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Designation: ~~F3218 – 17~~ F3218 – 19

Standard Practice for ~~Recording~~Documenting Environmental ~~Effects~~Conditions for Utilization with A-UGV Test Methods[1]

This standard is issued under the fixed designation F3218; 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~~

~~When conducting test methods, it is important to consider the role that the environmental conditions play in the A-UGV performance. Various A-UGVs are designed to be operated both indoors and outdoors under conditions specified by the manufacturer. Likewise, end users of the A-UGV will be operating these vehicles in a variety of environmental conditions. When conducting and replicating Committee F45 test methods by vehicle manufacturers and users, it is important to specify and record the environmental conditions under which the A-UGV is tested as there will be variations in vehicle performance caused by the conditions, especially when comparing and replicating sets of test results. It is also important to consider changes in environmental conditions during the course of operations (for example, transitions between conditions). As such, environmental conditions specified in this practice are both continuous and transitional; with the A-UGV stationary or in motion. This practice provides brief introduction to the following list of environmental conditions that can affect performance of the A-UGV: lighting, external sensor emission, temperature, humidity, electrical interference, ground surface, air quality.~~

~~This practice then breaks down each condition into sub-categories so that the user can record the various aspects associated with the category when conducting A-UGV tests defined in Committee F45 Test Methods , , those listed in the Related Materials section, and Terminology F3200. It is recommended that salient environment conditions be recorded when conducting Committee F45 test methods, but is not required.~~

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1. Scope

1.1 ~~This practice describes a means to record the following~~ When conducting test methods, it is important to consider the role that the environmental conditions play in the Automatic through Autonomous – Unmanned Ground Vehicle (A-UGV) performance. Various A-UGVs are designed to be operated both indoors and outdoors under conditions specified by the manufacturer. Likewise, end users of the A-UGV will be operating these vehicles in a variety of environmental conditions. When conducting and replicating F45 test methods by vehicle manufacturers and users, it is important to specify and document the environmental conditions under which the A-UGV is to be tested as there will be variations in vehicle performance caused by the conditions, especially when comparing and replicating sets of test results. It is also important to consider changes in environmental conditions during the course of operations (for example, transitions between conditions). As such, environmental conditions specified in this practice are static, dynamic, or transitional, or combinations thereof; with the A-UGV stationary or in motion. This practice provides brief introduction to the following list of environmental conditions that ~~may~~can affect ~~the~~ performance of ~~A-UGVs: lighting, external sensor emission, temperature, ground surface, air quality, humidity, and electrical interference.~~the A-UGV: Lighting, External sensor emission, Temperature, Humidity, Electrical Interference, Air quality, Ground Surface, and Boundaries. This practice then breaks down each condition into sub-categories so that the user can document the various aspects associated with the category prior to A-UGV tests defined in ASTM F45 Test Methods (for example, F3244). It is recommended that salient environment conditions be documented when conducting F45 test methods.

[1] This practice is under the jurisdiction of ASTM Committee F45 on Driverless Automatic Guided Industrial Vehicles and is the direct responsibility of Subcommittee F45.01 on Environmental Effects.

Current edition approved ~~July 1, 2017~~Sept. 1, 2019. Published ~~October 2017~~October 2019. Originally approved in 2017. Last previous edition approved in 2017 as F3218 – 17. DOI: ~~10.1520/F3218-17.~~10.1520/F3218-19.

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1.2 The ~~A-UGV operating ranges for each~~environmental conditions listed in 1.1 ~~of the conditions listed in~~to be documented for A-UGV(s) ~~1.1~~being tested are described and parameterized in Section 4 and allow a basis for performance comparison in test methods. The approach is to divide the list of environmental conditions into sub-conditions that represent the various aspects of the major category (for example, sunlight within ambient lighting). Where necessary, this practice also provides guidelines (for example, lighting direction) to ~~record~~document environmental conditions in an existing environment.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversion to imperial 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. 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:*[2]

E1155M Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers (Metric)

E1274 Test Method for Measuring Pavement Roughness Using a Profilograph

F3200 Terminology for Driverless Automatic Guided Industrial Vehicles

F3244 Test Method for Navigation: Defined Area

~~F3265 Test Method for Grid-Video Obstacle Measurement~~

2.2 *Other Standards:*

ANSI/ITSDF B56.5 Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles – section 8.11.2 describes Hazardous Zones[3]

ANSI B101.3 Test Method for Measuring Wet DCOF of Common Hard-Surface Floor Materials – specifies use of a BOT-3000 drag-sled meter

ISO 14644-1 Cleanrooms and Associated Controlled Environments – Part 1: Classification of Air Cleanliness by Particle Concentration[4]

BS 667 Illuminance Meters – Requirements and Test Methods

BS EN 12895 Electromagnetic Compatibility – Emissions and Immunity[5]

MIL-STD-462 EMI Emissions and Susceptibility[6]

ISO 15469 Spatial distribution of daylight – CIE standard general sky – defines a set of outdoor daylight conditions linking sunlight and skylight for theoretical and practical purposes

IEC 61000-4-1 Electromagnetic Compatibility (EMC) – Part 4-1: Testing and Measurement Techniques – Overview of Immunity Tests[7]

IEC 61000–6 Emission Standards for Industrial Environments[7]

UL 3100 Outline Investigation for Automated Guided Vehicles (AGVs)[8]

3. Terminology

3.1 Generic terminology for this practice are referenced in Terminology F3200.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *between area, n*—~~an~~the area of the apparatus that is between ~~the start and goal locations within each test~~different environmental conditions in a transitional environment (see ~~*apparatus*~~ *transitional*~~as defined by the test method.~~).

