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Enhanced Camera

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Technology Impairment Mobility Infrastructure

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LIST OF ABBREVIATIONS AND SYMBOLS

AGC	Automatic Gain Control
CTD	Center for Technology Development
DAS	Data acquisition system
DC	Direct current
EMC	Electromagnetic compatibility
FMVSS	Federal Motor Vehicle Safety Standards
FFOV	Full Field of View
FOV	Field of view
FPS	Frames per second
IR	Infrared
LED	Light-emitting diode
LVDS	Low Voltage Differential Signal
MTF	Modulation transfer function
NV-IPM	Night Vision Integrated Performance Model
OTS	Over-the-shoulder
RF	Radio frequency
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. BACKGROUND

Naturalistic driving studies have revolutionized the collection of detailed driver behavior data by collecting continuously recording video and kinematic data. The Virginia Tech Transportation Institute (VTTI) specializes, in part, in conducting naturalistic driving studies through the use of data acquisition systems (DASs) which are designed to capture continuous video data by utilizing a set of directional cameras. The quality of the video data collected throughout naturalistic driving studies is paramount to the success of each study. Therefore, the selection of robust cameras is critical to data collection projects in order to achieve the desired quality and quantity of collected data. Defective video cameras, or those that do not capture the desired output, can seriously impede data collection during naturalistic studies, resulting in data loss and costly project setbacks.

Due to the criticality of selecting the optimal camera solution for naturalistic driving studies, this research effort focused on the development of a standardized camera testing and selection process for VTTI, which did not previously exist. A standardized quality testing procedure is imperative so that researchers have assurances that each of the cameras selected for naturalistic driving studies have undergone the same rigorous testing procedure that all other cameras have been subjected to. This will ensure that the cameras selected for each DAS are of the utmost quality and perform as expected throughout the duration of the naturalistic study. Furthermore, camera selection criteria were identified as part of this research effort to assist researchers with the selection of an appropriate camera solution for each naturalistic driving study.

CHAPTER 2. OBJECTIVE

The goal of this project was to develop standardized camera testing procedures and apparatuses for use in determining whether new cameras would meet the requirements for use in VTTI's DASs. In addition, in order to provide a reference guide for researchers, the cameras currently in use at VTTI were tested according to the standardized procedures and catalogued on VTTI's internal Wiki, an intranet resource available to all VTTI researchers. Over time, and with each new camera tested using the procedures, the Wiki site will be expanded, providing researchers with the resources to make intelligent camera selections. These new standardized testing procedures will allow VTTI to utilize the most up-to-date and cost-effective cameras without the added risk of reliability concerns.

Additionally, this project identified camera performance and test recommendations to assist researchers in the selection and qualification of cameras for research studies at VTTI. The following tasks were completed as part of this effort:

1) A system description, application objectives, and imaging system requirements were developed to identify the components of a camera system, including video acquisition, data storage and transmission, display, and human perception (see the Additional Camera Evaluation Methods and Recommendations section below).
2) Standards and specifications were identified and used to develop recommendations for VTTI video systems:
    a. See the Imaging System Camera Requirements section below.
    b. See the Imaging System Camera Environmental Requirements section below.
3) Video resolution software was evaluated and recommendations were established (see Appendix A: System Level Resolution Testing).
4) The proposed video resolution methods were demonstrated (see Appendix A: System Level Resolution Testing).
5) An example specification for an in-cabin application was developed (see Appendix H: In-Cabin Specification Example).

CHAPTER 3. METHODS

The following section describes the process used throughout this effort to identify critical camera attributes, develop and build camera testing apparatuses, develop standardized testing procedures, acquire and test cameras of interest, and to identify additional camera evaluation methods and recommendations for future consideration at VTTI.

IDENTIFYING CRITICAL CAMERA ATTRIBUTES

The first step in creating standardized camera testing procedures was to survey VTTI researchers to determine the most important camera attributes and potential quality issues to address in the standardized testing procedures. In an effort to reach all researchers with potentially valuable knowledge and opinions to contribute to this project, a survey was developed and emailed to all VTTI researchers requesting feedback on important camera attributes to include in the quality testing procedures, as well as known camera issues that had occurred in the past during naturalistic driving studies. This survey resulted in a list, shown in Table 1 below, of known post-selection and post-installation camera issues that arose during previous VTTI research efforts. This list encompasses all of the past camera issues that were identified by VTTI researchers as a result of the online survey, in no particular order.

Table 1. Camera issues to address.

Camera Issue
Cameras stop working altogether
Poor clarity in a particular lighting condition
Poor clarity across all lighting conditions
Loss of focus
Color cameras only showing in black and white
Camera views flipping upside down
Failure of weather resistance
Cameras causing radio frequency (RF) interference
Issues caused by vibrations

Based on these known past issues, along with additional feedback gleaned from the survey responses, a number of critical camera attributes were identified and prioritized for examination throughout this project. Prioritization was based on a number of factors, including the criticality of each camera attribute to data collection and the feasibility of testing for each attribute in terms of cost and availability of required resources. These critical attributes are shown in Table 2 below, in no particular order.

Table 2. Critical camera attributes.

Critical Camera Attributes
Resolution
Sharpness
Field of View (FOV)
Dynamic Range
Minimum Lux
Temperature Range
Bias, Humidity, and Temperature
Immersion
Salt Atmosphere
Temperature Cycle
Vibration
Electromagnetic Compatibility (EMC) Immunity
RF Emissions

TESTING APPARATUSES

Using the list of critical camera attributes, the Center for Technology Development (CTD) at VTTI designed and built a camera testing apparatus and a field of view (FOV) testing apparatus.

The camera testing apparatus has a viewing monitor that allows visual verification of various attributes, including image clarity, black/white versus color display, and the quality of the image under various lighting conditions. Although the testing apparatus does not have the capabilities to test RF emittance, the CTD has the ability to test this using a Mixed Domain Oscilloscope. The camera testing apparatus, when used in conjunction with an infrared apparatus, also has the ability to detect infrared (IR) sources in cameras, which are important for data collection in low light levels. The testing apparatuses and associated operating procedures are described in detail in the following sections.

Camera Testing Apparatus

The camera testing apparatus is a small box with a number of inputs and features. The apparatus is shown in Figure 1 operating in conjunction with an FOV display, which is discussed further in the following section. Figure 2 and Figure 3 show the various buttons, plugs, and ports available on the apparatus.

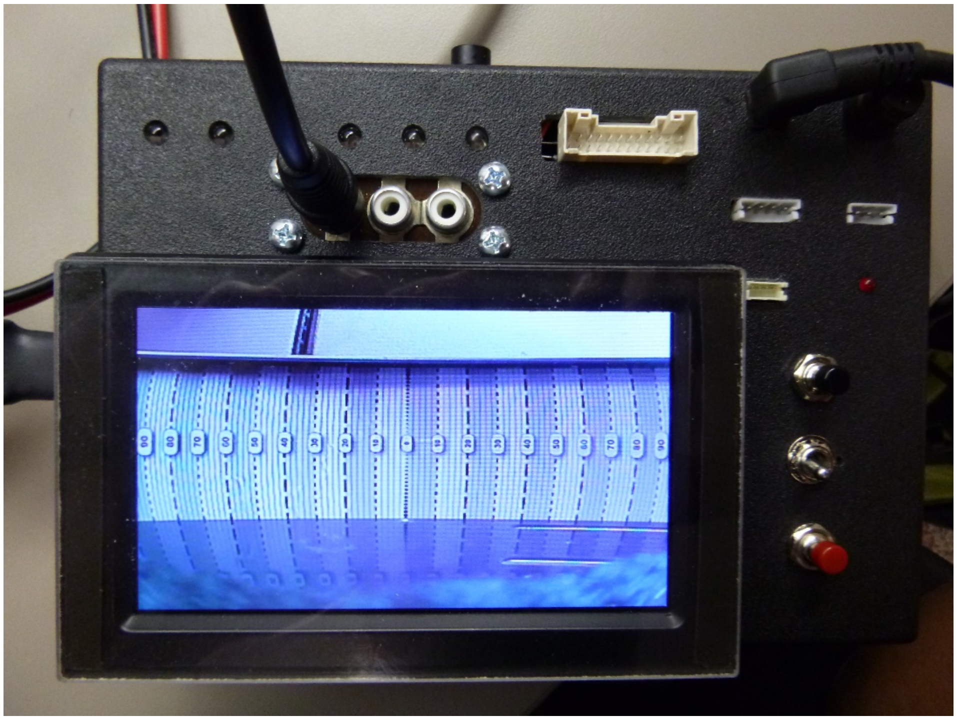

Figure 1. Photo. Camera testing apparatus.

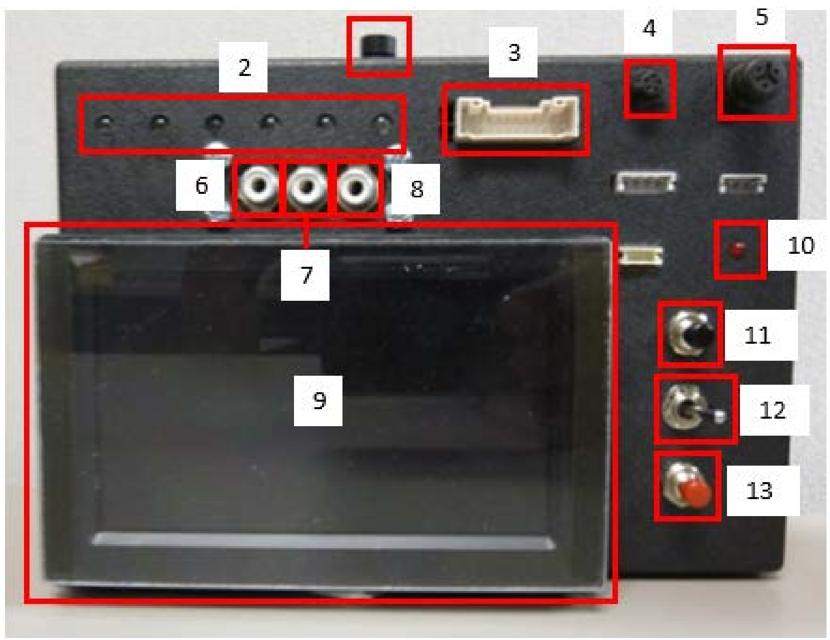

Figure 2. Photo. Camera testing apparatus buttons, plugs, and ports – front view.

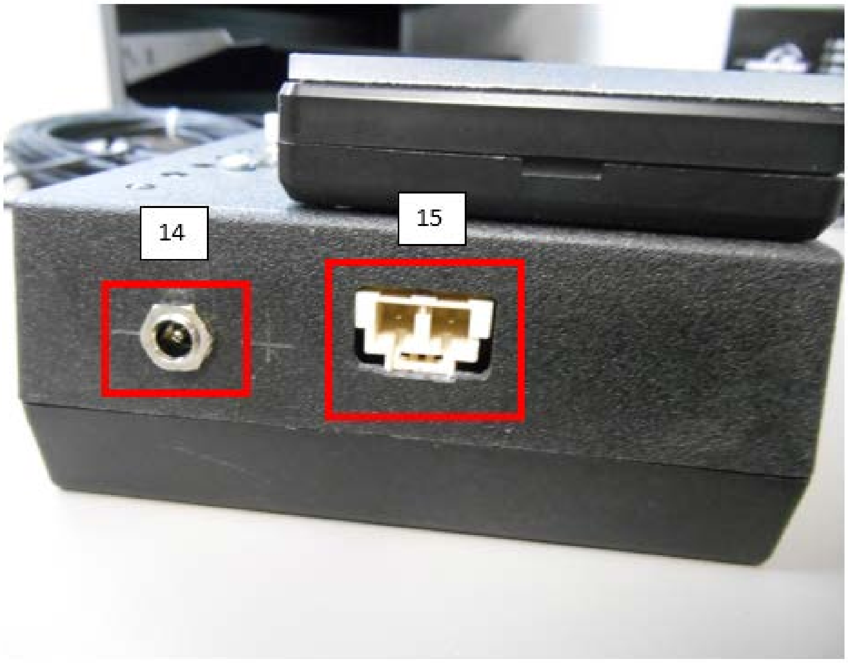

Figure 3. Photo. Camera testing apparatus buttons, plugs, and ports – side view.

Descriptions of each of the numbered items in Figure 2 and Figure 3 are provided below.

2—Light-emitting diodes (LEDs)

3—DAS port

This connection is used to connect the DAS to test cameras.

4—Motorcycle connection

5—DAS camera connection

6—Camera RCA connection

7—Not currently used

8—External monitor connection.

- An external monitor can be connected to this port to view a camera’s feed on a larger screen instead of on the built-in monitor.

