CMUcam4

Command List v1.01

For CMUcam4 v1.01 Firmware

Serial Communication Setup

The serial communication parameters are as follows:

- 19,200 Baud Rate – See "BM" (Baud Mode) command to change after startup
- 1 Start Bit
- 8 Data Bits
- 1 Stop Bit – See "DM" (Delay Mode) command to change after startup
- No Parity/Sticky Bit
- No Flow Control – software (Xon (ASCII 17) / Xoff (ASCII 19)) or hardware (RTS/CTS)

- '\t' (ASCII 9 – tab) is converted to ' ' (ASCII 32 – space)
- '\b' (ASCII 8 – backspace) is evaluated by deleting the last character received
- Lower case characters ('a' through 'z') are converted to upper case characters ('A' through 'Z')
- ASCII characters 0 – 7, 10 – 12, 14 – 31, 127 – 255 are ignored (thrown away)

All commands are sent using visible ASCII characters (123 is sent for example by sending the 3 bytes "123", additionally 123 can be sent as a hexadecimal value by sending "0x7B"). Upon the successful transmission of a command, the "ACK" string is returned by the system. If there was a problem in the syntax of the transmission, or if a detectable transfer error occurred, a "NCK" string is returned. After either an "ACK" or a "NCK" string, a '\r' is returned. When a prompt ('\r' followed by a ':') is returned, it means that the camera is waiting for another command in the idle state. White spaces (or tabs) do matter and are used to separate argument parameters. Quoted strings are treated as a single argument parameter – this is particularly useful for file system operations. The '\r' (ASCII 13 - carriage return) is used to end each line and activate each command. There should be no serial timeout for all system level, file system, and image capture operations – 600 ms for all other operations.

Contents

Recommended Serial Terminal Programs

The Parallax Serial Terminal is a handy tool for communication with serial-based microcontrollers such as the Parallax Propeller chip. It is the recommended serial terminal to use to communicate with the camera board.
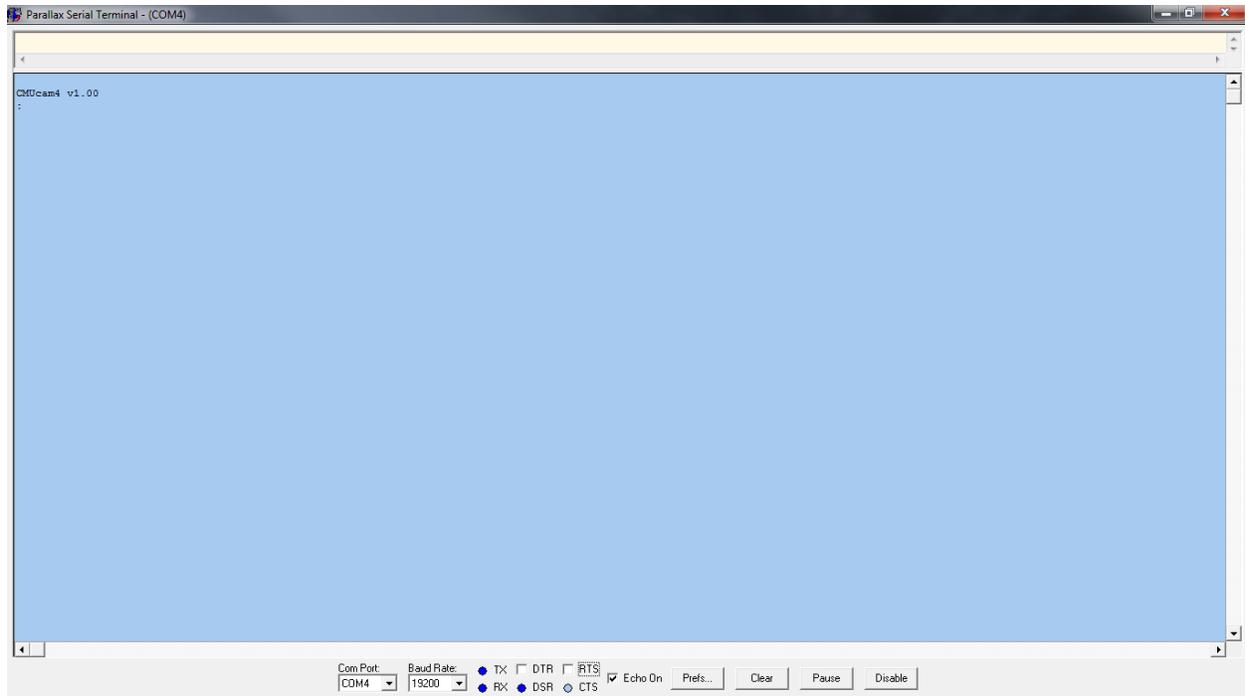
The Parallax Serial Terminal (PST) is a stand-alone application less than 1 MB in size and does not require installation to use. PST is available for download from Parallax Inc. here. Follow the below steps to setup PST:

1. Run **PST**
2. Go to **Echo On** and make sure it is checked
3. Go to **Com Port** and select the COM port the **CMUcam4** is connected to from the drop-down list
4. Go to **Baud Rate** and select **19200** from the drop-down list
   - Click **Enable** if necessary

For non-Windows users Brad's SPIN Tool (BST) is recommended. BST can be downloaded here. BST is a graphical user interface (GUI) integrated development environment (IDE) stand-alone application less than 10 MB is size designed for the Parallax Propeller Chip and does not require installation to use. BST includes a built-in easy-to-use serial terminal. Follow the below steps to setup BST's built-in easy-to-use serial terminal:

1. Run **BST**
2. Go to **View** and select **Serial Terminal** from the drop-down list
   - The **bst Terminal** should pop-up – please click on it
3. Go to **Baud** and select **19200** from the drop-down list
4. Go to **Format** and select **8 Bits** and **Parity None** from the drop-down list
5. Go to **Port** and select the COM port the **CMUcam4** is connected to from the drop-down list
   - Look for ports named /dev/tty/USB###
6. Go to **Communicate** and select **Connect**, **Terminal Echo**, and **Reset Propeller** from the drop-down menu
   - Go back to **Communicate** and select **Display ASCII** for ASCII output or **Display Hex** for hex output

Functionally Grouped Command Listing

- System Level Commands
  - "GV"   **G**et **V**ersion 24
  - "RS"   **R**eset **S**ystem 39
  - "SD"   **S**leep **D**eeply 41
  - "SL"   **S**leep **L**ightly 43
- Camera Module Commands
  - "CB"   **C**amera **B**rightness 10
  - "CC"   **C**amera **C**ontrast 10
  - "CR"   **C**amera Register **R**ead 12
  - "CW"   **C**amera Register **W**rite 13
- Camera Sensor Auto Control Commands
  - "AG"   **A**uto **G**ain Control 6
  - "AW"   **A**uto **W**hite Balance 7
- Camera Format Commands
  - "HM"   **H**orizontal **M**irror 25
  - "VF"   **V**ertical **F**lip 53
- Camera Effect Commands
  - "BW"   **B**lack and **W**hite Mode 8
  - "NG"   **N**e**g**ative Mode 34
- Auxiliary I/O Commands
  - "GB"   **G**et **B**utton State 19
  - "GD"   **G**et Button **D**uration 19
  - "GP"   **G**et Button **P**ressed 22
  - "GR"   **G**et Button **R**eleased 23
  - "PI"   **P**an **I**nput 34
  - "PO"   **P**an **O**utput 37
  - "TI"   **T**ilt **I**nput 48
  - "TO"   **T**ilt **O**utput 49
  - "GI"   **G**et **I**nputs 21
  - "SO"   **S**et **O**utputs 44
  - "L0"   **L**ED Off (**0**) 27
  - "L1"   **L**ED On (**1**) 28
- Servo Commands
  - "GS"   **G**et **S**ervo Position 23
  - "SS"   **S**et **S**ervo Position 44
  - "AP"   **A**utomatic **P**an 6
  - "AT"   **A**utomatic **T**ilt 7
  - "PP"   Auto **P**an **P**arameters 37
  - "TP"   Auto **T**ilt **P**arameters 50
- Data Rate Commands
  - "BM"   **B**aud **M**ode 8
  - "DM"   **D**elay **M**ode 17

- Television Commands
  - "M0"   **M**onitor Off (**0**) 30
  - "M1"   **M**onitor On (**1**) 30
  - "MF"   **M**onitor **F**reeze 31
  - "MS"   **M**onitor **S**ignal 32
- Color Tracking Commands
  - "GT"   **G**et **T**racking Params. 24
  - "GW"   **G**et Tracking **W**indow 25
  - "ST"   **S**et **T**racking Params. 45
  - "SW"   **S**et Tracking **W**indow 46
  - "TC"   **T**rack **C**olor 47
  - "TW"   **T**rack **W**indow 50
  - "GH"   **G**et **H**istogram 20
  - "GM"   **G**et **M**ean 21
  - "PM"   **P**oll **M**ode 36
  - "LM"   **L**ine **M**ode 28
  - "SM"   **S**witching **M**ode 43
  - "TM"   **T**est **M**ode 49
  - "CT"   **C**olor **T**racking 12
  - "HT"   **H**istogram **T**racking 26
  - "IF"   **I**nverted **F**ilter 27
  - "NF"   **N**oise **F**ilter 33
- File System Commands
  - "CA"   **C**hange **A**ttributes 9
  - "CD"   **C**hange **D**irectory 11
  - "DI"   **D**isk **I**nformation 16
  - "DS"   **D**isk **S**pace 17
  - "FM"   **F**or**m**at Disk 18
  - "LS"   **L**i**s**t Directory 29
  - "MK"   **M**a**k**e Directory 31
  - "MV"   **M**o**v**e Entry 32
  - "PL"   **P**rint **L**ine 35
  - "PR"   File **Pr**int 38
  - "RM"   **R**e**m**ove Entry 39
  - "UM"   **U**n**m**ount Disk 52
- Image Capture Commands
  - "DB"   **D**ump **B**itmap 13
  - "DF"   **D**ump **F**rame 14
  - "SB"   **S**end **B**itmap 40
  - "SF"   **S**end **F**rame 41

- Idle Command 26
- Invalid Command 26

Alphabetically Grouped Command Listing

- "AG"   **A**uto **G**ain Control 6
- "AP"   **A**utomatic **P**an 6
- "AT"   **A**utomatic **T**ilt 7
- "AW"   **A**uto **W**hite Balance 7
- "BM"   **B**aud **M**ode 8
- "BW"   **B**lack and **W**hite Mode 8
- "CA"   **C**hange **A**ttributes 9
- "CB"   **C**amera **B**rightness 10
- "CC"   **C**amera **C**ontrast 10
- "CD"   **C**hange **D**irectory 11
- "CR"   **C**amera Register **R**ead 12
- "CT"   **C**olor **T**racking 12
- "CW"   **C**amera Register **W**rite 13
- "DB"   **D**ump **B**itmap 13
- "DF"   **D**ump **F**rame 14
- "DI"   **D**isk **I**nformation 16
- "DM"   **D**elay **M**ode 17
- "DS"   **D**isk **S**pace 17
- "FM"   **F**or**m**at Disk 18
- "GB"   **G**et **B**utton State 19
- "GD"   **G**et Button **D**uration 19
- "GH"   **G**et **H**istogram 20
- "GI"   **G**et **I**nputs 21
- "GM"   **G**et **M**ean 21
- "GP"   **G**et Button **P**ressed 22
- "GR"   **G**et Button **R**eleased 23
- "GS"   **G**et **S**ervo Position 23
- "GT"   **G**et **T**racking Params. 24
- "GV"   **G**et **V**ersion 24
- "GW"   **G**et Tracking **W**indow 25
- "HM"   **H**orizontal **M**irror 25
- "HT"   **H**istogram **T**racking 26
- "IF"   **I**nverted **F**ilter 27
- "L0"   **L**ED Off (**0**) 27
- "L1"   **L**ED On (**1**) 28
- "LM"   **L**ine **M**ode 28
- "LS"   **Li**st Directory 29
- "M0"   **M**onitor Off (**0**) 30
- "M1"   **M**onitor On (**1**) 30
- "MF"   **M**onitor **F**reeze 31
- "MK"   **M**a**k**e Directory 31
- "MS"   **M**onitor **S**ignal 32

- "MV"   **M**o**v**e Entry 32
- "NF"   **N**oise **F**ilter 33
- "NG"   **Neg**ative Mode 34
- "PI"   **P**an **I**nput 34
- "PL"   **P**rint **L**ine 35
- "PM"   **P**oll **M**ode 36
- "PO"   **P**an **O**utput 37
- "PP"   Auto **P**an **P**arameters 37
- "PR"   File **Pr**int 38
- "RM"   **R**e**m**ove Entry 39
- "RS"   **R**eset **S**ystem 39
- "SB"   **S**end **B**itmap 40
- "SD"   **S**leep **D**eeply 41
- "SF"   **S**end **F**rame 41
- "SL"   **S**leep **L**ightly 43
- "SM"   **S**witching **M**ode 43
- "SO"   **S**et **O**utputs 44
- "SS"   **S**et **S**ervo Position 44
- "ST"   **S**et **T**racking Params. 45
- "SW"   **S**et Tracking **W**indow 46
- "TC"   **T**rack **C**olor 47
- "TI"   **T**ilt **I**nput 48
- "TM"   **T**est **M**ode 49
- "TO"   **T**ilt **O**utput 49
- "TP"   Auto **T**ilt **P**arameters 50
- "TW"   **T**rack **W**indow 50
- "UM"   **Un**mount Disk 52
- "VF"   **V**ertical **F**lip 53