3.2.2 *change time, n*—amount of time to change from one environmental condition to another (only applies to dynamic environments).

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[2] 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.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[5] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.

[6] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

[7] Available from International Electrotechnical Commission (IEC), 3, rue de Varembé, 1st Floor, P.O. Box 131, CH-1211, Geneva 20, Switzerland, http://www.iec.ch.

[8] ~~Health Aspect of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide, Report on a WHO Working Group, Bonn, Germany, 13–15 January 2003.~~Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.

3.2.3 ~~*continuous,*~~*dynamic, adj*—~~time exposed to a single environmental condition(s).~~when the environment changes over time within the test apparatus during a test.

3.2.3.1 *Discussion*—

The amount of time it takes for the environment to change is called change time (see *change time*).

3.2.4 *emitter, n*—external radiation sources that can affect the A-UGV performance, for example: multiple time-of-flight cameras, fork-lift pedestrian lights, structured light sensor, light detection and ranging sensors (LIDAR).

3.2.5 *transition distance, n*—amount of distance to change from one environmental condition to ~~another.~~another, that is, the length of the between area (see *between area*).

~~3.1.5 *transition time, n*—amount of time to change from one environmental condition to another.~~

3.2.6 *transitional, adj*—~~movement between environmental conditions and the time exposed to the condition.~~when the environment significantly differs in different areas within the test apparatus.

3.2.6.1 *Discussion*—

The area between the different environmental conditions is called the between area (see *between area*).

4. Significance and Use

4.1 This section provides a description of the environmental conditions listed in Section 1 and describes the sub-conditions within each condition. Examples provided for many of the conditions and sub-conditions are provided as guidance only. Each of the conditions described should be evaluated and documented as set forth in Sections 5, 6, and 7.

4.2 *Environmental Consistency: Static, Dynamic, Transitional:*

4.2.1 Static is when the environment is similar throughout the test apparatus. For example, there are minor fluctuations in temperature throughout the apparatus as shown in Fig. 1 and Fig. 2. Dynamic is when the environment significantly differs within the test apparatus. For example, when the temperature changes between repetitions as shown in Fig. 3. Transitional is when the environment significantly differs in different areas within the test apparatus as shown in Fig. 4. The intent here is to not give specific guidance, but to provide a high-level classification of a particular set of environmental conditions. If environment consistency is dynamic or transitional, or both, a report form (see Section 7) for each unique set of environmental conditions should be completed.

4.3 *Lighting:*

4.3.1 Various lighting conditions can potentially affect A-UGV optical sensor performance by affecting sensor and in turn, A-UGV responsiveness. Lighting sources can include ambient lighting as well as light emitters associated A-UGV operation. Two setups for lighting include direct ~~and indirect source~~or ambient source(s) applied to the A-UGV. Direct lighting can also include reflected light from a highly reflective surface and implies that the source is directed at the light-affected components of the A-UGV (for example, sensors). Indirect or ambient light includes lighting where the source is not directly applied to the light-affected components of the A-UGV. ~~Lighting exposure is either continuous light applied to the A-UGV or transitional in which the vehicle~~