9—Built-in monitor

- This displays the feed taken from a connected camera, as well as the IR camera’s feed.

10—System on/off indicator

11—LED control

12—Monitor switch

- This switch allows the user to switch between an external monitor display and the built-in display. When the switch is to the left, the built-in monitor will be active.

If the switch is to the right, the camera feed will be shown on a connected external monitor.

13—IR camera button

- Pressing this button activates the IR camera and displays the feed to a monitor. It must be held down continuously when conducting IR testing.

14—Direct current (DC) power supply port

- This port is for use with the power adaptor.

15—DAS power connection port

- This port connects the DAS cable adapter to the camera.

The testing apparatus also requires a DC power adapter (shown in Figure 4), which is plugged into the power supply. This provides power to the testing apparatus and the camera itself.

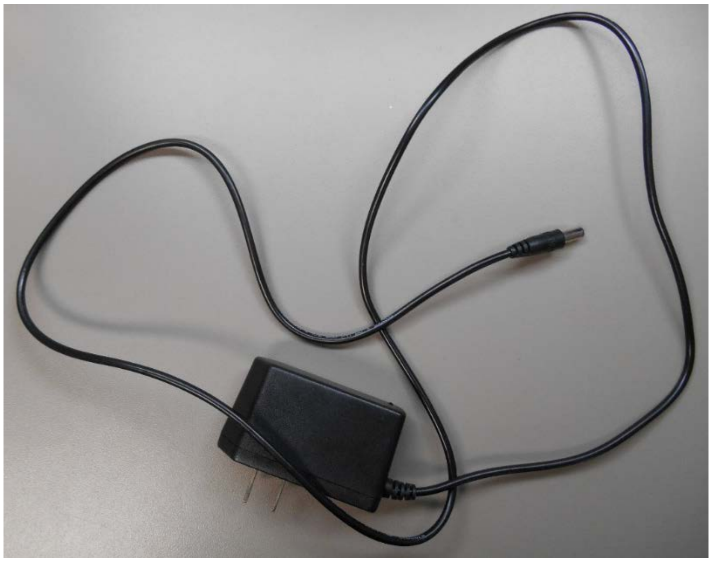

Figure 4. Photo. DC power adapter.

A DAS power cable (Figure 5) plugs into the DAS connection from the left side of the testing apparatus directly into the camera's power port.

Figure 5. Photo. DAS power cable.

Field of View Testing Apparatus

The FOV testing device is shown in Figure 6, below. Used in combination with the camera testing apparatus, the camera, and the power supply, this apparatus can determine a camera's horizontal and vertical FOVs. The Field of View Apparatus Testing Procedures section of this report describes the methods for configuration and use of this apparatus.

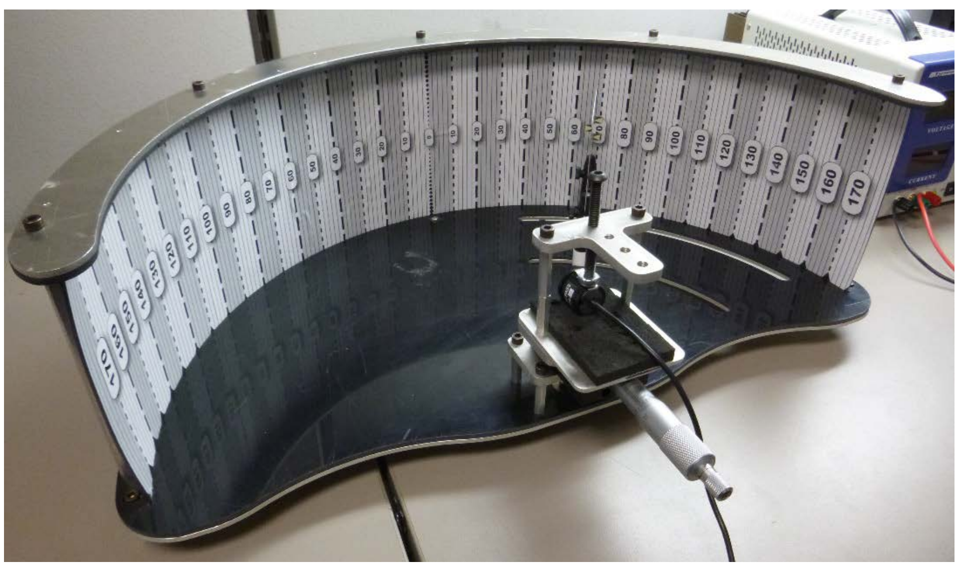

Figure 6. Photo. Field of view testing device.

Infrared Device

An infrared device, which contains eight IR LEDs, is shown in Figure 7 below. It attaches to the connection end of the motorcycle port on the camera testing apparatus, and can be used to determine whether or not the camera has an infrared filter.

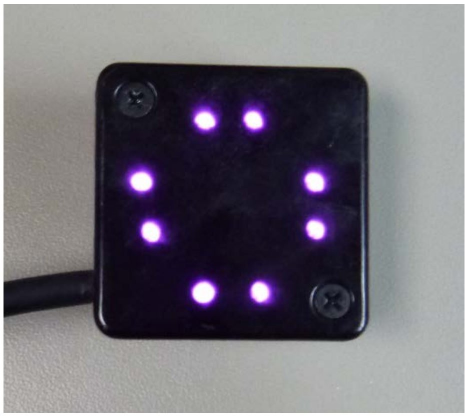

Figure 7. Photo. Infrared device.

STANDARD TEST PROCEDURES

Subsequent to the development of the testing apparatuses, a standardized set of camera testing procedures were developed for the purpose of ensuring that all cameras chosen for use in VTTI research projects undergo, and will continue to undergo, the same rigorous testing process. The following sections describe the procedures for using the testing apparatuses.

Camera Testing Apparatus Procedures

Step 1: The DC power adapter is plugged into a wall socket, as shown in Figure 8.

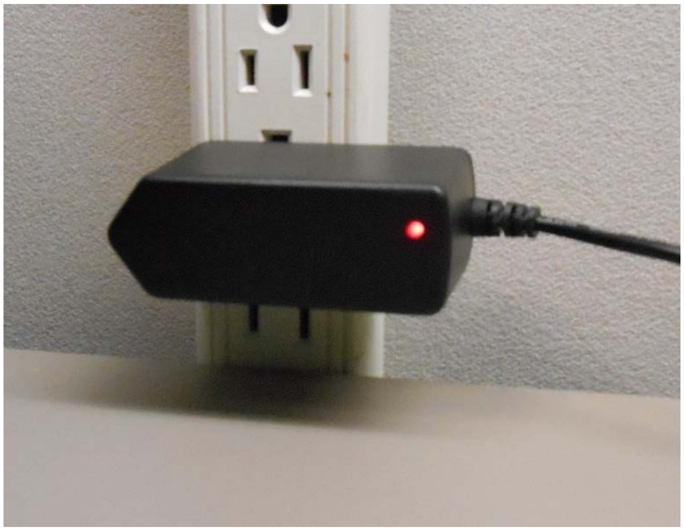

Figure 8. Photo. DC power adapter plugged into wall socket.

Step 2: The jack end is plugged into the side of the camera testing apparatus as shown in Figure 9.

Figure 9. Figure. Power adapter plugged into camera testing apparatus.

Step 3: Next, the DAS power cable is plugged into the side of the camera testing apparatus, as shown in Figure 10. If an LED indicator light appears, it must be deactivated by holding down the black button until the light goes out.

Figure 10. Photo. DAS power cable plugged into camera testing apparatus.

Step 4: The power from the DAS cable is then plugged into the camera's red RCA connection, as shown in Figure 11.

Figure 11. Photo. DAS cable plugged into RCA connection.

Step 5: The video cable is connected (Figure 12) to the plug on the camera testing apparatus. One end of the video cable should be plugged into the yellow cable socket coming from the camera. The other end should be plugged into the first RCA port located on the box, shown in Figure 13.

Figure 12. Photo. Video connection.

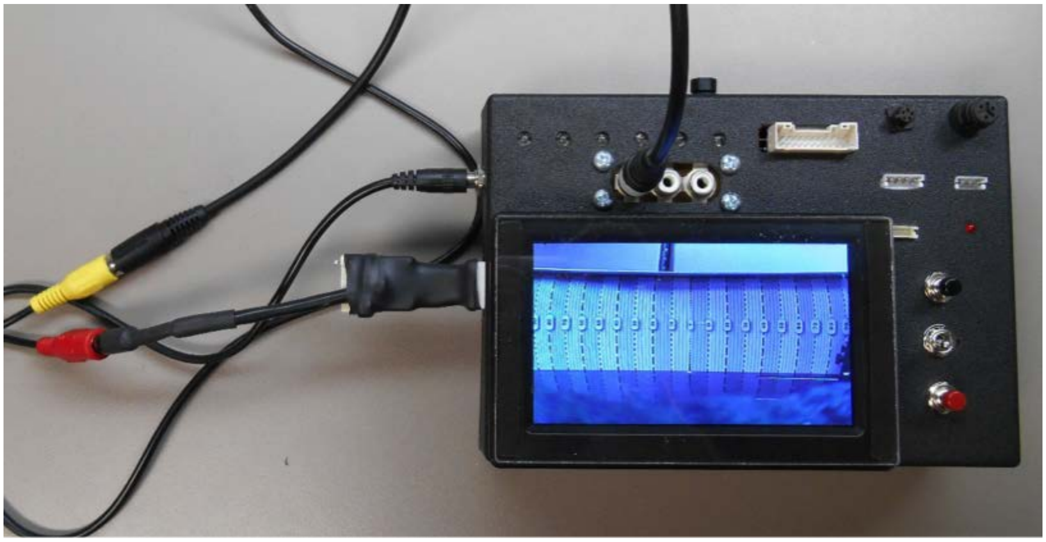

Figure 13. Photo. Video cable plugged into camera testing apparatus.

Once the power cable has been plugged in and the camera has been connected, the display should show the feed coming from the camera with the monitor switch in the left position. The camera and testing apparatus are now ready for testing.

Field of View Apparatus Testing Procedures

In order to test a camera's field of view, the camera must be set up in the FOV apparatus and configured so that proper measurements will be taken. For simplicity, the procedure to configure the camera will be dependent on the X-, Y-, and Z-axes, as shown in Figure 14. The testing procedure and camera set up process are described in the following steps.

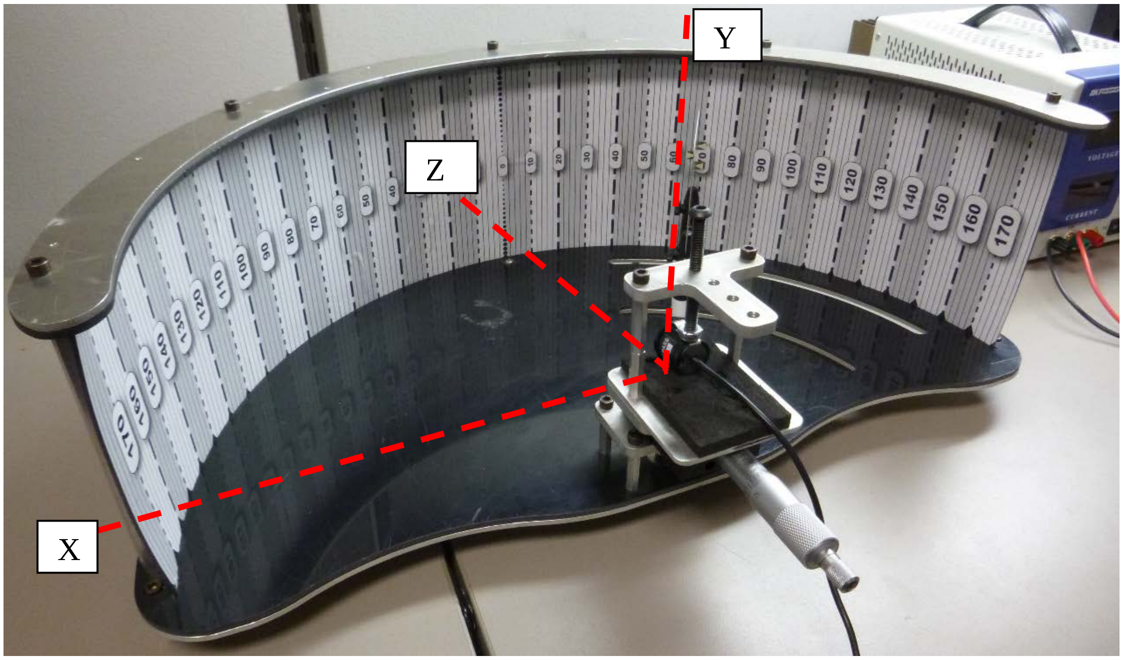

Figure 14. Photo. FOV testing apparatus with X, Y, and Z axes.

