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## 0-5708-P4

## CRACKSCOPE—AUTOMATIC PAVEMENT CRACKING INSPECTION SYSTEM

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*TxDOT Project 0-5708: Improving Capabilities of Automated Distress Rating*

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# Chapter 1. System Description

## 1.1 Product Description

The CrackScope system is an automated pavement crack rating system consisting of a digital line scan camera, laser-line illuminator, and proprietary crack detection and classification software. CrackScope is able to perform real-time pavement inspection with 100% distance coverage at travel velocities from 3 to 70 mph. It covers a 10- to 12-foot wide lane with a resolution of 1.5 mm to 1.75 mm/pixel. The system consumes approximately 200 w electrical power (12±0.5 VDC), and can perform both daytime and nighttime survey.

Figure 1.1 displays the CAD drawing of the Crackscope components in a custom design enclosure. The Crackscope uses one StockerYale Magnum II line projector (referred to as Laser), which has an 810 nm 4 w laser diode to illuminate the pavement for image acquisition. It is mounted side by side with a linescan camera in a custom design enclosure. The front plate of the enclosure has an 8-inch long and 0.5-inch wide open slot aligned with the central line of the optics of the Laser and the camera. The enclosure is installed vertically downward at a height of 7.5 feet above the ground, and the laser line covers approximately 12-foot wide pavement surfaces (see Figure 1.2).
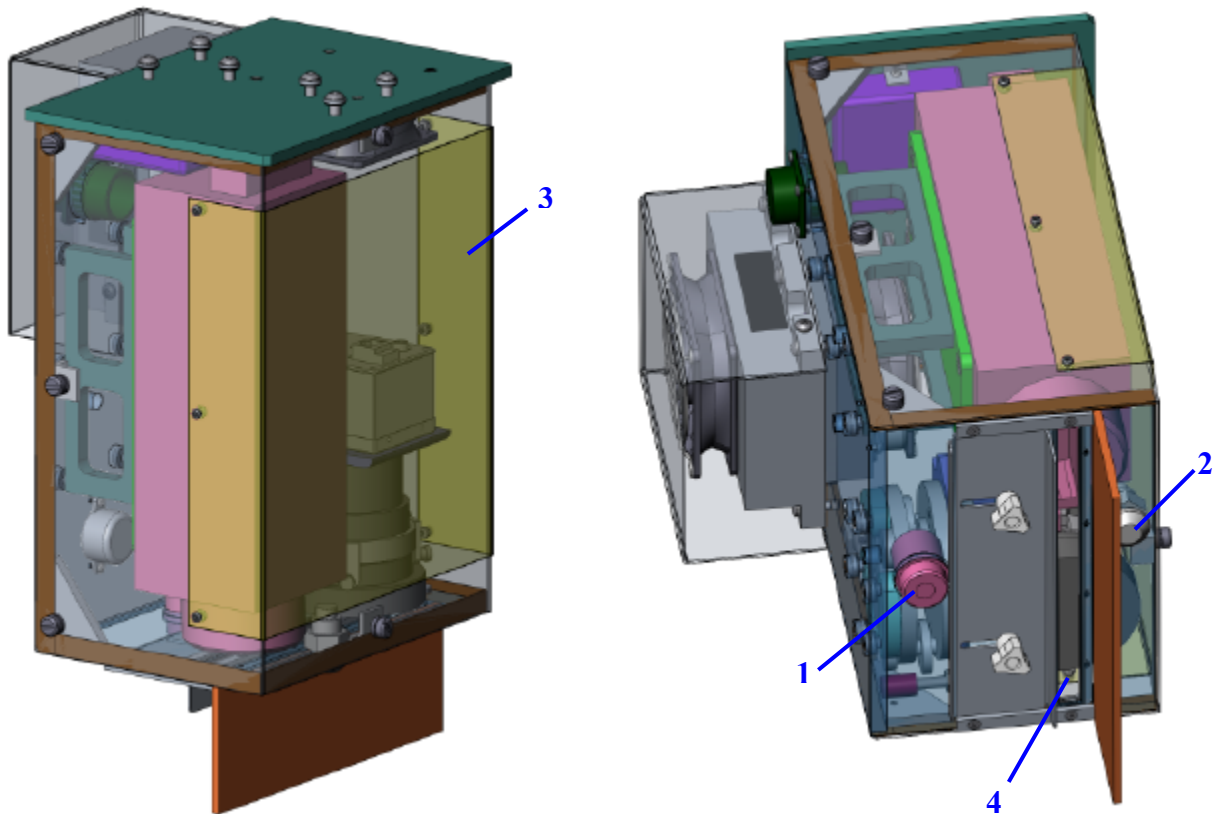


*Figure 1.1: Components in Crackscope*

1. Proximity Sensor   2. LED Power Indicator   3. Laser Warning Sign   4. Open Window
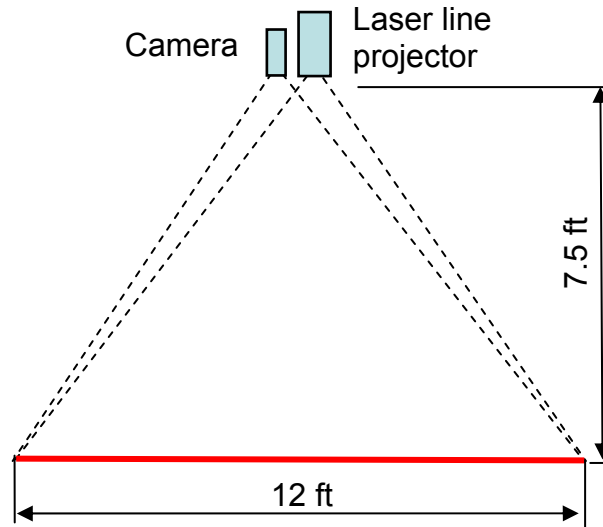
*Figure 1.2: Mounting Geometry*

## 1.2 Laser Safety

*Magnum II laser*
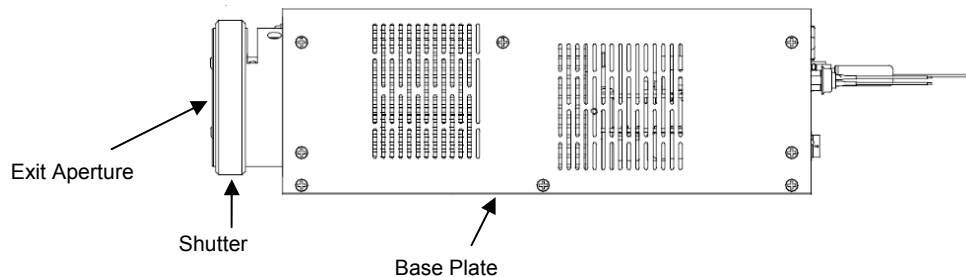


*Figure 1.3: StokerYale Magnum II Laser Projector*

Magnum II lasers are tested by the manufacturer prior to shipping to determine which class they belong to, and to provide CDHR and IEC certification. The safety label is affixed on top of the Laser. Magnum II Lasers are classified according to the output power and the wavelength of a laser beam in a particular setup, according to the United States Center for Device & Radiological Health (CDRH)–Document 21 CFR 1040.10. The International Electrotechnical Commission (IEC) has a similar document: 60825-1, version 1.2 2001-08. It is important to follow laser safety rules and wear appropriate protective eyewear when working around the Laser.