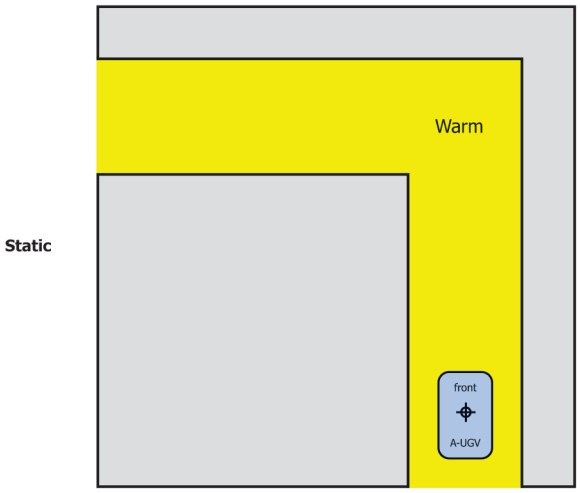

FIG. 1 Example of Static Environment using Temperature

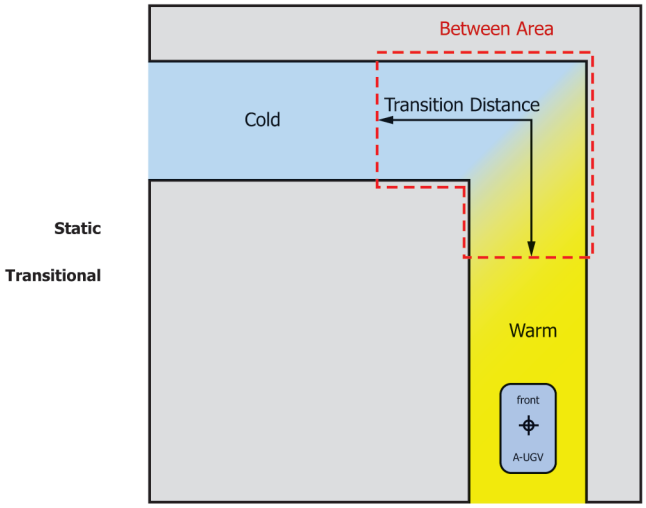

FIG. 2 Example of Static Environment using Temperature and Showing a Transition between Two Static Environments

~~passes through various lighting conditions and levels.~~ Light intensity is divided into five levels exemplified through dark, dim, typical indoor lighting, spotlight, and full sunlight.

4.3.2 *Ambient Lighting Type:*

4.3.2.1 Exposed bulb (for example, fluorescent, can lights),

4.3.2.2 Spotlight (for example, direct away from the A-UGV),

4.3.2.3 Sunlight (for example, the A-UGV is tested in bright sunlight),

4.3.2.4 Reflected (for example, bulb directed at the ceiling),

4.3.2.5 Filtered (for example, diffused light through translucent glass).

4.3.3 ~~*Ambient*~~*Directed Lighting Type:*

4.3.3.1 Exposed bulb,

4.3.3.2 Spotlight,

4.3.3.3 ~~Sunlight,~~Sunlight (for example, the A-UGV faces/navigates towards low sun position),

4.3.3.4 Reflected,

4.3.3.5 ~~Light from another vehicle,~~Filtered,

4.3.3.6 Laser,

4.3.3.7 ~~Filtered.~~Light from another vehicle.

~~*4.1.3 Ambient Lighting Source:*~~

~~4.1.3.1 Direct Highly-Concentrated, Directional Lighting,~~

~~4.1.3.2 Indirect and Diffused.~~

4.3.4 ~~*Ambient*~~ *Lighting Source Location*—~~Record~~ Document indirect and direct light source location and elevation with respect to the ~~vehicle~~A-UGV (refer to Fig. ~~1~~5).

~~4.1.4.1 Elevation with respect to A-UGV path.~~

~~4.1.4.2 Location with respect to the A-UGV (indicate light source on the test method drawing; for directional lighting only).~~

4.3.5 *Lighting Levels:*

4.3.5.1 Level 1: 0 to 1 ~~LUX~~lux (for example, dark).

4.3.5.2 Level 2: 2 to 99 ~~LUX~~lux (for example, dim).

4.3.5.3 Level 3: 100 to 1000 ~~LUX~~lux (for example, office environment).

4.3.5.4 Level 4: 1001 to 9999 ~~LUX~~lux (for example, ~~bright indoors, dim outdoors).~~high intensity work light, spotlight).

4.3.5.5 Level 5: 10 000 ~~LUX~~lux and above (for example, full sunlight).

4.3.6 *Spectrum*—~~If useful to the test method, record the spectrum color and approximate wavelength (for example, violet: 400 nm).~~Identify primary color and peak wavelength.

4.3.7 ~~*Light Exposure:*~~ *Polarization*—

~~4.1.7.1 *Continuous*—The same lighting sources and lighting levels throughout the test apparatus (for example, start, between area, and goal all have the same lighting condition).~~Identify the polarizing source and angle with respect to a known reference (for example, world coordinates).

~~4.1.7.2 *Transitional*—Moving between two lighting levels or lighting sources, or both.~~

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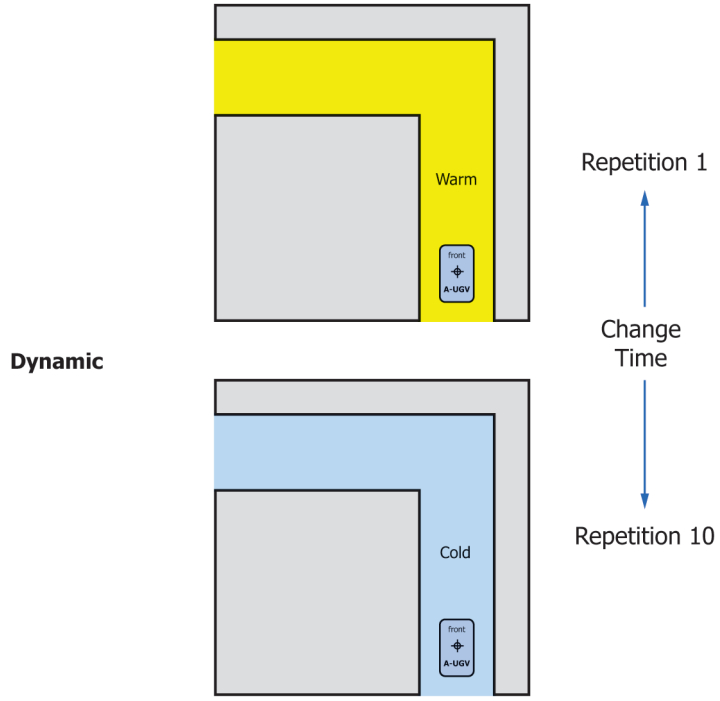