- Idle Command 26
- Invalid Command 26

Serial Communication Flowchart

The serial communication program control flow proceeds as follows:

Legend
Circle – Junction Connector
Oval – Start Point
Parallelogram – Data Output
Rectangle – System Process
Rhombus – Decision Point
Trapezoid – Data Input

Reset

Send "\rCMUcam4 v1.01\r"

Send the prompt character ':'

Wait for a command string terminated by a carriage return

Is valid command string? — No — Send "NCK\r"

Yes

Send "ACK\r"

Send "MSG: ...\r" ⟵ Optional

Execute command

Print Data

Encountered error? — Yes — Send "Err ...\r"

No

User abort? — Yes

No

Finished command? — No / Yes
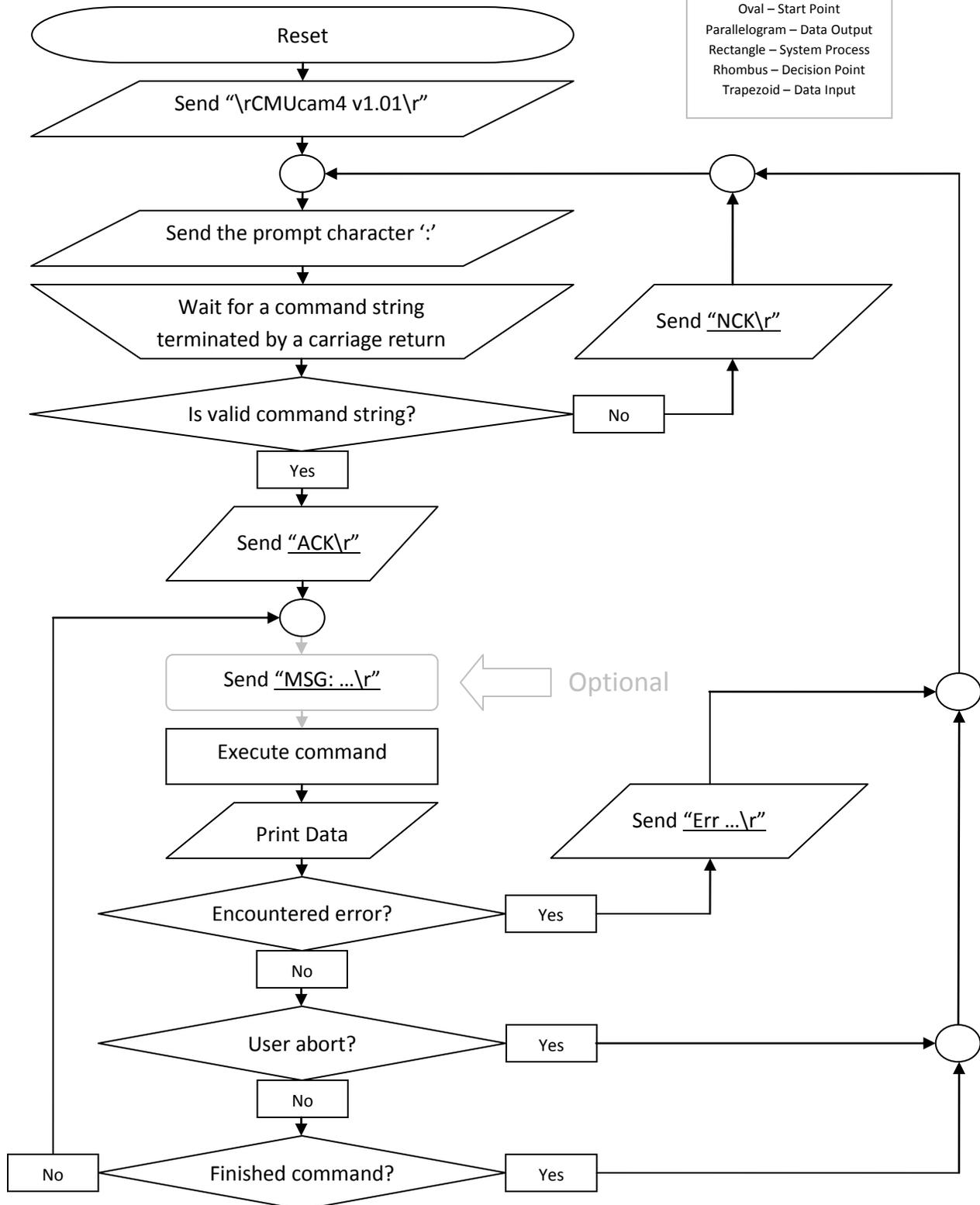
Automatic Gain Control   AG [*active – Boolean*] '\r'

This command turns the camera module's automatic gain control off or on. Automatic gain control is active by default after the camera board resets. Please note that "SD" (Sleep Deeply) and "SL" (Sleep Lightly) reset all camera module settings back to default on wakeup and will turn automatic gain control back on.

Example of how to turn automatic gain control off and on:

```
: AG 0 '\r'                              Turn automatic gain control off
ACK
: AG 1 '\r'                              Turn automatic gain control on
ACK
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: AG 0 '\r'                              Turn automatic gain control off
ACK
ERR: Camera Connection Error             A camera module error occurred
:
```

Automatic Pan   AP [*active – Boolean*] [*reverse – Boolean*] '\r'

This command turns the camera board automatic panning servo feedback control off or on. Automatic panning servo feedback control is not active by default after the camera board resets.

When automatic panning servo feedback control is active the pan servo pin on the camera board will send out pulses between 750 µs and 2,250 µs in length at 40 Hz to drive a pan servo that moves the camera module's X position. Use the "SS" (Set Servo Position) command to briefly override the pan pulse length if necessary.

The feedback control system will try to drive the pan servo to position the X part of the centroid of the tracked color to be in the center of the X field of view. This is done by integrating the proportional and differential parts of the error between the X part of the centroid and the center of the X field of view into the pan position at 40 Hz.

If the feedback control system appears to be driving the servo in the wrong direction, enable the reverse setting, which causes the feedback control system to drive the servo in the opposite direction. For non-reversed operation, pulse lengths lower than 1500 µs must move the camera module's X position to the right (from the camera module's point-of-view) and pulse lengths higher than 1500 µs must move the camera module's X position to the left (from the camera module's point-of-view).

Example of how to turn automatic panning servo feedback control off and on:

```
: AP 0 '\r'                              Turn AP off
ACK
: AP 1 '\r'                              Turn AP on – too few arguments
NCK
: AP 1 0 '\r'                            Turn AP on and non-reversed
ACK
: AP 1 1 '\r'                            Turn AP on and reversed
ACK
:
```

Automatic Tilt   AT [*active – Boolean*] [*reverse – Boolean*] '\r'

This command turns the camera board automatic tilting servo feedback control off or on. Automatic tilting servo feedback control is not active by default after the camera board resets.

When automatic tilting servo feedback control is active the tilt servo pin on the camera board will send out pulses between 750 μs and 2,250 μs in length at 40 Hz to drive a tilt servo that moves the camera module's Y position. Use the "SS" (Set Servo Position) command to briefly override the tilt pulse length if necessary.

The feedback control system will try to drive the tilt servo to position the Y part of the centroid of the tracked color to be in the center of the Y field of view. This is done by integrating the proportional and differential parts of the error between the Y part of the centroid and the center of the Y field of view into the tilt position at 40 Hz.

If the feedback control system appears to be driving the servo in the wrong direction, enable the reverse setting, which causes the feedback control system to drive the servo in the opposite direction. For non-reversed operation, pulse lengths lower than 1500 μs must move the camera module's Y position down (from the camera module's point-of-view) and pulse lengths higher than 1500 μs must move the camera module's Y position up (from the camera module's point-of-view).

Example of how to turn automatic tilting servo feedback control off and on:

```
: AT 0 '\r'                          Turn AT off
ACK
: AT 1 '\r'                          Turn AT on – too few arguments
NCK
: AT 1 0 '\r'                        Turn AT on and non-reversed
ACK
: AT 1 1 '\r'                        Turn AT on and reversed
ACK
:
```

Automatic White Balance   AW [*active – Boolean*] '\r'

This command turns the camera module's automatic white balance off or on. Automatic white balance is active by default after the camera board resets. Please note that "SD" (Sleep Deeply) and "SL" (Sleep Lightly) reset all camera module settings back to default on wakeup and will turn automatic white balance back on.

Example of how to turn automatic white balance off and on:

```
: AW 0 '\r'                          Turn automatic white balance off
ACK
: AW 1 '\r'                          Turn automatic white balance on
ACK
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: AW 0 '\r'                          Turn automatic white balance off
ACK
ERR: Camera Connection Error         A camera module error occurred
:
```

Baud Mode   **BM [***baud – Integer***]** '\r'

This command sets the camera board's serial communication baud rate. The camera board's serial communication baud rate is set to 19,200 BPS (bits per second) by default after the camera board resets.

The new baud rate can be any number between 1 BPS and 150,000 BPS inclusive. If the new baud rate setting is out of range it will be limited to be within 1 BPS and 150,000 BPS inclusive. E.g. a baud rate of 0, -1, etc. will be limited to 1 BPS. A baud rate of 150001, 150002, etc. will be limited to 150,000 BPS.

The new baud rate setting will be used until it is changed again or until the camera board is reset. The <u>"SD" (Sleep Deeply)</u> and <u>"SL" (Sleep Lightly)</u> commands do not affect the baud rate.

The camera board will perform the following steps after receiving this command:

1. Send the "ACK\r" string at the old baud rate.
2. Switch to the new range limited baud rate.
3. Wait to receive the '\r' (carriage return) character (other characters are ignored) at the new baud rate.
4. Send the "ACK\r" string and the prompt character ':' at the new baud rate and return to idling.

Example of how to change the baud rate:

: BM 115200 '\r'	*Set the baud rate to 115,200 BPS*
ACK	*Change baud rate after receiving "ACK\r"*
'\r'	*Send '\r' at 115,200 BPS*
ACK	*"ACK\r" sent at 115,200 BPS*
: BM 19200 '\r'	*Set the baud rate to 19,200 BPS*
ACK	*Change baud rate after receiving "ACK\r"*
'\r'	*Send '\r' at 19,200 BPS*
ACK	*"ACK\r" sent at 19,200 BPS*
:	

Black and White Mode   **BW [***active – Boolean***]** '\r'

This command turns the camera module's black and white mode off or on. Black and white mode is not active by default after the camera board resets. Please note that <u>"SD" (Sleep Deeply)</u> and <u>"SL" (Sleep Lightly)</u> reset all camera module settings back to default on wakeup and will turn black and white mode off.

Example of how to turn black and white mode off and on:

: BW 1 '\r'	*Turn black and white mode on*
ACK	
: BW 0 '\r'	*Turn black and white mode off*
ACK	
:	

Example of what happens if an error occurs while communicating with the camera module:

: BW 1 '\r'	*Turn black and white mode on*
ACK	
ERR: Camera Connection Error	*A camera module error occurred*
:	

Change Attributes   **CA [***file or directory path and name – String***] [***attributes – String***]** '\r'

This command changes a file or directory's attributes on the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

- If an 'R' is in the "attributes" string the file or directory will have its read-only attribute set.
  - Otherwise, the read-only attribute will be cleared.
- If an 'H' is in the "attributes" string the file or directory will have its hidden attribute set.
  - Otherwise, the hidden attribute will be cleared.
- If an 'S' is in the "attributes" string the file or directory will have its system attribute set.
  - Otherwise, the system attribute will be cleared.
- If an 'A' is in the "attributes" string the file will have its archive attribute set.
  - Otherwise, the archive attribute will be cleared.
- The camera board firmware will not modify any file or directory that has its read-only attribute set.
- The camera board firmware does not use the hidden attribute in any way – but other systems may.
- The camera board firmware does not use the system attribute in any way – but other systems may.
- The camera board firmware will set the archive attribute for a file after writing to it.
  - Please note that directories do not have the archive attribute.

Example of how to change a file or directory's attributes:

```
: CA FILENAME R '\r'              Make a file read-only
ACK
: CA FILENAME H '\r'              Make a file hidden
ACK
: CA FILENAME S '\r'              Make a file system
ACK
: CA FILENAME A '\r'              Make a file archive
ACK
: CA FILENAME _ '\r'             Clear all the attributes for a file
ACK
: CA FILENAME RHSA '\r'          Set all the attributes for a file
ACK
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: CA FILENAME R '\r'              Try to make a file read-only
ACK
ERR: Disk IO Error                A µSD card error occurred
: CA FILENAME R '\r'              Try to make a file read-only
ACK
ERR: File System Corrupted        A µSD card error occurred
: CA FILENAME R '\r'              Try to make a file read-only
ACK
ERR: File System Unsupported      A µSD card error occurred
: CA FILENAME R '\r'              Try to make a file read-only
ACK
ERR: Card Not Detected            A µSD card error occurred
:
```

Camera Brightness   CB [*brightness – Integer*] '\r'

This command changes the camera module's brightness adjustment settings. The brightness adjustment is 0 by default after the camera board resets. Please note that <u>"SD" (Sleep Deeply)</u> and <u>"SL" (Sleep Lightly)</u> reset all camera module settings back to default on wakeup and reset the brightness adjustment setting back to 0.

The new brightness adjustment setting can be any number between -255 and 255 inclusive. The camera board also accepts values sent in hexadecimal format if they are preceded with the string "0x". Values outside of this range will be truncated by taking modulo 256 of them. Brightness adjustment values below 0 result in an overall darker picture while brightness values above 0 result in an overall lighter picture. The default is 0.