### 1.2.2 Warning Sign

Figure 1.4 is the warning sign on the enclosure.
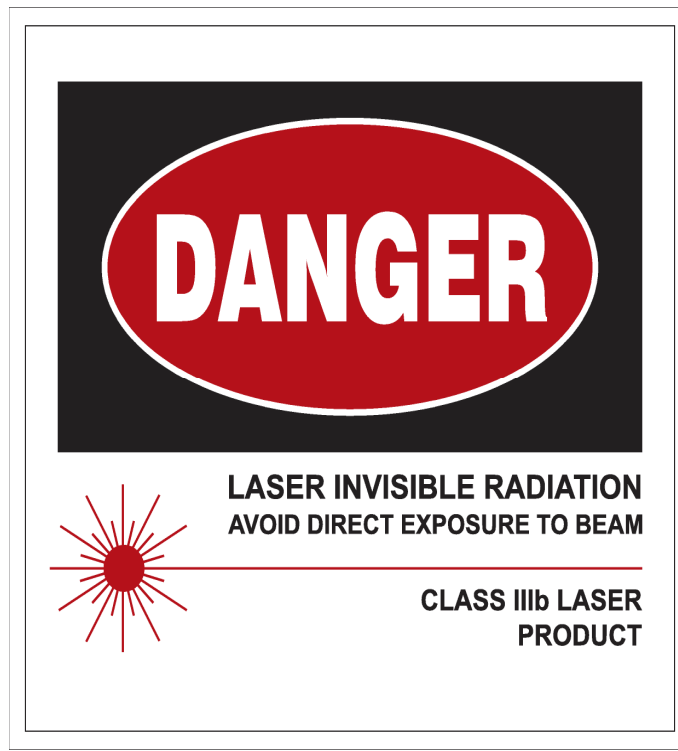


*Figure 1.4: Laser Warning Sign*

### 1.2.3 Proximity Sensors

The proximity sensor on the enclosure provides highly sophisticated, ultrasonic obstacle detection. It detects in three distinct 'Zones," which correspond with the distance from the enclosure to an approaching subject (Figure 1.5). "Zone 1" is a range of 6 to 4 feet, the sensor sends signals to the speaker to alert the subject with slow beeps, "Zone 2" the range of 4 to 2 feet with rapid beeps, and "Zone 3" is the range of 2 feet and inward with solid tones that also turns off the interlock switch of the Laser.
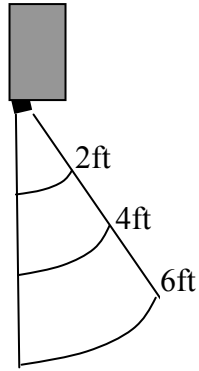
*Figure 1.5: Sensor Zone Divisions From The Enclosure*

The user is also required to install the proximity sensors on the rear bumper that provide a horizontal safety zone (Figure 1.6).



(side view)                              (top view)
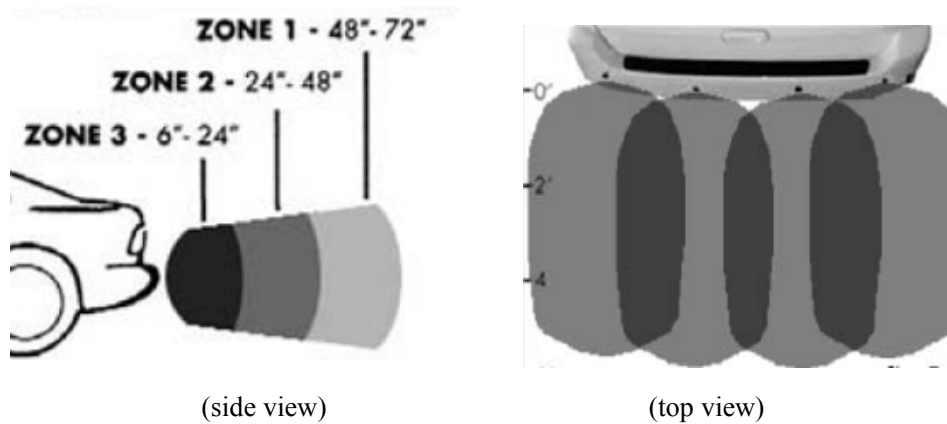
*Figure 1.6: Sensor Zone Divisions From The Rear Bumper*

### 1.2.4 Vehicle Speed Control

The computer will receive the speed information from DMI or GPS at least three times/second. When the vehicle runs at a speed below 5 mph, the computer will send a signal through a digital I/O to the modulation connector of the Laser to shut off the beam.

### 1.2.5 LED Power Indicator

When the power of the Laser is on, a red LED lamp on the bottom plate of the enclosure will remain on.

### 1.2.6 Controller (Operator's Control Box)

Inside the vehicle, a controller (control box) is placed near the operator to control the power supply and the interlock switch of the unit (Figure 1.7). The keylock switch is to turn on/off the 12 VDC to the unit. When it is in the OFF position, the entire unit is powered off. The rocker switch is to manually turn the interlock switch of the Laser on and off. When it is in the OFF position, no laser beam will be emitted from the unit, but the circuit is still powered on to maintain a constant diode temperature. When the vehicle stops, the operator should switch off the rocker switch to shut off the laser beam, regardless of the protective actions induced from the proximity sensor or from the vehicle speed signal.
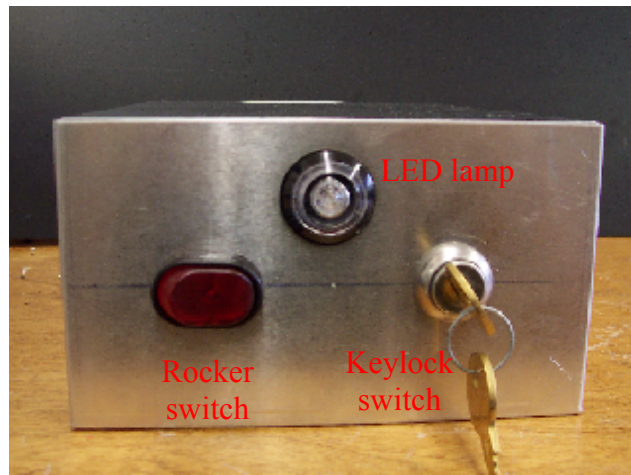


*Figure 1.7: Controller*

1. The GPS/DMI unit, which is not part of the Crackscope system but normally available on a pavement inspection vehicle, sends the actual speed of the vehicle to the computer at a rate of at least three times per second. Whenever the speed is below 5 mph, the computer sends a signal to the digital I/O unit, which is housed in the controller. The I/O unit in turn outputs +5V volt to the modulation control of the Laser, and the laser beam is shut off instantaneously. When the system is in maintenance or service, a pseudo speed can be set through the software to disable the digital I/O unit so that the beam can maintained.

2. The dashed box is the controller, in which there are five switches. Switch 1 is the keylock switch to turn on/off the power. The remaining four switches are in series and connected to the interlock switch of the Laser. Switch 2 is the rocker switch on the front panel of the controller. Switch 3 is a relay controlled by the proximity sensor on the Crackscope enclosure. Switch 4 is another relay controlled by the proximity sensor on the rear bumper. Switch 5 is the remote interlock switch.

1. Keylock switch
2. Rocker switch
3. Relay I
4. Relay II
5. Remote interlock
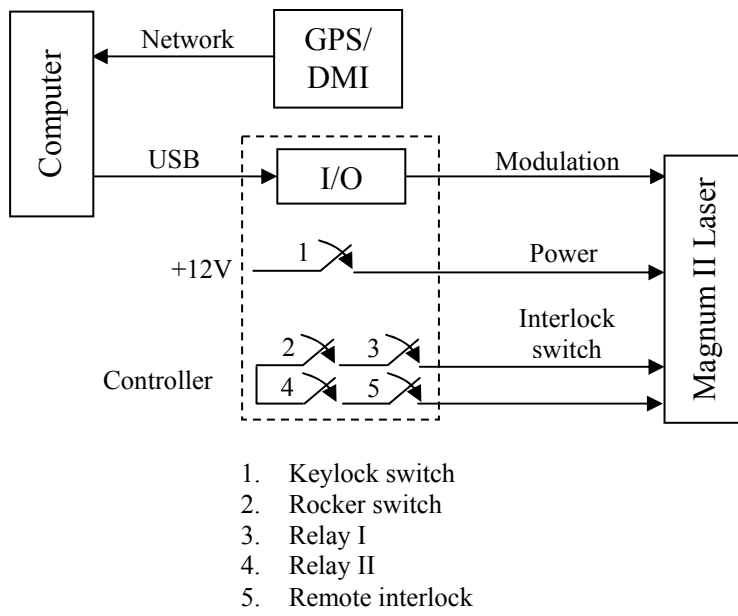
*Figure 1.8: Switches in the controller*

# Chapter 2.  System Operation Procedures

When the Crackscope is used inside the lab environment:

Turn on the 12V power by turning the keylock switch on the control box to the ON position. The red warning lights on the Crackscope enclosure and the control box will be on.