FIG. 3 Example of Dynamic Environment using Temperature and Showing that the Environment Changed during the Test

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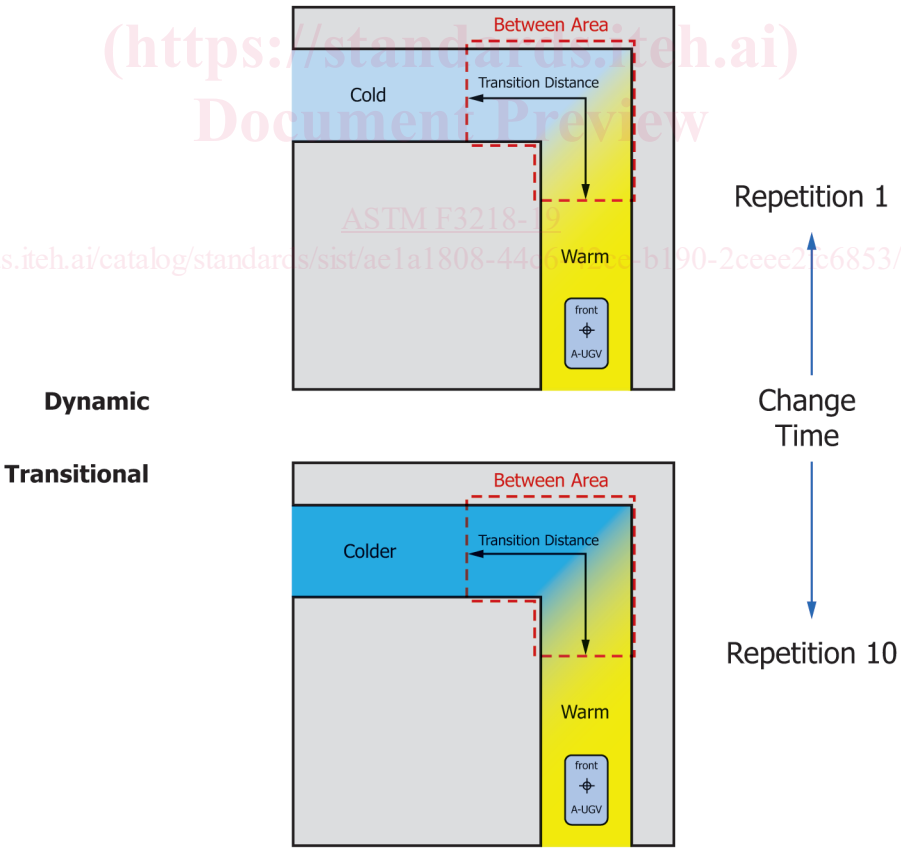
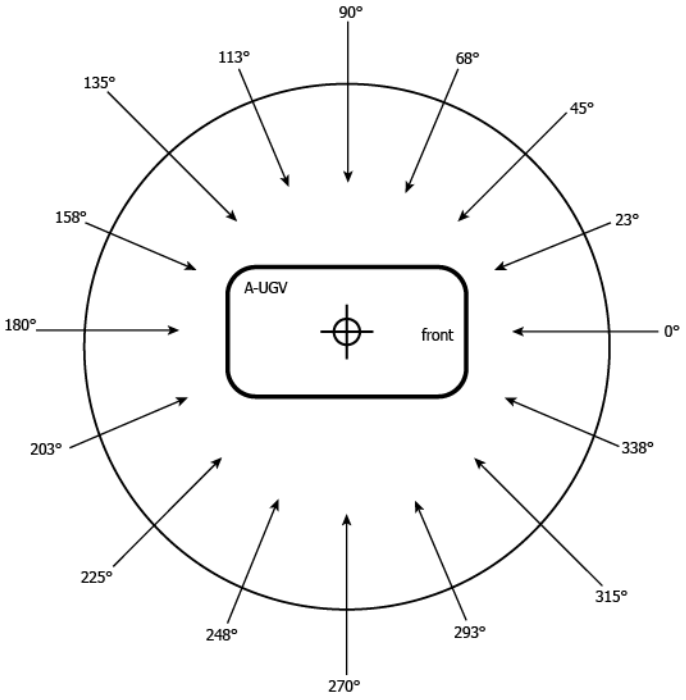


FIG. 4 Example of Transitional Environment using Temperature; Portions of the Environment May Remain Static or May Be Dynamic (for example, Cold to Colder)

