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Standard Test Method for Grid-Video Obstacle Measurement[1]

This standard is issued under the fixed designation F3265; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Safe control of automatic/automated/autonomous-unmanned ground vehicles (A-UGVs) is critical in industrial environments where workers are or may be present. A-UGV safe control is typically based on sensors that detect stationary standard test pieces (used in ANSI/ITSDF B56.5) representing humans. This and other test method developments have been experimented and published.[2, 3] The experimental results were used to recommend improvements to the ANSI/ITSDF B56.5 safety standard stopping distance exception language in 2014. Subcommittee consensus changed ANSI/ITSDF B56.5 to make it mandatory to reduce vehicle kinetic energy should an object (for example, person, materials, or equipment) appear in the vehicle path and within the stop detect range of the vehicle safety sensors. The language that has been proposed as an amendment to the ANSI/ITSDF B56.5 standard is: "Should an object suddenly appear in the path of the vehicle between the leading edge of the sensing field and the vehicle (for example, an object falling from overhead or a pedestrian stepping into the path of a vehicle at the last instant), the vehicle shall initiate braking in accordance with brake system (see 8.8.1), but may not be expected to stop in time to prevent contact with object." While manufacturers of A-UGVs may have access to internal system logs and data that demonstrate the successful initiation of braking as required, users may not have access to that information. This test method provides an optional, standard performance test method for A-UGVs to enable industrial vehicle manufacturers and users to implement a common test to demonstrate expected vehicle operation in the case of objects appearing in the A-UGV path and within the stop-detect range of the vehicle safety sensors.

1. Scope

1.1 This test method measures an automatic/automated/autonomous-unmanned ground vehicle (A-UGV) kinetic energy reduction when objects appear in the A-UGV path and within the stop-detect range of the vehicle safety sensors in situations in which the desired reaction is for the vehicle to stop as opposed to avoiding the obstacle by traveling on an alternative path. The test method measures the performance of the A-UGV only and does not measure the effect on the stability of loads. This test method describes the use of one test piece as described in ANSI/ITSDF B56.5. Other test pieces from ANSI/ITSDF B56.5 could be used. This test method is intended for use by A-UGV manufacturers, installers, and users. This test method does not substitute for required safety testing under ANSI/ITSDF B56.5 or other normative standards.

1.2 *Performing Location*—This test method shall be performed in a testing laboratory or the location where the apparatus and environmental test conditions are implemented. Environmental conditions are recorded as specified in Practice F3218.

1.3 *Units*—The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversion to inch-pound units. They are close approximate equivalents for the purpose of specifying material dimensions or quantities that are readily available to avoid excessive fabrication costs of test apparatuses while maintaining repeatability and reproducibility of the test method results.

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[1] This test method is under the jurisdiction of ASTM Committee F45 on Robotics, Automation, and Autonomous Systems and is the direct responsibility of Subcommittee F45.03 on A-UGV Object Detection and Protection.

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

[3] Bostelman, Roger, Norcross, Richard, Falco, Joe, and Marvel, Jeremy, "Development of Standard Test Methods for Unmanned and Manned Industrial Vehicles Used Near Humans," SPIE 2013, Baltimore, Maryland, May 2013.

These values given in parentheses are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[4]

F3200 Terminology for Robotics, Automation, and Autonomous Systems

F3218 Practice for Documenting Environmental Conditions for Utilization with A-UGV Test Methods

2.2 *ANSI/ITSDF Standard:*[5]

ANSI/ITSDF B56.5 Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles

3. Terminology

3.1 Terms not defined herein are defined in Terminology F3200.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *collide time, n*—when the automatic/automated/autonomous-unmanned ground vehicle (A-UGV) collides with the test piece.

3.2.2 *defined areas, n*—space constrained by test method boundaries for A-unmanned ground vehicle (A-UGV) operation.

3.2.3 *enter time, n*—when the test piece enters the stop zone triggering photosensor 1.

3.2.4 *start line, n*—line across the path of the vehicle used to signal when the test piece can be inserted into the stop detection range as measured in 7.3.