Turn on the rocker switch on the control box, which is connected to the interlock switch of the laser diode. If there is no object within the field of view (FOV), 6 feet of the proximity sensors, the laser line will be projected out of the open slot of the enclosure.

If there is an object in the six-foot FOV of the proximity sensors, the speakers in the enclosure or in the control box will start to send out a beeping sound.  The operator should examine the situation and turn off the rocker switch or the keylock switch on the control box whenever perceiving a danger.

If a subject or object comes into a two-foot range to a proximity sensor, the warning sound of the speaker and the LED light will become steady, the relay switch will be activated to shut off the laser line automatically. However, the operator must make sure the rocker switch is in the OFF position for redundant protection.


When the Crackscope is used outside for regular pavement survey:

The driver, operator or other personnel in the survey vehicle need to have correct laser protective eyewear ready to wear.

Do not turn on laser power when the vehicle does not move at least 5 mph.

When the vehicle runs at 5 mph, turn on the 12V power by turning the keylock switch on the control box to the ON position. The red warning lights on the Crackscope enclosure and the control box will be on.

Turn on the rocker switch on the control box, which is connected to the interlock switch of the laser diode. If there is no object in FOV of the proximity sensors, the laser line will be projected out of the open slot of the enclosure.

If a subject or object comes within a six-foot range of a proximity sensor, it will trigger the speaker in the enclosure or the control box to make a beeping sound, and make the LED light blink. The operator should turn off the rocker switch or the key switch on the control box immediately.

If a subject or object comes within a two-foot range of a proximity sensor, the warning sound of the speaker and the LED light will become steady and the relay switch will be activated to

shut off the laser line automatically. However, the operator must make sure the rocker switch is in the OFF position for a redundant protection.

When the Crackscope is used outside for services (calibration, exterior maintenance, etc.):

The vehicle should be parked in a controlled space where there is no access to an unauthorized person. If such a controlled space is not available, an appropriate laser barrier such as a fabric drapery must be used to set a screen around the working area.

Anyone who works in the controlled area must wear correct laser protective eyewear and avoid looking at the open slot of the Crackscope enclosure.

Do not expose the skin to the laser light path.

For exterior maintenance, the system should be powered off.

For calibration, the operator places a white reference (e.g., poster board) under the projector and camera, and stays out of the proximity sensor's range. The calibration can be done automatically by using the functions of the Crackscope software.

Proceed in the same steps as operation in lab environment.

Note: optical alignment and other services on the components have to be done by the manufacturer's trained personnel. The user should not open the enclosure of the Crackscope.


Shutdown procedures for this laser are as follows:

1. Switch off the rocker switch on the control box.
2. Turn off the key switch on the control box.

# Chapter 3.  Software Operation Manual

## 3.1 Installation and configuration

In order to run CrackScope, three software packages need to be installed:
- QuickCam (GigE camera)
- InstaCal (Digital camera)
- CrackScope

### 3.1.1 QuickCam

QuickCam is the GigE camera GUI provided by the camera manufacturer (DALSA). It enables the user to quickly configure the camera and to grab images right away. After QuickCam is installed, the camera drivers will be automatically registered in your Windows system.

QuickCam also provides a network adapter driver installation tool to help user install high performance GigE network driver. Open the "Start" menu, and go to "DALSA QuickCam → Tools → Driver Installation Tool" to launch this application (Figure 3.1).

In the "Driver Installation" dialog, all your GigE network adapters should be listed in the "Pro 1000 adapters" tab. Right click each item to uninstall the Intel/Windows driver and to install the "High Performance IP Device Driver" from the context menu.
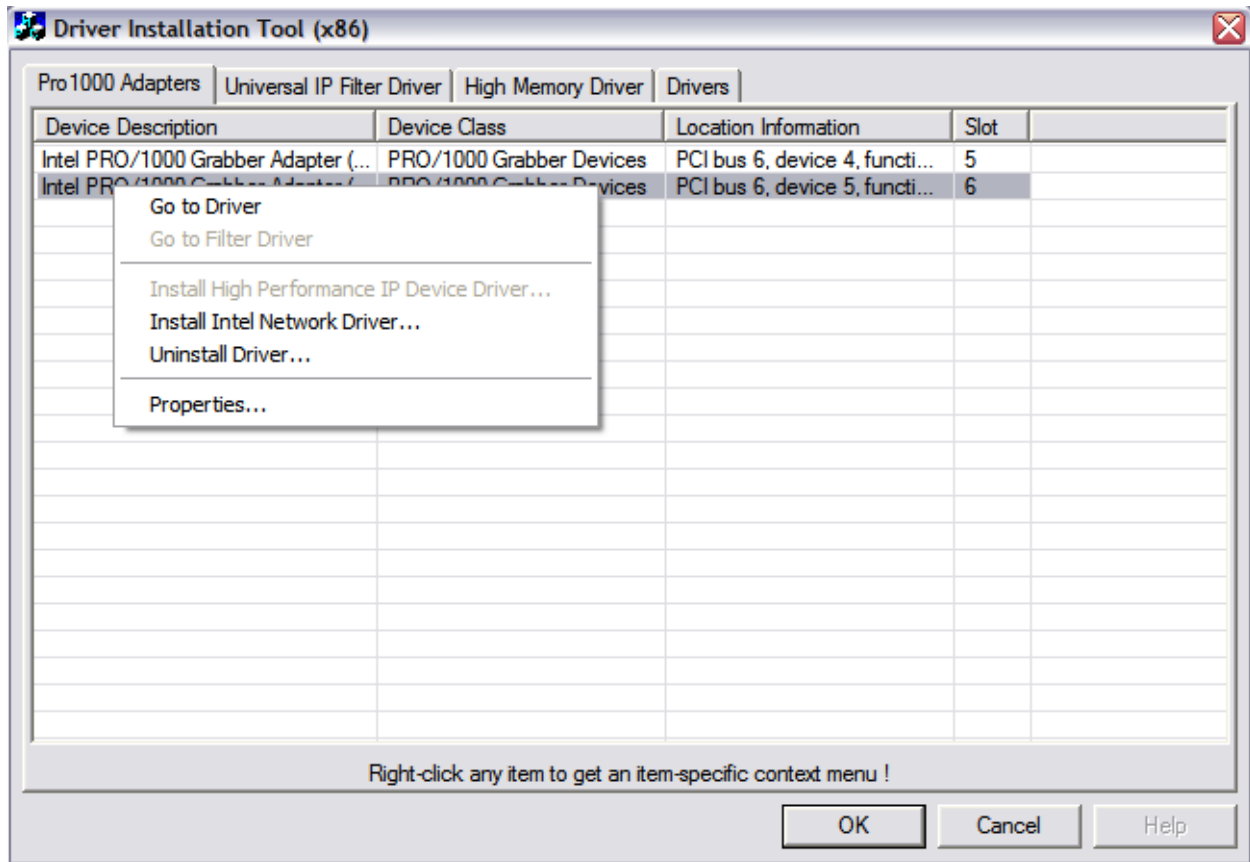
*Figure 3.1: Install high performance IP driver for GigE network adapter*

Normally, the GigE camera is fully configured before it is ready to be delivered to the end user. In any case should it be restored to its factory setting, some low level basic configuration must be performed before it can work with the CrackScope. Start the QuickCam, and do the following tasks:

1. In the "connection" tab, set the frame height to the size you want to grab. Then assign a name to the camera. CrackScope is capable of working with two cameras. If you use a two-camera system, make sure the exact key work, "left" or "right," appears in the camera's name field, e.g., Spider (left) and Spider (right). This is the only way for CrackScope to tell the channels from which images are coming.

2. In the "Readout" tab, set the bit depth to "8 bits."

3. In the "Exposure/GPIO" tab, set the exposure mode to "2: Programmable line rate & exposure time." Click the "Save image settings" push button.

4. Save these configurations into camera's EPROM by clicking "Save flash configuration" menu item in the "File" menu, so that the camera will not lose these configurations when it loses power. In the "Save" dialog, check the IP address, camera name and the configuration to save.