(a) top view



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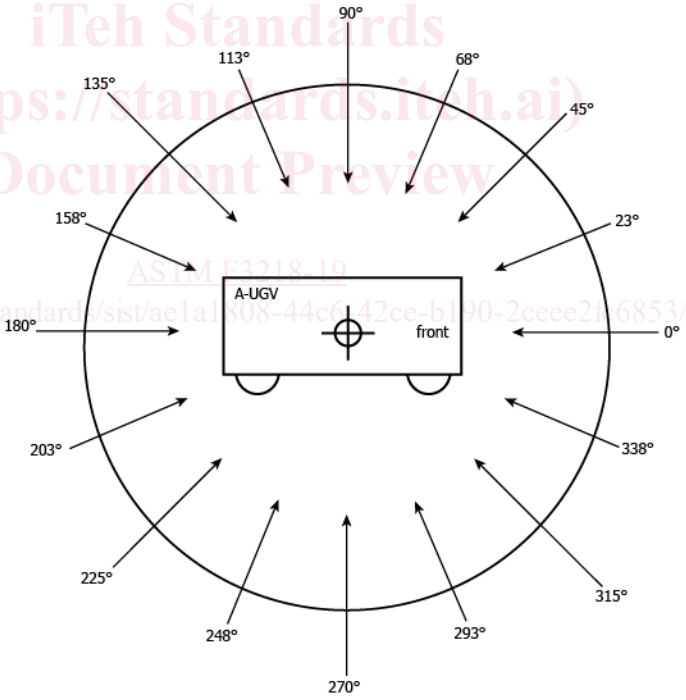
(b) side view



(c) elevation view

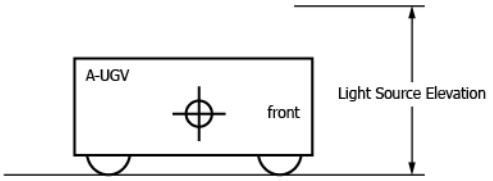


FIG. ~~1~~5 Lighting ~~and Air Velocity (see 4.7.4)~~ Direction (a) Top View and (b) Side View and (c) ~~Light Source~~ Elevation ~~Side~~ View with Respect to the ~~A-UGV; The "front" of the A-UGV is defined by vehicle manufacturer~~A-UGV

4.3.8 If more specificity of measurement is required, the following documents and standards may be used: "Recommended Light Levels" from the National Optical Astronomy Observatory[9] and ISO 15469.

4.4 *External ~~Sensor~~ Emission:*

4.4.1 When emitters are outside of the A-UGV (for example, from another A-UGV, the environment) that can potentially interfere with the A-UGV sensor system. ~~External, unnatural~~ External radiation sources can affect the A-UGV performance, for example: multiple time-of-flight cameras, fork-lift pedestrian lights, 3D structured light sensors, light detection and ranging sensors (LIDAR).

4.4.2 *External Emitter Configuration:*

4.4.2.1 Type of emitter(s).

4.4.2.2 ~~Number~~Quantity of emitter(s).

4.4.3 *External Emitter Source Location*—~~Record~~Document emitter source location and elevation with respect to the ~~vehicle~~A-UGV (refer to Fig. ~~1~~5~~).~~); add an external emitter symbol on the test method drawing in the appropriate location.

~~4.2.3.1 Elevation with respect to A-UGV path.~~

~~4.2.3.2 Location with respect to the A-UGV.~~

4.4.4 *Spectrum*—Identify primary color and peak wavelength.

4.5 *Temperature:*

4.5.1 Temperature variability and extremes can affect the A-UGV performance. ~~The temperature exposure on the A-UGV can be continuous or transitional while the vehicle is stationary or moving.~~ Temperature ranges span from low to high extremes expressed in five ~~categories.~~levels. Temperature variations can affect onboard electronics, create condensation, cause hydraulic fluid viscosity, reduce battery life and recharge rate.

~~4.3.2 *Temperature Exposure:*~~

~~4.3.2.1 *Continuous*—A single temperature for a period of time.~~

~~4.3.2.2 *Transitional*—Moving between two continuous temperature levels.~~

4.5.2 *Temperature Levels (in °C):*

4.5.2.1 Level 1: below ~~0~~0°C to 0°C (for example, ~~freezing conditions).~~freezer).

4.5.2.2 Level 2: ~~0~~0°C to 15°C (for example, perishable storage).

4.5.2.3 Level 3: ~~16~~16°C to 26°C (for example, office, warehouse).

4.5.2.4 Level 4: ~~27~~27°C to 49°C (for example, warehouse).

4.5.2.5 Level 5: above 49°C (for example, foundries, forges).

4.6 *Humidity:*

4.6.1 Humidity refers to the amount of water vapor contained in the air around the vehicle. High humidity combined with dew point temperature causes condensation that can short electronics and affect lenses and other A-UGV components. Greater than 60 % humidity causes a large increase in corrosion of metallic parts. Low humidity, on the other hand, will see a dramatic rise in static electricity and the need for adequate discharge.

