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14. ABSTRACT
This TOP describes procedures for measuring teleoperated system latencies of Unmanned Ground Vehicles (UGVs) for the purpose of analyzing system performance and compliance with Military Standard (MIL-STD)-1472G requirements. This TOP does not include procedures for measurement and ranking of discrete system components or measurements of latency in autonomous systems.

15. SUBJECT TERMS

Unmanned Ground Vehicles, Basic Video Latency, End-to-End System Latency, Command-to-Action Latency

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-546 — 11 January 2017
DTIC AD No.

TELEOPERATED UNMANNED GROUND VEHICLE (UGV) LATENCY MEASUREMENTS

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1. SCOPE.

This Test Operations Procedure (TOP) describes procedures for measuring the system latencies of teleoperated Unmanned Ground Vehicles (UGVs) for the purpose of test and evaluation. This TOP covers the measurement of basic video latency, end-to-end system latency, and command-to-action latency in the context of human operation of the UGV through the Operator Control Unit (OCU). Measurements will address requirements described in Military Standard (MIL-STD)-1472G[1*]. This TOP does not include procedures for measurement and ranking of discrete system components or measurements of latency in autonomous systems.

1.1 Basic Video Latency.

Teleoperation latency, or lag, describes the delay between a real-time event and the corresponding video display of the event through the OCU. Basic video latency is the time elapsed from the moment an event is presented to a UGV platform camera to the moment the event is displayed to the operator.

1.2 End-to-End System Latency.

End-to-end system latency describes the system transport delays between user input, system output, and display of system execution. End-to-end system latency is the time elapsed from the moment an input/command is initiated by the user to the display of observable system response through the OCU. In accordance with MIL-STD-1472G, paragraph 5.12.3.3.4, for a UGV, "The system transport delays between user input, system output, and display of system execution shall not exceed 250 milliseconds for vehicle motion control (left, right, forward, etc.). The system transport delays between user input, system output, and display of system execution shall not exceed 100 milliseconds for control of weapon systems."

1.3 Command-to-Action Latency.

Command-to-action latency describes the system transport delays between user input and observable system output. Observable command-to-action latency is time elapsed from the moment an input/command is initiated by the user to the moment the platform initiates the command. Examples include move left, move forward, close gripper, rotate camera, etc. Throughout this document observable command-to-action latency will be referred to as command-to-action latency.

* Superscript numbers correspond to Appendix B, References.

1.4 Limitations.

This document applies to latency testing of teleoperational UGVs only. Methodologies for testing of Unmanned Aerial Vehicles (UAVs) and Unmanned Submersible Vehicles (USVs) are not covered in this document. This document does not apply to automated subsystems that do not directly affect people or objects outside of the vehicle such as automated internal weapon loading systems or automated tracking subsystems. This document does not apply to automated driver-assist functions that require full-time on-board driver attention to perform a task such as cruise control, anti-lock brake systems, or self-leveling systems.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Testing will be conducted at the prescribed facilities and test courses to obtain the necessary baseline and latency measurements as follows:

2.1.1 Baseline Measurements.

Baseline measurements shall be obtained in a maintenance facility or lab facility with controllable lighting appropriate for electro-optical testing.

2.1.2 Line-of-Sight (LOS) Measurements.

Perform latency testing at LOS range along a flat, paved straightaway in an open area free from overhanging trees or other obstacles that might impede the radio frequency (RF) propagation between the OCU and UGV platform. Establish a LOS course based on system requirements and LOS measurements obtained in accordance with TOP 02-2-543[2].

2.1.3 Non-Line-of-Sight (NLOS) Measurements.

Establish a NLOS course based on system requirements and NLOS measurements obtained in accordance with TOP 02-2-543.

2.2 Instrumentation.

2.2.1 Real-Time Reference Clocks.

a. Global Positioning System (GPS) Network Time Protocol (NTP) servers meeting the requirements for a Stratum 1 primary time source (Figure 1) with antenna and accessories.

b. Numeric display for NTP Clock (Figure 2).

Figure 1. Example NTP Clock.**

Figure 2. Numeric display for NTP Clock.

2.2.2 <u>Recording System</u>.

A digital single-lens reflex (DSLR) or video camera with appropriate frame rate and video quality will be used to record the latency period. There shall be a 4:1 ratio between the DSLR/video camera frame rate and the system under test (SUT) video frame rate.