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### 3.1.2 InstaCal (Digital I/O)

A USB-connected digital I/O board is applied in our hardware configuration to implement the TTL modulation to control the ON/OFF status of the laser for safety consideration. InstalCal is an easy-to-use program shipped with the digital I/O board to help the user configure, calibrate and test their hardware. InstalCal installs a hardware driver for a specific I/O board into your Windows system so that the CrackScope can communicate with the I/O board based on the hardware driver. Only a properly installed and fully configured I/O board can work with the CrackScope.

Start the InstaCal. It will detect all currently connected digital I/O board and assign a unique ID number to each of the board. Write down the board number of the board whose output goes to the laser, as indicated in Figure 3.2. You will need this number in the configuration of CrackScope. The default board number in the configuration file (crackscope.xml) is "0". If you see a different number, you need modify the board number in crackscope.xml.
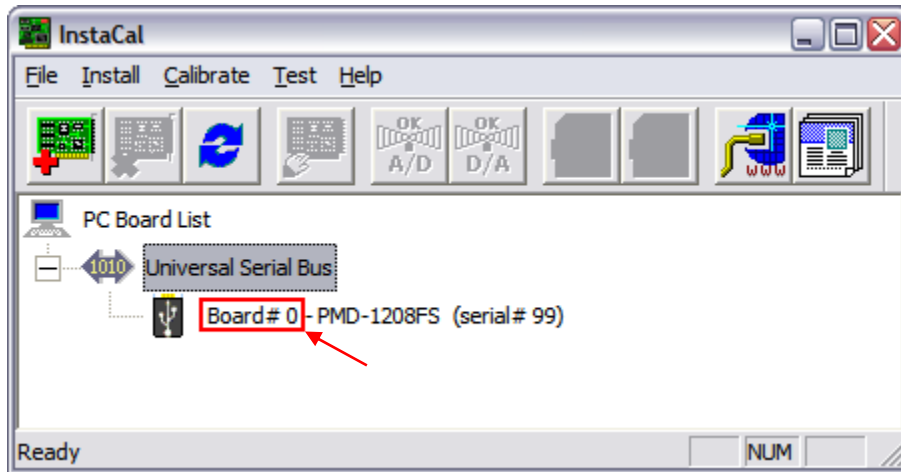


*Figure 3.2: Auto detect digital I/O board and assign board number within InstaCal*

### 3.1.3 CrackScope

An all-in-one setup program is provided for the easy installation of CrackScope. Upon successful installation of the setup program, the CrackScope executable, all the dependant DLLs, and configuration file are copied into the destination directory. CrackScope should start without problem. However the default behavior of CrackScope depends on its configuration.

The configuration file, named "CrackScope.xml," gives the user the flexibility to modify CrackScope's parameters before it starts. The user modification includes: network communication, image dimension, memory consumption, laser safety and so on. The detailed description of the configuration is listed in Table 3.1.

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**Table 3.1: CrackScope Configuration**

| `<networking>` | |
|---|---|
| `<socket_server_heartbeat>` | The listening socket from which server heartbeat is received |
| `<socket_server_command>` | The listening socket from which command is received |
| `<socket_dmi>` | The listening socket from which DMI broadcast is received |
| `<socket_client_heartbeat>` | The socket from which CrackScope heartbeat is broadcasted |
| `<socket_survey_data>` | The socket from which CrackScope data report is broadcasted |
| `<interval_heartbeat>` | The interval of CrackScope heartbeat |
| `<survey>` | |
| `<svy_work_dir>` | The default directory where images are saved |
| `<svy_save_image>` | `"true"` to enable image saving after CrackScope starts. Whether or not to save images can be changed in CrackScope |
| `<svy_save_image_type>` | `"bmp"`, `"avi"`, `"jpeg"` or `"xvid"` |
| `<sby_save_jpeg_quality>` | Integer value between 1 and 100 |
| `<svy_save_prefix>` | The prefix of saved image file |
| `<svy_speed_max>` | If vehicle speed is greater than this value, CrackScope will use this maximum speed as current speed to prevent frame buffer overflow |
| `<svy_speed_min>` | If vehicle speed is lower than this value, image streaming will be stopped |
| `<imaging>` | |
| `<img_frame_width>` | Define the frame width |
| `<img_frame_height>` | Define the frame height |
| `<video>` | |
| `<vid_interval_key_frame>` | The key frame interval of avi file |
| `<vid_frame_count>` | The number of frames composed in the avi file |
| `<vid_buffer_size>` | The count of frame buffer. In single camera configuration, this value must be greater than 2 * `<vid_frame_count>`. In dual camera configuration, this value must be greater than 4 * `<vid_frame_count>` |
| `<vid_frame_width>` | Width of video buffer. No lower than `<img_frame_width>` |
| `<vid_frame_hegiht>` | Height of video buffer. No lower than `<img_frame_height>` |
| `<acq>` | |
| `<acq_enable_ttl_modulation>` | Enable or disable laser TTL modulation |
| `<acq_digital_IO_board_number>` | The digital I/O board number |
| `<acq_idle_speed>` | If vehicle speed is lower than this value, laser will be shut down |

By default, Windows® firewall blocks all the data coming through TCP/UDP ports that are not in the public domain for security reasons. To open these ports, go to "Control Panel" → "Windows Firewall." Switch to "Exceptions" tab, then use "Add Port" to add these ports to the exception list to allow data coming from these port pass through the Windows firewall. The list below tells what kind of data passes through these ports.

**Table 3.2: List of Data Passing Through Ports**

| Port number | Port type | Description |
|---|---|---|
| 4006 | UDP | Heartbeat signal |
| 4008 | UDP | GPS signal |
| 4009 | UDP | Command |
| 4220 | UDP | Data report |

## 3.2 Camera connection

CrackScope is capable of working with two cameras streaming live images simultaneously. Each camera must be configured with a different IP address. CrackScope can assist the user to discover camera(s). Click the "Add camera" push button in the "Connection" tab of the "Console" window to initiate the "Select device" dialog, as shown in Figure 3.3.
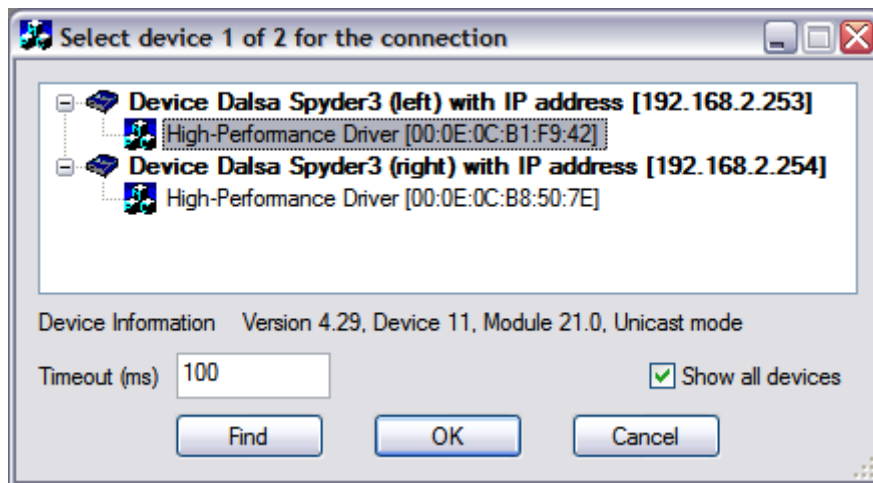