3.2.5 *start location, n*—the initial zero velocity position of A-UGV at beginning of each test repetition; the start location should be at a point from which the vehicle can accelerate up to test speed before the leading edge crosses the start line along the test trajectory.

3.2.6 *start time, n*—when the A-UGV crosses the start line while traveling at speed.

3.2.7 *stop time, n*—when the A-UGV stops because of detection of the test piece.

3.2.8 *stop zone, n*—the area in front of the direction of travel of the A-UGV where activation of the obstruction sensor causes a safety stop of the vehicle as per ANSI/ITSDF B56.5.

3.2.9 *stopping distance, n*—distance required for vehicle to stop after detecting obstruction.

3.2.10 *repetition, n*—performance of a task.

3.2.11 *task, n*—sequence of movements and measurements that compromise one repetition within a test.

3.2.12 *test, n*—a collection of task repetitions.

4. Significance and Use

4.1 Assuming the vehicle stays on its path and an obstacle appears within the stop zone, the vehicle will collide with the obstacle. Even within the stop zone, obstacle detection should cause the vehicle to slow down as early as possible using non-contact sensing or contact bumpers. ANSI/ITSDF B56.5:2012 discusses a test method to detect standard test pieces beyond the minimum vehicle stopping distance at 50 % and 100 % of vehicle rated speeds.

4.2 This test method can apply to A-UGVs for testing obstacle-sensing capabilities and automatic guided industrial vehicles in automatic mode of operation in non-restricted areas as described in ANSI/ITSDF B56.5.

4.3 Researchers[2, 3] used two-dimensional (2D) laser detection and ranging (LADAR) sensors mounted to an A-UGV. In contrast to the earlier experiments in which the test piece was static, in these experiments the A-UGV and the test piece were both moving. The 2D sensor was mounted to the A-UGV to scan horizontally with the beam approximately 10 cm (4 in.) above and parallel to the floor and confined to detecting the vehicle path (vehicle width) at the maximum stopping distance (coasting or braking). Note that the sensor scan width can be set to any width, including the ANSI/ITSDF B56.5 standard, non-hazard zone vehicle path width of the vehicle plus 0.5 m (1.6 ft). The test piece entered the A-UGV path within the exception zone, was detected by the safety sensor, and the distance of the test piece to the A-UGV and the A-UGV stopping distance measurements were calculated and analyzed.

5. Apparatus

5.1 *List of Materials:*

5.1.1 Grid printed on paper or marked on the floor at regular intervals.

5.1.2 Photosensors 1 and 2.

5.1.3 Lights 1 and 2.

5.1.4 Video camera and recorder with nominal 30 frames per second (fps) frame rate or higher.

5.1.5 Straight bar and clamp (or optional length of rope or string, or both, not shown in Fig. 1).

5.1.6 A-UGV.

5.1.7 Vertical cylinder test piece, 70 mm (2.75 in.) diameter by 400 mm (16 in.), as described in safety standards and representing a human leg.

5.1.8 Onboard A-UGV camera or sighting scope (optional) (see Fig. 2).

5.1.9 Timer to be placed in camera field of view.

5.2 *Experimental Setup:*

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[5] Available from the Industrial Truck Standards Development Foundation (ITSDF), 1750 K St. Nw, Suite 460, Washington, DC 20006, www.itsdf.org.