2.2.3 <u>System Positioning</u>.

A GPS device with permissible measurement uncertainty of 3 meters will be used to mark the positions of the UGV OCU and UGV platform.

** The use of brand names does not constitute endorsement by the Army or any other agency of the Federal Government, nor does it imply that it is best suited for its intended application.

3. REQUIRED TEST CONDITIONS.

3.1 Test Item Configuration.

a. The SUT shall be tested in its exact operating configuration, if known, and such testing is feasible.

b. The conditions of the test shall be detailed in the test report. Include drawings, photos, and ground truth information such as location and environmental conditions.

c. The test shall be conducted indoors, if possible, to allow ambient lighting to be tailored for video recording. There are cases where testing indoors is not possible due to safety concerns, vehicle operating characteristics, operating range requirements, LOS/NLOS requirements, etc. If the system must be tested outdoors, then select a test course and time of day that will provide acceptable video recording of latency test data.

d. Prior to testing, a digital spectrum analyzer will be used to examine the spectral composition of RF in the testing area. The data collected will be analyzed to ensure that RF signals in the testing area will not cause interference with the test item.

3.2 Safety.

a. Tests will not be conducted at night or during inclement weather. Test course safety and operational procedures will be carefully followed.

b. Prior to the start of testing, all test personnel will receive operator familiarization and training on the SUT.

c. Safety measures for UGV testing outlined in TOP 02-2-543 will be followed.

d. Testing shall be conducted with exclusive use of test courses to mitigate potential safety hazards to personnel, buildings, and test items.

e. If military personnel are required for testing, determine if Military Occupational Specialty (MOS) qualified Soldier-Operator/-Maintainer Test and Evaluation (SOMTE) personnel assigned to the U.S Army Test and Evaluation Command (ATEC) are available to support the testing. If SOMTE are not available, ensure a Test Schedule and Review Committee (TSARC) request is submitted one year prior to the start of testing, or as early as possible. A Safety Release (SR) and Human Research Protection Plan (HRPP) must be obtained from ATEC prior to using military personnel as test participants.

4. TEST PROCEDURES.

4.1 Basic Video Latency.

4.1.1 Baseline Measurement.

a. Position the UGV platform where an NTP clock is observed through the UGV platform cameras and captured on the UGV OCU display screen. Position the DSLR where a second NTP clock and the UGV OCU display screen are observed directly through the DSLR. Variable lighting may be required. An example of the test setup for baseline latency measurements is depicted in Figure 3.