Step 1: The camera must be properly secured in the device. The camera testing apparatus is required for this step to ensure proper camera orientation. With the built-in monitor turned on, the camera is placed in its holder on the apparatus and clamped down loosely with the screw (shown in Figure 15).

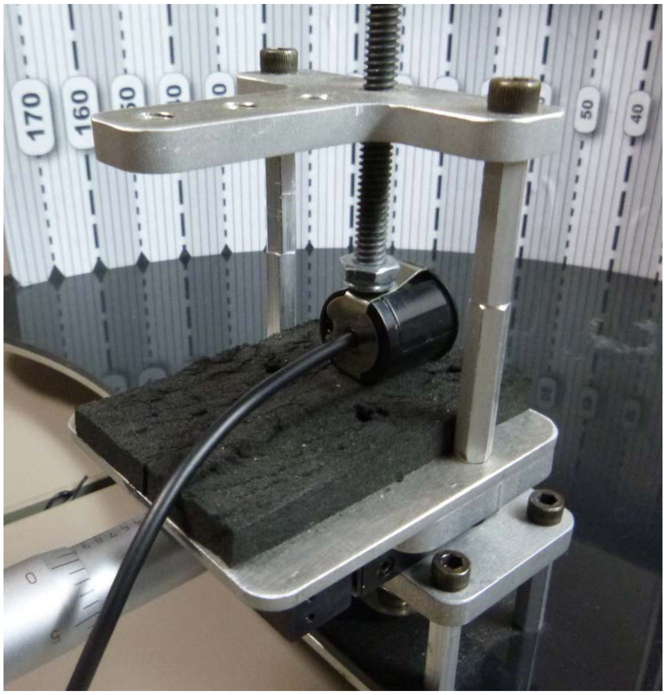

Figure 15. Photo. Camera secured in FOV apparatus.

Step 2: The orientation of the camera feed is determined in the monitor and the camera is rotated on the Z-axis until the display shows that the top of the FOV testing device is parallel with the upper edge of the display (as shown in Figure 16).

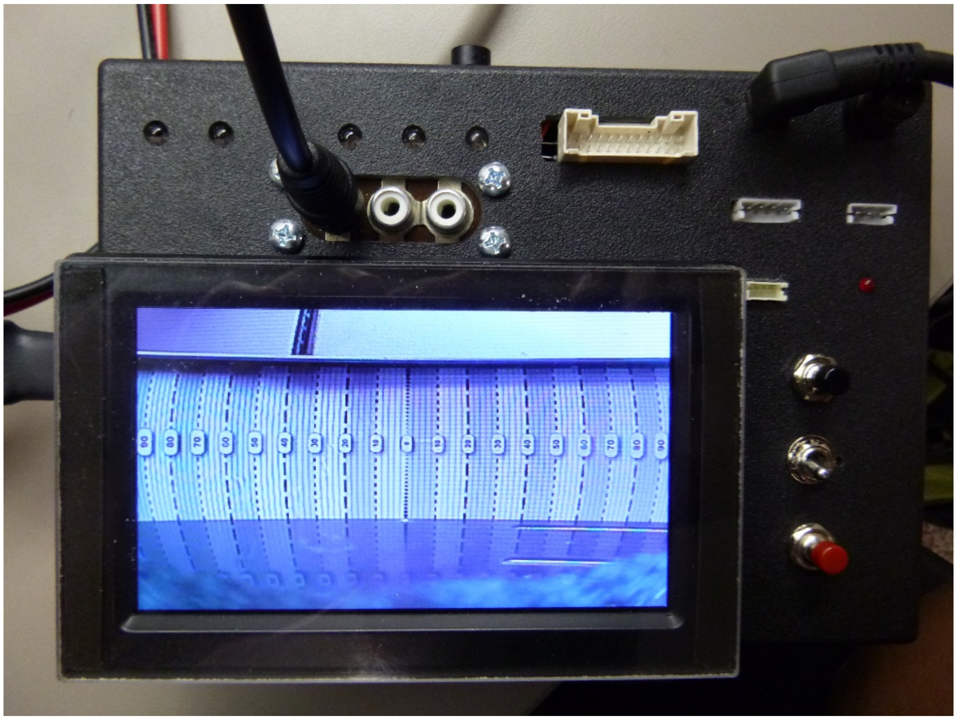

Figure 16. Photo. Horizontal camera feed orientation.

Step 3: Now the camera must be rotated (around the Y-axis) so that it is centered on the 0° line. The camera is centered by positioning it so that the numbers and quantity of lines are the same on both the left and right edges of the screen. This is illustrated in Figure 16 above, showing that the outer edges of the ovals labeled 90 are displayed on both sides of the screen.

Step 4: Once the camera has been properly oriented and the view is centered, the screw is tightened so that it will not move during testing. Minor adjustments around the Y- and Z-axes may be needed during tightening.

Step 5: The next step is adjusting the platform's position using the dial on its front. Turning the platform adjustment knob (shown in Figure 17) moves the platform back and forth. The platform must be moved to a point where the very front of the camera's lens is in line with the outermost edges of the FOV device, as shown in Figure 18. The easiest way to achieve this alignment is to use a string or a ribbon. The string or ribbon is attached to one side and pulled to the opposite side of the apparatus in front of the camera until it is taut (shown in Figure 19).

Figure 17. Photo. Platform adjustment knob.

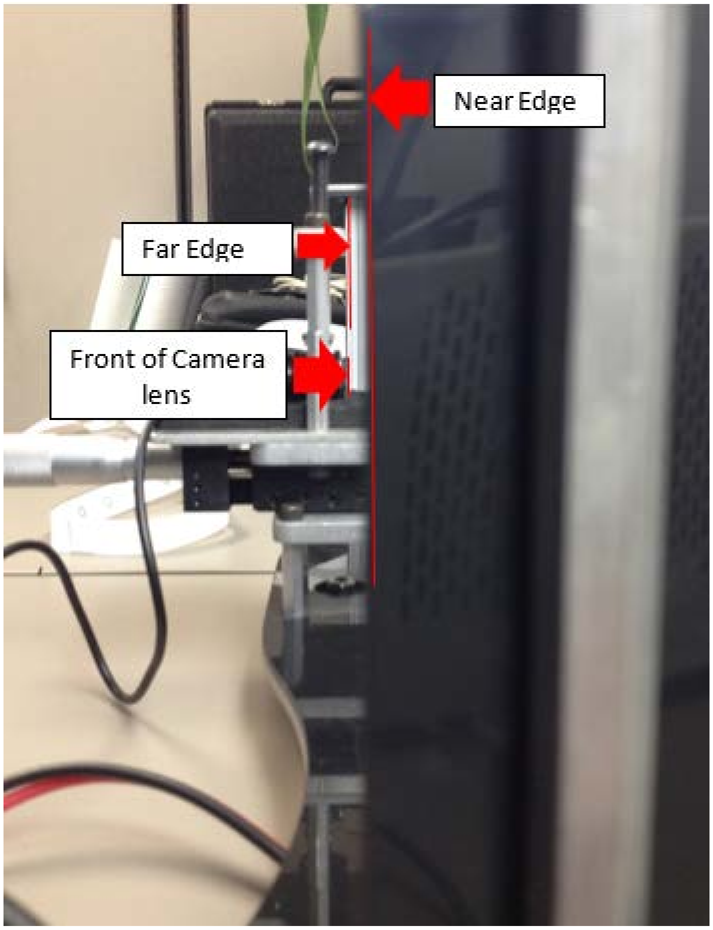

Figure 18. Photo. Platform adjustment.

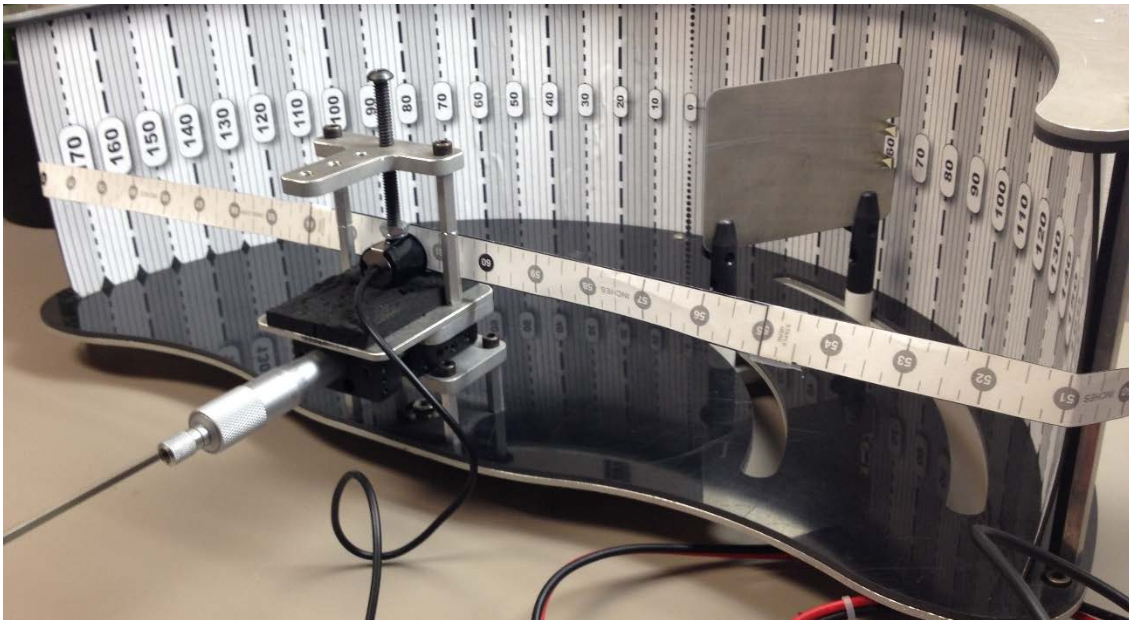

Figure 19. Photo. Alignment adjustment with ribbon.

Step 6: The dial is rotated until the front of the lens is just touching the ribbon or string (Figure 20). Once it touches, the camera is in proper positioning for FOV testing.

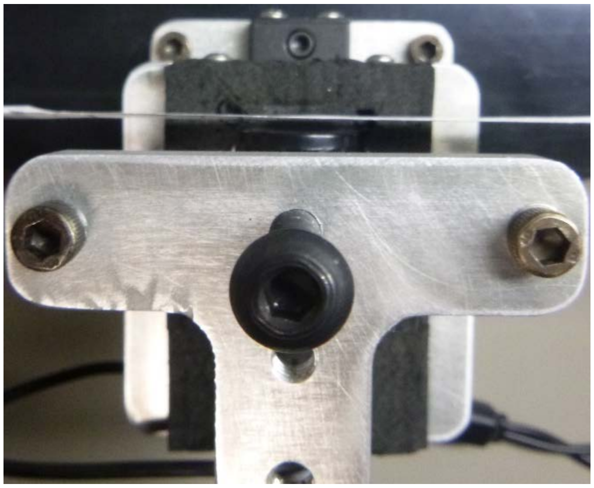

Figure 20. Photo. Camera lens touching ribbon.

Step 7: Once the camera has been secured in the FOV testing device, testing for FOV can begin. The metal plate shown in Figure 21 is used to measure the camera's FOV. Note the yellow arrows on either side of the metal plate (Figure 22).

Figure 21. Photo. FOV testing plate.

Figure 22. Photo. Arrows on sides of plate.

Step 8: To measure the FOV angle, the plate is moved until it comes into view on the camera testing monitor, as shown in Figure 23.