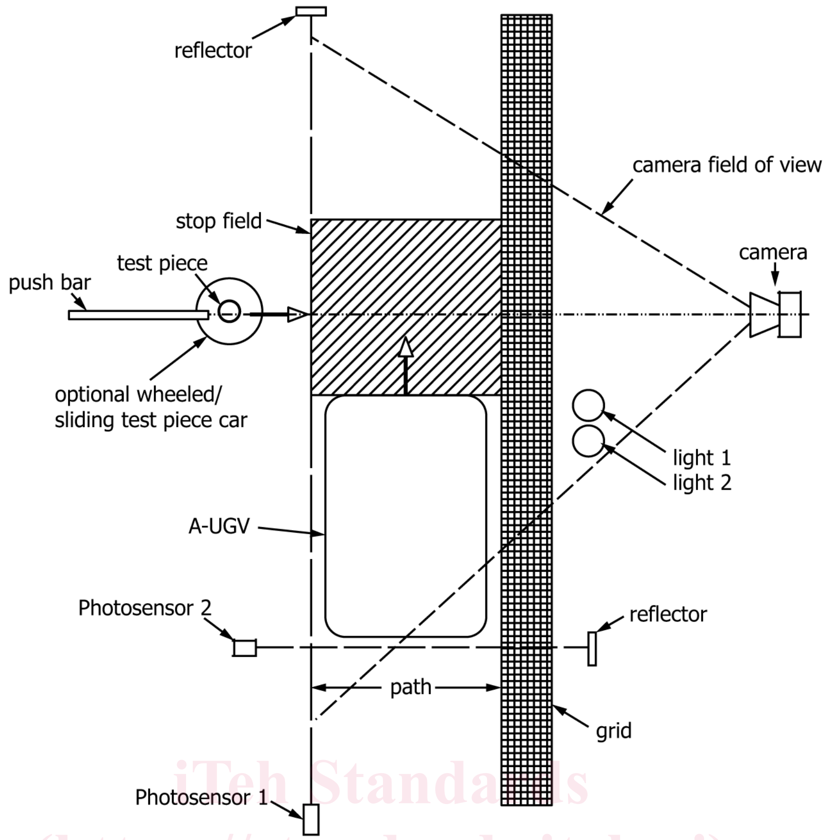

FIG. 1 Apparatus for Grid-Video Test Method

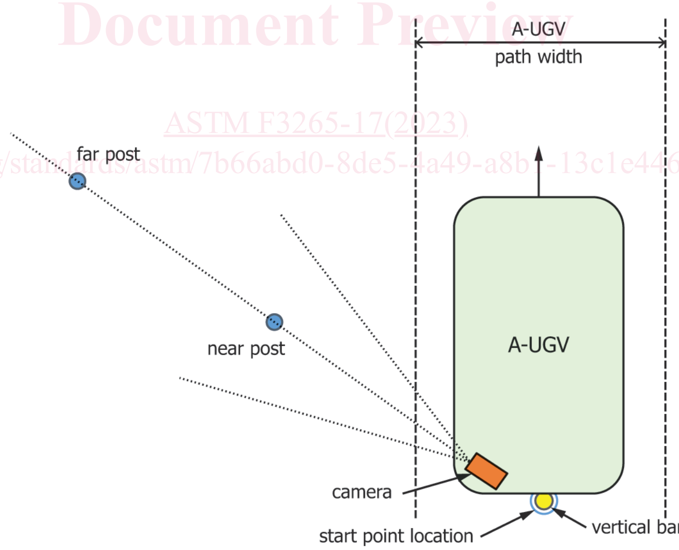

FIG. 2 A-UGV Start Location Calibration Setup with Aligned Posts Using the Onboard Camera FOV and Clamped Bar on the A-UGV Rear Bumper Pointing Down to a Start Location Marked on the Floor

5.2.1 A printed, grid on paper, taped to the floor, or other measurement marks, shall be next to and as close to the A-UGV as possible along its path without changing vehicle performance. The grid shall be at least 4 m (13 ft) long by 0.25 m (0.8 ft) wide and divided into 5 cm (2 in.) segments. The grid should also be labeled every 1 m (3 ft) to provide additional location information.

5.2.2 A 70 mm (2.75 in.) diameter by 400 mm (16 in.) tall vertical cylinder test piece as specified in safety standards shall be mounted on a short cart with wheels or other low friction means so that it can be easily pushed into the A-UGV path without tipping. Optionally, the test piece may be attached to a rope suspended from overhead. The rope should be attached to one end of the test piece so that the piece hangs vertically and hangs just short of making contact with the floor. Setting the rope vertically, with the target in position, a length of rope is attached to the top of the target and extended horizontally to the tester location.