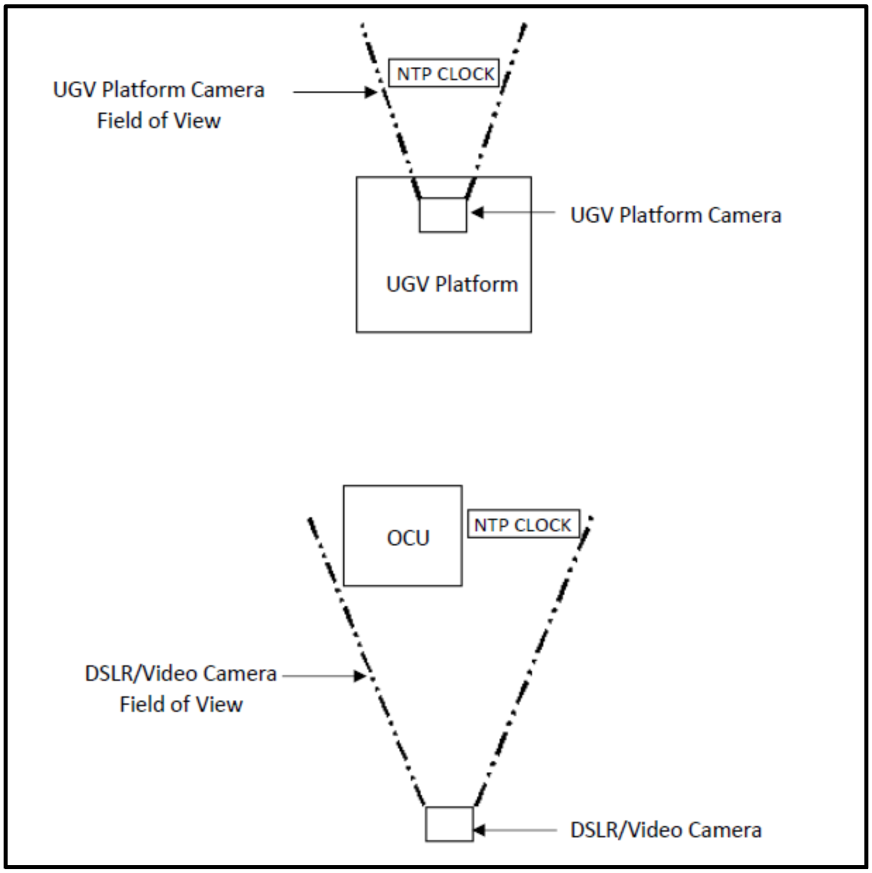

Figure 3. Typical baseline latency test setup.

b. Synchronize UGV OCU and UGV platform clocks to satellite time.

c. Utilize the UGV platform camera to observe NTP clock tickover. Operate the platform camera(s) in all relevant modes and configurations via the UGV OCU. Collect and record data for each case with the DSLR.

d. Repeat the above procedure a minimum of three times for comparison purposes and to establish consistency of system performance.

4.1.2 LOS Measurement.

a. Perform this test along a flat, paved straightaway in an open area free from overhanging trees or other obstacles that might impede the RF connection between the UGV OCU and UGV platform.

b. Establish a test range with appropriate maximum range, based on systems requirements and LOS measurements, minus 5% in accordance with TOP 02-2-543, and increments to challenge the teleoperation of the SUT.

c. Position the UGV platform where an NTP clock is observed through the UGV platform cameras and captured on the UGV OCU display screen. Position the DSLR where a second NTP clock and the UGV OCU display screen are observed directly through the DSLR. Variable lighting may be required. An example of the test setup for LOS latency measurements is depicted in Figure 4.

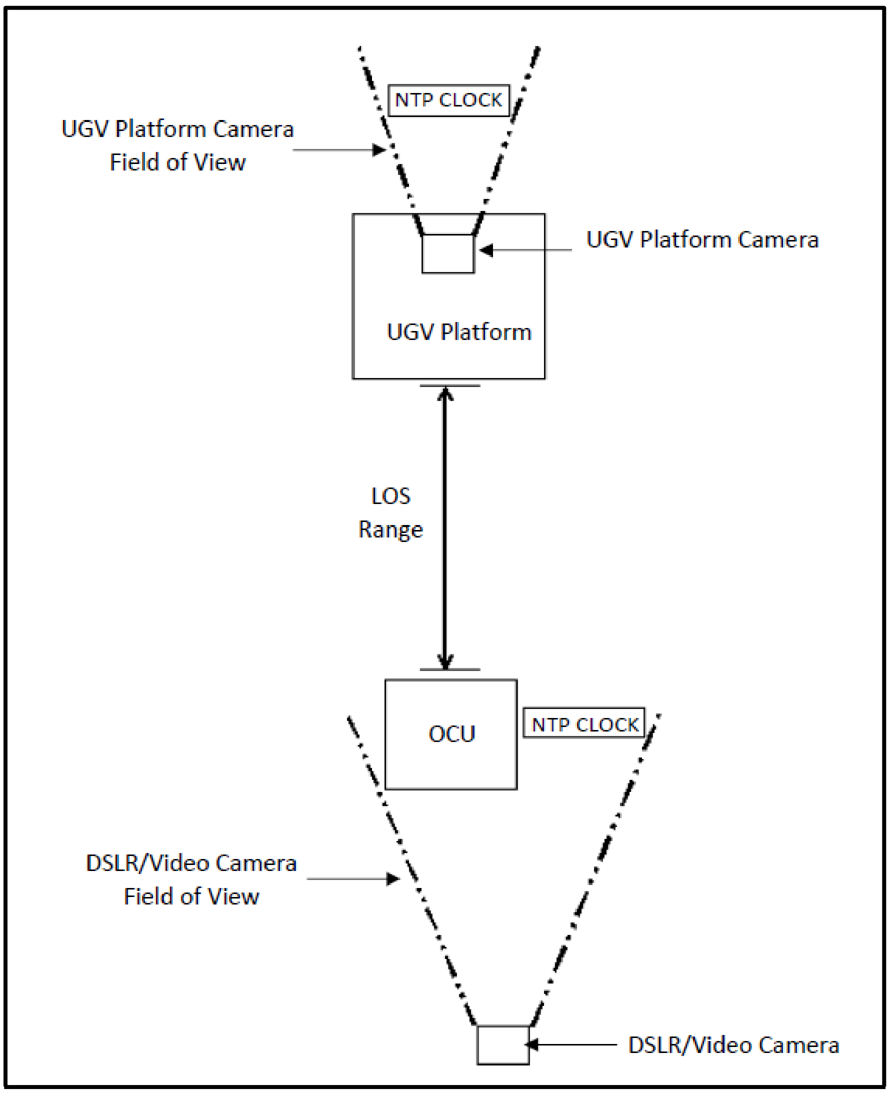

Figure 4. Typical LOS latency test setup.