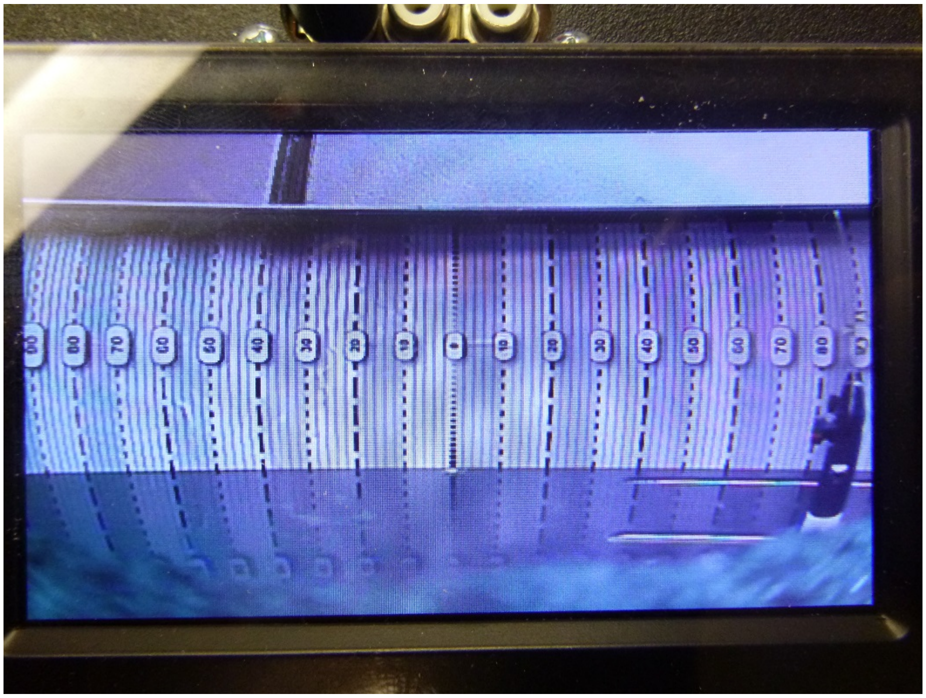

Figure 23. Photo. Plate in view of monitor.

Step 9: Once the plate has entered the camera's view, it is moved back out of frame until the single yellow arrow is pointing at the edge of the monitor, as shown in Figure 24.

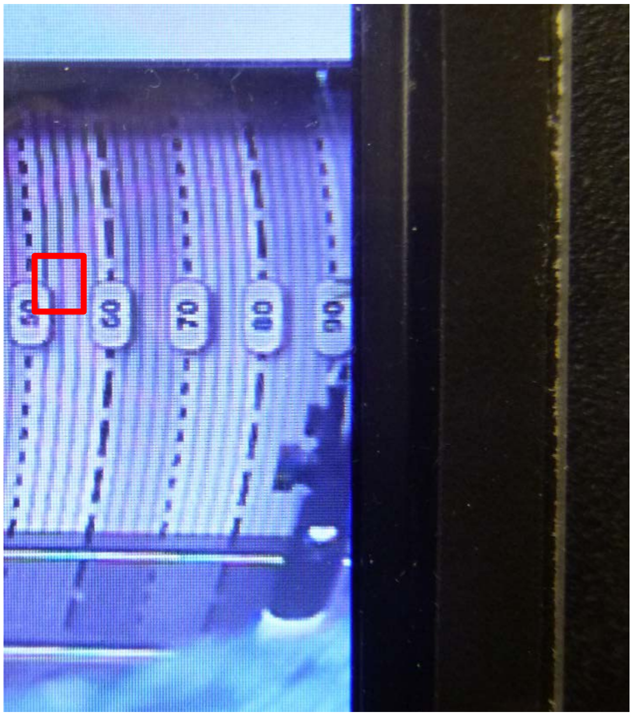

Figure 24. Photo. Yellow arrow at edge of monitor.

Step 10: When looking directly down the plate, the line that the plate is on shows the resulting FOV angle, as seen in Figure 25. The lines indicate an increase in angle of 2° increments. For example, the camera shown in Figure 25 has roughly a 93° horizontal FOV.

Figure 25. Photo. FOV measurement.

Step 11: A similar process is used for testing the vertical FOV. The camera is rotated 90° around the Z-axis until the top of the FOV device is parallel to the sides of the monitor. The camera is pivoted around the Y-axis in a similar fashion as before to make sure the view is centered on the 0° line, as shown in Figure 26.

Figure 26. Photo. Vertical camera feed orientation.

Step 12: Just as before, the plate is moved until it is visible on the monitor, as shown in Figure 27 .

Figure 27. Photo. Plate in view of monitor.

Step 13: The plate is moved until it is almost out of view and the single yellow arrow is at the edge of the screen (Figure 28).

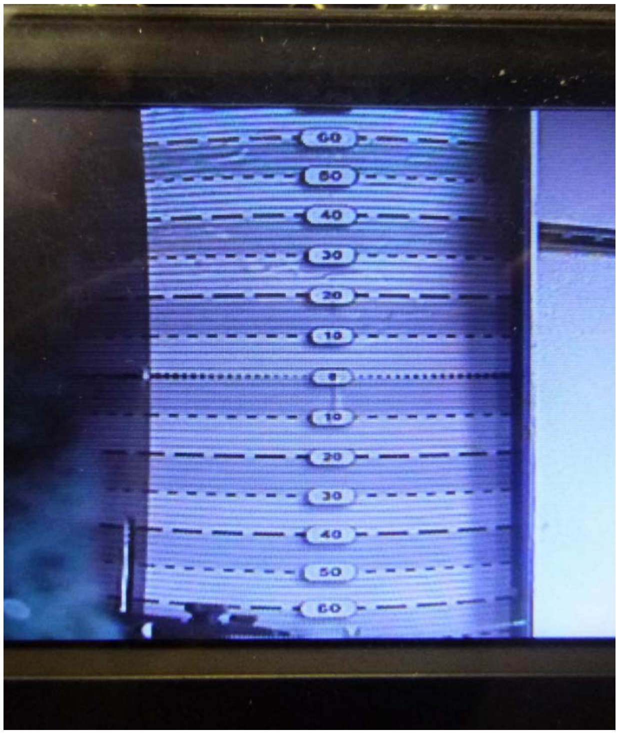

Figure 28. Photo. Yellow arrow at edge of monitor.

Step 14: When looking directly down the plate, the line that the plate is on shows the resulting FOV angle, as seen in Figure 29. This camera has a vertical FOV of approximately 68°.

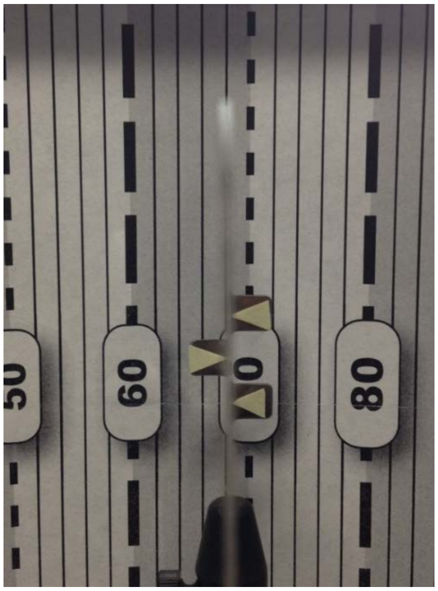

Figure 29. Photo. Vertical FOV measurement.

Infrared Source Testing Procedures

To test whether a camera has IR sources, the built-in camera must be used (shown in Figure 30).

Figure 30. Photo. Built-in camera on testing apparatus.

The external camera cannot be connected to the RCA port at the same time the IR camera is in use, as interference between the external camera and built-in camera will result. The RCA connection must therefore be unplugged (the power remains plugged in). To test the camera for IR sources, the red button must be continuously depressed. If IR sources are present, the lights on the infrared device will be illuminated.

CAMERA ACQUISITION AND TESTING

Once the camera testing devices were built and the standard testing procedures developed, VTTI's current collection of cameras was tested. An internal VTTI Wiki page was created to record the results of each set of camera tests. This Wiki is available for all VTTI researchers to reference when determining what cameras may be suitable for various research projects. The results posted on the Wiki are presented in Table 3 below.

In addition, three new cameras were acquired and tested using the new apparatuses and testing procedures. The CTD determined that acquiring the TOP-211M-M, TOP-313M-M, and the TOP-313M-S cameras would provide the most benefit to VTTI. These cameras are manufactured by a company from which VTTI has previously purchased cameras that have performed to standards. These cameras were also deemed suitable replacements for the bumper/over-the-shoulder (OTS)/ rear cameras which were used in prior VTTI studies but did not perform to standards. The testing results of these newly acquired cameras are shown in Table 4.

Table 3. Camera attributes for VTTI's current collection.

Model	Video System	Color B/W	Resolution	Lux	Voltage	Out-put	Temp. range	FOV	ζH	ζV
VTK302N	NTSC	Color	420 TVL	1	12V	1.0 p-p	-20 °C to 70 °C	3.3 mm lens	96°	69°
1372R/ VTK360	NTSC	Color	480 TVL	0.2	DC12V	1.0 p-p	-30 °C to 65 °C	(3.58 mm X 2.69 mm lens)	101°	76°
VTTI-Cam RV-2	NTSC	BW	5-12 V			Video NTSC	-40 °C to 105 °C	1.5 mm lens	92°	67°
PC213XS	NTSC	Color	380 Lines	1.0	DC12V	1V p-p 750 MS	-10 °C to 50 °C	3.6 mm lens	51°	40°
PC6EX4	NTSC	Color	320 TV Lines	0 @ F1.2	DC12V	1V p-p 75 Ohm	-20 °C to 55 °C	3.6 mm lens	73°	44°
InMotion in30S1N1 L38	NTSC	Color	690HTVLe	0.1	DC12V	1V p-p	-10 °C to 50 °C	3.8 mm lens	80°	63.5°
InMotion in30S1N1 L25	NTSC	Color	690HTVLe	0.1	DC12V	1V p-p	-10 °C to 50 °C	2.5 mm lens	104°	72°
NextGEN Face Camera VTTI-CAMFV-2 (Standard Car)	NTSC	BW	420 TVL	1	DC12V	1V p-p	-10 °C to 45 °C	3.3 mm lens	64.5°	52.8°
NextGEN Face Camera VTTI-CAMFV-2 (Standard Truck)	NTSC	BW	420 TVL	1	DC12V	1V p-p	-10 °C to 45 °C	3.3mm lens	49.6°	38.5°

Table 4. Camera attributes for newly acquired cameras.

Model	Video System	Color B/W	Resolution	Lux	Voltage	Out-put	Temp. range	FOV	ζH	ζV
TOP-211 M-M	NTSC	Color	420 TVL	1 @ F1.2	DC 12V	1.0 p-p	-68 °F to 158 °F	1.7 mm lens	103°	74°
TOP-313 M-S	NTSC	Color	420 TVL	0.5	DC12V	1V p-p	-68 °F to 158 °F	1.7 mm lens	92°	67°
TOP-313 M-M	NTSC	Color	420 TVL	0.5	DC12V	1V p-p	-68 °F to 158 °F	1.7 mm lens	103°	73°

Prior to making any large-volume purchases of a new camera, VTTI will purchase and test a small sample of the new camera model. Once the camera has successfully undergone the standardized camera testing procedure and the results of the camera tests have been posted on the VTTI Wiki, the camera will be approved for future use in naturalistic driving studies. The results will be posted on the VTTI Wiki page to be used as a quick reference for VTTI researchers and CTD engineers.

ADDITIONAL CAMERA EVALUATION METHODS AND RECOMMENDATIONS

An additional set of camera evaluation methods and recommendations were developed to test critical camera attributes that the testing apparatuses could not evaluate. These additional procedures also aimed to provide researchers with pertinent information for selecting appropriate cameras for various research projects, and are discussed in more detail in the following sections of this report. Specifically, these additional evaluation methods provide researchers with potential application objectives and imaging system requirements in order to assist with the identification of important camera system components, including video acquisition, data storage and transmission, display, and human perception. Standards and specifications were identified to assist with the development of recommendations for VTTI video systems. Furthermore, video resolution software was evaluated and recommendations for various software packages were provided along with accompanying instructions on how to test video resolution.

The following camera evaluation methods and recommendations provide testing recommendations that should be followed in order to verify that a given imaging system and camera is suitable for a specified application, and has the critical camera attributes defined in the technical committee’s list.

In order to verify that a given imaging system and camera is suitable for an application, this report includes the following recommendations:

A. A system-level resolution test based on the ISO 12233 standard should be completed (using commercial software such as Quick MTF) to determine performance curves for the system using the spatial frequency or modulation transfer function (MTF).[1,3] (The commercial software includes many useful features that the free software does not offer.)

B. The range performance of the system, on-axis and off-axis, with a given target size and target distance should be determined using the Johnson Criteria (see Appendix B).[2] For more in-depth performance predictions, the measured system performance can be used as an input to a system-level model such as the Night Vision Integrated Performance Model used by the Department of Defense for tactical day/night applications.[4]
C. The image sharpness of systems should be compared using the measured MTF curves.
D. Environmental testing should include bias humidity and temperature, salt atmosphere, temperature cycling, vibration, EMC immunity, and RF emissions tests.

Table 5 lists the details of the recommended tests as well as the specific requirements associated with each test. Furthermore, Table 5 provides details as to which of the recommended tests can currently be performed at VTTI with resources already on hand, and which tests require, or would be improved by, additional resources. As can be seen in Table 5, only temperature range and immersion tests can currently be carried out at VTTI without the need for additional resources, and the remaining imaging tests and environmental tests would require additional resources to be completed as effectively as possible.