5.2.3 A video camera shall be mounted in a fixed location, with the image plane parallel to the travel surface and aligned with the A-UGV path to capture simultaneously both the test piece and A-UGV motions and stop positions. The video camera shall have a high enough resolution to capture simultaneously and clearly, frame-by-frame, the floor grid, test piece, and A-UGV throughout the test piece motions and stops and the location where the A-UGV detects test piece motion and subsequently travels and stops or decelerates. Video recording shall continue for at least 5 s after the full A-UGV crosses the point of entry of the test piece or the A-UGV stops.

5.2.4 Along the path, a photosensor, Photosensor 1, shall be placed on or within 400 mm (16 in.) above the floor next to the A-UGV so that the emitted beam is along the edge of the A-UGV stop zone and detects the crossing test piece. The emitted beam shall reflect back to the photosensor by a reflector placed beyond the A-UGV stop zone. Photosensor 1 shall control a light, Light 1, on/off that is pointed towards the video camera upon detection of the test piece crossing into the A-UGV path. Light 1 shall be simultaneously detected by the video camera during the test. This simplifies identifying the time that the test piece crosses into the stop zone boundary.

5.2.5 Similarly, the beam from a second photosensor, Photosensor 2, shall cross the A-UGV path to detect the approaching A-UGV and shall be used to turn on a second light, Light 2. Light 2 shall be simultaneously detected by the video camera during the test. Again, this simplifies identifying the time the vehicle enters the test area.

5.2.6 A test technician and an A-UGV operator are normally required to implement the test method.

5.2.7 If the A-UGV ground clearance is greater than 70 mm, a front shroud should be added to the A-UGV so that the test piece cannot roll beneath the vehicle.

5.2.8 Examples of the test setup are shown in Figs. 1-4.

6. Hazards

6.1 In addition to the requirements of 1.4, which addresses the human safety and health concerns, users of this test method shall also address the equipment preservation concerns and human A-UGV coexistence concerns.

NOTE 1—The test requestor and test supervisor agree upon and have the authority to decide upon the environmental conditions under which the test(s) is/are to be conducted. Such conditions can be stressful not only to the humans but also to the A-UGVs, such as, high or low temperatures, excessive moisture, and rough terrain that can damage the A-UGV components or cause unexpected A-UGV motions. Testing of an A-UGV may result in exposing the A-UGV, the test area and equipment, and observers to extraordinary risks. In addition to any other warnings or concerns, the test designer shall include a safety plan specific to the A-UGV being tested and the test method being used. This plan shall be briefed to all personnel involved and shall include an emergency response plan should an uncontrolled event occur.

7. Calibration

7.1 *Calibration of the A-UGV and Start Location:*

7.1.1 The A-UGV shall be calibrated to move at 50 % and 100 % of rated speed before testing.

7.1.2 The A-UGV shall be positioned at the same start location and orientation for each trial. A calibration method, shown in Fig. 2, independent of A-UGV sensors, shall be used to determine vehicle pose. An example method includes the use of a video camera or sighting scope mounted to the vehicle and two posts spaced at approximately 5 m and 10 m along a line at an angle other than 0° and 90° from the A-UGV. When the A-UGV is at the start location, the two posts are aligned in the camera's field of view (FOV). Also, a thin bar is clamped to the rear A-UGV bumper pointing down to a spot marked on the floor. This ensures that the vehicle was positioned at the same start location while the camera/post setup was used to ensure proper vehicle orientation.

7.1.3 Tape lines on the floor or other start location calibration means can also be used, so long as they allow repeatable setup of start locations and orientation of the vehicle. At least two points of alignment are required to ensure the vehicle is