d. Synchronize UGV OCU and UGV platform clocks to satellite time.

e. Utilize the UGV platform camera to observe NTP clock tickover. Operate the platform camera(s) in relevant modes and configurations via the UGV OCU. Collect and record data for each case with the DSLR.

f. Repeat the above procedure a minimum of three times for comparison purposes and to establish consistency of system performance.

4.1.3 NLOS Measurement.

a. Perform this test in a NLOS environment and range determined by NLOS testing in accordance with TOP 02-2-543. In order to establish the NLOS natural terrain environment, conduct testing in an area containing a natural obstruction. The test may be conducted along the curve of a course, with thick foliage. If testing in an urban environment, the NLOS urban environment should consist of several buildings or simulated buildings situated close together with network of paths or roads between them.

b. Establish a test range with appropriate maximum range, based on systems requirements and NLOS measurements, minus 5% in accordance with TOP 02-2-543, and increments to challenge the teleoperation of the SUT.

c. Position the test UGV platform where an NTP clock is observed through the UGV platform cameras and captured on the UGV OCU display screen. Position the DSLR where a second NTP clock and the UGV OCU display screen are observed directly through the DSLR. Variable lighting may be required. An example of test setup for NLOS latency measurements is depicted in Figure 5.

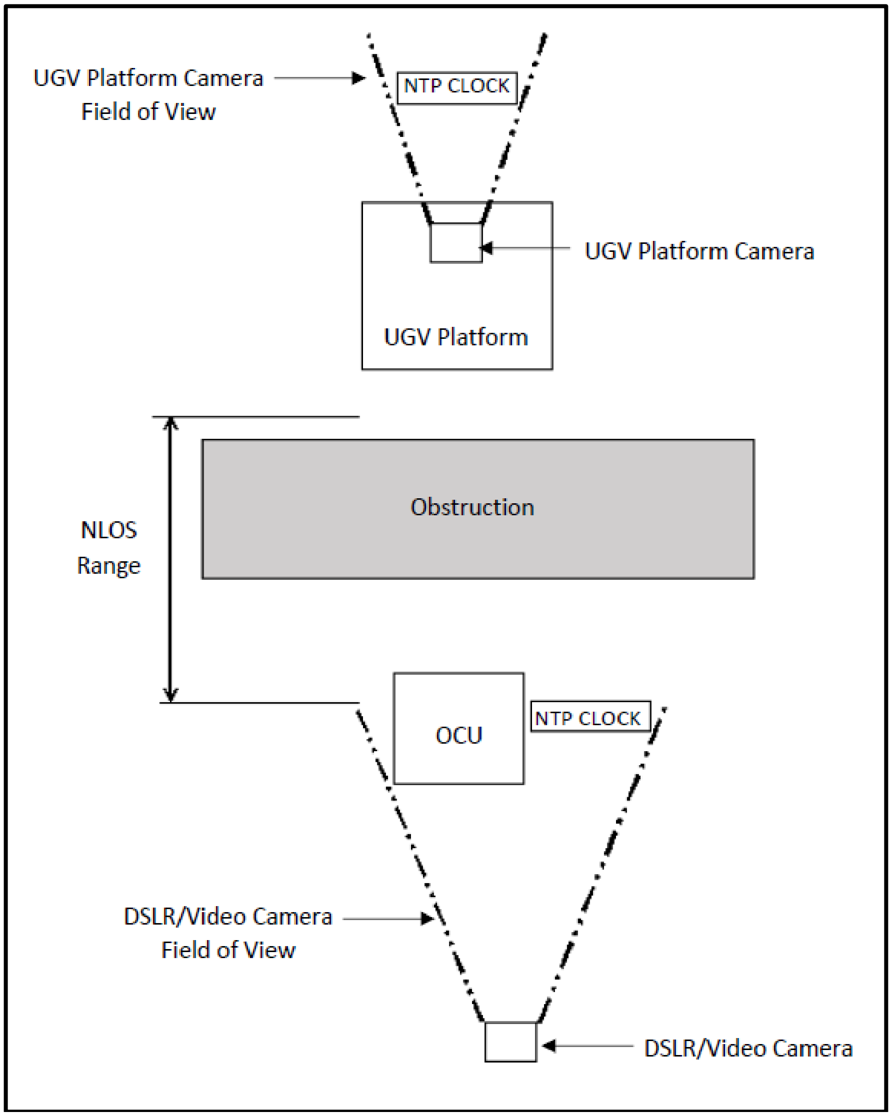

Figure 5. Typical NLOS latency test setup.

d. Synchronize UGV OCU and UGV platform clocks to satellite time.