Table 5. Recommended tests for camera selection and qualification and resources required.

System Resolution	Requirement	Additional Resources	Equipment
Resolution 1) On-Axis 2) Off-Axis	Appendix A: System Level Resolution Testing. From one bench level test, the on-axis and off-axis resolution for the system can be established.	Improved with Equipment	A test target from a prior version of the ISO 12233 standard is available online and is provided as part of this study. The newest test target can be purchased to resolve some test issues.
Image Sharpness	A comparison is made using the curves generated in the resolution test.	Improved with Equipment	Free software, ImageJ, can be used to measure sharpness. Commercial software is easier to use and would decrease the learning curve for the operator.
FFOV	Use the existing VTTI FOV test or the resolution test. Use the resolution test to determine the performance off-axis.	Improved with Equipment	A test target from a prior version of the ISO 12233 standard is available online and is provided as part of this study. The newest test target can be purchased to resolve some test issues.

System Resolution	Requirement	Additional Resources	Equipment
Dynamic Range	Camera range: Measure resolution at the maximum and minimum light levels. Requires lamps with filters. Instantaneous: Measure using Department of Homeland Security Method.(5)	Equipment Required	This test requires lamps with neutral-density filters and/or test targets.
Minimum Lux	See Dynamic Range	Equipment Required	This test requires lamps with neutral-density filters and/or test targets.
Environmental Specs	**Requirement**	**Additional Resources**	**Equipment**
Temperature Range	-40 °C to 85 °C suggested temp range. See Appendix L for test.	No Equipment Required	NA
Bias, Humidity, and Temperature	1,000 hr. (>60 cycles); 30 °C-65 °C; >90% humidity power applied(6)	Equipment Required	See Appendix I: Cycled Temperature-Humidity-Bias
Immersion	None if Bias, Humidity, and Temp is tested. Otherwise, 1 m immersion tap water for 30 min.(7)	No Equipment Required	See Appendix J: Immersion
Salt Atmosphere	If mounted outside: two 24-hour salt fog cycles; 35 °C(8)	Equipment Required	See Appendix K: Salt Atmosphere
Temperature Cycle	Ten cycles -40 °C to 85 °C(7)	Improved with Equipment	See Appendix L: Temperature Cycling
Mechanical Shock	Approximate 1-m drop to a concrete floor in all orientations of the device. No apparent physical damage or damage to image.	No Equipment Required	See Appendix M: Mechanical Shock
Vibration	Peak Acceleration 20 g; 20-2,000 Hz or alternate PSD method(9)	Equipment Required	See Appendix N: Vibration
EMC Immunity	RF Immunity RI-112, RI-114, RI-115(10)	Equipment Required	See Appendix O: EMC Immunity and RF Emissions
RF Emissions	RF Emissions RE-310, CE-420(10)	Equipment Required	See Appendix O: EMC Immunity and RF Emissions

Imaging System Application Objectives

In order to identify the best camera for a specific application, the system objectives must be established. Table 6 includes a list of objectives and examples to assist in defining the system for a specific application.

Table 6. System objectives.

Objectives	Examples
Mount Location	External: Exposed to weather Internal: Inside of an enclosed vehicle cabin
Target Size	Examples: - Face: 0.16 m (12) - Pedestrian: 0.75 m (4) - Vehicle: 3.1 m (4) - Road Speed Sign (13) o Single lane 0.61 × 0.76 m (24" × 30") o Multi-lane 0.76 × 0.91 m (30" × 36") o Expressway 0.76 × 1.22 m (36" × 48") o Freeway 1.22 × 1.52 m (48" × 60")
Target Range	Examples: - Occupant: 1 m - Highway Sign: Application specific; for reference, 220 m range equals the 715 ft. minimum sight distance at 60 mph (13)
Target Contrast	Examples: - 30% for humans and objects in cluttered background (4)
Full Field of View (FFOV) and Specific Angle of Interest	Example: FFOV of 180° = 90° to the right and 90° to the left of on-axis. Specific angle of interest = Camera will be mounted forward and will be reading signs at a 30° angle.
Illuminance	Standard Lighting Intensity: 200–500 lux (5) Reduced Lighting Intensity: 30–60 lux (5) Dim Lighting Intensity: 5–10 lux (5) Appendix C contains a list of the lux levels in common conditions.
Speed of Target in Reference to Camera	Examples: • 60 mph = road sign and 60 mph vehicle equipped with a DAS • 120 mph = vehicle traveling 60 mph in opposite direction to another 60 mph vehicle equipped with a DAS
Atmospheric Transmission	Example: Imaging in rain/fog/dust Note: Requires range testing or performance modeling

Imaging System Requirements

A resolution test that includes all of the system components that influence the image capture, storage and transmission, display, and eye perception can be performed using a resolution test method from ISO 12233.[1] In-Cabin and outside recommended levels are given in Table 7, but specific applications may require establishing new target levels.

Both the ISO 12233 visual resolution method and the edge-based spatial frequency response methods can be used to determine the system resolution.[1] The differences between the two should be understood.

1) The visual resolution method, using the free download software provided by the Camera and Products Imaging Association, includes the system performance plus the human perception of the display, while the edge-based method includes the entire system performance but not human display perception.[14] In practice, the MTF contrast value that correlates with the visual-based method can be established in order to eliminate performance of the visual-based measurement.
2) The edge-based method can be used to compare cameras' sharpness by comparing the MTF at 50% lower contrast than the peak MTF. This value is referred to as MTF M50P.[15] The peak MTF is used to account for camera process sharpening.
3) The edge-based method MTF curve can be used to estimate the contrast and resolution of a target at different distances without making additional measurements.

Table 7. Imaging system requirements.

Requirement	System Objectives	Recommendation
Resolution 1) On-Axis 2) Off-Axis	System Objectives: Target size, range, contrast, illuminance, reflection, atmospheric transmission Line pair MTF M30 calculation: $O_{LP} = \frac{Target\ Size * MTF\ M30 * f}{Target\ Range}$ O_{LP} = Line pairs on the target object See Appendix D: Example System Resolution Calculation Off-axis testing is required if the primary use is not on-axis. The lens performance typically degrades off-axis. Most resolution targets have features for evaluating on-axis and off-axis performance at the same time.	a. Measure the MTF M30 value. See Appendix A: System Level Resolution Testing - Obtain f = focal length from camera supplier - Obtain pixel pitch and array size from supplier - Calculate # of line pairs at the object (O_{LP}) • In-Cabin (O_{LP}) > 20 (minimum) • Outside (O_{LP}) > 10 (minimum)
Image Sharpness	MTF M50P = The spatial frequency where MTF is half the peak MTF value	Compare the MTF M50P for different systems. See Appendix A. System Level Resolution Testing.

Imaging System Camera Requirements

The system resolution measurement is needed to verify that the system is suitable for the application. Camera specifications are also needed to identify camera candidates for the system. Even though another part of the system may limit the resolution, minimum specifications for the camera are still needed to guide the purchase of cameras for system testing. Table 8 includes a list of camera-level specifications.

Table 8. Camera imaging specifications.

Camera Specifications	Notes	Recommendation
Camera Resolution	An estimate of camera resolution can be used in order to eliminate cameras from consideration. Quick estimate: See Appendix E: Camera Resolution Quick Estimate. More complete estimate: Step 1: Find the smallest resolvable feature by choosing the larger of the diffraction limited spot size (optical limit) to the pixel size (imager limit). $Diffraction\ limited\ spot\ size = 2.44\lambda\ F/\#$ Step 2: Use the smallest resolvable feature instead of the pixel size in the quick estimate method. See Appendix F: Diffraction Limited Spot Size vs. Pixel Size.	• Request the camera MTF curve and use the MTF M30 value to determine the O_{LP} • Estimate the camera O_{LP} • Internal (O_{LP}) > 20 • External (O_{LP}) > 10
Full Field of View (FFOV)	System Objective is FFOV. The term *Useful FOV* is sometimes used to specify the FOV at which the camera can meet a required resolution. See Off-axis system resolution.	Test with existing VTTI FOV test station. • In-Cabin: Approximately 90-180° • Outside: Approximately 90-120°
Frame Rate and Shutter	System Objectives: Speed of target in reference to camera. Notes: *Frame rate:* Number of times per second that all of the rows of the imager are exposed. *Rolling shutter:* Imager rows are exposed one row at a time and read when the next row is exposed. *Global shutter:* All rows are exposed at the same time and then all rows are read in the following frame.	• <10% motion blur of target.

Camera Specifications	Notes	Recommendation
	<u>*Time Period for 10% Motion blur*</u>: $$T \leq \frac{\Delta x}{10v}$$ Where T = time for object to move 10% of its length; Δx = the object's length; v = the object's velocity across the face of the imager. See Appendix G: Motion Blur Calculation	
Dynamic Range	System Objective: Min and Max Illuminance Notes: Typical dynamic range is 60 dB for an imager but some scenes are greater than 100 dB. $Dynamic\ Range = 20 * LOG(\frac{Max\ Lux}{Min\ Lux})$ Several methods are used to adjust the camera to cover the full range. - Camera Automatic Gain Control (AGC): Gain of all pixels are changed. Does not simultaneously allow imaging in dark and light regions. - Pixel level extended dynamic range (HDR/WDR/XDR): Allows simultaneous imaging of light and dark regions but may be non-linear which affects ability to image in color.	• Dynamic Range: >100 dB ideal - Ask supplier for the scene dynamic range and the method for achieving the dynamic range. - Test resolution in Standard, Reduced, and Dim Intensity.[5]
Minimum Lux	System Requirement: Illumination Note: A Lux specification on a camera spec sheet does not give enough information to predict performance.	See Dynamic range testing
Other	Output: - Low Voltage Differential Signal (LVDS) preferred for long cables in noisy environments. - Analog or Digital: Almost all image sensors are digital and the output is converted to analog or possibly a different digital format. If the system can display >480 rows, then a digital output is preferred for higher resolution. Also, the signal path in analog systems can sometimes reduce horizontal resolution. • Ability to configure the camera • Color capability *Array format, pixel size, and signal to noise ratio included in the system resolution test.	

Imaging System Camera Environmental Requirements

The environmental requirements are shown in Table 9. The Federal Motor Vehicle Safety Standards (FMVSS) rules for rear visibility cameras, specifications used by automotive manufacturers or suppliers, and military standards for ground vehicles are listed.[16,10,7,17,18] In determining the environmental requirements, the FMVSS categories were first selected as minimal requirements. Next, testing performed by automotive manufacturers or suppliers was selected, and then the military standards were applied.

Table 9. Environmental requirements.

	FMVSS; Rear Visibility; Final Rule[16]	Automotive Manufacturer or Supplier Specs[10] and Other	Military Standards[7, 17, 18]	Recommended Tests
Temperature Range		-40 °C to 85 °C (Tier 1 Supplier Input)	-46 °C to 50 °C	No test. -40 °C to 85 °C suggested temperature range
Bias, Humidity, and Temp	24 3-hr. cycles 0 °C 30% humidity and 38 °C 90% humidity	1,000 hr. (>60 cycles) 30 °C to 65 °C >90% humidity power applied[6]	10 cycles -10 °C, 25 °C to 65 °C 80% humidity power applied	1,000 hr. (>60 cycles); 30 °C to 65 °C; >90% humidity power applied[6]; See Appendix I: Cycled Temperature-Humidity-Bias
Immersion			1 m immersion in tap water for 30 min. (B) or IEC standard 60529 (IP67 and IP68)	1 m immersion in tap water for 30 min.[7]; See Appendix J: Immersion
Salt Atmosphere	Two 24-hour salt fog cycles 35 °C[8]	24-hr. cycles # of cycles not defined 35 °C[8]	24 hr. 95 °C 95% humidity (A) 4 cycles of 24 hr. wet/24 hr. dry at 35 °C (B)	Outside: two 24-hour salt fog cycles; 35 °C[8]; see Appendix K: Salt Atmosphere In-Cabin: No test
Temperature Cycling	Four 2-hour cycles (80 °C 1 hr. 0 °C 1 hr.)		10 cycles -55 °C to 85 °C	10 cycles -40 °C to 85 °C[7]; see Appendix L: Temperature Cycling
Steady State Life		1,000 hrs. at 125 °C[6]	1,000 hrs. at 125 °C	No test
Thermal Shock			15 cycles 0 °C to 100 °C	No test
Mechanical Shock		1 m (weight dependent) drop test [19]	1,500 g peak 0.5 ms pulse 5 shocks 6 orientations	1 m (weight dependent) drop test[19]; see Appendix M: Mechanical Shock