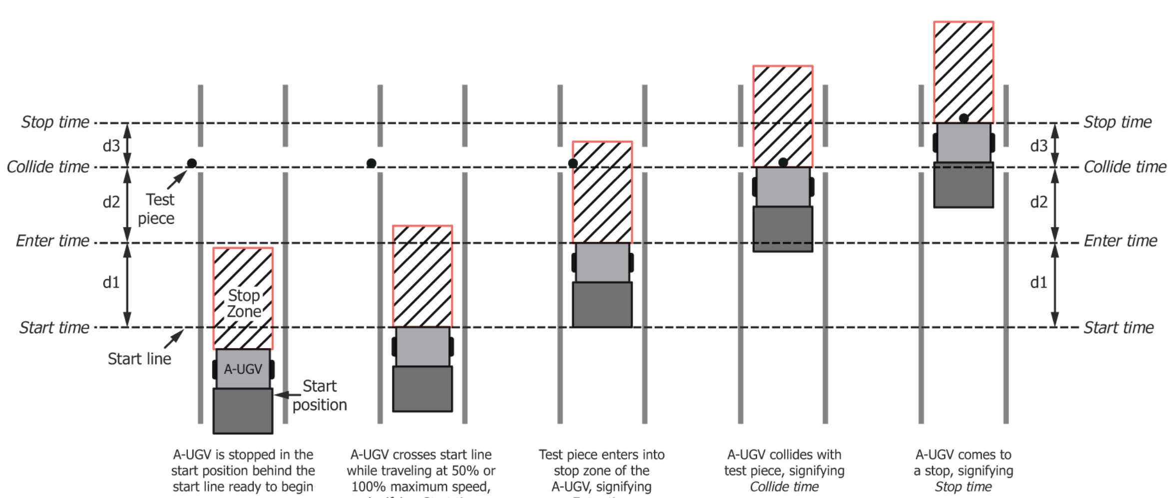

FIG. 3 Overhead View of the A-UGV Test Piece Positions, Distance Variables, and Moments in Time to be Recorded