e. Utilize the UGV platform camera to observe NTP clock tickover. Operate the platform camera(s) in relevant modes and configurations via the UGV OCU. Collect and record data for each case with the DSLR.

f. Repeat the above procedure a minimum of three times for comparison purposes and to establish consistency of system performance.

4.2 End-to-End System Latency.

4.2.1 Baseline Measurement.

a. Position the UGV platform where an NTP clock is observed through the UGV platform cameras and captured on the UGV OCU display screen. Position the DSLR where a second NTP clock and the UGV OCU display screen are observed directly through the DSLR. Position the UGV OCU so command input is observed directly through the DSLR. Variable lighting may be required. An example of test setup for baseline latency measurements is depicted in paragraph 4.1.1, Figure 3. An example of NTP clock setup for end-to-end system latency where gripper rotation is the action of interest is illustrated in Figure 6.

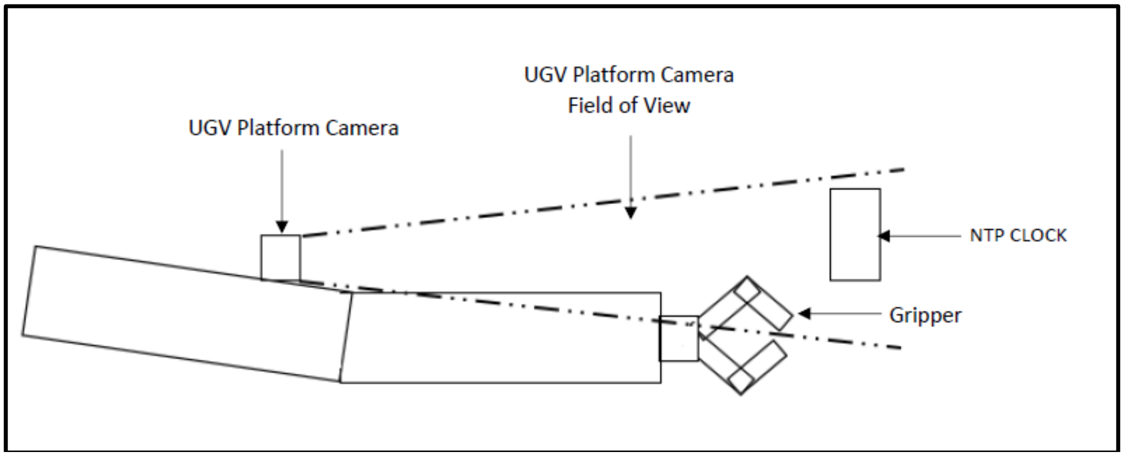

Figure 6. Example NTP clock setup for end-to-end system latency where gripper rotation is action of interest.

b. Synchronize UGV OCU and UGV platform clocks to satellite time.

c. Operate the UGV platform (example: rotate gripper, pan camera) via the UGV OCU and utilize the UGV platform camera to observe UGV platform response and NTP clock tickover through UGV OCU. Operate the UGV platform in relevant modes and configurations. Collect and record data for each case with the DSLR.

d. Repeat the above procedure a minimum of three times for comparison purposes and to establish consistency of system performance.

