal test piece where it is placed against the vertical test piece (see Figure 2) and the above test method is repeated.

3. Sudden Obstacles and Discussion of 'Exception' to Standard

As described in section 1 Introduction, test pieces are to be detected beyond the stop zone so that the AGV has time to decelerate to a stop prior to contacting the test piece. However, there is an exception in the standard for when obstacles suddenly appear within the stop zone:

"EXCEPTION: Although the vehicle braking system may be performing correctly and as designed, it cannot be expected to function as designed and specified in para 4.3.1 should an object suddenly appear in the path of the vehicle and within the designed safe stopping distance. Examples include, but are not limited to, an object falling from overhead or a pedestrian stepping into the path of a vehicle at the last instant."

Currently in B56.5 there is no language within the 'Exception' that states that the AGV must attempt to slow, stop, or use an alternative maneuver to avoid contact with an obstacle that suddenly appears within the stop zone (defined as maximum stopping distance x vehicle width including onboard equipment and payload). Also, there is no test method for how to measure that an obstacle appeared suddenly within the stop zone of the AGV, as opposed to outside of the stop zone, or that the vehicle reduced energy upon obstacle detection. The proposed test method does not suggest any changes to AGVs. Instead, the proposal provides more explanation of the exception along with means to measure that the test piece is indeed within the stop zone without using onboard sensors, and means to measure that upon detection the vehicle energy was reduced. A formally proposed test method[**] is therefore:

Add to 8.11.1.2 Noncontact Sensing Devices: *As referenced in (the Exception), should an obstacle suddenly appear between the vehicle and the leading edge of the sensing field in the main direction of travel, the sensing device and braking system cannot be expected to function as designed. In this case, the vehicle shall demonstrate through braking and/or safe maneuvers (e.g., obstacle avoidance), that action was taken to avoid or reduce the contact energy between the vehicle and the obstacle. An example test method for measuring the demonstrated action is shown in Section 8.11.1.2.2.*

Add to section 8.11.1.2.2 Test Method for Obstacles Within the Stop Zone: *AGV manufacturers should use the following test method for measuring reduced vehicle energy when a test piece enters the vehicle stop zone:*

1. *Measure and record the stop distance of the vehicle or obstacle avoidance maneuverability while traveling at half and full speeds for the various braking methods used (e.g., emergency, controlled, coast, etc.) and for the typical loading, terrain, and environment where the vehicle will be used.*
2. *A grid representing the vehicle width and twice the vehicle stopping distance (e.g., 4 m (L) x 1 m (W) divided into 5 cm sections for a vehicle controlled to stop in 2 m), is printed on paper and taped to the floor or painted on the floor in the main direction of vehicle travel within the test space. For each 1 m x 1 m square, diagonal lines are drawn from the corners to provide additional location information and for easy review of particular squares.*
3. *Mount the 70 mm diameter x 400 mm tall vertical cylinder test piece on wheels.*

[**] Roger Bostelman, Will Shackleford, Geraldine Cheok, Kamel Saidi, "Safe Control of Manufacturing Vehicles Research Towards Standard Test Methods" Progress in Material Handling Practice (Book Chapter), June 2012.