<table>
<tr><th></th><th>FMVSS; Rear Visibility; Final Rule[16]</th><th>Automotive Manufacturer or Supplier Specs[10] and Other</th><th>Military Standards[7, 17, 18]</th><th>Recommended Tests</th></tr>
<tr><td>Vibration</td><td></td><td>Peak Acceleration 20 g
20-2,000 Hz or alternate PSD method[9]</td><td>Peak Acceleration 20 g
32 hrs. Each orientation (A) or Shaker table with power spectral density (PSD)(B)</td><td>Peak Acceleration 20 g; 20-2,000 Hz or alternate PSD method[9]; see Appendix N: Vibration</td></tr>
<tr><td>EMC Immunity</td><td></td><td>RF Immunity RI112, RI114, RI115</td><td>MIL-STD 461</td><td>RF Immunity RI-112, RI-114, RI-115[10]; see Appendix O: EMC Immunity and RF Emissions</td></tr>
<tr><td>RF Emissions</td><td></td><td>RF Emissions RE-310, CE-420</td><td></td><td>RF Emissions RE-310, CE-420[10]; see Appendix O: EMC Immunity and RF Emissions</td></tr>
<tr><td>Other EMC or Irradiation</td><td></td><td>-Conducted AF
-Coupled disturbances
-Voltage Dropout
-ESD</td><td>- Conducted AG Coupled Disturbances
-Transients
-Neutron Irradiation
-Ionizing Radiation Dose
-Soft Error
-Solar Radiation</td><td>No test</td></tr>
<tr><td>Other MIL STD</td><td colspan="3">-Barometric Pressure, Insulation Resistance, Intermittent Life, Agree Life, Seal Dew point, Seal, Internal Water Vapor Content, Constant Acceleration, Vibration fatigue, Rain, Sand Dust, Power Cycle, Ground Offset, Voltage Dropout, Voltage Stress, ESD</td><td>No test</td></tr>
</table>

CHAPTER 4. DISCUSSION AND CONCLUSION

This project served to standardize the way VTTI engineers and researchers select and test cameras to be used in conjunction with the DASs utilized throughout VTTI's various transportation research projects. The two apparatuses built by the CTD will allow the standardized testing of a number of important camera attributes, including image clarity, black/white versus color display, FOV, and the quality of the image under various lighting conditions. The camera testing apparatus also has the ability to detect infrared (IR) sources in cameras. Going forward, VTTI engineers and researchers will be able to view the test results of current VTTI cameras and newly acquired cameras using the available apparatuses and test procedures. As noted, the results of these tests will be posted on the VTTI Wiki for a quick reference and to assist researchers in selecting appropriate cameras for their research needs.

Though it was not within the budget of this project to incorporate testing capabilities for all of the critical camera attributes that were identified by the technical committee, a set of additional testing methods, described in the previous sections, was still developed to provide recommendations for more comprehensive testing of those critical attributes and associated procedures if and when additional resources become available. These guidelines provide testing recommendations and procedures for system resolution using the ISO 12233 standard test target and image sharpness using free software or commercial software that would provide increased accuracy and decreased training times.(1) Additionally, procedures were described for testing temperature range and temperature cycling as well as immersion using materials that would be relatively easy to acquire. However, testing dynamic range and minimum lux would require the purchase of lamps with special filters and/or test targets, while testing cycled bias, humidity, and temperature would require the purchase of a humidity controlled oven and a camera interface and display. Testing salt atmosphere would require the purchase of a salt water reservoir, and in order to test vibration, the purchase of a vibration table would be necessary.

APPENDIX A. SYSTEM LEVEL RESOLUTION TESTING

Background:
ISO 12233 describes the test configuration for resolution testing.(1) The ISO standard includes three methods for measuring resolution.

1) Visual measurement using a test chart (see Figure 31). Observers identify the smallest features on the wedge patterns that can be observed on a display. This method can introduce operator error, which has been addressed by the Camera and Products Imaging Association (CIPA) with the HYRes software that includes an algorithm that has been shown to correlate well with the values obtained by trained operators.(14)

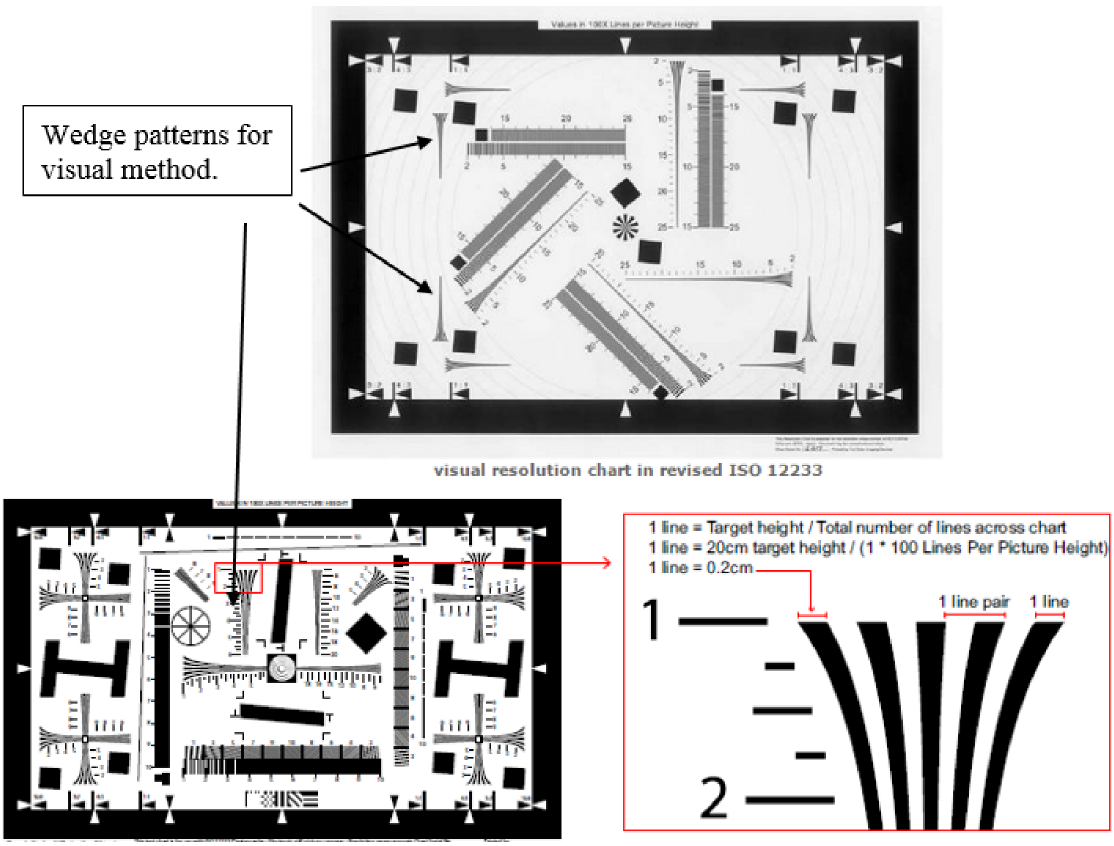

Figure 31. Image. Top – visual resolution chart in revised ISO 12233. (1) Bottom – visual resolution wedge patterns on previous ISO 12233 Chart. (1)

2) MTF Methods:
    a. Edge-based Spatial Frequency Measurement
    b. Sine-based (Star Chart) Spatial Frequency Measurement

The edge- and sine-based measurements are used to measure the modulation transfer function (MTF), which is a more contemporary approach compared to the visual method. MTF is the name given by optical engineers to Spatial Frequency Response (SFR). MTF is an improved method for evaluating resolution and sharpness since it includes both the contrast of the target and how close features are spaced on the target (spatial frequency). Figure 32 shows an MTF curve and the relationship to both contrast and spatial frequency.

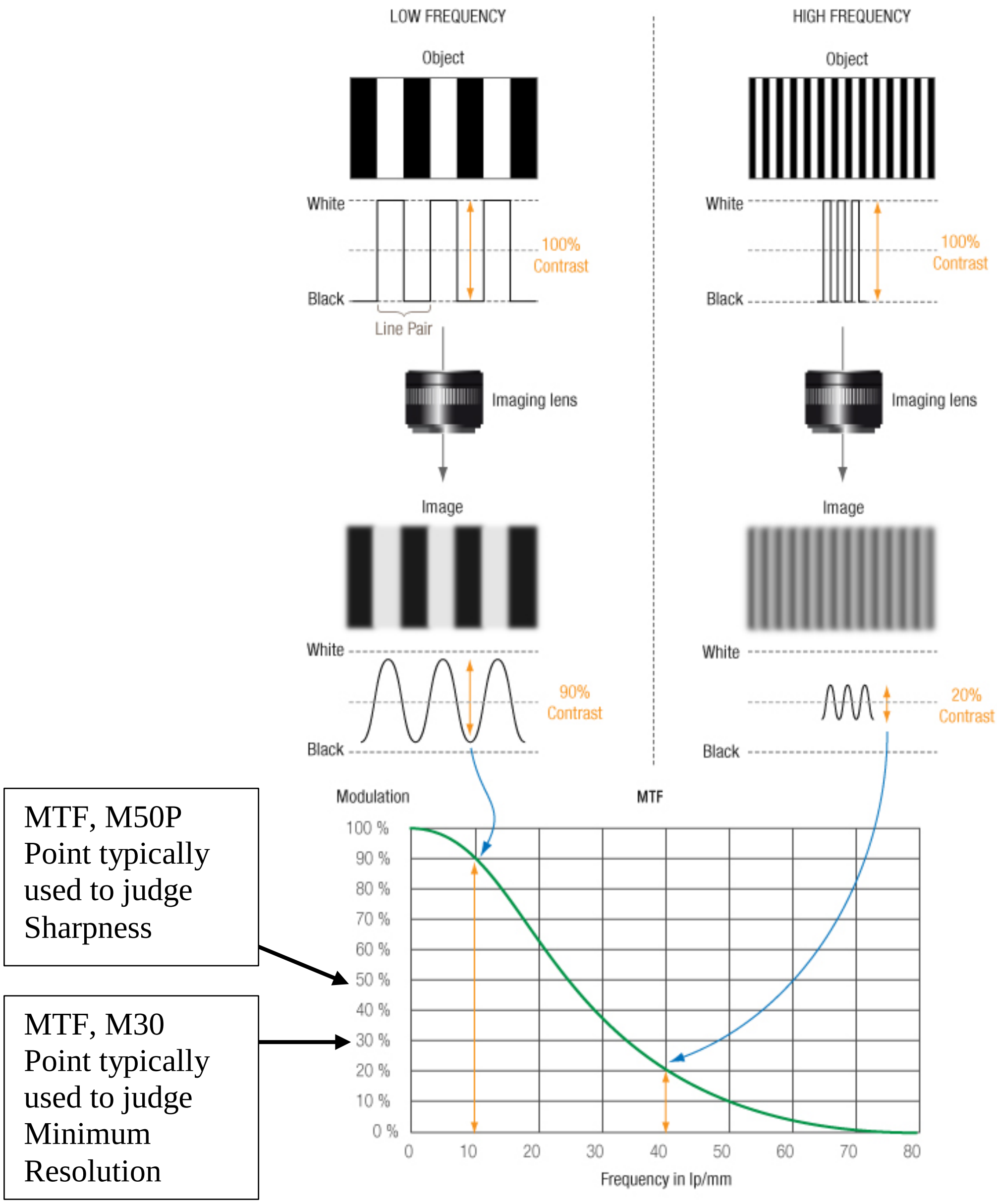

Figure 32. Image. MTF curve: A function of contrast and spatial frequency.