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[9] ~~For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For~~ "Recommended Light Levels", National Optical Astronomy Observatory, https://www.noao.edu/, accessed April 20, 2018 – includes common ~~Annual Book of ASTM Standards~~recommended indoor/outdoor light levels. ~~volume information, refer to the standard's Document Summary page on the ASTM website.~~

4.6.2 *Relative Humidity Level:*
4.6.2.1 Low – less than 30 %.
4.6.2.2 Moderately Low – 31 to 55 %.
4.6.2.3 Moderately High – 56 to 75%.
4.6.2.4 High – greater than ~~75 % and above.~~75 %.
4.6.3 *Dew Point Temperature*—The highest temperature at which airborne water vapor will condense to form liquid dew.

4.7 *Electrical Interference:*
4.7.1 Some surfaces are not conductive enough to provide adequate grounding for an A-UGV. ~~Most ground~~ Ground vehicles have a floating ~~ground and all electronics are typically grounded to the vehicle chassis.~~ electrical ground. As static builds up ~~causing the voltage difference between~~on the vehicle and the voltage drop from the positive lead of the battery and the chassis ~~to change, the performance of the~~ changes, the electronic components of the vehicle ~~may be~~ are negatively impacted. Strong magnetic fields can impact the onboard electrical components, and in particular, any data storage within the onboard computer. Many A-UGVs require wireless network connections for full functionality. Radio frequency (RF) interference can degrade these networks and A-UGV capability.
4.7.2 For Electro-magnetic compatibility issues, refer to:
4.7.2.1 BS EN 12895 Electromagnetic Compatibility – Emissions and Immunity.
4.7.2.2 MIL-STD-462 – EMI Emissions and Susceptibility.
4.7.2.3 IEC 61000-4-1 Electromagnetic Compatibility (EMC) – Part 4-1: Testing and Measurement Techniques – Overview of Immunity Tests
4.7.2.4 IEC 61000-6 – Emission Standards for Industrial Environments

~~4.6 *Ground Surface:*~~
~~4.6.1 A-UGV mobility is affected by ground surface conditions including surface: consistency and texture/roughness, gaps or step changes to elevation, deformability, grade (ramp) or undulation (lack of flatness), friction and particulates.~~
~~4.6.2 *Ground Surface Consistency:*~~
~~4.6.2.1 *Continuous*—A single condition for a period of time.~~
~~4.6.2.2 *Transitional*—Moving between two continuous ground surface conditions.~~
~~4.6.3 *Ground Surface Type (record 'Smooth' or 'Rough' and the surface type):*~~
~~4.6.3.1 Smooth (for example, concrete, tile, linoleum, carpet).~~
~~4.6.3.2 Rough (for example, gapped wood, cobblestone, large gravel, vegetation, raised metal floors, catwalks).~~
~~4.6.4 *Elevation Change:*~~
~~4.6.4.1 *Gap*—Depth and length of gap.~~
~~4.6.4.2 *Step*—Height and length of step.~~
~~4.6.5 *Deformability:*~~
~~4.6.5.1 Rigid (for example, concrete, asphalt).~~
~~4.6.5.2 Semi-rigid (for example, compacted dirt or gravel, wet sand, industrial carpet).~~
~~4.6.5.3 Soft – malleable (for example, snow, mud, dry sand, padded carpet).~~
~~4.6.6 *Grade (Ramp):*~~
~~4.6.6.1 Level 1: 0 to 5 % (for example, transitional ramp in factories).~~
~~4.6.6.2 Level 2: 6 to 10 % (for example, yard ramp = 8 to 9 %).~~
~~4.6.6.3 Level 3: 11 to 15 % (for example, steep road grade).~~
~~4.6.6.4 Level 4: 16 % and above.~~
~~4.6.7 *Undulation (Lack of Flatness):*~~
~~4.6.7.1 Flat ground surface – 0 to 6 mm variation over 3 m.~~
~~4.6.7.2 Moderately flat ground surface – more than 6 to 12 mm variation over 3 m.~~
~~4.6.7.3 Non-flat ground surface – more than 13 to 51 mm variation over 3 m.~~
~~4.6.7.4 Outdoor – more than 51 mm variation over 3 m.~~
~~4.6.8 *Coefficient of Friction:*~~
~~4.6.8.1 High friction (for example, brushed concrete, asphalt).~~
~~4.6.8.2 Moderate friction (for example, polished/sealed concrete, steel plates, packed dirt).~~
~~4.6.8.3 Low friction (for example, icy, wet, lubricated, dry sand).~~
~~4.6.9 *Ground Surface Particulates (record category and the type):*~~
~~4.6.9.1 None (for example, dry, clean).~~
~~4.6.9.2 Fine (for example, cardboard dust, concrete dust).~~
~~4.6.9.3 Coarse (for example, sand, pebbles).~~

4.8 *Air Flow and Quality:*
4.8.1 Air flow and quality refers to the ability that an A-UGV can discern an object or light in the presence of ~~precipitation or~~ air ~~particulates,~~particulates or wind, or both. Air quality can affect the A-UGV performance in terms of object detection, navigation,

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and docking. Air quality depends upon the size and volumetric density of particulates in the air. For relative comparison, the average human eye cannot see ~~particulates~~particles smaller than 40 µm, fog from water vapor typically includes particle sizes from 5 µm to 50 µm, and dust particles are typically 0.1 µm to 100 µm. An ISO Class 1 cleanroom has no more than 10 particles larger than 0.1 µm in a cubic meter of air. Fog (water vapor) particle density of 1 amg allows human visibility of about 125 m at ground level. ~~(See ISO 14644-1 and Footnote 6 for further information.) The sub-conditions and parameters for air quality include:~~

4.8.2 ~~*Visibility Continuity:*~~ *Air Velocity and Direction*—

~~4.7.2.1 *Continuous*—A single condition for a period of time.~~Document air flow source location and elevation with respect to the A-UGV (refer to Fig. 5).