*Figure 3.3: "Select device" dialog box*

The dialog box lists all the cameras that are currently connected to your system by GigE link. Each camera is displayed with its name and IP address (if it has already been assigned one). As described in section 3.1.1, it is suggested that the user to save the camera name and its IP address to the camera's flash memory. An intelligible name containing "left" or "right" key word not only helps the user identify the physical location of camera, but also works as the only identity for CrackScope to organize the image streams. The dialog title shows how many cameras are needed to be selected in this session as well as the current index that will be assigned to the currently selected camera.
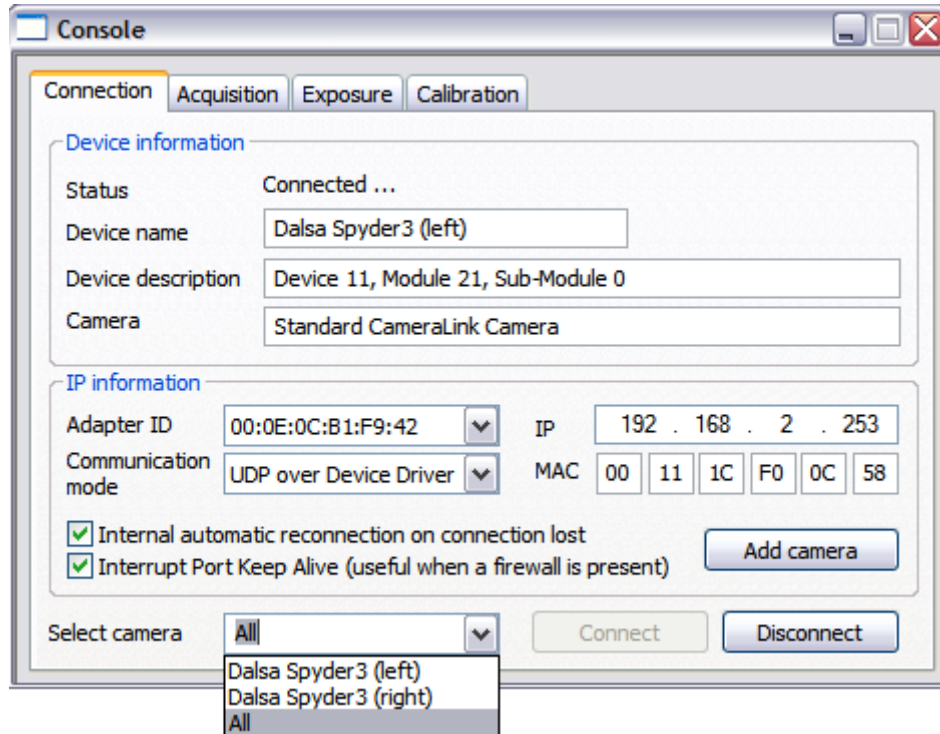
*Figure 3.4: Basic information of currently selected camera*

All the selected cameras will be added to the combo box after camera detection (Figure 3.4). By switching items in the "Select camera" combo box, the "Console" dialog update information and parameters for the currently selected camera. If "All" is selected, the dialog will show the information for the first camera listed in the combo box.

User operations are only submitted to the currently selected camera. If you want to have the two cameras work simultaneously, select "All" cameras before performing any acquisition task.

## 3.3 Image acquisition

Frames can be saved when live image acquisition is in progress. The format of a saved frame is limited to:

- Lossless AVI (8-bpp grayscale)
- Windows bitmap (8-bpp grayscale)
- XviD encoded lossy AVI (24-bpp true color)
- And JPEG (8-bpp grayscale)

If images are saved in the lossless avi or bitmap format, the grayscale value of each pixel is directly written into the file, so the disk files of these formats are large in size. High speed disk sub system is highly recommended for lossless avi and bitmap format. In our test environment, which features two, 15000 RPM high speed hard drives configured in RAID 0, CrackScope is capable of working at 45 mph with two cameras attached saving images in lossless avi or

bitmaps at real time. If only one camera is connected to the system, CrackScope should work at its full design speed while lossless avi or bitmap is selected.

The XviD and JPEG are both in a compressed format, so the file size of images encoded in these formats is significantly reduced compared with lossless avi or bitmap. However a high-performance CPU is required to perform the live encoding. Our test has proved that a quad-core 2.4 GHz CPU can handle the incoming frames streamed from two cameras at 75 mph when JPEG is applied.
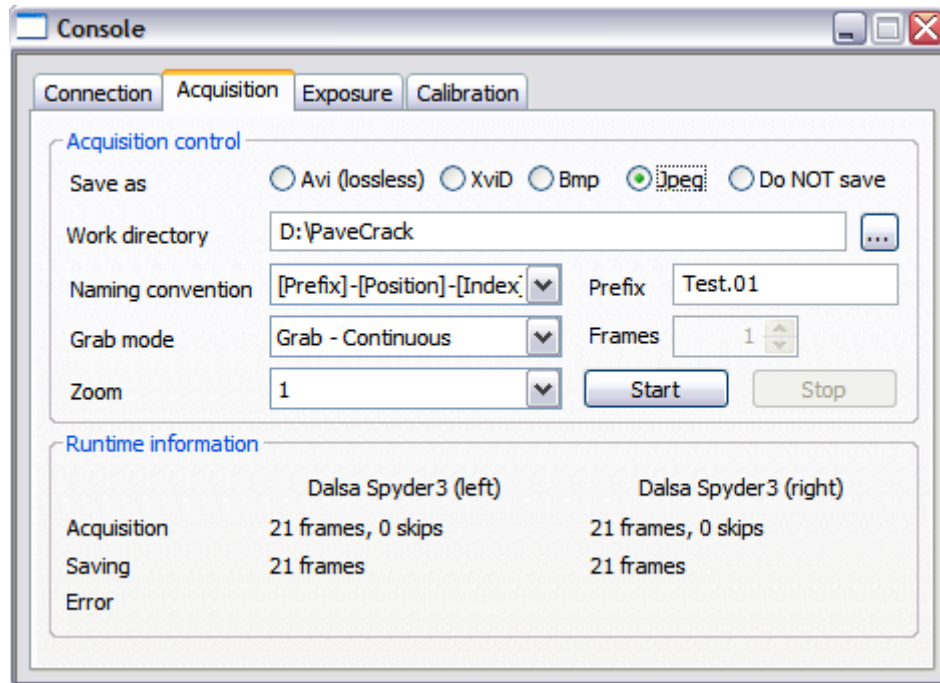


*Figure 3.5: Image acquisition dialog*

The "Runtime information" area (Figure 3.5) shows the statistic for each image acquisition task. The "Acquisition" line shows the frame count for the current task. The number rolls up every time a new frame passes through. This line also shows the skip count whenever a frame is skipped due to the vehicle running under minimum speed. The saving line shows the total number of frames that have been saved into the hard drive. This line is updated periodically when a specific count of frames are saved.

The user should pay attention to "Runtime information" to monitor frame loss. It is likely that if the vehicle runs at a high speed, the image saving cannot keep up with the incoming frames because of the high data throughput that the hard drive cannot handle, or the high computation/compression requirement that the CPU cannot meet. If the saving count falls way below the acquisition count, CrackScope will drop frames without warning. The user should slow down the vehicle to prevent future frame loss.

## 3.4 Camera control

### 3.4.1 Line rate

The frame rate of image acquisition is determined by the camera line rate. However users are not asked to figure out which line rate should be applied when the vehicle speed changes. If the "Speed SYNC" check box (Figure 3.6) is checked and the DMI broadcast is received from network, CrackScope will adjust the line rate automatically, so it is not manually adjustable when "Speed SYNC" is checked. The change of line rate is submitted to all the cameras that are currently connected, regardless of which one is currently selected.
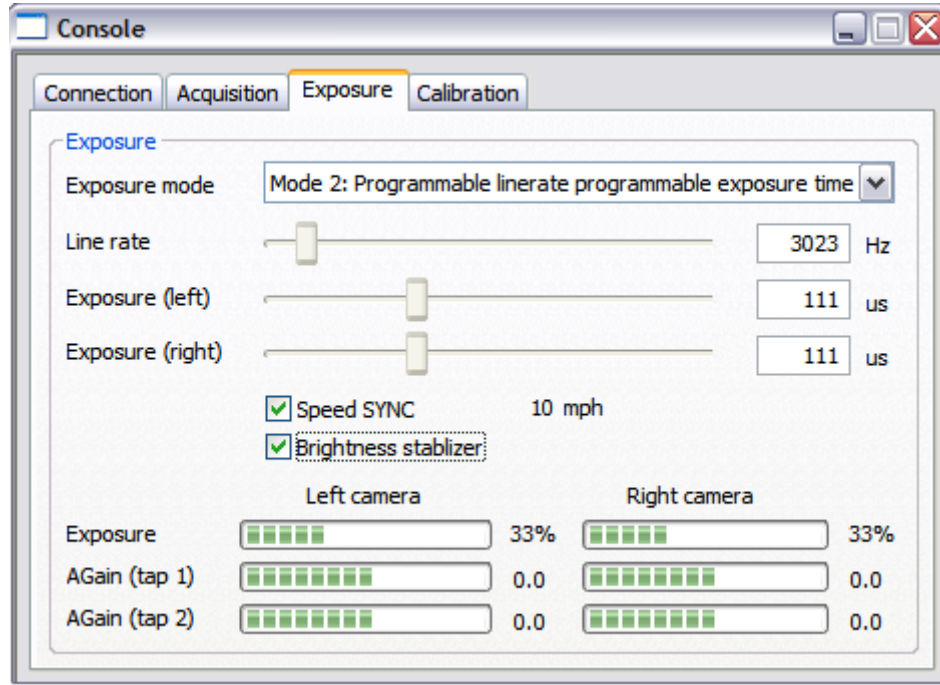


*Figure 3.6: Line rate and exposure control*

The actual line rate can be calculated based on the pixel size (configurable in "CrackScope.xml") and vehicle speed. High line rate should be expected if small pixel size is applied in narrow lens coverage in order to cover the same distance.