The ISO 12233 standard contains a powerful technique for measuring MTF from a simple, slanted-edge target image that is present in the ISO 12233 resolution test chart (see Figure 33).[1]

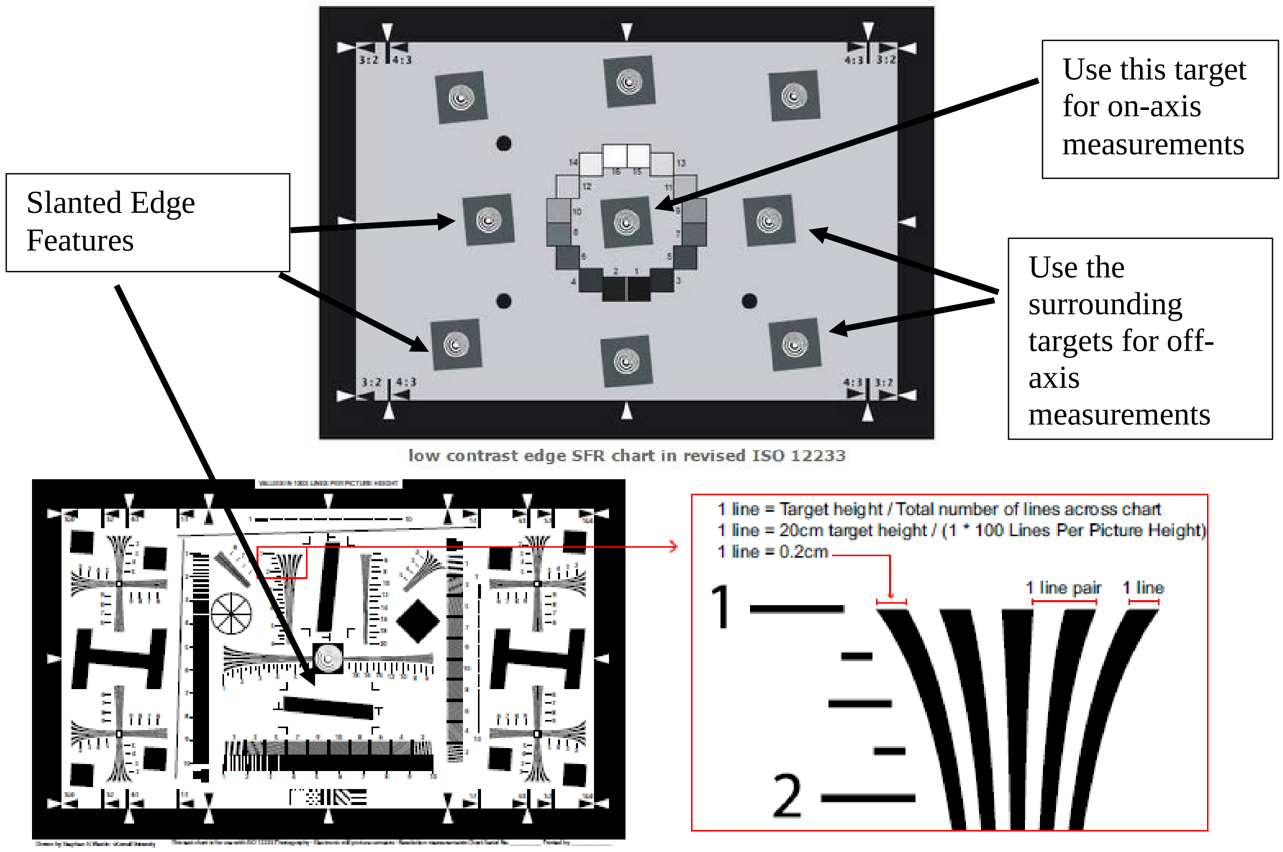

Figure 33. Image. Top – revised ISO 12233 chart for slanted-edge spatial frequency response.[1] Bottom – original ISO 12233 chart for slanted-edge spatial frequency response.[1]

Procedure:

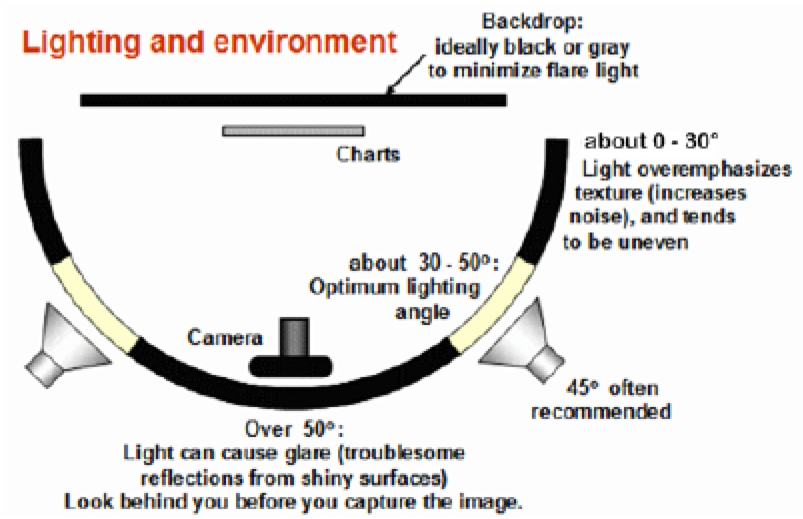

Figure 34. Image. Test chart illumination method.[(5)]

- Frame the camera. Adjust the distance and lateral alignment, using the arrows on the test chart.
- Make sure the camera is in focus.
- Adjust the camera settings to represent the intended settings for the application.
- Set white balance to equal red, green, and blue signal levels if possible. If not then the analysis software can average the different channels.
- If using a color camera then refer to ISO 12233 for luminance setting.[(1)]
- Try to provide glare-free, even illumination, with no light sources behind the camera.
- Use only high-quality daylight lamps and make sure that light falls at the angle of about 45°. Refer to DHS documents: sections 3.2, 3.3, and 3.4 for more information about the lighting levels and lighting equipment.[(5)]
- Take images in raw format if available. Open software (ImageJ, Quick MTF, etc.) and follow software instructions to obtain the MTF chart.
- (Optional) Linearize the pixels in the image. Most cameras add a gamma of 0.5 to the image in anticipation of a display gamma of 2.2. One method is to use ImageJ to read the pixel values from the density patches in the revised ISO 12233 chart (Figure 33).[(1)] Plot the values. If not linear then use the Process>Math>Gamma function in ImageJ to change the gamma of the image. Other software such as Quick MTF allows the user to change the gamma.[(3)]
- The following software can be used for the slanted-edge measurements:
  - ImageJ SE MTF 2xNyquist plug-in. Must load free ImageJ analysis software (http://rsb.info.nih.gov/ij/) and the SE MTF 2xNyquist plug-in (http://rsb.info.nih.gov/ij/plugins/se-mtf/index.html).
  - Alternate: Slant Edge Analysis Tool sfredge_v6 Windows File (http://burnsdigitalimaging.com/software/sfredge-and-sftmat3/). This program does not include linearization (OECF) but the image can be linearized in ImageJ.

- Commercial: Quick MTF (see Figure 35, which shows the automatic selection of slant edge features which are automatically used to calculate MTF across the field of view), estimated $290 cost, and Imatest (http://www.imatest.com/), estimated cost of $2,000 for a university, are examples of commercial software that provide different amounts of support and automated features reflected by the price.[3,15]

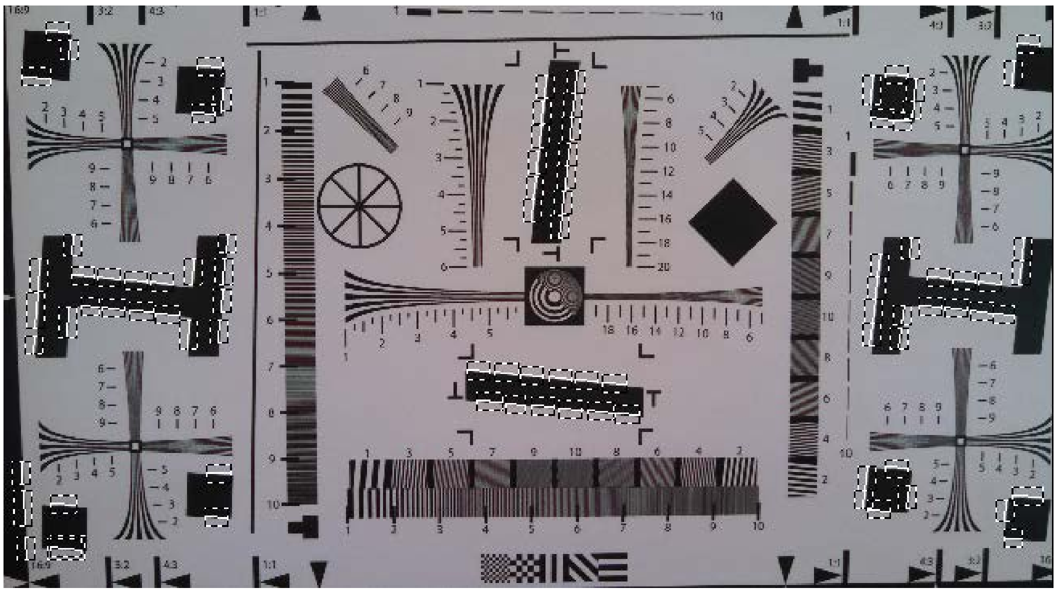

Figure 35. Image. Example of automatic features using commercial software. [3]

- Record the M50P and M30 values in lp/mm at the imager and save the chart for later analysis.

Required Equipment:

1) Lamps
2) Neutral density filters to cover lamps for low light testing
3) Test targets
    a. ISO 12233 printable targets are available from several suppliers for less than $100 and printed targets are available for $100–$600.[1]
    b. Cornell free download of 12233 original target.[20,1]
4) A stand to hold the camera

Selection of the MTF M30 Metric:

According to NV_IPM, 30% contrast targets are a good estimate for many real-world situations.[4] The MTF M5-M10 points are often used to estimate a system's minimal resolution, which should correlate to the value obtained using the visual resolution method. Since the objective of most applications is to achieve good resolution and not minimal resolution, the M30 point was selected. In addition, the M50P and M30 points are output by commercial software for this reason.[3]

Resolution Testing Method Selection:

At the most basic form, the requirements for an optical performance of a system consist of the ability to detect or recognize an object of a specific size at a given distance and a given environment. Direct testing in the application (Range Testing), resolution target bench testing, and mathematical models such as the Night Vision Integrated Performance Model can be used.[4]

As shown in Table 10, the range test can be used to verify the performance of the system in the actual use case while the bench test can predict the actual use case performance, which provides flexibility by allowing predictions of performance for different target sizes and distance from the initial test data, and does not require access to test facilities. Performance models, such as the NV-IPM model, can be used to predict the performance of the system in various environments but the model requires detailed knowledge of the optics and imagers, which are not always available when purchasing components.[4] Once test data are available for the components, the NV-IPM model can be used to predict the system performance in other use cases.[4]

Table 10. System resolution test comparison.

Test Method	**Verification**	**Flexibility**	**Cost per Test**	**Detailed Camera Information Available**
Range Test				
Bench Test Target				
Modeling (example: NV-IPM)				

Best | Better | Not as Good

Resolution Test Demonstration:
The rear and forward cameras from a Motorola Razr M phone were used to demonstrate the edge-based resolution method using the Cornell (20) target and ImageJ software.[20] As shown in Table 11, the rear camera has high resolution for the face application and minimal resolution for the sign application, and the front camera has sufficient resolution for the face application but not for the sign application.

Table 11. Resolution test demonstration results.

Application	Camera	Format, Pixel, Focal Length	MTF M30
Face (160 mm target @ 1,000 mm)	Rear	1920 × 1080, 1.4 µm pixel, 4.36 mm	129.6 lp on target
			9.9 lp on target
Sign (610 mm target @ 50,000 mm)	Front	640 × 480, 2.2 µm pixel, 1.83 mm	40 lp on target
			3 lp on target

APPENDIX B: JOHNSON CRITERIA FOR DETECTION, ORIENTATION, RECOGNITION, AND IDENTIFICATION

The Johnson Criteria[(2)], shown in Table 12, defines four discrimination levels:

1) Detection: The object is present.
2) Orientation: The object is approximately symmetric or asymmetric and orientation may be discerned.
3) Recognition: The class to which the object belongs may be discerned (e.g., house, truck, man, etc.).
4) Identification: The target can be described to the limit of the observer's knowledge (e.g., motel, truck, policeman, etc.).

Table 12. Johnson Criteria.

Discrimination Level	Line Pairs (2 pixels) on Object for 50% probability of Human Perception[(2)]	Facial Recognition
Detection	1.5 lp or 3 pixels (1 ± 0.25 line pairs OR 2 ± 0.5 pixels)	2 lp or 4 pixels
Orientation	2 lp or 4 pixels (1.4 ± 0.35 line pairs OR 2.8 ± 0.75 pixels)	
Recognition	5 lp or 10 pixels (4 ± 0.8 line pairs OR 8 ± 1.6 pixels)	10 lp or 20 pixels
Identification	8 lp or 16 pixels (6.4 ± 1.5 line pairs OR 13 ± 3 pixels)	20 lp or 40 pixels. This value doubles for difficult situations.