Example of how to change the brightness adjustment setting:

: CB -16 '\r'	*Set the brightness adjustment to -1 (-16)*
ACK	
: CB 16 '\r'	*Set the brightness adjustment to +1 (16)*
ACK	
:	

Example of what happens if an error occurs while communicating with the camera module:

: CB 0 '\r'	*Set the brightness adjustment to 0*
ACK	
ERR: Camera Connection Error	*A camera module error occurred*
:	

Camera Contrast   CC [*contrast – Integer*] '\r'

This command changes the camera module's contrast adjustment settings. The contrast adjustment is 0 by default after the camera board resets. Please note that <u>"SD" (Sleep Deeply)</u> and <u>"SL" (Sleep Lightly)</u> reset all camera module settings back to default on wakeup and reset the contrast adjustment setting back to 0.

The new contrast adjustment setting can be any number between -31 and 31 inclusive. The camera board also accepts values sent in hexadecimal format if they are preceded with the string "0x". Values outside of this range will be truncated by taking modulo 32 of them. Contrast adjustment values below 0 result in a picture with less contrast while contrast values above 0 result in a picture with more contrast. The default is 0.

Example of how to change the contrast adjustment setting:

: CC -16 '\r'	*Set the contrast adjustment to 0.5X*
ACK	
: CC 16 '\r'	*Set the contrast adjustment to 1.5X*
ACK	
:	

Example of what happens if an error occurs while communicating with the camera module:

: CC 0 '\r'	*Set the contrast adjustment to 1X*
ACK	
ERR: Camera Connection Error	*A camera module error occurred*
:	

Change Directory   **CD [***directory path and name – String***]** '\r'

This command changes the working directory on the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card. The working directory is set to the root directory by default after the camera board resets. Please note that "SD" (Sleep Deeply) and "SL" (Sleep Lightly) reset the working directory back to the root directory on wakeup. Additionally, "DI" (Disk Information), "FM" (Format Disk), "RS" (Reset System), and "UM" (Unmount Disk) reset the working directory back to the root directory.

- If '/' or '\' are not found at the beginning of a file or directory path string, the path string is treated as a relative path that begins in the working directory ('/' or '\' can be used interchangeably in path strings).
    - E.g. "DIRNAME/DIRNAME/.../FILENAME" or "DIRNAME/DIRNAME/.../DIRNAME"

- If '/' or '\' are found at the beginning of a file or directory path string, the path string is treated as an absolute path that begins in the root directory ('/' or '\' can be used interchangeably in path strings).
    - E.g. "/DIRNAME/DIRNAME/.../FILENAME" or "/DIRNAME/DIRNAME/.../DIRNAME"

- The ".." directory entry, in every directory except the root directory, points to the parent directory of the directory the ".." entry is in. The ".." directory entry is useful for navigating the file system.

- The "." directory entry, in every directory except the root directory, points the directory the "." entry is in. The "." directory entry is useless for navigating the file system.

Example of how to change the working directory:

```
: CD DIRNAME '\r'              Change the working directory to "DIRNAME"
ACK
: CD .. '\r'                   Go up one level
ACK
: CD / '\r'                    Go to the root directory
ACK
: CD \ '\r'                    Go to the root directory
ACK
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: CD DIRNAME '\r'              Try to change the working directory
ACK
ERR: Disk IO Error            A µSD card error occurred
: CD DIRNAME '\r'             Try to change the working directory
ACK
ERR: File System Corrupted    A µSD card error occurred
: CD DIRNAME '\r'             Try to change the working directory
ACK
ERR: File System Unsupported  A µSD card error occurred
: CD DIRNAME '\r'             Try to change the working directory
ACK
ERR: Card Not Detected        A µSD card error occurred
:
```

Camera Register Read   CR [*register – Address*] '\r'

This command gets any camera module register setting value. Please note that <u>"SD" (Sleep Deeply)</u> and <u>"SL"</u> <u>(Sleep Lightly)</u> reset all camera module settings back to default on wakeup.

The "register" can be any number between 0 and 255 inclusive. Values outside of this range will be truncated by taking modulo 256 of them. For convenience, the camera board accepts values sent in hexadecimal format if they are preceded with the string "0x" – this is true for any command, not just "CR".

Example of how to get a camera module register setting value:

: CR 0x00 '\r'	*Get camera module register 0*
ACK	
255	*Result returned in decimal format*
: CR 0xFF '\r'	*Get camera module register 255*
ACK	
0	*Result returned in decimal format*
:	

Example of what happens if an error occurs while communicating with the camera module:

: CR 255 '\r'	*Get camera module register 255*
ACK	
ERR: Camera Connection Error	*A camera module error occurred*
:	

Color Tracking   CT [*active – Boolean*] '\r'

This command switches between the camera module's RGB mode and YUV mode. RGB mode is active by default after the camera board resets. Please note that <u>"SD" (Sleep Deeply)</u> and <u>"SL" (Sleep Lightly)</u> reset all camera module settings back to default on wakeup and will switch the camera module to RGB mode.

In RGB mode, the camera module returns RGB565 (16 bits per pixel) data. In RGB mode, "red" refers to the "R" (5-bits) component, "green" refers to the "G" (6-bits) component, and "blue" (5-bits) refers to the "B" component. In YUV mode, the camera module returns YUV655 (16 bits per pixel) data. In YUV mode, "red" refers to the "V" (5-bits) component, "green" refers to the "Y" (6-bits) component, and "blue" refers to the "U" (5-bits) component.

Example of how to switch between RGB mode and YUV mode:

: CT 1 '\r'	*Switch to YUV mode*
ACK	
: CT 0 '\r'	*Switch to RGB mode*
ACK	
:	

Example of what happens if an error occurs while communicating with the camera module:

: CT 1 '\r'	*Switch to YUV mode*
ACK	
ERR: Camera Connection Error	*A camera module error occurred*
:	

Camera Register Write   **CW [***register – Address***] [***value – Integer***] [***mask – Integer***] '\r'**

This command sets any camera module register setting value. Please note that <u>"SD" (Sleep Deeply)</u> and <u>"SL" (Sleep Lightly)</u> reset all camera module settings back to default on wakeup.

The "register", "value", and "mask" can be any number between 0 and 255 inclusive. Values outside of this range will be truncated by taking modulo 256 of them. For convenience, the camera board accepts values sent in hexadecimal format if they are preceded with the string "0x" – this is true for any command, not just "CW".

```
                    /* Register, value, and mask relationship. */
*((char*) register) = ((~((char)mask))&(*((char*)register))) | (((char) mask)&((char) value))
```

Example of how to set a camera module register setting value:

: CW 0x00 0x01 0x11 '\r'	*Set register 0 bit 0 to 1 and bit 4 to 0*
ACK	
: CW 0xFF 0x10 0x11 '\r'	*Set register 255 bit 0 to 0 and bit 4 to 1*
ACK	
:	

Example of what happens if an error occurs while communicating with the camera module:

: CW 255 255 255 '\r'	*Set register 255 to 255*
ACK	
ERR: Camera Connection Error	*A camera module error occurred*
:	

Dump Bitmap   **DB '\r'**

This command dumps an 80x60 monochrome black and white bitmap image of the untracked and tracked pixels to the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

This command automatically names the image file it dumps "XXXXXBM.BMP", where the "XXXXX" part of the file name is an automatically generated five digit number that is one greater than the maximum number of the first five digits of all the names of files or directories in the working directory. E.g., this command creates a file called "00001BM.BMP" then "00002BM.BMP", etc. in the working directory. Please note that a directory can have a maximum number of 65536 files or directories inside of it. File system operations will become linearly slower as the number of files and directories increase inside of the working directory.

Example of how to dump an 80x60 monochrome black and white bitmap image:

: DB '\r'	*Dump an 80x60 monochrome bitmap image*
ACK	*"00001BM.BMP" created*
: DB '\r'	*Dump an 80x60 monochrome bitmap image*
ACK	*"00002BM.BMP" created*
: DB '\r'	*Dump an 80x60 monochrome bitmap image*
ACK	*"00003BM.BMP" created*
: DB '\r'	*Dump an 80x60 monochrome bitmap image*
ACK	*"00004BM.BMP" created*
:	

Example of what happens when different unrelated errors occur while communicating with the µSD card:

: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: Disk IO Error	*A µSD card error occurred*
: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: File System Corrupted	*A µSD card error occurred*
: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: File System Unsupported	*A µSD card error occurred*
: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: Card Not Detected	*A µSD card error occurred*
: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: Disk May Be Full	*A µSD card error occurred*
: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: Directory Full	*A µSD card error occurred*
: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: Entry Already Exist	*A µSD card error occurred*
:	

Example of what happens if an error occurs while communicating with the camera module:

: DB '\r'	*Try to dump a bitmap image*
ACK	
ERR: Camera Timeout Error	*A camera module error occurred*
:	

Dump Frame   **DF [***horizontal resolution – Integer***] [***vertical resolution – Integer***] '\r'**

This command dumps an *640:320:160:80x480:240:120:60 RGB565* bitmap image to the µSD card formatted with a FAT16 or FAT32 partition and causes the AUX LED to blink at 10 Hz, if not disabled by "L0" (LED Off), while executing. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

The "horizontal resolution" value can be any number between 0 and 3 inclusive and will be limited to be within 0 and 3 inclusive. A "horizontal resolution" value of 0 selects a resolution of 640 pixels requiring approximately 80 seconds to save the image, 1 selects a resolution of 320 pixels requiring approximately 40 seconds, 2 selects a resolution of 160 pixels requiring approximately 20 seconds, and 3 selects a resolution 80 pixels requiring approximately 10 seconds.

The "vertical resolution" value can be any number between 0 and 3 inclusive and will be limited to be within 0 and 3 inclusive. A "vertical resolution" value of 0 selects a resolution of 480 pixels, 1 selects a resolution of 240 pixels, 2 selects a resolution of 120 pixels, and 3 selects a resolution 60 pixels.

To abort this command, send the '\r' (carriage return) character (other characters are ignored).

This command automatically names the image file it dumps "XXXXXBM.BMP", where the "XXXXX" part of the file name is an automatically generated five digit number that is one greater than the maximum number of the first five digits of all the names of files or directories in the working directory. E.g., this command creates a file called "00001BM.BMP" then "00002BM.BMP", etc. in the working directory. Please note that a directory can have a maximum number of 65536 files or directories inside of it. File system operations will become linearly slower as the number of files and directories increase inside of the working directory.

The RGB565 bitmap image will be saved rotated left by 90° and must be rotated right by 90° to view.

Example of how to dump an 640:320:160:80x480:240:120:60 RGB565 bitmap image:

: DF 0 0 '\r'	*Dump an 640x480 RGB565 bitmap image*
ACK	*"00001BM.BMP" created*
: DF 1 1 '\r'	*Dump an 320x240 RGB565 bitmap image*
ACK	*"00002BM.BMP" created*
: DF 2 2 '\r'	*Dump an 160x120 RGB565 bitmap image*
ACK	*"00003BM.BMP" created*
: DF 3 3 '\r'	*Dump an 80x60 RGB565 bitmap image*
ACK	*"00004BM.BMP" created*
:	

Example of what happens when different unrelated errors occur while communicating with the µSD card:

: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: Disk IO Error	*A µSD card error occurred*
: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: File System Corrupted	*A µSD card error occurred*
: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: File System Unsupported	*A µSD card error occurred*
: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: Card Not Detected	*A µSD card error occurred*
: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: Disk May Be Full	*A µSD card error occurred*
: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: Directory Full	*A µSD card error occurred*
: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: Entry Already Exist	*A µSD card error occurred*
:	

Example of what happens if an error occurs while communicating with the camera module:

: DF 0 0 '\r'	*Try to dump a bitmap image*
ACK	
ERR: Camera Timeout Error	*A camera module error occurred*
:	

Disk Information   **DI** '\r'

This command prints the disk information on the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

This command prints the following information about the µSD card formatted with a FAT16 or FAT32 partition:

1. The volume label surrounded by quotes (11 characters)
2. The file system type surrounded by quotes (11 characters)
3. The disk signature number in hexadecimal (32-bit number)
4. The volume identification number in hexadecimal (32-bit number)
5. The count of data sectors in decimal (32-bit number)
6. The bytes per sector in decimal (32-bit number)
7. The sectors per cluster in decimal (32-bit number)
8. The count of clusters in decimal (32-bit number)

*"Disk Size" == "Bytes per Sector" * "Data Sectors" == "Bytes per Sector" * "Sectors per Cluster" * "Count of Clusters"*

Example of how to print the disk information:

```
: DI '\r'                                Print the disk information
ACK
"NO NAME    " "FAT16     "               THIS
0x00000000 0x01234567                     IS
2097152 512                              ONE
128 16384                               LINE
: DI '\r'                                Print the disk information
ACK
"NO NAME    " "FAT32     "               THIS
0x00000000 0x89ABCDEF                     IS
16777216 512                            ONE
128 131072                              LINE
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: DI '\r'                                Try to print the disk information
ACK
ERR: Disk IO Error                       A µSD card error occurred
: DI '\r'                                Try to print the disk information
ACK
ERR: Card Not Detected                   A µSD card error occurred
: DI '\r'                                Try to print the disk information
ACK
ERR: File System Corrupted               A µSD card error occurred
: DI '\r'                                Try to print the disk information
ACK
ERR: File System Unsupported             A µSD card error occurred
:
```

Delay Mode   DM [*delay – Integer*] '\r'

This command sets the camera board's serial communication extra stop bits count. The camera board's serial communication extra stop bits count is set to 0 bits by default after the camera board resets.

This command can give slower processors the time they need to handle serial data sent from the camera board.