### 3.4.2 Exposure

Exposure is adjustable only in "Mode 2" (Figure 3.6). If the camera's exposure mode is not "Mode 2," change it in QuickCam. Exposure can be adjusted separately for each camera regardless of which one is currently selected. However, it is not recommended for user to adjust the exposure manually in the real time image acquisition. Because the condition of pavement surface changes rapidly, it is impossible to adjust the exposure by human interaction. Refer to section 3.3.4.4 for further details about how to control the brightness of an image.

### 3.4.3 Analog gain

Analog gain is another parameter to improve image brightness. It applies by amplifying/attenuating the electrical signal without introducing significant noise. However, analog gain should always stay close to 0 unless the exposure reaches its limit (minimum or maximum). Refer to section 3.3.4.4 for further details about how to control the brightness of an image.
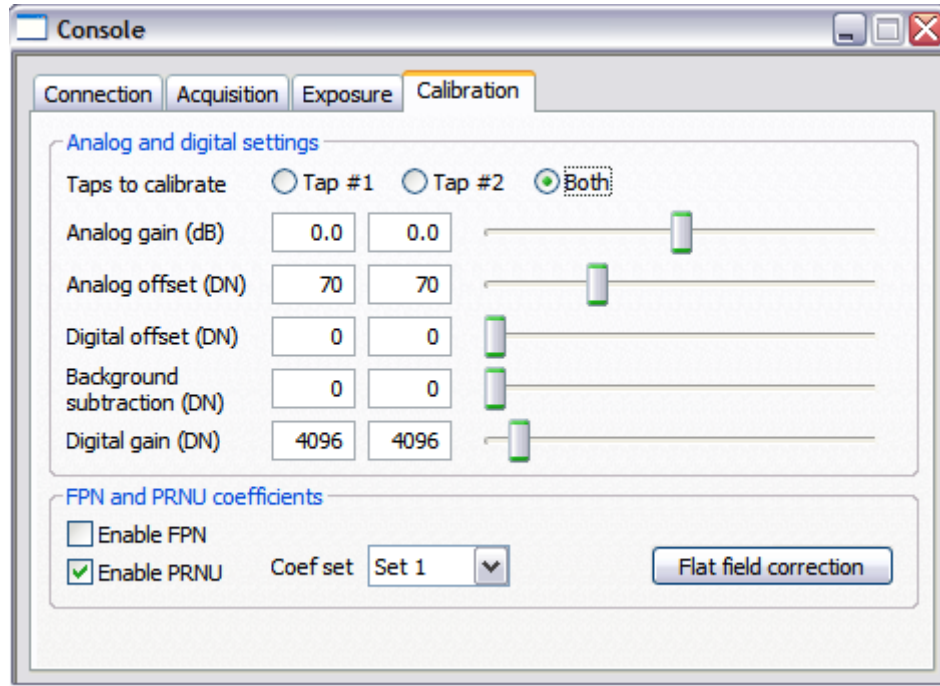


*Figure 3.7: Analog and digital settings*

### 3.4.4 Brightness control

CrackScope is designed to adjust the camera exposure and analog gain adaptively when the condition of pavement surface and illumination change, so that the image brightness will always remain at an acceptable level. To switch on the feature, check the "Bright stabilizer" check box in the "Exposure" tab in the "Console" dialog (Figure 3.6). When the brightness control is enabled, the camera exposure and analog gain is no longer adjustable by human interaction.

Bright adjustment is performed by steps. When a new frame comes, its overall brightness is evaluated and the decision of whether or not to change camera parameters is made. Camera parameters will be adjusted by a small delta value (positive or negative) to prevent over-adjustment. By continuously performing this action every time a new frame is grabbed, the image brightness will finally fall into a predefined region. The bottom area of the "Exposure" tab of the "Console" dialog shows the dynamic progress of the adjustment (Figure 3.6).

## 3.5 Calibration (Non-uniform illumination correction)

Non-uniform illumination will introduce vertical patterns into the image. In the worst condition, it can cause some vertical regions to be over bright but leave some regions un-illuminated. Non-uniform illumination imposes great challenges to the image processing

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algorithms, so its effect should be limited. Therefore, flat field correction should be performed each time the laser-camera alignment is adjusted. Figure 3.8 shows the images grabbed before and after flat field correction.



Figure 3.8a: Image grabbed before correction      Figure 3.8b: Image grabbed after correction
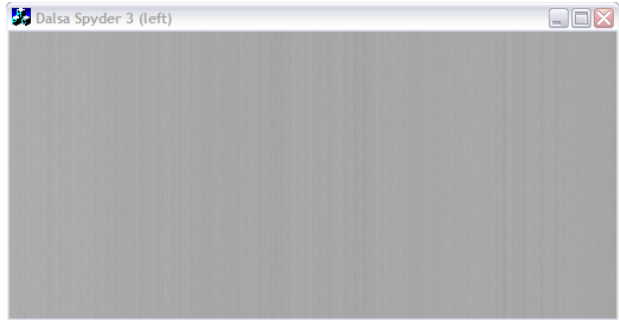
*Figure 3.8: Images Grabbed Before and After Flat Field Correction*
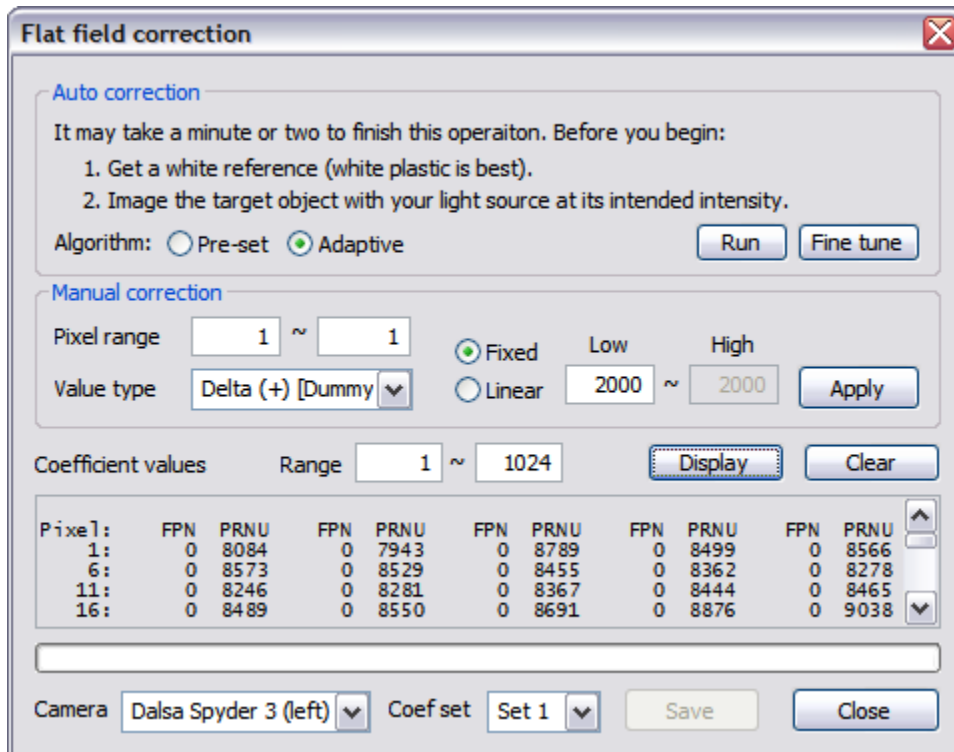


*Figure 3.9: Flat field correction*

Flat field correction is to adjust the pixel coefficients which are individually applied to every pixel on the camera's CCD. By increasing the coefficients for the pixels in a dark region, the electrical signal for these pixels can be amplified more than those in a bright region. After pixel coefficients are applied, the uniformity of output image can be significantly improved even if the uniformity of illumination is poor. Each camera supports four sets of pixel coefficients. To

enable the pixel coefficients, switch on the "Enable PRNU" check box and select the coefficient set in the combo box (Figure 3.7).