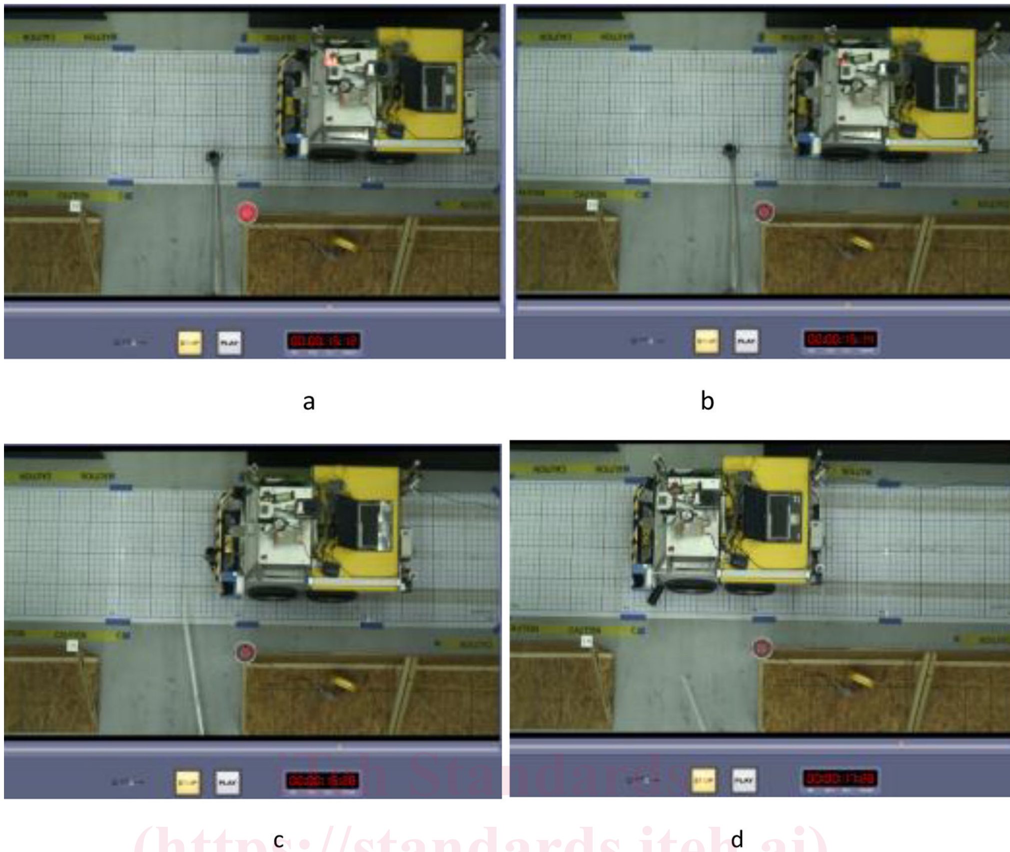

FIG. 4 Snapshots from the Overhead Video Showing when: (a) the Test Piece Crosses the Photosensor, (b) the Test Piece is Detected by the A-UGV Safety Sensor, (c) the A-UGV Hits the Test Piece (or when the Test Piece Stops in the A-UGV Path), and (d) the A-UGV Stops

positioned and oriented properly. The alignment points should be separated as far apart as possible to minimize Abbe errors[6] in vehicle orientation. Also, the alignment points on the vehicle and the markings on the floor should be small to minimize parallax effects during positioning.

7.2 *Calibration of the Camera with Grid*—Because the grid is visible in all of the images, calibration of the camera distortion is not required. To determine the speed of the vehicle, however, checking the frame rate of the cameras is required. The camera shall be set to run at a specified frame rate of at least 29 fps. A timer display shall be placed in the field of view of the camera and set to run. Images shall be captured for at least 10 s. The collected images shall be reviewed, and the averages time intervals among all images will be calculated to be within 5 % of the selected rate, with no single-second long period more than 10 % off. For example, in 10 s a camera set at 30 fps collects 310 images for an average of 31 frames per second. This is within 1/30 = 0.033, or 3.3 %. The number of frames for any single second's worth of images shall not exceed or be below 10 % of the expected rate. In this case, it would need to be between 27 fps and 33 fps. This method allows the use of low resolution timers measuring 0.01 s intervals such as an application on a cellphone, personal computer (PC) display, or a timer.

7.3 *Measurement of Stop Field Length at Test Speeds of 50 % and 100 % of Rated Speed:*

7.3.1 A static test piece shall be placed in the A-UGV path and the A-UGV stopping distance checked to ensure that the A-UGV stops before contacting the test piece. The pre-test shall be performed five times at A-UGV speeds of 50 % of rated A-UGV speed and 100 % of rated A-UGV speed. This pre-test is also used to determine the test piece detection or stop distance width, or both, along the A-UGV path within which the test piece is inserted as described in the procedure in Section 8.

8. Procedure

8.1 *Pre-Test Information Collection*—For data traceability and organization purposes, the test supervisor shall obtain and record the pre-test information first using the form shown in Section 10. 8.1.1 – 8.1.14 will assist the test supervisor in completing this form.

8.1.1 *Date-Testing Date*—Some test methods, when explicitly specified, can allow the tasks or repetitions to be distributed into multiple days; the time-of-the-day information may also be included.

[6] https://en.wikipedia.org/wiki/Abbe_error.

8.1.2 *Facility*—Name of laboratory or field where the test is to be conducted.

8.1.3 *Location*—Names of campus, address, city, and state in which the facility is located.

8.1.4 *Event*—This field shall record the reason the test has been requested or shall be recorded as the word "general" when an A-UGV is tested for its performance record purposes independent of any particular event.

8.1.5 *A-UGV Make*—The name of the manufacturer or developer of the A-UGV and the contact information.

8.1.6 *A-UGV Model*—The specific name and model number, including any extension or remark to identify fully the particular configuration of the A-UGV as tested.

8.1.7 *A-UGV User Organization*—The name of the organization with which the A-UGV operator is associated; it could be the user, potential user, manufacturer, or installer of the A-UGV. Also, provide the contact information.

8.1.8 *Environment*—Conditions under which the test will be conducted, including the light level, temperature, humidity, and ground surface. The test requestor, in agreement with the test supervisor, has the authority to specify these conditions. See Practice F3218 for details on measuring and recording environmental conditions.

8.1.9 *Repetition*—Enter repetition number.

8.1.10 *Test Requestor*—Give name, organization, and contact information.