4.2.2 LOS Measurement.

a. Perform this test along a flat, paved straightaway in an open area free from overhanging trees or other obstacles that might impede the RF connection between the UGV OCU and UGV platform.

b. Establish a test range with appropriate maximum range, based on systems requirements and LOS measurements, minus 5% in accordance with TOP 02-2-543, and increments to challenge the teleoperation of the SUT.

c. Position the UGV platform where an NTP clock is observed through the UGV platform cameras and captured on the UGV OCU display screen. Position the DSLR where a second NTP clock and the UGV OCU display screen are observed directly through the DSLR. Position the UGV OCU so that command input is observed directly through the DSLR. Variable lighting may be required. An example of test setup for LOS latency measurements is depicted in paragraph 4.1.2, Figure 4. An example of NTP clock setup for end-to-end system latency where gripper rotation is the action of interest is depicted in paragraph 4.2.1, Figure 6.

d. Synchronize UGV OCU and UGV platform clocks to satellite time.

e. Operate the UGV platform (example: rotate gripper, pan camera) via the UGV OCU and utilize the UGV platform camera to observe UGV platform response and NTP clock tickover through UGV OCU. Operate the UGV platform in relevant modes and configurations. Collect and record data for each case with the DSLR.

f. Repeat the above procedure a minimum of three times for comparison purposes and to establish consistency of system performance.

4.2.3 NLOS Measurement.

a. Perform this test in a NLOS environment and range determined by NLOS testing in accordance with TOP 02-2-543.

b. Establish a test range with appropriate maximum range, based on systems requirements and LOS/NLOS measurements, minus 5% in accordance with TOP 02-2-543, and increments to challenge the teleoperation of the SUT.

c. Position the test UGV platform where an NTP clock is observed through the UGV platform cameras and captured on the UGV OCU display screen. Position the DSLR where a second NTP clock and the UGV OCU display screen are observed directly through the DSLR. Position the UGV OCU so that command input is observed directly through the DSLR. Variable lighting may be required. An example of test setup for NLOS latency measurements is depicted in paragraph 4.1.3, Figure 5. An example of NTP clock setup for end-to-end system latency where gripper rotation is the action of interest is depicted in paragraph 4.2.1, Figure 6.

d. Synchronize UGV OCU and UGV platform clocks to satellite time.

e. Operate the UGV platform (example: rotate gripper, pan camera) via the UGV OCU and utilize the UGV platform camera to observe UGV platform response and NTP clock tickover through the UGV OCU. Operate the UGV platform in relevant modes and configurations. Collect and record data for each case with the DSLR.

f. Repeat the above procedure a minimum of three times for comparison purposes and to establish consistency of system performance.

4.3 Command-to-Action Latency.

4.3.1 Baseline Measurement Calculation.

Baseline command-to-action latency is calculated using the following equation:

$$L_{cb} = L_{eb} - L_{vb} \qquad \text{(Equation 1)}$$

Where:
L_{cb} = baseline command-to-action latency
L_{eb} = baseline end-to-end system latency
L_{vb} = baseline video latency

4.3.2 LOS Measurement Calculation.

LOS command-to-action latency is calculated using the following equation:

$$L_{cl} = L_{el} - L_{vl} \qquad \text{(Equation 2)}$$

Where:
L_{cl} = LOS range command-to-action latency
L_{el} = LOS range end-to-end system latency
L_{vl} = LOS range video latency

4.3.3 NLOS Measurement Calculation.

NLOS command-to-action latency is calculated using the following equation:

$$L_{cn} = L_{en} - L_{vn} \qquad \text{(Equation 3)}$$

Where:
L_{cn} = NLOS range command-to-action latency
L_{en} = NLOS range end-to-end system latency
L_{vn} = NLOS range video latency

5. DATA REQUIRED.

5.1 Video Latency.

a. System configuration.

b. Description of RF environment.

c. Description of test setup.

d. DSLR/video camera frame rate.

e. Distance between the UGV OCU and UGV platform.

f. Position of the vehicle relative to obstacles/obstructions.

5.2 End-to-End System Latency.

a. System configuration.

b. Description of RF environment.

c. Description of test setup.

d. DSLR/video camera frame rate.

e. Distance between the UGV OCU and UGV platform.

f. Position of the vehicle relative to obstacles/obstructions.

g. Command given.

6. PRESENTATION OF DATA.

6.1 Video Latency.

a. Analyze recorded data to determine latency with video software. Count frames from the time the NTP clock initiated a change until the UGV OCU display of the clock registered the response. Multiply the elapsed frames by the video sampling period to obtain the latency product.

b. Tabulate all latency measurements.

c. Present video latency data as shown in Figure 7 and Table 1.