The new extra stop bits count can be any number between 0 bits and 2,147,483,647 bits inclusive. If the new extra stop bits count setting is out of range it will be limited to be within 0 bits and 2,147,483,647 bits inclusive. E.g. a extra stop bits count of -1, -2, etc. will be limited to 0 bits.

The new extra stop bits count setting will be used until it is changed again or until the camera board is reset. The "SD" (Sleep Deeply) and "SL" (Sleep Lightly) commands do not affect the extra stop bits count.

The camera board will perform the following steps after receiving this command:

1. Switch to the new range limited extra stop bits count.
2. Send the "ACK\r" string and the prompt character ':' at the new extra stop bits count and return to idling.

Example of how to change the extra stop bits count:

: DM 19190 '\r'	*Set the extra stop bits count to 19,190*
ACK	*The "ACK\r:" string is sent at 1 char/sec*
: DM 182 '\r'	*Set the extra stop bits count to 182 BPS*
ACK	*The "ACK\r:" string is sent at 100 char/sec*
:	

Disk Space   DS '\r'

This command prints the free and used sector count on the µSD card formatted with a FAT16 or FAT32 partition and causes the AUX LED to blink at 10 Hz, if not disabled by "L0" (LED Off), while executing. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card, the count of clusters on the µSD card partition, and the file system type of the µSD card partition.

Warning: This command normally takes a very long time to execute!

This command prints the following information about the µSD card formatted with a FAT16 or FAT32 partition:

1. The free sector count for files and directories to use (32-bit number)
2. The used sector count by files and directories (32-bit number)

*"Disk Size" == "Bytes per Sector" * "Data Sectors" == "Bytes per Sector" * ("Free Sectors" + "Used Sectors")*

Example of how to print the disk space:

: DS '\r'	*Print the disk space*
ACK	
MSG: Scanning Partition	
65536 256	*65536 Free Sectors + 256 Used Sectors*
:	

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: DS '\r'                              Try to print the disk space
ACK
ERR: Disk IO Error                     A µSD card error occurred
: DS '\r'                              Try to print the disk space
ACK
ERR: Card Not Detected                 A µSD card error occurred
: DS '\r'                              Try to print the disk space
ACK
ERR: File System Corrupted             A µSD card error occurred
: DS '\r'                              Try to print the disk space
ACK
ERR: File System Unsupported           A µSD card error occurred
:
```

Format Disk   **FM '\r'**

This command erases all data on the µSD card formatted with a FAT16 or FAT32 partition and causes the AUX LED to blink at 10 Hz, if not disabled by "L0" (LED Off), while executing. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card, the count of clusters on the µSD card partition, and the file system type of the µSD card partition.

Warning: This command normally takes a very long time to execute!

Example of how to erase all data on the disk:

```
: FM '\r'                              Erase all data on the disk
ACK
MSG: Formatting Partition
: LS '\r'                              The root directory is now empty
MSG: ---FILENAME----ATTRIB---SIZE----
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: FM '\r'                              Try to format the disk
ACK
MSG: Scanning Partition
ERR: Disk IO Error                     A µSD card error occurred
: FM '\r'                              Try to format the disk
ACK
MSG: Scanning Partition
ERR: Card Not Detected                 A µSD card error occurred
: FM '\r'                              Try to format the disk
ACK
MSG: Scanning Partition
ERR: File System Corrupted             A µSD card error occurred
: FM '\r'                              Try to format the disk
ACK
MSG: Scanning Partition
ERR: File System Unsupported           A µSD card error occurred
:
```

Get Button State   GB '\r'

This command returns the state of the user button. The value returned will be between 0 and 1 inclusive. The user button is de-bounced and must stay pressed for at least 32 ms to be registered as pressed (1) and must stay released for at least 32 ms to be registered as released (0). On reset, the camera board sets the initial state of the user button to the physical state of the user button.

Example of how to get the user button state:

```
: GB '\r'                               Get the button state – released (0)
ACK
0
: GB '\r'                               Get the button state – pressed (1)
ACK
1
:
```

Get Button Duration in State   GD '\r'

This command returns the duration in state of the user button in milliseconds. The value returned will be between 0 ms and 65,535 ms inclusive with 1 ms resolution. The user button is de-bounced and must stay pressed for at least 32 ms to be registered as pressed (1) and must stay released for at least 32 ms to be registered as released (0). On reset, the camera board sets the initial state of the user button to the physical state of the user button.

Example of how to get the user button duration in state in milliseconds:

```
: GB '\r'                               Get the button state – released (0)
ACK
0
: GD '\r'                               Get the button duration in state – 500 ms
ACK
500
: GD '\r'                               Get the button duration in state – 1000 ms
ACK
1000
: GD '\r'                               Get the button duration in state – 1500 ms
ACK
1500
: GB '\r'                               Get the button state – pressed (1)
ACK
1
: GD '\r'                               Get the button duration in state – 500 ms
ACK
500
: GD '\r'                               Get the button duration in state – 1000 ms
ACK
1000
: GD '\r'                               Get the button duration in state – 1500 ms
ACK
1500
```

Get Histogram   **GH [**channel – Integer**] [**bins – Integer**] '\r'**

This command returns histogram data about the image. If a sub region of the image is selected via the "SW" (Set Tracking Window) command, this command will only operate on the selected sub region. Additionally, if "HT" (Histogram Tracking) is active this command will only operate on the tracked pixels in the selected sub region.

The "channel" value selects which color channel to return the histogram of and the "bins" value selects the number of bins for the histogram.

- If the "channel" value is 0 the histogram for the red channel will be sent.
  - The "bins" value can then be between 0 and 5 and the histogram sent will have $2^{"bins"}$ bins.
- If the "channel" value is 1 the histogram for the green channel will be sent.
  - The "bins" value can then be between 0 and 6 and the histogram sent will have $2^{"bins"}$ bins.
- If the "channel" value is 2 the histogram for the blue channel will be sent.
  - The "bins" value can then be between 0 and 5 and the histogram sent will have $2^{"bins"}$ bins.

This command returns Type 'H' Data Packets only by default, per frame at 8 FPS (frames per second), which contain ACSII viewable formatted data. They start with 0x48 followed by 0x20 ('H' followed by the space character) followed by 1-64 packets of data and a terminating carriage return. Each packet of data contains a decimal number separated from other packets by a space character.

H bin0 bin1 … binN**\r**

If "LM" (Line Mode) is active, this command will send a Type 'F' Data Packet, per frame at 8 FPS, after sending a Type 'H' Data Packet.

If "PM" (Poll Mode) is active this command will send only one Type 'H' Data Packet followed by a Type 'F' Data Packet, if "LM" (Line Mode) is active, and then send the prompt character ':' and return to idling.

To abort this command, if "PM" (Poll Mode) is not active, send the '\r' (carriage return) character (other characters are ignored). The camera board will then finish sending whatever packets it was sending and then send the prompt character ':' and return to idling.

If "CT" (Color Tracking) is not active, this command will return histogram data about the RGB565 image. Otherwise, this command will return data about the YUV655 image. In YUV mode R:G:B map to V:Y:U (Cr:Y:Cb).

Example of how to get histogram data about the image:

```
: GH 0 3 '\r'                              Get histogram data
ACK
H 1 2 4 8 16 32 64 128
'\r'                                       Abort
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: GH 0 3 '\r'                              Try to get histogram data
ACK
ERR: Camera Timeout Error                  A camera module error occurred
:
```

Get Inputs   **GI** '\r'

This command returns the state of the pan pin and tilt pin. The value returned will be between 0 and 3 inclusive. The value returned is the actual state of the pan pin (bit 1) and tilt pin (bit 0) regardless of whether they are an input or output. Please note that the pan pin and tilt pin are not pulled high or low by the camera board and float. They must be driven to be a valid input source. Also, note that series limiting current resistors on the camera board protect the pan pin and tilt pin from being shorted to ground.

Example of how to get the pan pin and tilt pin state:

: GI '\r' ACK 0	*Get inputs – pan pin low and tilt pin low*
: GI '\r' ACK 1	*Get inputs – pan pin low and tilt pin high*
: GI '\r' ACK 2	*Get inputs – pan pin high and tilt pin low*
: GI '\r' ACK 3 :	*Get inputs – pan pin high and tilt pin high*

Get Mean   **GM** '\r'

This command returns statistics data about the image. If a sub region of the image is selected via the "SW" (Set Tracking Window) command, this command will only operate on the selected sub region. Additionally, if "HT" (Histogram Tracking) is active this command will only operate on the tracked pixels in the selected sub region.

This command returns Type 'S' Data Packets only by default, per frame at 8 FPS (frames per second), which contain ACSII viewable formatted data. They start with 0x53 followed by 0x20 ('S' followed by the space character) followed by 12 packets of data and a terminating carriage return. Each packet of data contains a decimal number separated from other packets by a space character.

S *RMean GMean BMean RMedian GMedian BMedian RMode GMode BMode RStDev GStDev BStDev***\r**

If "SM" (Switching Mode) is active this command will alternative between sending Type 'S' Data Packets and Type 'T' Data Packets per frame at 8 FPS. If "LM" (Line Mode) is active, this command will send a Type 'F' Data Packet, per frame at 8 FPS, after sending a Type 'S' Data Packet or Type 'T' Data Packet.

If "PM" (Poll Mode) is active this command will send only one Type 'S' Data Packet followed by a Type 'F' Data Packet, if "LM" (Line Mode) is active, and then send the prompt character ':' and return to idling.

To abort this command, if "PM" (Poll Mode) is not active, send the '\r' (carriage return) character (other characters are ignored). The camera board will then finish sending whatever packets it was sending and then send the prompt character ':' and return to idling.

If "SM" (Switching Mode) is active and "PM" (Poll Mode) is not active, this command causes the AUX LED to turn on, if not disabled by "L0" (LED Off), whenever there are any tracked pixels in the image and off when there are no tracked pixels in the image while executing.

If "CT" (Color Tracking) is not active, this command will return statistics data about the RGB565 image. Otherwise, this command will return data about the YUV655 image. In YUV mode R:G:B map to V:Y:U (Cr:Y:Cb).

Example of how to get statistics data about the image:

: GM '\r'	*Get statistics data*
ACK	
S 98 97 98 148 149 148 197 198 197 8 8 8	
'\r'	*Abort*
:	

Example of what happens if an error occurs while communicating with the camera module:

: GM '\r'	*Try to get statistics data*
ACK	
ERR: Camera Timeout Error	*A camera module error occurred*
:	

Get Button Pressed   **GP '\r'**

This command returns if the user button was pressed since the last call to this command. The value returned will be between 0 and 1 inclusive where 0 represents "false" and 1 represents "true". The user button is de-bounced and must stay pressed for at least 32 ms to be registered as pressed (1) and must stay released for at least 32 ms to be registered as released (0). On reset, the camera board sets the initial state of the user button to the physical state of the user button.

Example of how to get if the user button was pressed (not is pressed):

: GP '\r'	*Get if pressed – false (0) was not pressed*
ACK	
0	
: GP '\r'	*Get if pressed – true (1) was pressed*
ACK	
1	
:	

Get Button Released GR '\r'

This command returns if the user button was released since the last call to this command. The value returned will be between 0 and 1 inclusive where 0 represents "false" and 1 represents "true". The user button is de-bounced and must stay pressed for at least 32 ms to be registered as pressed (1) and must stay released for at least 32 ms to be registered as released (0). On reset, the camera board sets the initial state of the user button to the physical state of the user button.

Example of how to get if the user button was released (not is released):

```
: GR '\r'                        Get if released – false (0) was not released
ACK
0
: GR '\r'                        Get if released – true (1) was released
ACK
1
:
```

Get Servo Position GS [*servo – Address*] '\r'

This command gets the position of either the pan or tilt servo. The value returned will be either 0 or between 750 and 2,250 inclusive and represents the pulse length in microseconds that is driving either the pan or tilt servo. By default after the camera board resets, both the pan and tilt servo are disabled.

The "servo" value selects either the pan or tilt servo. A "servo" value of 0 selects the pan servo and a "servo" value of 1 selects the tilt servo. All other values of "servo" are illegal.

If the pan servo position is non-zero the pan pin is set as an output, otherwise it is set as an input – unless set to be an output by "SO" (Set Outputs) or "PO" (Pan Output). If the tilt servo position is non-zero the tilt pin is set as an output, otherwise it is set as an input – unless set to be an output by "SO" (Set Outputs) or "TO" (Tilt Output).

Example of how to get the servo position:

```
: GS 0 '\r'                      Get the pan servo pulse length
ACK
0                                Pan servo disabled
: SS 0 1 1500 '\r'               Set the pan servo pulse length
ACK
: GS 0 '\r'                      Get the pan servo pulse length
ACK
1500                             Pan servo enabled w/ 1500 µs pulse length
: GS 1 '\r'                      Get the tilt servo pulse length
ACK
0                                Tilt servo disabled
: SS 1 1 1500 '\r'               Set the tilt servo pulse length
ACK
: GS 1 '\r'                      Get the tilt servo pulse length
ACK
1500                             Tilt servo enabled w/ 1500 µs pulse length
:
```

Get Tracking Parameters   GT '\r'

This command gets the color-tracking threshold parameters used to segment the 160x120 RGB565/YUV655 image that the camera board processes at 8 FPS. By default the camera board color-tracking threshold parameters are set to track all possible colors. Use the "ST" (Set Tracking Parameters) command to set the color-tracking threshold parameters to constrain the color field of view and change the values returned by this command.

This command prints the following values separated by a space and terminated with a '\r' (carriage return):

1. The red channel minimum threshold value – between 0 and 255
2. The red channel maximum threshold value – between 0 and 255
3. The green channel minimum threshold value – between 0 and 255
4. The green channel maximum threshold value – between 0 and 255
5. The blue channel minimum threshold value – between 0 and 255
6. The blue channel maximum threshold value – between 0 and 255

Because the camera board does all image processing with 5 bits for the red channel, 6 bits for the green channel, and 5 bits for the blue channel, the thresholds will be scaled up before being printed. The red channel thresholds will be scaled from 5 bits to 8 bits rounded down, the green channel thresholds will be scaled from 6 bits to 8 bits rounded down, and the blue channel thresholds will be scaled from 5 bits to 8 bits rounded down.

Example of how to get the tracking parameters:

```
: ST '\r'                                    Reset the tracking parameters
ACK
: GT '\r'                                    Get the tracking parameters
ACK
0 255 0 255 0 255                            Output not necessarily equal to input
: ST 100 200 100 200 100 200 '\r'            Set the tracking parameters
ACK
: GT '\r'                                    Get the tracking parameters
ACK
106 205 101 202 106 205                      Output not necessarily equal to input
:
```

Get Version   GV '\r'

This command prints the version string. Please note that the camera board prints a '\r' (carriage return) followed by the version string terminated with a '\r' on startup.

Example of how to print the version string:

```
: GV '\r'                                    Print the version string
ACK
CMUcam4 v1.00                                Version string returned
: RS '\r'                                    Reset the camera system
ACK

CMUcam4 v1.00                                Version string returned
:
```

Get Tracking Window   **GW** '\r'

This command gets the color-tracking window parameters used to segment the 160x120 RGB565/YUV655 image that the camera board processes at 8 FPS. By default the camera board color-tracking window parameters are set to track all possible pixels. Use the "SW" (Set Tracking Window) command to set the color-tracking window parameters to constrain the pixel field of view and change the values returned by this command.

This command prints the following values separated by a space and terminated with a '\r' (carriage return):

1. The top left X tracking window coordinate (X1) – Between 0 and 159
2. The top left Y tracking window coordinate (Y1) – Between 0 and 119
3. The bottom right X tracking window coordinate (X2) – Between 0 and 159
4. The bottom right Y tracking window coordinate (Y2) – Between 0 and 119

Example of how to get the tracking window:

```
: SW '\r'                              Reset the tracking window
ACK
: GW '\r'                              Get the tracking window
ACK
0 0 159 119
: SW 40 30 119 89 '\r'                 Set the tracking window
ACK
: GW '\r'                              Get the tracking window
ACK
40 30 119 89
:
```

Horizontal Mirror   **HM [**_active – Boolean_**]** '\r'

This command turns the camera module's horizontal mirror mode off or on. Horizontal mirror mode is not active by default after the camera board resets. Please note that "SD" (Sleep Deeply) and "SL" (Sleep Lightly) reset all camera module settings back to default on wakeup and will turn horizontal mirror mode off.

Example of how to turn horizontal mirror mode off and on:

```
: HM 1 '\r'                            Turn horizontal mirror mode on
ACK
: HM 0 '\r'                            Turn horizontal mirror mode off
ACK
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: HM 1 '\r'                            Turn horizontal mirror mode on
ACK
ERR: Camera Connection Error           A camera module error occurred
:
```

Histogram Tracking   HT [*active – Boolean*] '\r'

This command turns the camera board's histogram tracking mode off or on. Histogram tracking mode is not active by default after the camera board resets.

When histogram tracking is disabled, the camera board produces histogram and statistics information for "GH" (Get Histogram) and "GM" (Get Mean) from all tracked and untracked pixels that are within the color-tracking window. The color-tracking window can be changed by using the "SW" (Set Tracking Window) command.

When histogram tracking is enabled, the camera board produces histogram and statistics information for "GH" (Get Histogram) and "GM" (Get Mean) from all tracked pixels that are within the color-tracking window. The color-tracking window can be changed by using the "SW" (Set Tracking Window) command.

Example of how to turn histogram tracking mode off and on:

```
: HT 1 '\r'                          Turn histogram tracking mode on
ACK
: HT 0 '\r'                          Turn histogram tracking mode off
ACK
:
```

Idle Command   '\r'

This command is used to set the camera board into an idle state. Like all other commands, you should receive the acknowledgment string "ACK" or the not acknowledge string "NCK" on failure. After acknowledging the idle command, the camera board waits for further commands, which is shown by the ':' prompt. While in this idle state a '\r' (carriage return) by itself will return an "ACK" followed by '\r' and ':' character prompt. This is how to stop the camera board while it is streaming data.

Example of how to check if the camera board is alive while in the idle state:

```
: '\r'
ACK
:
```

Invalid Command   [*garbage*] '\r'

This is what happens when a garbage command is sent to the camera board, a command does not receive enough arguments, or one of the arguments provided to a command is out of range. This is not an actual command.

Example of what happens if an invalid command is sent:

```
: qwertyuiopasdfghjklzxcvbnm '\r'
NCK
:
```

Inverted Filter   **IF [**_active – Boolean_**]** '\r'

This command turns the camera board's inverted color-tracking filter mode off or on. Inverted color-tracking filter mode is not active by default after the camera board resets.

When inverted color-tracking filter mode is disabled, the camera board tracks all pixels that fall inside the color tracking bounds set by either <u>"ST" (Set Tracking Parameters)</u>, <u>"TC" (Track Color)</u>, or <u>"TW" (Track Window)</u>.

When inverted color-tracking filter mode is enabled, the camera board tracks all pixels that fall outside the color tracking bounds set by either <u>"ST" (Set Tracking Parameters)</u>, <u>"TC" (Track Color)</u>, or <u>"TW" (Track Window)</u>.

Example of how to turn inverted filter mode off and on:

: IF 1 '\r'	_Turn inverted filter mode on_
ACK	
: IF 0 '\r'	_Turn inverted filter mode off_
ACK	
:	

LED Off (0)   **L0** '\r'

This command disables the AUX LED and turns the LED off. By default after the camera board resets the LED is set to be enabled, on, and blink at 0 Hz.

Example of how to turn the AUX LED off:

: L0 '\r'	_Turn the AUX LED off_
ACK	
:	

LED On (1)   **L1 [**_frequency – Integer_**]** '\r'

This command enables the AUX LED and turns the LED on. By default after the camera board resets the LED is set to be enabled, on, and blink at 0 Hz.

The "frequency" value can be any number between -1 and 10,000,000 inclusive. All other values of "frequency" are illegal. A "frequency" value of -1 will turn the AUX LED off. A "frequency" value of 0 will turn the LED on to blink at 0 Hz, a "frequency" value of 1 will turn the LED on to blink at 1 Hz, …, a "frequency" value of 10,000,000 will cause the LED to blink at 10,000,000 Hz.

Please note that "DF" (Dump Frame), "DS" (Disk Space), "FM" (Format Disk), "GH" (Get Mean), "TC" (Track Color), and "TW" (Track Window) may override the "frequency" value, if not disabled by "L0" (LED Off), while executing.

 Example of how to turn the AUX LED on:

: L1 '\r' NCK	_Turn the AUX LED on – too few arguments_
: L1 -1 '\r' ACK	_Turn the AUX LED off – but not disabled_
: L1 0 '\r' ACK	_Turn the AUX LED on to blink at 0 Hz_
: L1 1 '\r' ACK	_Turn the AUX LED on to blink at 1 Hz_
: L1 2 '\r' ACK	_Turn the AUX LED on to blink at 2 Hz_
: L1 10000 '\r' ACK :	_Turn the AUX LED on to blink at 10000 Hz_

Line Mode   **LM [**_active – Boolean_**]** '\r'

This command turns the camera board's line mode off or on. Line mode is not active by default after the camera board resets. If line mode is active, the camera board will send Type 'F' Data Packets after Type 'H' Data Packets, Type 'S' Data Packets, or Type 'T' Data Packets sent by the "GH" (Get Histogram), "GM" (Get Mean), "TC" (Track Color), and "TW" (Track Window) commands.

Example of how to turn line mode off and on:

: LM 1 '\r' ACK	_Turn line mode on_
: LM 0 '\r' ACK :	_Turn line mode off_

List Directory   **LS** '\r'

This command prints information about the files and directories inside of the working directory on the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

This command prints the following information about the files and directories inside of the working directory. Please note that the files and directories inside of the working directory are not necessarily printed in sorted order:

- The name of the file or directory surrounded by quotes (12 characters)
    - The file or directory name consists of the first 8 characters before '.' (including spaces)
        - Trailing spaces in the file or directory name will not be printed for better readability
    - The file or directory extension consists of the last 3 characters after '.' (including spaces)
        - Trailing spaces in the file or directory extension will not be printed for better readability
            - File names normally have a file extension
            - Directory names normally do not have a directory name extension

- The attributes of the file or directory (6 characters)
    - Files can have the following attributes: 'R' (Read-only), 'H' (Hidden), 'S' (System), 'A' (Archive)
        - All files do not have the 'D' attribute – this is what makes a file a file
    - Directories can have the following attributes: 'R' (Read-only), 'H (Hidden), 'S' (System)
        - All directories have the 'D' attribute – this is what makes a directory a directory

- The size of the file or directory (32-bit number)
    - Files have a size – it can be between 0 and 2,147,483,647 bytes
    - Directories do not have a size

This command will print the name, attributes, and size of every file or directory in the working directory.

Please note that a directory can have a maximum number of 65536 files or directories inside of it. File system operations will become linearly slower, taking a very long time to execute and print information, as the number of files and directories increase inside of the working directory.

Example of how to print information about the files and directories inside of the working directory:

```
: LS '\r'                                    Print information
ACK
MSG: ---FILENAME----ATTRIB---SIZE----        Message header
    ".           " ____D_                    "." Directory link
    "..          " ____D_                    ".." Directory link
    "FOLDER      " ____D_                     A directory called "FOLDER"
    "00002BM.BMP" _____ 614466               640x480 RGB565 image file
    "00003BM.BMP" _____A 153666               320x240 RGB565 image file
    "00004BM.BMP" __S__A 38466                160x120 RGB565 image file
    "00005BM.BMP" _HS__A 9666                 80x60 RGB565 image file
    "PICTURES    " __S_D_                      A system folder called "PICTURES"
    "LOGS        " _HS_D_ 662                  A hidden and system folder called "LOGS"
    "00001BM.BMP" RHS__A                       80x60 BW image file
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: LS '\r'                                    Try to print information
ACK
ERR: Disk IO Error                           A µSD card error occurred
: LS '\r'                                    Try to print information
ACK
ERR: File System Corrupted                   A µSD card error occurred
: LS '\r'                                    Try to print information
ACK
ERR: File System Unsupported                 A µSD card error occurred
: LS '\r'                                    Try to print information
ACK
ERR: Card Not Detected                       A µSD card error occurred
:
```

Monitor Off (0)   **M0 '\r'**

This command turns the camera board's television signal off. The television signal is active by default after the camera board resets.

Example of how to turn the television signal off:

```
: M0 '\r'                                    Turn the television signal off
ACK
:
```

Monitor On (1)   **M1 '\r'**

This command turns the camera board's television signal on. The television signal is active by default after the camera board resets.

Example of how to turn the television signal on:

```
: M1 '\r'                                    Turn the television signal on
ACK
:
```

Monitor Freeze   **MF [**_active – Boolean_**]** '\r'

This command freezes the camera board's television signal. A value of 0 causes the video generator to update the television screen with the tracked image pixels (in blue) and untracked image pixels (in black) and draw the bounding box (in red) and centroid (in white) overlaid on the tracked pixels. A value of 1 causes the video generator to stop updating the television screen with the tracked pixels (in blue) and untracked pixels (in black) and stop drawing the bounding box (in red) and centroid (in white) overlaid on the currently tracked image. The monitor is frozen by default after the camera board is reset.

Example of how to freeze the television signal:

```
: MF 0 '\r'                             Unfreeze the monitor
ACK
: MF 1 '\r'                             Freeze the monitor
ACK
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: MF 0 '\r'                             Try to unfreeze the monitor
ACK
ERR: Camera Timeout Error               A camera module error occurred
:
```

Make Directory   **MK [**_directory path and name – String_**]** '\r'

This command creates a new directory on the μSD card formatted with a FAT16 or FAT32 partition. Because this command uses the μSD card it can take a very long time to execute which depends on the speed of the μSD card and the size of directories on the μSD card.

Example of how to create a new directory:

```
: MK DIRNAME '\r'                       Create a new directory
ACK
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: MK DIRNAME ‘\r’                              Try to create a new directory
ACK
ERR: Disk IO Error                            A µSD card error occurred
: MK DIRNAME ‘\r’                              Try to create a new directory
ACK
ERR: File System Corrupted                    A µSD card error occurred
: MK DIRNAME ‘\r’                              Try to create a new directory
ACK
ERR: File System Unsupported                  A µSD card error occurred
: MK DIRNAME ‘\r’                              Try to create a new directory
ACK
ERR: Card Not Detected                        A µSD card error occurred
: MK DIRNAME ‘\r’                              Try to create a new directory
ACK
ERR: Disk May Be Full                         A µSD card error occurred
: MK DIRNAME ‘\r’                              Try to create a new directory
ACK
ERR: Directory Full                           A µSD card error occurred
:
```

Monitor Signal   MS [*active – Boolean*] ‘\r’

This command switches the camera board's television signal from NTSC to PAL. A value of 0 causes the video generator to produce an NTSC television signal. A value of 1 causes the video generator to produce an PAL television signal. The monitor television signal is NTSC by default after the camera board is reset.

Example of how to switch the television signal:

```
: MS 1 ‘\r’                                   Generate an PAL television signal
ACK
: MS 0 ‘\r’                                   Generate an NTSC television signal
ACK
:
```

Move Entry   MV [*old entry path and name – String*] [*new entry path and name – String*] ‘\r’

This command moves and/or renames a file or directory on the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

Example of how to move and/or rename a file or directory:

```
: MV NAME DIRNAME/NAME ‘\r’                    Move a file or directory
ACK
: MV OLDNAME NEWNAME ‘\r’                       Rename a file or directory
ACK
:
```

Example of what happens when different unrelated errors occur while communicating with the μSD card:

```
: MV OLDFNAME DIRNAME/NEWFNAME '\r'        Try to move and/or rename a file
ACK
ERR: Disk IO Error                         A μSD card error occurred
: MV OLDFNAME DIRNAME/NEWFNAME '\r'        Try to move and/or rename a file
ACK
ERR: File System Corrupted                 A μSD card error occurred
: MV OLDFNAME DIRNAME/NEWFNAME '\r'        Try to move and/or rename a file
ACK
ERR: File System Unsupported               A μSD card error occurred
: MV OLDFNAME DIRNAME/NEWFNAME '\r'        Try to move and/or rename a file
ACK
ERR: Card Not Detected                     A μSD card error occurred
: MV OLDFNAME DIRNAME/NEWFNAME '\r'        Try to move and/or rename a file
ACK
ERR: Disk May Be Full                      A μSD card error occurred
: MV OLDFNAME DIRNAME/NEWFNAME '\r'        Try to move and/or rename a file
ACK
ERR: Directory Full                        A μSD card error occurred
: MV OLDFNAME DIRNAME/NEWFNAME '\r'        Try to move and/or rename a file
ACK
ERR: Directory Link Missing                A μSD card error occurred
:
```

Noise Filter   **NF [**threshold – Integer**] '\r'**

This command turns the camera board's noise color-tracking filter mode off or on. Noise color-tracking filter mode is not active by default after the camera board resets.

The "threshold" value can be any number between 0 and 255 inclusive. Values outside of this range will be truncated by taking modulo 256 of them. A "threshold" value of 0 will turn noise color-tracking filter mode off. A "threshold" value of 1 or greater will turn noise color-tracking filter mode on.

For each tracked pixel 'P' (e.g. a pixel that is within the color-tracking window and the color-tracking thresholds). 'X' tracked pixels (where 'X' is the "threshold" value) must appear before that tracked pixel 'P', in the same row of pixels as the tracked pixel 'P', after an untracked pixel is encountered, in the same row of pixels as the tracked pixel 'P', for the pixel 'P' to be tracked. Tracked pixels 'P' not satisfying this statement become untracked pixels.

Example of how to turn noise filter mode off and on:

```
: NF 1 '\r'                                Turn the noise filter on to threshold level 1
NCK
: NF 10 '\r'                               Turn the noise filter on to threshold level 10
ACK
: NF 30 '\r'                               Turn the noise filter on to threshold level 30
ACK
: NF 0 '\r'                                Turn the noise filter off
ACK
:
```

Negative Mode   NG [*active – Boolean*] '\r'

This command turns the camera module's negative mode off or on. Negative mode is not active by default after the camera board resets. Please note that "SD" (Sleep Deeply) and "SL" (Sleep Lightly) reset all camera module settings back to default on wakeup and will turn negative mode off.

If negative mode is enabled, the camera module sends an inverted image to the camera board.

Example of how to turn negative mode off and on:

```
: NG 1 '\r'                           Turn negative mode on
ACK
: NG 0 '\r'                           Turn negative mode off
ACK
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: NG 1 '\r'                           Turn negative mode on
ACK
ERR: Camera Connection Error          A camera module error occurred
:
```

Pan Input   PI '\r'

This command returns the state of the pan pin. The value returned will be between 0 and 1 inclusive. The value returned is the actual state of the pan pin regardless of whether it is an input or output. Please note that the pan pin is not pulled high or low by the camera board and floats. It must be driven to be a valid input source. Also, note that a series limiting current resistor on the camera board protects the pan pin from being shorted to ground.

Example of how to get the pan pin state:

```
: PI '\r'                             Get the pan pin state – logical low (0)
ACK
0
: PI '\r'                             Get the pan pin state – logical high (1)
ACK
1
:
```

Print Line   **PL [***file path and name – String***] [***text to append – String***] '\r'**

This command appends a string of text to a file on the μSD card formatted with a FAT16 or FAT32 partition. Because this command uses the μSD card it can take a very long time to execute which depends on the speed of the μSD card and the size of directories on the μSD card.

A '\r' (carriage return) character will terminate the string of text appended to the file. Microsoft Windows users should view and edit text files created by this command with **WordPad** and not **Notepad** because of this.

If the file to append the string of text to does not exist, the file will be created and the string of text will be appended to the newly created empty file.

Please note that the string of text to append to the file should be surrounded by quotes. Otherwise, only the first token of the string of text to append to the file will be appended to the file. For example:

- : PL FILENAME THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG\r results in "THE\r" being appended to the file called "FILENAME".

- : PL FILENAME "THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG"\r results in "THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG\r" being appended to the file called "FILENAME".

Additionally, the length of the command string sent to the camera board must not exceed 255 characters. Any characters beyond this limit will be discarded. This is true for any command – not just "PL". In general, try to avoid "text to append" strings longer than a length of 80 characters.

Example of how to append a string of text to a file:

```
: PL FILENAME "THE QUICK BROWN FOX" '\r'     Create a new file
ACK
: PL FILENAME "THE LAZY DOG" '\r'            Append to the file
ACK
: PR FILENAME '\r'                           View the new file
ACK
33                                           Both strings are present
THE QUICK BROWN FOX
THE LAZY DOG
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

: PL FILENAME "JUMPS OVER" '\r'	*Try to append "JUMPS OVER" to a file*
ACK	
ERR: Disk IO Error	*A µSD card error occurred*
: PL FILENAME "JUMPS OVER" '\r'	*Try to append "JUMPS OVER" to a file*
ACK	
ERR: File System Corrupted	*A µSD card error occurred*
: PL FILENAME "JUMPS OVER" '\r'	*Try to append "JUMPS OVER" to a file*
ACK	
ERR: File System Unsupported	*A µSD card error occurred*
: PL FILENAME "JUMPS OVER" '\r'	*Try to append "JUMPS OVER" to a file*
ACK	
ERR: Card Not Detected	*A µSD card error occurred*
: PL FILENAME "JUMPS OVER" '\r'	*Try to append "JUMPS OVER" to a file*
ACK	
ERR: Disk May Be Full	*A µSD card error occurred*
: PL FILENAME "JUMPS OVER" '\r'	*Try to append "JUMPS OVER" to a file*
ACK	
ERR: Directory Full	*A µSD card error occurred*
:	

Poll Mode   **PM [***active – Boolean***]** '\r'

This command turns the camera board's poll mode off or on. Poll mode is not active by default after the camera board resets. If poll mode is active, the camera board will send only one Type 'H' Data Packet, Type 'S' Data Packet, or Type 'T' Data Packet sent by the "GH" (Get Histogram), "GM" (Get Mean), "TC" (Track Color), and "TW" (Track Window) commands and then send the prompt character ':' and return to idling.

Example of how to turn poll mode off and on:

: PM 1 '\r'	*Turn poll mode on*
ACK	
: PM 0 '\r'	*Turn poll mode off*
ACK	
:	

Pan Output   **PO [**_direction – Boolean_**] [**_output – Boolean_**]** '\r'

This command sets the state of the pan pin. If the "direction" value is 0, the pin is set to an input state and the "output" value is not needed and ignored. If the "direction" value is 1, the pin is set to an output and the "output" value becomes the state of the pin. Additionally, the pan pin cannot be set to an input while driving a servo and if set to output high will stop driving any servo being driven.

Please note that the pan pin is not pulled high or low by the camera board and floats when not set as an output. Also, note that a series limiting current resistor on the camera board protects the pan pin from shorting to ground.

Example of how to set the pan pin state:

: PO 0 '\r'	_Pan pin set to input_
ACK	
: PO 1 '\r'	_Pan pin set to output – too few arguments_
NCK	
: PO 1 0 '\r'	_Pan pin set to output low_
ACK	
: PO 1 1 '\r'	_Pan pin set to output high_
ACK	
:	

Automatic Pan Parameters   **PP [**_proportional gain – Integer_**] [**_derivative gain – Integer_**]** '\r'

This command changes the proportional and derivative gain values used for automatic panning servo feedback control. The default proportional and derivative gains are 400 and 100 respectively.

The "proportional gain" value can be any number from 0 to 1000 inclusive. All other values of "proportional gain" are illegal. A higher "proportional gain" value will cause the pan servo to respond more to the speed of the X part of the centroid while a lower value will cause the pan servo to respond less. A value of 0 turns the gain off.

The "derivative gain" value can be any number from 0 to 1000 inclusive. All other values of "derivative gain" are illegal. A higher "derivative gain" value will cause the pan servo to respond more to the acceleration of the X part of the centroid while a lower value will cause the pan servo to respond less. A value of 0 turns the gain off.

Example of how to change the proportional (P) and derivative (D) gain values:

: PP 0 0 '\r'	_Change P to 0 and D to 0_
ACK	
: PP 1000 0 '\r'	_Change P to 1000 and D to 0_
ACK	
: PP 0 1000 '\r'	_Change P to 0 and D to 1000_
ACK	
: PP 1000 1000 '\r'	_Change P to 1000 and D to 1000_
ACK	
:	

File Print   **PR [**_file path and name – String_**]** '\r'

This command prints the size and contents of a file on the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

The size of the file terminated by a '\r' (carriage return) will be printed first followed by the contents of the file. If an error occurs while communicating with the µSD card, the remaining bytes of the file that have not been printed yet will be returned as zeros, followed an "ERR: …\r" string. The camera board will then send the prompt character ':' and return to idling regardless of whether an error occurred or not.

Please note that if the contents of the file are in binary then binary data will be printed.

 Example of how to print the size and contents of a file:

: PL FILENAME "THE QUICK BROWN FOX" '\r'	_Create a new file_
ACK	
: PL FILENAME "THE LAZY DOG" '\r'	_Append to the file_
ACK	
: PR FILENAME '\r'	_View the new file_
ACK	
33	_Both strings are present_
THE QUICK BROWN FOX	
THE LAZY DOG	
:	

Example of what happens when different unrelated errors occur while communicating with the µSD card:

: PR FILENAME '\r'	_Try to print the size and contents of a file_
ACK	
ERR: Disk IO Error	_A µSD card error occurred_
: PR FILENAME '\r'	_Try to print the size and contents of a file_
ACK	
ERR: File System Corrupted	_A µSD card error occurred_
: PR FILENAME '\r'	_Try to print the size and contents of a file_
ACK	
ERR: File System Unsupported	_A µSD card error occurred_
: PR FILENAME '\r'	_Try to print the size and contents of a file_
ACK	
ERR: Card Not Detected	_A µSD card error occurred_
:	

Remove Entry   **RM [**_file or directory path and name – String_**]** '\r'

This command deletes a file or empty directory on the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

Example of how to delete a file or empty directory:

: RM FILENAME '\r'	_Delete a file_
ACK	
: RM DIRNAME '\r'	_Delete a directory_
ACK	
:	

Example of what happens when different unrelated errors occur while communicating with the µSD card:

: RM DIRNAME '\r'	_Try to delete directory "DIRNAME"_
ACK	
ERR: Disk IO Error	_A µSD card error occurred_
: RM DIRNAME '\r' r'	_Try to delete directory "DIRNAME"_
ACK	
ERR: File System Corrupted	_A µSD card error occurred_
: RM DIRNAME '\r'	_Try to delete directory "DIRNAME"_
ACK	
ERR: File System Unsupported	_A µSD card error occurred_
: RM DIRNAME '\r'	_Try to delete directory "DIRNAME"_
ACK	
ERR: Card Not Detected	_A µSD card error occurred_
: RM DIRNAME '\r'	_Try to delete directory "DIRNAME"_
ACK	
ERR: Directory Not Empty	_A µSD card error occurred_
:	

Reset System   **RS** '\r'

This command resets the camera board and the camera module. Please note that the camera board prints a '\r' (carriage return) followed by the version string terminated with a '\r' on startup.

Example of how to reset the camera board and the camera module:

: RS '\r'	_Reset the camera system_
ACK	
CMUcam4 v1.00	_Version string returned_
:	

Send Bitmap   **SB '\r'**

This command prints an 80x60 monochrome black and white bitmap image of the untracked and tracked pixels terminated by a '\r' (carriage return).

The 80x60 monochrome B&W image is 4,800 pixels where each white (1) pixel represents a tracked pixel and each black (0) pixel represents an untracked pixel. The image fits in 600 bytes by packing eight pixels into a single byte. The 600 bytes are sent organized in an unpadded pixel array 80x60 monochrome B&W image BMP file format.