4. *Mount a video camera(s) in the test space to view the entire grid or more to capture the vehicle speed prior to obstacle detection (e.g., 1 m) and the end of the vehicle path where the vehicle slows and/or stops. Above the space is the ideal camera vantage point. The camera(s) must have a high enough resolution to clearly view the 5 cm or smaller grid blocks.*
5. *At the start position, a photosensor, Photosensor 1, is placed on the floor next to the vehicle so that the emitted laser beam is along the edge of the vehicle stop zone. The emitted beam is reflected back to the photosensor along the grid edge by a reflector placed beyond the vehicle stop zone. Detection occurs when the photosensor triggers a light visible by the camera, indicating the time when and location where the test piece entered the vehicle path.*
6. *Similarly, the beam from a second photosensor, Photosensor 2, is placed to cross the vehicle path to detect the approaching vehicle and is used to turn on a second light. Photosensor 2 is placed 1 m from the point where the test piece is pushed into the path indicating to the test piece operator when to push the test piece into the path. [Note: The 1 m distance was chosen to ensure that the test piece would be struck when the vehicle travels at 1 m/s and is well within the vehicle stop zone and distance at this speed.]*
7. *Position the vehicle at the start position in front of the grid and begin video recording.*
8. *Ensure that the test piece operator and other test viewers will not be in any danger while performing the test. Control the vehicle to move at half speed over the grid.*
9. *When the Photosensor 2 light turns on, the test piece operator pushes the test piece into the path with a long bar and stops the test piece within the vehicle path. Photosensor 1, pointed at the video camera, turns on when the test piece enters the vehicle path.*
10. *When the onboard vehicle obstacle detection sensor(s) detect(s) the obstacle in the path, the vehicle should reduce kinetic energy and stop. Alternatively, the vehicle may be controlled to avoid the obstacle. Note that the vehicle may contact the obstacle.*
11. *Analyze the video after the test to ensure that the test piece entered the stop zone and that the vehicle reduced kinetic energy upon detection of the obstacle.*
12. *Repeat steps 7 through 11 with the vehicle controlled at full speed.*

4. A New 'Human' Test Piece

The geometric test pieces included in current AGV safety standards represent limited portions of humans, as shown in Figure 3 (a), or other equipment and products. In contrast, examples of various human poses are shown in Figure 3 (b). These are quite different from the standard test pieces. Test pieces that better represent the human form are informally recommended to the safety standards committees to be required for AGV human detection sensor systems. The reconfigurable "human" surrogate could be a mannequin that can reposition extremities or possibly a variety of human shape and image cutouts.

To explore possible surrogate test pieces, NIST procured movable mannequins to position into various human poses and test with current off-theshelf sensor systems for their use on AGVs. Typical clothes were placed on the mannequins and three poses were chosen (pose 1 crouching, pose 2 standing, and pose 6 sitting) to be detected using static stereo vision, Xtion, and Kinect[††] sensors mounted to an AGV (see Figure 4 (a)). Both Xtion and Kinect sensors are based on the same infra-red technology.[‡‡] Also, two dynamic tests were performed using the AGV to move the three sensors toward the pose 2 standing mannequin at 0.5 m/s and 1 m/s (see Figure 4 (b)).

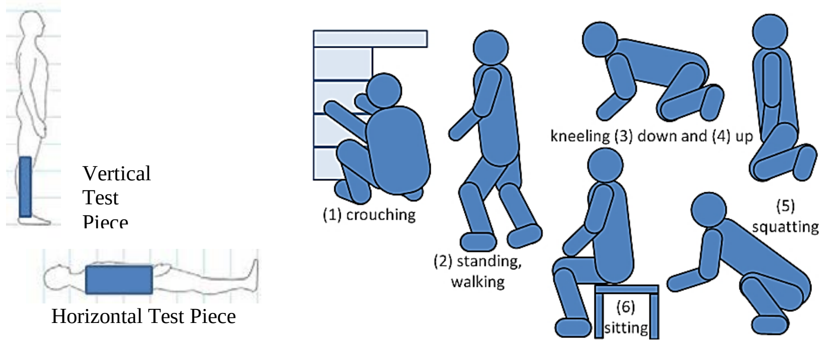

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Figure 3 – (a) Portions of humans that the current standard test pieces may represent. (b) Examples of various human poses not represented by the test pieces.

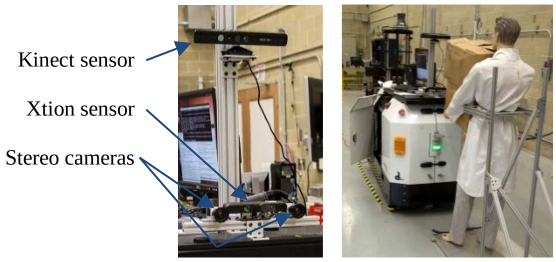

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Figure 4 - Photos of the (a) sensors and (b) AGV used for testing. In (b), the AGV was moving towards the mannequin for dynamic data collection purposes.