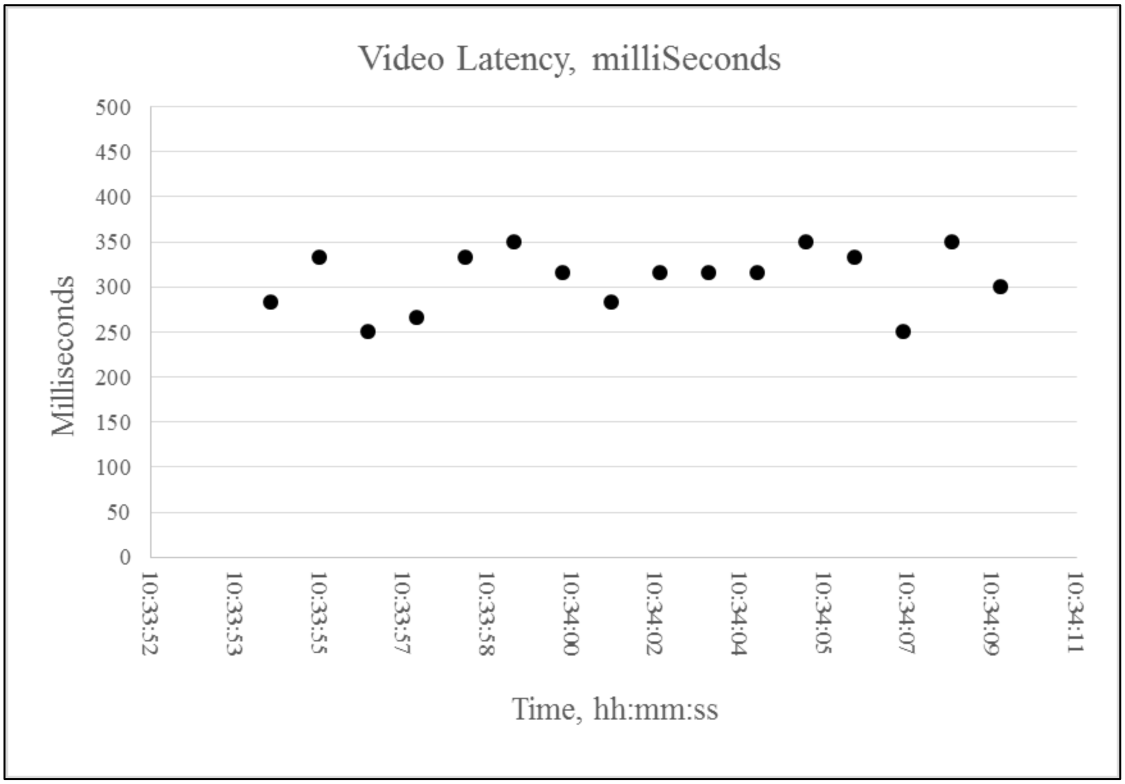

Figure 7. Example video latency.

TABLE 1. EXAMPLE VIDEO LATENCY RESULTS

VIDEO LATENCY, GRIPPER CAMERA						
Location	Number of Samples	Range		Averaged Latency, milliseconds	Maximum, milliseconds	Minimum, milliseconds
		meter	feet			
Lab, Baseline	20	0	0	309	350	249
Dynamometer Course	18	0	0	312	356	248
	20	200	656	360	433	242
	10	400	1312	410	550	194
	12	600	1969	300	433	204
	18	800	2625	325	403	311

6.2 End-to-End System Latency.

a. Analyze recorded data to determine latency with video software. Count frames from the time the command is initiated until UGV OCU display of the UGV platform observable response. Multiply the elapsed frames by the video sampling period to obtain the latency product.

b. Tabulate all latency measurements.

c. Present end-to-end latency data as shown in Table 2.

TABLE 2. EXAMPLE END-TO-END LATENCY RESULTS

END-TO-END SYSTEM LATENCY					
	Range				
Location	meter	feet	Camera	Function	Average Latency, milliseconds
Lab, Baseline	0	0	Gripper camera	Rotate gripper	305
	0	0	Surveillance camera	Pan surveillance camera	639
Dynamometer Course, LOS	200	656	Gripper camera	Rotate gripper	316
			Surveillance camera	Pan surveillance camera	652
	400	1312	Gripper camera	Rotate gripper	303
			Surveillance camera	Pan surveillance camera	661
	600	1969	Gripper camera	Rotate gripper	314
			Surveillance camera	Pan surveillance camera	651
	800	2625	Gripper camera	Rotate gripper	307
			Surveillance camera	Pan surveillance camera	647
Dense Foliage, NLOS	200	656	Gripper camera	Rotate gripper	321
			Surveillance camera	Pan surveillance camera	654
	400	1312	Gripper camera	Rotate gripper	335
			Surveillance camera	Pan surveillance camera	717
	600	1969	Gripper camera	Rotate gripper	337
			Surveillance camera	Pan surveillance camera	720

6.3 Command-to-Action Latency.

Present command-to-action latency data as presented in Table 3.