To perform the flat field correction, click the "Flat field correction" push button (Figure 3.7). Before you start to run the correction procedure, make sure:
1. There is a "white" reference target to cover the entire laser beam
2. The camera is grabbing images continuously
3. The overall brightness of the image is around a grayscale value of 128 (not too dark and not too bright)

Then click the "Run" button to initiate the adaptive correction. Some cameras with an old firmware version may not respond well. If the dialog shows "Failed to adjust pixel coefficients," try to start over by clicking the "Run" button again. It is recommended to perform the correction 2-3 times for better results. After the correction, save the coefficients to the specified set.

Manual flat field correction is designed for diagnostic purpose only. Users are not encouraged to perform manual correction.

# Chapter 4. Laser Hazard Evaluation for the Crackscope

Performed by: Tracy N. Tipping, CLSO
Office of Environmental Health and Safety
University of Texas at Austin, Austin TX 78712
17 October 2007

The Crackscope System is being developed by the research group of Dr. Bugao Xu at the UT-Austin Center for Transportation Research. It is a device to be used for mobile detection of pavement defects. The device will be vehicle-mounted and will image pavement surface on public roadways. The device consists of a CW diode laser operating at 810 nm at 4 W with a built-in beam spreader to generate a "line" that is 12 feet long and 0.25 inches wide at a distance of 7 feet. The device is mounted on the rear of a vehicle, seven feet above the pavement surface, and oriented such that the laser radiation is emitted vertically downward. A control computer uses input from a GPS unit to monitor vehicle speed to prohibit emission of laser radiation unless a minimum vehicle speed is maintained.

The system was evaluated using criteria in ANSI Z136.1 "Safe Use of Lasers." The beam spreader attached to the laser effectively converts the beam to an elliptical Gaussian beam profile with divergence of 3 mrad on the minor axis and 1800 mrad on the major axis. Using these laser parameters, the Nominal Ocular Hazard Distance (NOHD) was calculated to be 10.6 meters for a 10 second exposure. During static use of the system (laboratory setting and field service), anyone within this distance or within any barrier system which limits this distance, the Nominal Hazard Zone (NHZ), would be required to wear proper laser protective eyewear. Required Optical Density (OD) for such eyewear would be 3.8.

For mobile use, the NOHD may vary since the default static exposure time of 10 seconds is not realistic due to motion of the vehicle. While the system is operating in mobile mode, the laser operators, vehicle driver, and other vehicle occupants are not at significant risk for exposure to the laser beam due to its location outside of and at the rear of the vehicle and its orientation vertically downward. As most members of the general public would tend to move out of the path of a moving vehicle, exposure of the direct laser beam to the general public is also considered a low probability event. Thus, the most credible exposure path to the general public would be from a specular reflection of the beam from some reflective surface on the pavement. The desired minimum vehicle speed for operation of the laser system is five miles per hour. As higher vehicle speed would result in the laser passing over a reflective surface more quickly (resulting in a shorter time of reflection and thus a shorter exposure time), a vehicle speed of 5 mph will be used to determine a "worst case" NOHD for the laser system in mobile operation.

At 5 mph (2235 mm/s), the 0.25 inch (6.3 mm) wide laser beam would pass over a given point on the pavement surface in 2.8 ms. However, since an evaluation of NOHD is being performed, passing over a single point is not relevant. The evaluation must be done for the beam passing over a 7 mm distance (the diameter of the human pupil when dark adapted). Thus, the actual exposure time would be the time between the leading edge of the beam intersecting the leading

edge of the 7 mm gap and the trailing edge of the beam departing the 7mm gap. Thus, the 6.3 mm beam would have to completely traverse the 7 mm distance giving a total distance of travel of 13.3 mm. At 2235 mm/s, the exposure time to be used in the NOHD calculation is 6 ms resulting in a 4.2 m NOHD. As the beam must travel 2.1 m from the device to the pavement surface directly below the device, the actual NHZ is within 2.1 m of the reflective surface. Considering that eye level of a person standing near the path of the vehicle would be approximately 1.5 m from the surface of the pavement, that person would have to be standing within 0.6 m of the reflective surface on the pavement to be within the NHZ. This would be very unlikely due to most people tending to stay clear of the path of a moving vehicle. In addition, proximity sensors mounted on the rear of the vehicle will provide a warning to the laser operator whenever any object comes within six feet of the rear of the vehicle. Thus, if someone were to run behind the vehicle and overtake it, the operator would receive a warning before the runner entered the NHZ. As the vehicle speed increases, the exposure time (and thus the NOHD) decreases. For a vehicle speed of 10 mph, the NOHD is 3.8 m. For a vehicle speed of 15 mph, the NOHD is 3.6 m.

Based on the above parameters, assumptions, and calculations, it appears the Crackscope System operated in mobile mode would not pose a significant laser radiation hazard to the general public.

# Chapter 5.  Socket Communication Protocol

## 5.1 Socket port number

4006:  [IN]    Receive Server heartbeat;
         [OUT] Broadcast CrackScope heartbeat to Server;
4008:  [IN]    Receive DMI/GPS information
4009:  [IN]    Receive commands: "INIT" "RUN" and "STOP" from Server;
4220   [OUT] Broadcast PMIS/AASHTO data and crack map to Server;
4229   [IN]    Receive server message;

## 5.2 Conventions

As for network communication, these symbols below define how package is organized:

[...]: content between " [" and "]" is optional
{...}: content between "{" and "}" is repeated at least once

## 5.3 Server heartbeat signal

```
"TimeStamp,ServiceName,ServerIP,Message" + CR LF
```

TimeStamp format: `yyyymmddhhmmss.ssss`

## 5.4 Server commands

CrackScope has a listening socket bonded at 4009 to receive operational commands from Server. Server command prototype:

```
"CmdName[,ParamList]" + CR LF
```

### 5.4.1 `Run` command: Start CrackScope surveying

1) Run real time survey:

```
"RUN,run_live=true,save_image=value,dir=value,file_title=value
   ,image_processing=value,report_interval=value,zoom_factor=v
   alue,crack_map_frame_count=value,save_image_type=value" +
   CR LF
```

- `run_live`: must be "`true`" (run real time survey);
- `save_image`: be either "`true`" or "`false`" (case sensitive);
- `dir`: the local directory to save data;

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- `image_processing`: if "`true`" CrackScope will perform live image processing in capturing;
- `file_title`: the file name (no extension) of the images to be saved;
- `report_interval`: in unit of mile. CrackScope will report survey data at this designated interval, e.g., 0.1 mile (survey data only).
- `zoom_factor`: save the images in a smaller size;
- `crack_map_frame_count`: the number of frames per report interval (crack map only);
- `save_image_type`: "bmp", "avi" or "N/A" (do not save).