~~4.7.2.2 *Transitional*—Moving between two continuous air quality conditions.~~

4.8.3 *Air Particle Density*—Optionally, measure the air particle size and volumetric density.

4.8.3.1 ~~Clear (for~~ Clear – (for example, clean room, no visible air particulates).

4.8.3.2 ~~Moderate (for~~ Moderate – (for example, visible fog, dust, light to moderate rain/snow/fog).

4.8.3.3 ~~Dense (for~~ Dense – (for example, dust storm, heavy snow/rain/fog).

4.8.4 ~~*Air Velocity/Direction*—Refer to~~If more ~~Fig. 1 (a and b) for direction.~~specificity of measurement is required, the following standards may be used:

4.8.4.1 ~~0 kph (0 mph) (for example, calm).~~Air particle density – Clear: ISO 14644-1.

~~4.7.4.2 24 kph (15 mph) (for example, breezy).~~

~~4.7.4.3 40 kph (25 mph) (for example, windy).~~

~~4.7.4.4 68 kph (42 mph) (for example, gale).~~

~~4.7.4.5 116 kph (72 mph) or above (for example, hurricane).~~

4.9 *Floor or Ground Surface:*

4.9.1 A-UGV mobility is affected by ground surface conditions including: surface texture/roughness, deformability, sloped (ramp) or undulation (lack of flatness). Ground surface conditions can affect A-UGV: traction, vibration affecting the electronics integrity, positioning, and stability.

4.9.2 *Type(s):*

4.9.2.1 Approximate similar to the following examples where multiple floor types may be present and indicated on the report form: for example, concrete, linoleum tile, carpet, dirt, grass, asphalt, wood plank, etc.

4.9.2.2 Indicate floor anomalies within the test space: for example, floor grate, manhole cover, undetectable (by vehicle sensors) divots, transparent flooring, etc.

4.9.3 *Coefficient of Friction:*

4.9.3.1 High (for example, brushed concrete, asphalt).

4.9.3.2 Moderate (for example, polished/sealed concrete, steel plates, packed dirt).

4.9.3.3 Low (for example, icy, wet, lubricated, dry sand).

4.9.4 *Gap/Step*—Known infrastructure that could be a part of the A-UGV map (see Fig. 6).

4.9.4.1 *Gap*—Length, width, depth, and angle of gap with respect to a reference frame.

4.9.4.2 *Step*—Length, width, depth, and angle of step with respect to a reference frame.

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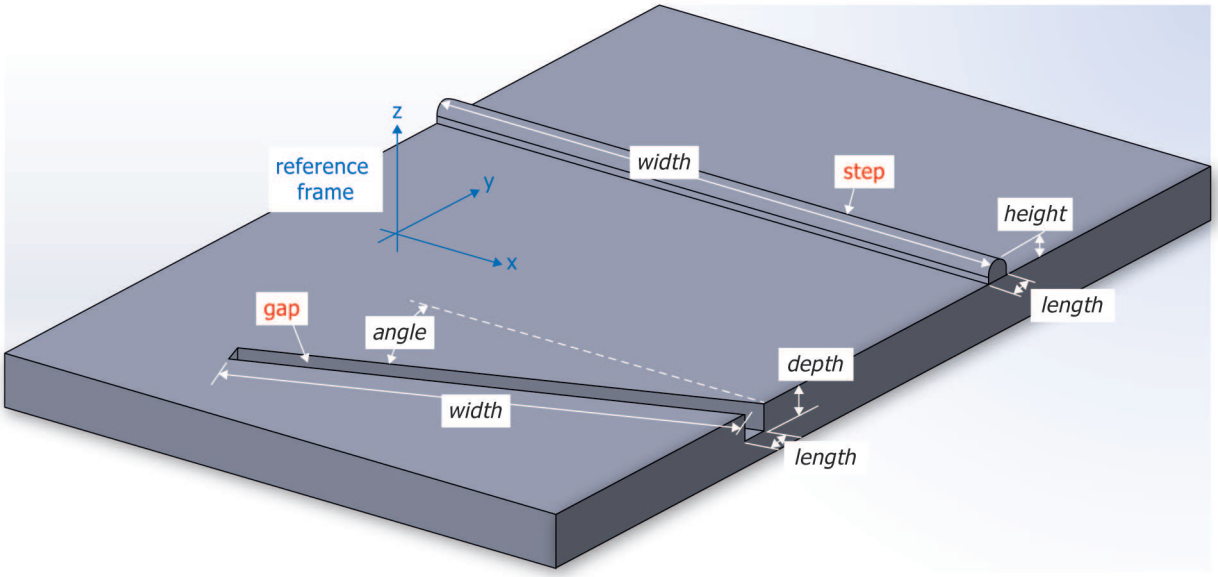

FIG. 6 Gap and Step

4.9.4.3 For each gap/step, a description of the gap/step should also be documented. Examples: sharp gap (between loading dock and truck) vs. rounded gap (pothole, floor divot); sharp step (square channel metal) vs. rounded step (cable or cable cover, speed bump/hump).