Most surveillance camera companies use the Johnson criteria to describe the range performance of their cameras. Since the Johnson criteria is for a 50% probability of human perception, a higher number of line pairs or pixels on the target should be the goal.[(2)]

APPENDIX C: ILLUMINATION CHART

Table 13. Illuminance in different environments.[21]

Illumination Condition	Illuminance
Full Moon	1 lux
Street Lighting	10 lux
Home Lighting	30 to 300 lux
Office Desk Lighting	100 to 1,000 lux
Surgery Lighting	10,000 lux
Direct Sunlight	100,000 lux

APPENDIX D: EXAMPLE SYSTEM RESOLUTION CALCULATION

Example Requirements and Objectives:

1) Focal length = 3.3 mm
2) Target Size = 0.16 m
3) Target Range = 1 m
4) MTF M30 = 80 lp/mm

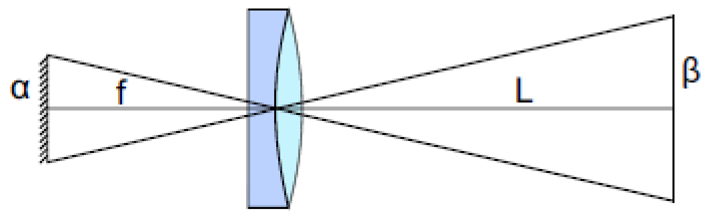

Figure 36. Image. Calculate image plane size (pixels, pixel subtended angle, lp) to the target or object space.[22]

$$\frac{\alpha}{f} = \frac{\beta}{L}; \beta = \frac{\alpha L}{f}$$

Where $\alpha =$ size at image sensor, $f =$ focal length, $\beta =$ size at object space, $L =$ range to target

A pixel or lp of size 5 µm would back-project to a distance of 1.5 mm on the target.

For the example case using the requirements and objectives:

$$O_{LP} = \frac{Target\ Size * MTF_{M10} * f}{Target\ Range}$$

$$O_{LP} = \frac{160mm * 80lp/mm * 3.3mm}{1{,}000mm}$$

$$O_{LP} = 42.24\ lp\ on\ the\ target$$

From Table 12, 40 pixels or 20 line pairs are required for facial recognition. This camera meets the requirements for the application.

Note: It is more formal to specify the object plane in angular space. Cycles/mrad would be used instead of cycles (or lp)/mm. But, since the targets are small compared to the FFOV, a linear approximation can be used instead. The lens focal length is used to convert from linear to angular space.

Example: 80 lp/mm resolution with a 3.3 mm focal length lens = 80 cycle/mm*$\frac{3.3}{1{,}000}$ = $0.264\ cycles/mrad$.

APPENDIX E: CAMERA RESOLUTION QUICK ESTIMATE

Given:

1) FFOV = 100°
2) Imager Horizontal Pixels = 640
5) Target Size = 0.16 m
6) Target Range = 1 m

Option A:

$$IFOV(pixel\ FOV) = \frac{100}{640}$$

IFOV = Instantaneous Field of View
Each pixel has a FOV of 0.156°.
For small angles, which are usually the case with IFOV, the back projected pixel size on the object plane can be estimated using:

$$Back - projected\ pixel\ size = Target\ Range * IFOV(radians)$$
$$Back - projected\ pixel\ size = 1{,}000\ mm * 0027(radians)$$
$$= 2.7\ mm\ on\ the\ target\ object$$

Since the target is 160 mm wide, the number of pixels per target is 59 and the estimate for the number of line pairs on the target is 29.6.

Option B:
If the camera is already available, then another quick approach is to estimate the percentage of the horizontal FOV that covers the target and multiply the number of horizontal pixels by that same percentage. Divide by two to obtain the lp/target.

APPENDIX F: DIFFRACTION LIMITED SPOT SIZE VS. PIXEL SIZE

Diffraction limited spot size is the smallest feature the optics can resolve.[22] Pixel size is the smallest feature the imager can resolve. The larger of the diffraction limited spot size and pixel size will limit the resolution of the camera.

1) Pixel size = 5 μm
2) F/# of lens = 5
3) Average Visible Wavelength (λ) = 550 nm or 0.550 μm

$$Diffraction\ limited\ spot\ size = 2.44\lambda\ F/\#$$

$$Diffraction\ limited\ spot\ size = 2.44 * 0.550 * 5$$

$$Diffraction\ limited\ spot\ size = 6.71\ \mu m$$

The diffraction limited spot size is larger than the pixel size. The smaller pixels do not contribute to better resolution.

$$Nyquist\ Limit = \frac{1}{2 * Smallest\ resolvable\ feature}$$

$$Nyquist\ Limit = \frac{1}{2 * 6.71}$$

$$Nyquist\ Limit = 74.5\ lp/mm$$

If the optics of the camera are perfect, then the best resolution achievable with the camera is 63 lp/mm. If 63 lp/mm spatial resolution is not suitable for the application, then this camera should not be considered for the application.

$$O_{LP} = \frac{Target\ Size * Nyquist\ Limit * f}{Target\ Range}$$

$$O_{LP} = \frac{160 * 74.5 * 3.3}{1{,}000}$$

$$O_{LP} = 39.3\ lp\ on\ the\ target$$

The 33.2 lp on the object is greater than the 20 lp specification, so this camera may be suitable for the application. Resolution of the full system should be tested.

APPENDIX G: MOTION BLUR CALCULATION

Requirements and Objectives:

- Speed sign (object) width: 24 inches.
- Speed of object: 60 mph toward the vehicle; but assume at a far distance the sign moves at 1 mph in direction across face of the imager.
- Imager frame rate: 15 fps.

Motion blur of <10% for moving object (23):

$$T \leq \frac{\Delta x}{10v}$$

where T = exposure time; Δx = the object's length; v = the object's velocity.

For this example, T = 136 ms. It takes 136 ms for the object to move 10% of its length. If the object moves 10% of its length while the imager is exposed, there will be some blur in the image. A 15 fps imager has a frame time of 66 ms. 136 ms is greater than 66 ms so there will be less than 10% motion blur.

APPENDIX H: IN-CABIN SPECIFICATION EXAMPLE

Objective	
-Target Size: 0.16 m -f: Needed from supplier -Image Sensor Pixel Pitch and Array: Needed from Supplier -Target Range: 1 m -System Resolution of >20 line pairs on target	
Camera Specification	**Requirement**
Resolution 1) On-Axis 2) Off-Axis	• On-Axis (O_{LP}) > 20 (minimum) • Off-Axis (O_{LP}) at 50 degrees from axis > 20 (minimum) * Ask supplier for MTF chart of the camera. If given then calculate O_{LP}. *Alternate: If FFOV is approximately 100° and number of horizontal pixels is 640, then Appendix E: Camera Resolution Quick Estimate suggests that the camera may have sufficient resolution for the application. Lp/target is 29.6.
Image Sharpness	None. But the MTF M50P point can be measured and compared for different cameras or systems to select the best level of sharpness.
FFOV	>90
Frame Rate and Shutter	≥15 fps for human movement in the vehicle Rolling or global shutter
Dynamic Range	>100 dB native preferred but with AGC may be all that is available >60 dB native without use of AGC
Minimum Lux	No reduction in resolution at 1 Lux
Environmental Specs	**Requirement**
Temp Range	-40 °C to 85 °C suggested temp range. See Temp Cycling for Test.
Bias, Humidity, and Temp	1,000 hr. (>60 cycles); 30 °C to 65 °C; >90% humidity power applied(6)
Immersion	None if Bias, Humidity, and Temp is tested. Otherwise; 1 m immersion tap water for 30 min.(7)
Salt Atmosphere	None
Temperature Cycle	10 cycles -40 °C to 85 °C(7)
Vibration	Peak Acceleration 20 g; 20-2000 Hz or alternate PSD method(9)
EMC Immunity	RF Immunity RI-112, RI-114, RI-115(10)
RF Emissions	RF Emissions RE-310, CE-420(10)

APPENDIX I: CYCLED TEMPERATURE-HUMIDITY-BIAS

Standard: JESD22-A100C[6]

Introduction:
Even though the specification scope lists the testing of electronic cavity packages, Table 9 shows that the MIL Standards and FMVSS rule both include the test. A camera is a cavity package of electronic components.

Procedure:
1) Place camera in a humidity-controlled oven and connect the interface to electronics that are external to the oven.
2) The temperature profile is listed in section 3.1 of the JESD22-A100C standard (30 °C to 65 °C; >90% humidity. [6]
3) Use continuous bias. Camera is powered throughout the test.
4) Periodically record video from the camera during the test in order to locate the moment when a failure occurs.
5) A device will be considered to have failed the Cycled Temperature-Humidity-Bias Life Test parametric if functionality cannot be demonstrated under nominal and worst-case conditions.

Required Equipment:
1) Humidity-controlled oven
2) Camera interface and display

APPENDIX J: IMMERSION

Standard: MIL STD 883[7]

Introduction:
This test is performed to determine the effectiveness of the seal of microelectronic devices.

Procedure:
1) Fill a container with greater than 1 m of tap water.
2) Immerse the camera in 1 m of water for 30 minutes using MIL-STD 883E Test Condition A with the time modified to 30 minutes to conform to IEC Standard 60529 for IP67 and IP68. [7]
3) A failure has occurred if the camera is not operational or has changed in operation.

Required Equipment:
1) Water container with 1 m depth
2) Camera interface electronics and display

APPENDIX K: SALT ATMOSPHERE

Standard: ASTM B117-03[8]

Introduction:
The salt spray test is intended to identify areas of the electronic devices that would corrode during use in the field.

Procedure:
1) A spray nozzle is attached to a reservoir of salt solution.
2) The parts are positioned 15 to 30 degrees from vertical and facing the spray nozzles.
3) The test is performed at 35 °C.
4) Two 24-hour salt fog cycles are run.
5) Failures occur if the camera is not functional or if corrosion is evident that would cause the camera to malfunction if the corrosion were allowed to continue.

Required Equipment:
1) Salt water reservoir heated to 35 °C and a spray nozzle
2) Method of holding parts during the test
3) Camera interface electronics and display

APPENDIX L: TEMPERATURE CYCLING

Standard: MIL STD 883[(7)]

Introduction:

The temperature cycling test is conducted to determine the resistance of a part to extremes of high and low temperatures, and the effect of alternate exposure to these extremes.

Procedure:

1) The camera is loaded into an oven that allows temperature cycling through external or programmable controls or alternatively the camera can be moved between one oven that is set at the maximum temperature and one oven that is set at the minimum temperature.
2) If a transfer is used, then the transfer time shall not exceed 1 minute.
3) Failure has occurred if the camera operation has changed or if a visual inspection shows damage.

Required Equipment:

1) Oven with programmable temperature profiles or an interface for external control (for automated testing.)
2) Two ovens for manual testing

APPENDIX M: MECHANICAL SHOCK

Standard: JESD22-B104C[19]

Introduction:
Intended to determine the ability of the component(s) to withstand moderately severe shocks as a result of suddenly applied forces or abrupt change in motion produced by handling, transportation, or field operation.

Procedure:
1) Use service condition B in Table 1 of the JESD22-B104C standard.[19] This is an approximate 1-m drop to a concrete floor in all orientations of the device.
2) Failure has occurred if the camera operation has changed or if a visual inspection shows damage or if the immersion requirement cannot be met.

Required Equipment:
1) Camera interface with display
2) Immersion test

APPENDIX N: VIBRATION

JEDEC Standard: JESD22-B103B[9]
Peak Acceleration 20 g; 20-2,000 Hz or alternate PSD method

Introduction:
It is intended to determine the ability of the component(s) to withstand moderate to severe vibration as a result of motion produced by transportation or field operation.

Procedure:
Mount the camera to a vibration table using Test Level Service Condition 1 of JEDEC Standard JESD22-B103B.[9] Test camera mounted in x-, y-, and z-axes.

Failure has occurred if the camera operation has changed or if a visual inspection shows damage or if the immersion requirement cannot be met.

Required Equipment:
1) Vibration table
2) Camera interface with display
3) Immersion test

APPENDIX O: EMC IMMUNITY AND RF EMISSIONS

Specification: FMC 1278[10]

RF Immunity:

1) RI-112
2) RI-114
3) RI-115

RF Emissions:

Chapter 1 RE-310

Chapter 2 CE-420

Introduction:

These tests require specialized equipment. The following labs advertise the ability to perform the tests.

Preliminary List of Commercial Testing Labs Certified for Ford EMC Testing:

1) Elite (www.elitetest.com/testing-services/emc-testing/automotive-truck-emc-testing/domestic-automotive-emcwww)
2) TUV SUD America (http://www.qualitydigest.com/inside/standards-news/t-v-s-d-america-receives-recognition-ford-emc-cs-2009.html#)
3) Yazaki Testing Laboratory (www.yazakiemc.com/wp/)
4) EMC Technologies (http://www.emctech.com.au/emc-testing/automotive-emc-testing/)

Pulse Probes Certified for Ford EMC Testing:

1) AR. www.ar-worldwide.com. (http://www.arworld.us/pr_html/100330-PL7004-FORD-E-Field-Probe.asp)
2) Faraday (www.ferret.com.au/c/faraday/faraday-pulse-probes-approved-for-ford-emc-cs-2009-specification-n888033)

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