The parameters can be in any order.
Example:

> "RUN,run_live=true,dir=c:\Crack,file_title=Video,image_proc
> essing=true,report_interval=0.1,zoom_factor=4,crack_map_
> frame_count=5,save_image_type=avi" + CR LF

- Save video file to C:\Crack\Video.avi;
- Report survey data every 0.1 mile;
- Zoom video size to ¼ on both of the frame width and the frame height
- Server requires CrackScope to report crack map at a 5-frame interval

2) Run remote simulation:

> "RUN,run_live=false,dir=*value*,file_title=*value*,run_full_range=
> *value*,range_low=*value*,range_high=*value*,crack_map_frame_coun
> t=*value*" + CR LF

- `run_live`: must be "`false`" (run remote simulation);
- `dir`: the directory where image files locate. The value of the `dir` should not end with "\";
- `file_title`: the file name of the image file. Only avi files are accepted;
- `run_full_range`: be either "`true`" or "`false`". If value is "`true`", all frames in avi will be tested. If value is "`false`", only frames between `range_low` and `range_high` will be tested;

Example:

> "RUN,run_live=false,dir=D:\test_data,file_title=concrete000
> 1.avi,run_full_range=true,crack_map_frame_count=1" + CR
> LF

> "RUN,run_live=false,dir=D:\test_data,file_title=concrete000
> 1.avi,run_full_range=false,range_low=4,range_high=16,cra
> ck_map_frame_count=1" + CR LF

### 5.4.2 `Stop` command*: stop CrackScope survey

Example:

```
"STOP" + CR LF
```

## 5.5 Server message

CrackScope can switch its image processing routines when pavement type (flex/rigid) changes. The pavement type information is contained in server message which can be received at port 4229.

```
"META,pave_type=value"
```

- META: server message keyword;
- pave_type: "flex" or "rigid".

Example:

```
"META,pave_type=flex" + CR LF
```

## 5.6 DMI Data

DMI/GPS information broadcast:

```
"timestamp,DMI,distance_since_reset,GPS_latitude,GPS_longitude,G
    PS_speed" + CR LF
```

Example:

```
"20070417182516.3875,DMI,0,0,0,25.0"
```

Remark:
GPS coordinates will not be processed in current version of CrackScope. So the value for "*distance_since_reset*", "*GPS_latitude*" and "*GPS_longitude*" segments can be any character (except for ",") of any length.

## 5.7 CrackScope Survey Data

1) crack data in PMIS format:

```
"PMIS,survey_id,distance,Lng_L=value,Lng_S1=value,Lng_S2=value
  ,Lng_S3=value,Trs_N=value,Trs_S1=value,Trs_S2=value,Trs_S3=v
  alue,Allg_P=value,Allg_W=value,Lng_Se=value,Trs_Se=value" +
  CR LF
```

- PMIS: PMIS packet keyword;
- *survey_id\**: code name for current survey;

- *distance*: vehicle running distance since the start of current survey;
- *Lng_L*: total length of longitudinal cracks in current report;
- *Lng_S1, Lng_S2, Lng_S3*: total length of longitudinal cracks of severity level 1, 2 and 3, respectively;
- *Trs_N*: the count of transverse cracks in current report; (a full lane width/count);
- *Trs_S1, Trs_S2, Trs_S3*: counts of transverse cracks of severity level 1, 2 and 3, respectively;
- *Allg_P*: percentage of alligator cracks contained in current survey distance;
- *Allg_W*: average width of alligator cracks;
- *Lng_Se*: total length of sealed longitudinal cracks;
- *Trs_Se*: count of sealed transverse cracks;

\* In real time survey mode, the survey_id is the file title assigned to all frames (e.g. "PraveCrack"). However, in slide show mode, if the CrackScope is running on AVI files, the survey_id will be "SIMULATION" constantly.

2) crack data for ASSHTO pavement

```
"AASHTO,survey_id,Lwp_S1,Lwp_S2,Lwp_S3,Rwp_S1,Rwp_S2,Rwp_S3,Bw
p_S1,Bwp_S2,Bwp_S3,Lowp_S1,Lowp_S2,Lowp_S3,Rowp_S1,Rowp_S2,R
owp_S3" + CR LF
```

- "AASHTO": AASHTO packet keyword;
- *survey_id*: code name for current survey;
- *Lwp_S1*, *Lwp_S2*, *Lwp_S3*: percentage of cracks of severity level 1, 2 and 3 found in left wheel path;
- *Rwp_S1*, *Rwp_S2*, *Rwp_S3*: percentage of cracks of severity level 1, 2 and 3 found in right wheel path;
- *Rwp_S1*, *Rwp_S2*, *Rwp_S3*: percentage of cracks of severity level 1, 2 and 3 found in between wheel path;
- *Lowp_S1*, *Lowp_S2*, *Lowp_S3*: percentage of cracks of severity level 1, 2 and 3 found in left out wheel path;
- *Rwp_S1*, *Rwp_S2*, *Rwp_S3*: percentage of cracks of severity level 1, 2 and 3 found in right out wheel path;
- 

## 5.8 Crack map

```
"CRACKMAP,packet_id,width,height,num_profiles[,crack_dir,sever
ity_level,num_points{,pt.x,pt.y}]" + CR LF
```

- "CRACKMAP": crack map data packet keyword;
- *packet_id*: unique ID for current packet;
- *width*, *height*: coordinate system in which the crack map profile is defined;
- *num_profiles*: number of profiles reported in current packet;

- *crack_dir*: be either "crk_t" for transverse crack or "crk_l" for longitudinal crack (case sensitive);
- *severity_level*: "s1"—severity level 1, "s2"—severity level 2, "s3"—severity level 3;
- *num_points*: total number of points contained in the profile.
- *pt.x*, *pt.y*: coordinates of points contained in the profile.

## Splitting the crack map packet into multiple fragments:

The UDP data packet is limited to 256 bytes in our development environment, although in TCP/IP, UDP packet is limited to 512 bytes (not including the Internet header). For this reason, any data packet whose length is greater than 256 bytes will be sent in fragments. A fragment packet is defined by:

```
"FRAGEMNT,uid,index,total,len:[data]"
```

- FRAGMENT: keyword to identify current packet is a fragment.
- *uid*: all fragments belong to a packet share the same uid.
- *index*: index of the current fragment.
- *total*: number of fragments that the packet is split into.
- *len*: length of data (in bytes) transferred in current fragment.

# Chapter 6.  Definition of Crackscope Data

Crackscope data are reported in two different formats at every interval, which can be one image or a group of images in a certain distance.

Crack severity is estimated based on approximate measurements on crack width, and is classified as: low (0 – 3mm), moderate (3 – 6mm) and severe (> 6mm).

**PMIS format for flex pavement**

- *Lng_1, Lng_2, Lng_3*: total length (feet) of longitudinal cracks of severity levels 1, 2 and 3, respectively;
- *Trs_N*: the count of transverse cracks in a report interval; (a full lane width/count);
- *Trs_1, Trs_2, Trs_3*: counts of transverse cracks of severity level 1, 2 and 3, respectively;
- *Allg_P*: percentage of alligator cracking areas as opposed to the surveyed area;
- *Allg_W*: average width of alligator cracks;
- *Lng_S*: total length of sealed longitudinal cracks (feet);
- *Trs_S*: count of sealed transverse cracks;

**ASSHTO format**

ASSHTO divides a lane into five paths, and calculates the percent of the total length (m) of the cracks out of the survey area ($m^2$) for each path. The output is a crack density data ($m/m^2$).

- *Lwp_1*, *Lwp_2*, *Lwp_3*: percentage of cracks of severity levels 1, 2 and 3 found in the left wheel path;
- *Rwp_1*, *Rwp_2*, *Rwp_3*: percentage of cracks of severity levels 1, 2 and 3 found in the right wheel path;
- *Rwp_1*, *Rwp_2*, *Rwp_3*: percentage of cracks of severity levels 1, 2 and 3 found in the between wheel path;
- *Lowp_1*, *Lowp_2*, *Lowp_3*: percentage of cracks of severity levels 1, 2 and 3 found in the left outside wheel path;
- *Rwp_1*, *Rwp_2*, *Rwp_3*: percentage of cracks of severity levels 1, 2 and 3 found in the right outside wheel path;

# Chapter 7.  Professionals for Laser Safety Training and Registration

Laser Institute of America (www.laserinstitute.org)
Rockwell Laser Industries (www.rli.com)
Laser Professionals (www.laser-professionals.com) 1-888-79-LASER
Bob Weiner, Weiner Associates, bob@weinerassociates.com, 310-545-1190