4.9.5 *Deformability:*

4.9.5.1 Rigid (for example, concrete, asphalt).

4.9.5.2 Semi-rigid (for example, compacted dirt or gravel, wet sand, industrial carpet).

4.9.5.3 Soft – malleable (for example, snow, mud, dry sand, padded carpet).

4.9.6 *Grade (Ramp)*—Known infrastructure that could be a part of the A-UGV map.

4.9.6.1 Level 1*: 0 % to 3 % (for example, nominally flat floor).

4.9.6.2 Level 2*: 4 % to 7 % (for example, transitional ramp in factories).

4.9.6.3 Level 3: 8 % to 10 % (for example, yard ramp = 8 % to 9 %).

4.9.6.4 Level 4: 11 % to 15 % (for example, steep road grade).

4.9.6.5 Level 5: 16 % and above.

NOTE 1—ITSDF B56.5 defines a ramp as "a variation in floor grade in excess of 3 % and of a length where rating data variance is required." UL 3100 Section 16.1 states "The AGV shall be capable of meeting all requirements for operation and control on an even grade and a sloped grade up to 3 % of grade."

4.9.7 *Undulation (Lack of Flatness on the Apparatus Ground Surface):*

4.9.7.1 Flat – 0 mm to 6 mm variation over 3 m.

4.9.7.2 Moderately flat – more than 6 mm to 12 mm variation over 3 m.

4.9.7.3 Non-flat – more than 12 mm to 51 mm variation over 3 m.

4.9.7.4 Outdoor – more than 51 mm variation over 3 m.

4.9.8 *Particulates (document type and describe):*

4.9.8.1 None (for example, dry, clean).

4.9.8.2 Fine (for example, cardboard dust, concrete dust).

4.9.8.3 Coarse (for example, sand, pebbles).

4.9.9 If more specificity of measurement is required, the following standards may be used:

4.9.9.1 Deformability: ASTM Test Method E1274.

4.9.9.2 Undulation: ASTM Test Method E1155M.

4.9.9.3 Coefficient of Friction: ANSI B101.3.

4.10 *Boundaries:*

4.10.1 Boundaries refer to the defining apparatus, existing structure, or ground anomalies, or combinations thereof, within which the A-UGV navigates. The characteristics for boundaries include:

4.10.2 Opaque walls (for example, white drywall, opaque plastic, reflective or flat black test boundaries, corrugated metal, curb from the road).

4.10.3 Semi-transparent walls – (for example, clear glass, frosted glass, translucent plastic).

4.10.4 Negative obstacles (for example, cliff, curb from the sidewalk, loading dock, drainage channel).

4.10.5 Virtual walls (for example, A-UGV prohibited areas mapped within the vehicle controller at edges of pedestrian walkways, edges of negative obstacles, restricted areas).

4.10.6 Porous walls (for example, wire mesh fencing, chain-link fencing).

4.10.7 Elevated dividers (for example, racking, post and beam fencing, retractable-belt dividers).

4.10.8 Building infrastructure (for example, machinery, equipment, A-UGV chargers).

4.10.9 Floor markings (for example, tape, paint).

4.10.10 Mixture of the above boundaries (for example, railing and kickplate in front of a negative drop-off at edge of a platform, post and beam fencing with wire mesh covering).

4.10.11 Moving boundaries (for example, moving sliding or hinged doors, moving curtains); the environment should be labeled as static unless the boundary moves during a test, in which case the environment should be labeled as dynamic, for example, an A-UGV drives past a soft partition that moves or an A-UGV drives through a soft partition that causes it to move.

4.10.12 If more specificity of measurement is required, the following standards and references may be used:

4.10.12.1 Floor Markings:

(1) Automotive Industry Action Group (AIAG) Occupational Health and Safety OH-2, Pedestrian and Vehicle Safety Guideline (includes description and marking depictions).

(2) ANSI/ITSDF B56.5 (section 8.11.2 describes Hazardous Zones).

(3) "Implementation of 5S Quality Tool in Manufacturing Company: A Case Study."[10]

[10] ~~WK48955. This is an unpublished ASTM standard in development.~~V. Kakkar, V. S. Dalal, V. Choraria, A. S. Pareta, A Bhatia, "Implementation of 5S Quality Tool in Manufacturing Company: A Case Study," *International Journal of Scientific and Technology Research*, Vol 4, Issue 02, February 2015, ISSN 2277-8616.

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