8.1.11 *Test Supervisor*—Give name, organization, and contact information.

8.1.12 *Test Technician(s)*—Give name, organization, and contact information.

8.1.13 *A-UGV Operator*—Give name, organization, and contact information.

8.1.14 *File Naming Convention*—The performance-capturing video files shall be named according to the convention as noted by the test supervisor on the form.

8.2 *Test Method*—The test requestor and supervisor shall agree on the test, as defined in Sections 5 and 8.

8.2.1 The A-UGV is brought to the start location (see Fig. 2) for the test, agreed upon by the test supervisor and A-UGV operator, ready to test.

8.2.2 The A-UGV operator either abstains or proceeds with the test. The abstention shall not be granted after this point.

8.2.3 The test supervisor sets and verifies the apparatus or path setting and announces the number of repetitions to be performed.

8.2.4 The test requestor and test supervisor agree to and verify the test conditions, for example: surface requirements, environmental conditions, and so forth. Test conditions are recorded.

8.2.5 *A-UGV Conditions*—Consistent loading, speed, and path.

8.2.5.1 The A-UGV test supervisor and requestor shall define if the test will be conducted with load.

8.2.5.2 The person responsible for programming/training the A-UGV shall be permitted to setup the A-UGV and perform test runs with the vehicle before the actual test begins.

8.2.6 The A-UGV operator places the A-UGV at the start location. The A-UGV may perform the traverse tasks in any order (for example, 50 % rated speed or 100 % rated speed), but each task shall be performed for the required number of repetitions.

8.2.7 The supervisor instructs the A-UGV operator to begin the task and starts the video recorder. A timer may also be used to record the total elapsed time.

8.2.8 The A-UGV operator commands the A-UGV to perform the traversing task fully until the test piece is detected and the vehicle stops, or an emergency stop condition occurs, or until 5 s have elapsed after the vehicle has collided with the test piece. The A-UGV operator may not control the vehicle while the test is being performed except to emergency stop the vehicle in the case of dangerous operation, not to stop the vehicle as part of the test. If the A-UGV operator or any other personnel activates the e-stop, the test is stopped and recorded as an incomplete repetition.

8.2.9 The test supervisor and A-UGV operator agree upon whether the vehicle returns to the start location autonomously or is returned to the start location by the A-UGV operator after the A-UGV stops. The supervisor records the results on the test form. If, after the A-UGV collides with the test piece, it comes to a stop on its own because of the detection of the test piece, then the repetition is complete. If the A-UGV fails to complete the task, this constitutes a fault condition in which the partially completed task is not credited. The supervisor shall pause the overall test time and allow the A-UGV operator to interact with the A-UGV, reset the A-UGV back to the start location, and resume the test when the supervisor signals. The supervisor shall note, on the test form, the indication of the fault condition and the time at which the pause occurred and shall provide a comprehensive maintenance and repair report if any such actions occur.

8.3 In the repetitive testing situation, follow the specification in 8.8. The A-UGV repeats the procedure of 8.7 until all repetitions are completed or until any of the fault conditions, as specified in 8.6, occur.

8.4 Upon completion of the specified number of repetitions of the task at the apparatus setting, adjust the apparatus to the next incremental speed setting and repeat procedure of 8.7 until either the A-UGV fails to complete the task or the specified apparatus setting is successfully negotiated for the specified number of repetitions.

8.5 Note the last fully successful apparatus setting as the test capability.

8.6 *Fault Conditions:*

8.6.1 A-UGV leaves the path or contacts any wall (virtual or otherwise) while traversing.

8.6.2 Failure to complete a task once started.

8.6.3 Human intervention with the A-UGV, such as adjustment, maintenance, or repair, any time other than while testing is paused because of a fault condition.

8.7 *Test Procedure:*

8.7.1 It is considered a repetition for each occurrence of the A-UGV moving from the start location towards the test piece and a test piece is pushed or released into the A-UGV path.

8.7.2 The test procedure shall begin after all calibrations (7.1 and 7.2) and pre-tests (8.7) are completed.