TABLE 3. EXAMPLE COMMAND-TO-ACTION LATENCY RESULTS

COMMAND-TO-ACTION SYSTEM LATENCY					
	Range				Average Latency,
Type	meter	feet	Camera	Function	millisecond
Baseline	0	0	Gripper camera	Rotate gripper	55
	0	0	Surveillance camera	Pan surveillance camera	398
LOS	200	656	Gripper camera	Rotate gripper	66
			Surveillance camera	Pan surveillance camera	402
	400	1312	Gripper camera	Rotate gripper	53
			Surveillance camera	Pan surveillance camera	411
	600	1969	Gripper camera	Rotate gripper	64
			Surveillance camera	Pan surveillance camera	401
	800	2625	Gripper camera	Rotate gripper	57
			Surveillance camera	Pan surveillance camera	424
NLOS	200	656	Gripper camera	Rotate gripper	71
			Surveillance camera	Pan surveillance camera	404
	400	1312	Gripper camera	Rotate gripper	85
			Surveillance camera	Pan surveillance camera	467
	600	1969	Gripper camera	Rotate gripper	87
			Surveillance camera	Pan surveillance camera	470

APPENDIX A. ABBREVIATIONS.

ATEC	U.S. Army Test and Evaluation Command
DSLR	digital single-lens reflex
DTIC	Defense Technical Information Center
GPS	Global Positioning System
HRPP	Human Research Protection Plan
L_{cb}	baseline command-to-action latency
L_{cl}	LOS range command-to-action latency
L_{cn}	NLOS range command-to-action latency
L_{eb}	baseline end-to-end system latency
L_{el}	LOS range end-to-end system latency
L_{en}	NLOS range end-to-end system latency
LOS	line-of-sight
L_{vb}	baseline video latency
L_{vl}	LOS range video latency
L_{vn}	NLOS range video latency
MIL-STD	Military Standard
MOS	Military Occupational Specialty
NLOS	non-line-of-sight
NTP	Network Time Protocol
OCU	Operator Control Unit
RF	radio frequency
SOMTE	Soldier-Operator/-Maintainer Test and Evaluation
SR	Safety Release
SUT	system under test
TOP	Test Operations Procedure
TSARC	Test Schedule and Review Committee
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
USV	Unmanned Submersible Vehicle

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APPENDIX B. REFERENCES.

1. MIL-STD-1472G, Department of Defense Design Criteria Standard, Human Engineering, 11 January 2012.

2. TOP 02-2-543, Line-of-Sight/Non-Line-of-Sight (LOS/NLOS) Testing of Unmanned Ground Vehicle (UGV) Systems, 24 November 2008.

3. TOP 02-2-540, Testing of Unmanned Ground Vehicle (UGV) Systems, 12 February 2009.

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APPENDIX C. APPROVAL AUTHORITY.

CSTE-TM 11 January 2017

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 02-2-546 Teleoperated Unmanned Ground Vehicle (UGV) Latency Measurements, Approved for Publication

1. TOP 02-2-546 Teleoperated Unmanned Ground Vehicle (UGV) Latency Measurements, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP describes procedures for measuring the system latencies of teleoperated UGVs for the purpose of test and evaluation. This TOP covers the measurement of basic video latency, end-to-end system latency, and command-to-action latency in the context of human operation of the UGV through the Operator Control Unit. Measurements address requirements described in Military Standard (MIL-STD)-1472G. This TOP does not include procedures for measurement and ranking of discrete system components or measurements of latency in autonomous systems.

2. This document is approved for publication and will be posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Unmanned Vehicle Test Division, Automotive Directorate (TEDT-AT-AD-U), U.S. Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, Maryland 21005-5059. Additional copies can be requested through the following website: http://www.atec.army.mil/publications/topsindex.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.