Sensor performance was also subjectively measured when detecting mockup materials (e.g., boxes, wire spool, etc.) formed into similar shapes as to the posed mannequin being tested. A more complex scene was set up with a crouched worker in front of industrial shelves. See data comparisons in Figure 5.

[††] NIST does not endorse products discussed within this report nor manufacturers of these products. Products mentioned are for information purposes only and are not expressed as an endorsement for them or their manufacturer.

[‡‡] Depth Sensors Comparison, http://wiki.ipisoft.com/Depth_Sensors_Comparison, 2013.

We suggest that other objects could be mistaken for a human form creating a false positive when detected by sensors and may cause the same AGV reaction as if a person was detected. Even worse would be that an algorithm interprets the data to not be a person when it is a person. Subjective results showed that depth-only sensors provided data too difficult to interpret as mockup materials or a person without an overlaid image as with the Kinect (also available with the Xtion sensor). The authors therefore suggest that interpretation of the various sensor data using a computer algorithm would draw similar conclusions.

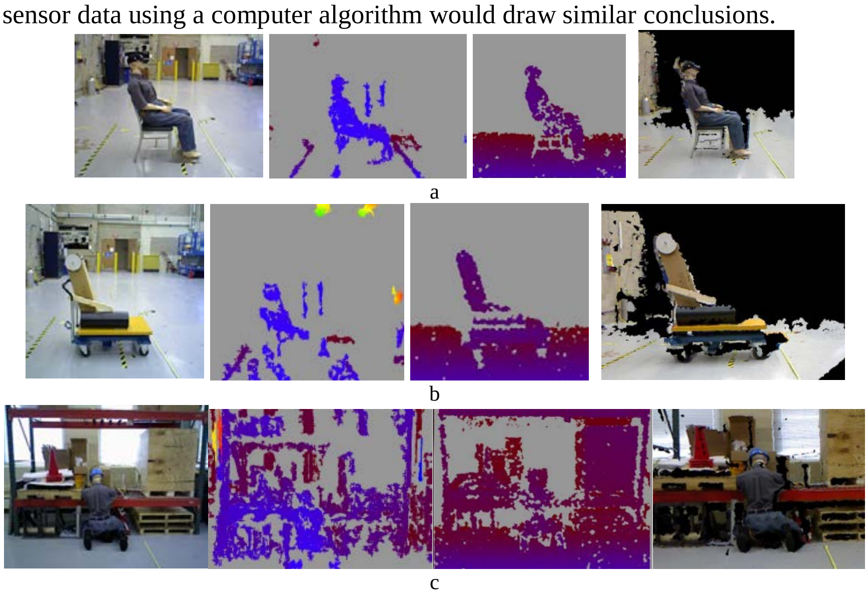

Figure 5 – (left to right) Xtion/Kinect color data, stereo depth data, Xtion/Kinect depth, and Xtion/Kinect fused color and depth data of (a) a seated mannequin, (b) mocked materials, and (c) a crouched worker in front of industrial shelving.

5. Conclusions

Two test methods and a new human form test piece are being proposed by NIST to the ANSI/ITSDF B56.5 committee for acceptance into the standard for improved standard clarification and so that all AGV manufacturers follow the same test procedures. The formal outcome will be presented at CLAWAR.[§§] Also, a new AGV Performance standard was approved by ASTM[***] and will be presented. For AGV developers and users, standard performance test methods would provide tangible representations of AGV operational requirements to help understand task-supporting needs, make trade-off decisions, etc.

[§§] Climbing and Walking Robots 2014, 17th Int'l Conference, Poznan, Poland, 21-23 July.
[***] www.astm.org, 2013.