Bit 7 in byte 0 = pixel 0.   **Row 0 = Bytes (0 – 9)**
Bit 6 in byte 0 = pixel 1.   **Row 1 = Bytes (10 – 19)**
…   **…**
Bit 0 in byte 0 = pixel 7.   **Row 59 = Bytes (590 – 599)**
…
Bit 0 in byte 599 = pixel 4,799.   *(A column is the group of pixels with the same offset in all rows)*

Example of how to print an 80x60 monochrome black and white bitmap image:

```
: ST '\r'                                 Reset the tracking parameters
ACK
: SB '\r'                                 Print an 80x60 monochrome
ACK                                       black and white bitmap image
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                   T
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                   H
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                   I
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                   S
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                   I
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                   S
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                   O
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```

Example of what happens if an error occurs while communicating with the camera module:

```
: SB '\r'                                 Try to print a bitmap image
ACK
ERR: Camera Timeout Error                 A camera module error occurred
:
```

Sleep Deeply   **SD '\r'**

This command puts the camera board and camera module into a low power state to reduce the amount of current consumed by the camera board and the camera module. This command does reduce current consumption by more than "SL" (Sleep Lightly) but does not drive the pan and tilt servo while sleeping. Note that this command reinitializes the camera module and resets all camera module settings back to default on wakeup.

The camera board will perform the following steps after receiving this command:

1. Send the "ACK\r" string.
2. Turn the AUX LED, TV, and pan and tilt servo off.
3. Put the camera module into power down mode.
   (The camera board is now sleeping deeply)
4. Wait indefinitely to receive the '\0' (null) character (please do not send any other characters).
5. Reinitialize the camera module.
6. Turn the AUX LED, TV, and pan and tilt servo on.
7. Send the "ACK\r" string and the prompt character ':' and return to idling.

Example of how to make the camera board and module sleep deeply:

: SD '\r'	*Put the system to sleep*
ACK	
'\0'	*Send '\0' to wake the system up*
ACK	
:	

Send Frame   **SF [***horizontal resolution – Integer***] [***vertical resolution – Integer***] '\r'**

This command sends an *640:320:160:80x480:240:120:60 RGB565* bitmap image and causes the AUX LED to blink at 10 Hz, if not disabled by "L0" (LED Off), while executing.

This command returns "DAT: …\r" packets, per frame at 8 FPS (frames per second), which contain RGB565 binary formatted data. They start with 0x44, 0x41, and 0x54 followed by 0x3A ("DAT" followed by the colon character) followed by 60-480 pixels of data and a terminating carriage return. Each pixel of data contains a binary **16-BIT (2 Bytes – Least Significant Byte First)** number and **IS NOT** separated from other pixels by a space character. The pixels in each packet represent a single column of the RGB565 bitmap image.

DAT: *pixel0 pixel1 … pixelN***\r**

The "horizontal resolution" value can be any number between 0 and 3 inclusive and will be limited to be within 0 and 3 inclusive. A "horizontal resolution" value of 0 selects a resolution of 640 pixels requiring approximately 80 seconds to send the image, 1 selects a resolution of 320 pixels requiring approximately 40 seconds, 2 selects a resolution of 160 pixels requiring approximately 20 seconds, and 3 selects a resolution 80 pixels requiring approximately 10 seconds. The number of packets sent is equal to the resolution chosen.

The "vertical resolution" value can be any number between 0 and 3 inclusive and will be limited to be within 0 and 3 inclusive. A "vertical resolution" value of 0 selects a resolution of 480 pixels, 1 selects a resolution of 240 pixels, 2 selects a resolution of 120 pixels, and 3 selects a resolution 60 pixels. The number of pixels in each packet is equal to the resolution chosen.

The columns in each packet should be stored in an image array from left to right. Where the first data packet sent is column 0, and the second is column 1, and so forth. The pixels in each packet should be stored in an image array from top to bottom. Where the first pixel sent is pixel 0 in the column, and the second is pixel is pixel 1 in the column, and so forth.

The top 5 bits, in the 16-bit RGB565 pixel, represent the red color component, the middle 6 bits represent the green color component, and the bottom 5 bits represent the blue color component. If "CT" (Color Tracking) is active, this command will return data about the YUV655 image. In YUV mode R:G:B map to V:Y:U (Cr:Y:Cb).

To abort this command, send the '\r' (carriage return) character (other characters are ignored).

If an error occurs while communicating with the camera module, or the command is aborted, the remaining pixels of the column that have not been printed yet will be sent, terminated by a carriage return, followed an "ERR: Camera Timeout Error\r" string if an error occurred while communicating with the camera module. The camera board will then send the prompt character ':' and return to idling.

Example of how to send an 80x60 RGB565 bitmap image:

```
: SF 3 3 '\r'                                    Send an 80x60 RGB565 bitmap image
ACK
DAT:                                             THIS
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                                 IS
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               …
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               ONE
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               LINE
DAT:                                             THIS
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                                 IS
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               …
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               ONE
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               LINE

…                                                77 more packets later…

DAT:                                             THIS
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                                 IS
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               …
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               ONE
ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ                               LINE
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: SF 0 0 '\r'                                    Try to send a bitmap image
ACK
ERR: Camera Timeout Error                        A camera module error occurred
:
```

Sleep Lightly   **SL** '\r'

This command puts the camera board and camera module into a low power state to reduce the amount of current consumed by the camera board and the camera module. This command does not reduce current consumption by more than "SD" (Sleep Deeply) but does drive the pan and tilt servo while sleeping. Note that this command reinitializes the camera module and resets all camera module settings back to default on wakeup.

The camera board will perform the following steps after receiving this command:

1. Send the "ACK\r" string.
2. Turn the AUX LED and TV off.
3. Put the camera module into sleep mode.
   (The camera board is now sleeping lightly)
4. Wait indefinitely to receive the '\r' (carriage return) character (other characters are ignored).
5. Reinitialize the camera module.
6. Turn the AUX LED and TV on.
7. Send the "ACK\r" string and the prompt character ':' and return to idling.

Example of how to make the camera board and module sleep lightly:

: SL '\r'	*Put the system to sleep*
ACK	
'\r'	*Send '\r' to wake the system up*
ACK	
:	

Switching Mode   **SM [***active – Boolean***]** '\r'

This command turns the camera board's switching mode off or on. Switching mode is not active by default after the camera board resets. If switching mode is active "GM" (Get Mean), "TC" (Track Color), and "TW" (Track Window) will alternative between sending Type 'S' Data Packets and Type 'T' Data Packets per frame at 8 FPS. Additionally, if switching mode is active and "PM" (Poll Mode) is not active, "GM" (Get Mean), "TC" (Track Color), and "TW" (Track Window) will cause the AUX LED to turn on, if not disabled by "L0" (LED Off), whenever there are any tracked pixels in the image and off when there are no tracked pixels in the image while executing.

Example of how to turn switching mode off and on:

: SM 1 '\r'	*Turn switching mode on*
ACK	
: SM 0 '\r'	*Turn switching mode off*
ACK	
:	

Set Outputs   SO [*directions – Boolean*] [*outputs – Boolean*] '\r'

This command sets the state of the pan pin (bit 1) and tilt pin (bit 0). If the direction is 0 for the pan pin and/or tilt pin, it is set to an input state and the output value is not needed and ignored. If the direction is 1 for the pan pin and/or tilt pin, it is set to an output and the output value becomes the state of the pin. Additionally, the pan pin and tilt pin cannot be set to inputs while driving servos and if set to output high will stop driving any servo being driven.

Please note that the pan pin and tilt pin are not pulled high or low by the camera board and float when not set as outputs. Also, note that series limiting current resistors on the camera board protect the pan pin and tilt pin from shorting to ground.

Example of how to set the pan pin and tilt pin state:

```
: SO 0 '\r'                          Pan pin input and tilt pin input
ACK
: SO 1 '\r'                          Pan pin input and tilt pin output – invalid
NCK
: SO 2 '\r'                          Pan pin output and tilt pin input – invalid
NCK
: SO 3 '\r'                          Pan pin output and tilt pin output – invalid
NCK
: SO 3 0 '\r'                        Pan pin output low and tilt pin output low
ACK
: SO 3 1 '\r'                        Pan pin output low and tilt pin output high
ACK
: SO 3 2 '\r'                        Pan pin output high and tilt pin output low
ACK
: SO 3 3 '\r'                        Pan pin output high and tilt pin output high
ACK
:
```

Set Servo Position   SS [*servo – Address*] [*active – Boolean*] [*pulse length – Integer*] '\r'

This command sets the position of either the pan or tilt servo. By default after the camera board resets, both the pan and tilt servo are disabled.

The "servo" value selects either the pan or tilt servo. A "servo" value of 0 selects the pan servo and a "servo" value of 1 selects the tilt servo. All other values of "servo" are illegal.

The "active" value selects whether the servo is active. An "active" value of 0 turns the servo off and an "active" value of 1 turns the servo on.

If the "active" value is 1 then the "pulse length" value, which can be a number between 750 and 2,250 inclusive, represents the pulse length in microseconds to drive the servo with. All other values of "pulse length" are illegal.

If the pan servo is active the pan pin is set as an output, otherwise it is set as an input – unless set to be an output by "SO" (Set Outputs) or "PO" (Pan Output). If the tilt servo active the tilt pin is set as an output, otherwise it is set as an input – unless set to be an output by "SO" (Set Outputs) or "TO" (Tilt Output).

Example of how to set the servo position:

: SS 0 '\r'	*Select the pan servo – too few arguments*
NCK	
: SS 0 0 '\r'	*Turn the pan servo off.*
ACK	
: SS 0 1 '\r'	*Turn the pan servo on – too few arguments*
NCK	
: SS 0 1 1500 '\r'	*Turn the pan servo on with a 1500 µs pulse*
ACK	
:	

Set Tracking Parameters   **ST [**red min – Integer**] [**red max – Integer**] [**green min – Integer**]**
                    [green max – Integer**] [**blue min – Integer**] [**blue max – Integer**] '\r'**

This command sets the color tracking threshold parameters used to segment the 160x120 RGB565/YUV655 image that the camera board processes at 8 FPS. By default the camera board color tracking threshold parameters are set to track all possible colors. If this command is executed with no arguments the color tracking threshold parameters are reset to track all possible colors.

The camera board will track all pixels that have a red component that is between "red min" and "red max" inclusive, a green component that is between "green min" and "green max" inclusive, and a blue component that is between "blue min" and "blue max" inclusive. "red min", "red max", "green min", "green max", "blue min", and "blue max" can be any number between 0 and 255 inclusive. If a parameter is out of range it will be range limited to be within 0 and 255 inclusive. E.g. -1, -2, etc. will be limited to 0 and 256, 257, etc. will be limited to 255.

Because the camera board does all image processing with 5 bits for the red channel, 6 bits for the green channel, and 5 bits for the blue channel, the thresholds will be scaled down before being saved. The red channel thresholds will be scaled from 8 bits to 5 bits rounded up, the green channel thresholds will be scaled from 8 bits to 6 bits rounded up, and the blue channel thresholds will be scaled from 8 bits to 5 bits rounded up.

The TV monitor will automatically be unfrozen after this command is finished executing to show the image being tracked with the bounding box and the centroid overlaid on the tracked image. Untracked pixels will be black on the TV monitor, tracked pixels will be blue on the TV monitor, the bounding box will be shown as a red box outline on the TV monitor, and the centroid will be shown as a white dot on the TV monitor.

Use the "TC" (Track Color) or "TW" (Track Window) command to get the bounding box and centroid coordinates.

Example of how to set the tracking parameters:

: ST '\r'	*Reset the tracking parameters*
ACK	
: ST 0 100 0 100 0 100 '\r'	*Set the tracking parameters*
ACK	
: ST 100 200 100 200 100 200 '\r'	*Set the tracking parameters*
ACK	
: ST 0 '\r'	*Set the tracking parameters*
NCK	*– too few arguments – must be 0 or 6.*
:	

Example of what happens if an error occurs while communicating with the camera module:

```
: ST '\r'                                    Reset the tracking parameters
ACK
ERR: Camera Timeout Error                    A camera module error occurred
:
```

Set Tracking Window   **SW [***top left X – Integer***] [***top left Y – Integer***]**
                               [*bottom right X – Integer***] [***bottom right Y – Integer***] '\r'**

This command sets the color tracking window parameters used to segment the 160x120 RGB565/YUV655 image that the camera board processes at 8 FPS. By default the camera board color tracking window parameters are set to track all possible pixels. If this command is executed with no arguments the color tracking window parameters are reset to track all possible pixels.

The camera board will track all pixels that have a X position that is between "top left X" and "bottom right X" inclusive and a Y position that is between "top left Y" and "bottom right Y" inclusive. "top left X" and "bottom right X" can be any number between 0 and 159 inclusive. "top left Y" and "bottom right Y" can be any number between 0 and 119 inclusive. If a parameter is out of range it will be range limited to be within 0 and 159 inclusive, for X positions, and 0 to 119 inclusive, for Y positions. E.g. -1, -2, etc. will be limited to 0 and 160, 161, etc. will be limited to 159, for X positions, and 120, 121, etc. will be limited to 119, for Y positions.

The TV monitor will automatically be unfrozen after this command is finished executing to show the image being tracked with the bounding box and the centroid overlaid on the tracked image. Untracked pixels will be black on the TV monitor, tracked pixels will be blue on the TV monitor, the bounding box will be shown as a red box outline on the TV monitor, and the centroid will be shown as a white dot on the TV monitor.

Use the "TC" (Track Color) or "TW" (Track Window) command to get the bounding box and centroid coordinates.

Example of how to set the tracking window:

```
: SW '\r'                                    Reset the tracking window
ACK
: SW 0 0 159 59 '\r'                         Set the tracking window to the upper half
ACK
: SW 0 60 159 119 '\r'                       Set the tracking window to the lower half
ACK
: SW 0 '\r'                                  Set the tracking window
NCK                                          – too few arguments – must be 0 or 4.
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: SW '\r'                                    Reset the tracking window
ACK
ERR: Camera Timeout Error                    A camera module error occurred
:
```

Track Color   TC [*red min – Integer*] [*red max – Integer*] [*green min – Integer*]
                       [*green max – Integer*] [*blue min – Integer*] [*blue max – Integer*] '\r'

This command returns tracking data about the image. If a sub region of the image is selected via the "SW" (Set Tracking Window) command, this command will only operate on the selected sub region. This command also sets the color tracking threshold parameters used to segment the 160x120 RGB565/YUV655 image that the camera board processes at 8 FPS. By default the camera board color tracking threshold parameters are set to track all possible colors. If this command is executed with no arguments it returns tracking data about the image using the past color tracking threshold parameters set by this command or "ST" (Set Tracking).

The camera board will track all pixels that have a red component that is between "red min" and "red max" inclusive, a green component that is between "green min" and "green max" inclusive, and a blue component that is between "blue min" and "blue max" inclusive. "red min", "red max", "green min", "green max", "blue min", and "blue max" can be any number between 0 and 255 inclusive. If a parameter is out of range it will be range limited to be within 0 and 255 inclusive. E.g. -1, -2, etc. will be limited to 0 and 256, 257, etc. will be limited to 255.

Because the camera board does all image processing with 5 bits for the red channel, 6 bits for the green channel, and 5 bits for the blue channel, the thresholds will be scaled down before being saved. The red channel thresholds will be scaled from 8 bits to 5 bits rounded up, the green channel thresholds will be scaled from 8 bits to 6 bits rounded up, and the blue channel thresholds will be scaled from 8 bits to 5 bits rounded up.

The TV monitor will automatically be unfrozen after this command is finished initializing to show the image being tracked with the bounding box and the centroid overlaid on the tracked image. Untracked pixels will be black on the TV monitor, tracked pixels will be blue on the TV monitor, the bounding box will be shown as a red box outline on the TV monitor, and the centroid will be shown as a white dot on the TV monitor.

This command returns Type 'T' Data Packets only by default, per frame at 8 FPS (frames per second), which contain ACSII viewable formatted data. They start with 0x54 followed by 0x20 ('T' followed by the space character) followed by 8 packets of data and a terminating carriage return. Each packet of data contains a decimal number separated from other packets by a space character.

T *mx my x1 y1 x2 y2 pixels confidence***\r**

If "SM" (Switching Mode) is active this command will alternative between sending Type 'T' Data Packets and Type 'S' Data Packets per frame at 8 FPS. If "LM" (Line Mode) is active, this command will send a Type 'F' Data Packet, per frame at 8 FPS, after sending a Type 'T' Data Packet or Type 'S' Data Packet.

If "PM" (Poll Mode) is active this command will send only one Type 'T' Data Packet followed by a Type 'F' Data Packet, if "LM" (Line Mode) is active, and then send the prompt character ':' and return to idling.

To abort this command, if "PM" (Poll Mode) is not active, send the '\r' (carriage return) character (other characters are ignored). The camera board will then finish sending whatever packets it was sending and then send the prompt character ':' and return to idling.

If "PM" (Poll Mode) is not active, this command causes the AUX LED to turn on, if not disabled by "L0" (LED Off), whenever there are any tracked pixels in the image and off when there are no tracked pixels in the image while executing.

If "CT" (Color Tracking) is not active, this command will return tracking data about the RGB565 image. Otherwise, this command will return data about the YUV655 image. In YUV mode R:G:B map to V:Y:U (Cr:Y:Cb).

Example of how to get tracking data about the image:

```
: TC '\r'                              Get tracking data
ACK
T 79 59 0 0 159 119 255 255
'\r'                                   Abort
: ST 0 100 0 100 0 100 '\r'            Get tracking data
ACK
T 59 79 50 25 109 94 85 170
'\r'                                   Abort
: TC 0 '\r'                            Get the tracking data
NCK                                    – too few arguments – must be 0 or 6.
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: TC '\r'                              Try to get tracking data
ACK
ERR: Camera Timeout Error              A camera module error occurred
:
```

Tilt Input   **TI** '\r'

This command returns the state of the tilt pin. The value returned will be between 0 and 1 inclusive. The value returned is the actual state of the tilt pin regardless of whether it is an input or output. Please note that the tilt pin is not pulled high or low by the camera board and floats. It must be driven to be a valid input. Also, note that a series limiting current resistor on the camera board protects the tilt pin from being shorted to ground.

Example of how to get the tilt pin state:

```
: TI '\r'                              Get the tilt pin state – logical low (0)
ACK
0
: TI '\r'                              Get the tilt pin state – logical high (1)
ACK
1
:
```

Test Mode   **TM [**active – Boolean**] '\r'**

This command turns the camera module's test mode off or on. Test mode is not active by default after the camera board resets. Please note that "SD" (Sleep Deeply) and "SL" (Sleep Lightly) reset all camera module settings back to default on wakeup and will turn test mode off.

If test mode is enabled, the camera module sends an image of color bars to the camera board.

Example of how to turn test mode off and on:

```
: TM 1 '\r'                              Turn test mode on
ACK
: TM 0 '\r'                              Turn test mode off
ACK
:
```

Example of what happens if an error occurs while communicating with the camera module:

```
: TM 1 '\r'                              Turn test mode on
ACK
ERR: Camera Connection Error            A camera module error occurred
:
```

Tilt Output   **TO [**direction – Boolean**] [**output – Boolean**] '\r'**

This command sets the state of the tilt pin. If the "direction" value is 0, the pin is set to an input state and the "output" value is not needed and ignored. If the "direction" value is 1, the pin is set to an output and the "output" value becomes the state of the pin. Additionally, the tilt pin cannot be set to an input while driving a servo and if set to output high will stop driving any servo being driven.

Please note that the tilt pin is not pulled high or low by the camera board and floats when not set as an output. Also, note that a series limiting current resistor on the camera board protects the tilt pin from shorting to ground.

Example of how to set the tilt pin state:

```
: TO 0 '\r'                              Tilt pin set to input
ACK
: TO 1 '\r'                              Tilt pin set to output – too few arguments
NCK
: TO 1 0 '\r'                            Tilt pin set to output low
ACK
: TO 1 1 '\r'                            Tilt pin set to output high
ACK
:
```

Automatic Tilt Parameters   TP [*proportional gain – Integer*] [*derivative gain – Integer*] '\r'

This command changes the proportional and derivative gain values used for automatic tilting servo feedback control. The default proportional and derivative gains are 400 and 100 respectively.

The "proportional gain" value can be any number from 0 to 1000 inclusive. All other values of "proportional gain" are illegal. A higher "proportional gain" value will cause the tilt servo to respond more to the speed of the Y part of the centroid while a lower value will cause the tilt servo to respond less. A value of 0 turns the gain off.

The "derivative gain" value can be any number from 0 to 1000 inclusive. All other values of "derivative gain" are illegal. A higher "derivative gain" value will cause the tilt servo to respond more to the acceleration of the Y part of the centroid while a lower value will cause the tilt servo to respond less. A value of 0 turns the gain off.

Example of how to change the proportional (P) and derivative (D) gain values:

```
: TP 0 0 '\r'                          Change P to 0 and D to 0
ACK
: TP 1000 0 '\r'                       Change P to 1000 and D to 0
ACK
: TP 0 1000 '\r'                       Change P to 0 and D to 1000
ACK
: TP 1000 1000 '\r'                    Change P to 1000 and D to 1000
ACK
:
```

Track Window   TW [*red range – Integer*] [*green range – Integer*] [*blue range – Integer*] '\r'

This command returns tracking data about the image. If a sub region of the image is selected via the "SW" (Set Tracking Window) command, this command will only operate on the selected sub region. Additionally, if "HT" (Histogram Tracking) is active this command will only operate on the tracked pixels in the selected sub region. This command also sets the color tracking threshold parameters used to segment the 160x120 RGB565/YUV655 image that the camera board processes at 8 FPS. By default the camera board color tracking threshold parameters are set to track all possible colors.

The camera board will track all pixels that have a red component that is between the **red average** plus and minus the "red range" value inclusive, a green component that is between the **green average** plus and minus the "green range" value inclusive, and a blue component that is between the **blue average** plus and minus the "blue range" value inclusive. The "red range", "green range", and "blue range" values can be any number between 0 and 255 inclusive. All other values for the "red range", "green range", and "blue range" are illegal.

The following steps are performed internally to compute **red average**, **green average**, and **blue average**:

1. Shrink the horizontal and vertical color-tracking window dimensions to ¼ their size.
2. Center the new horizontal and vertical color-tracking window coordinates inside of the old coordinates.
3. Compute the **red average**, **green average**, and **blue average** for all tracked and untracked pixels that are within the color-tracking window. If "HT" (Histogram Tracking) is active, instead compute the **red average**, **green average**, and **blue average** for all tracked pixels that are within the color-tracking window.
4. Restore the original horizontal and vertical window dimensions and coordinates.

The TV monitor will automatically be unfrozen after this command is finished initializing to show the image being tracked with the bounding box and the centroid overlaid on the tracked image. Untracked pixels will be black on the TV monitor, tracked pixels will be blue on the TV monitor, the bounding box will be shown as a red box outline on the TV monitor, and the centroid will be shown as a white dot on the TV monitor.

This command returns Type 'T' Data Packets only by default, per frame at 8 FPS (frames per second), which contain ACSII viewable formatted data. They start with 0x54 followed by 0x20 ('T' followed by the space character) followed by 8 packets of data and a terminating carriage return. Each packet of data contains a decimal number separated from other packets by a space character.

T *mx my x1 y1 x2 y2 pixels confidence***\r**

If "SM" (Switching Mode) is active this command will alternative between sending Type 'T' Data Packets and Type 'S' Data Packets per frame at 8 FPS. If "LM" (Line Mode) is active, this command will send a Type 'F' Data Packet, per frame at 8 FPS, after sending a Type 'T' Data Packet or Type 'S' Data Packet.

If "PM" (Poll Mode) is active this command will send only one Type 'T' Data Packet followed by a Type 'F' Data Packet, if "LM" (Line Mode) is active, and then send the prompt character ':' and return to idling.

To abort this command, if "PM" (Poll Mode) is not active, send the '\r' (carriage return) character (other characters are ignored). The camera board will then finish sending whatever packets it was sending and then send the prompt character ':' and return to idling.

If "PM" (Poll Mode) is not active, this command causes the AUX LED to turn on, if not disabled by "L0" (LED Off), whenever there are any tracked pixels in the image and off when there are no tracked pixels in the image while executing.

If "CT" (Color Tracking) is not active, this command will return tracking data about the RGB565 image. Otherwise, this command will return data about the YUV655 image. In YUV mode R:G:B map to V:Y:U (Cr:Y:Cb).

Example of how to get tracking data about the image:

: TW 30 30 30 '\r'	*Get tracking data*
ACK	
T 59 79 50 25 109 94 85 170	
'\r'	*Abort*
:	

Example of what happens if an error occurs while communicating with the camera module:

: TW 30 30 30 '\r'	*Try to get tracking data*
ACK	
ERR: Camera Timeout Error	*A camera module error occurred*
:	

Unmount Disk   **UM** '\r'

This command unmounts the µSD card formatted with a FAT16 or FAT32 partition. Because this command uses the µSD card it can take a very long time to execute which depends on the speed of the µSD card and the size of directories on the µSD card.

The µSD card should be unmounted before being removed from the camera board. Otherwise, it will be considered dirty by operating systems like Microsoft Windows. Microsoft Windows, for example, will ask to run Check Disk on a µSD card that it considers dirty. Additionally, unmounting the µSD card allows the camera board's file system driver to write out meta-data to the µSD card that increases the performance of FAT32 formatted partitions on the µSD card. FAT16 partitions on the µSD card will not see a similar performance increase.

Not unmounting the µSD card will not cause corruption. However, if there was damage to the µSD card file system previously, for example, by removing the µSD card from the camera board while executing the "DB" (Dump Bitmap) or "DF" (Dump Frame) commands. Then when Microsoft Windows runs Check Disk on the µSD card it will find the corrupted XXXXXBM.BMP file, report it, and try to fix it.

If the µSD card is not unmounted before being removed from the camera board then the next file system command that is executed will return "ERR: Disk IO Error\r", once, even if the µSD card is re-inserted. The camera board's file system driver generates this error because the µSD card was not unmounted properly.

Example of how to unmount the µSD card:

```
: UM '\r'                                      Unmount the µSD card
ACK
:
```

Example of what happens when different unrelated errors occur while communicating with the µSD card:

```
: UM '\r'                                      Try to unmount the µSD card
ACK
ERR: Disk IO Error                             A µSD card error occurred
: UM '\r'                                      Try to unmount the µSD card
ACK
ERR: File System Corrupted                     A µSD card error occurred
: UM '\r'                                      Try to unmount the µSD card
ACK
ERR: File System Unsupported                   A µSD card error occurred
: UM '\r'                                      Try to unmount the µSD card
ACK
ERR: Card Not Detected                         A µSD card error occurred
:
```

Vertical Flip   **VF [**_active – Boolean_**]** '\r'

This command turns the camera module's vertical flip mode off or on. Vertical flip mode is not active by default after the camera board resets. Please note that "SD" (Sleep Deeply) and "SL" (Sleep Lightly) reset all camera module settings back to default on wakeup and will turn vertical flip mode off.

Example of how to turn vertical flip mode off and on:

: VF 1 '\r'	_Turn vertical flip mode on_
ACK	
: VF 0 '\r'	_Turn vertical flip mode off_
ACK	
:	

Example of what happens if an error occurs while communicating with the camera module:

: VF 1 '\r'	_Turn vertical flip mode on_
ACK	
ERR: Camera Connection Error	_A camera module error occurred_
:	

Data Packet Descriptions

"ACK\r"
This acknowledgement string is sent after a command is received and the command was valid, had a valid number of arguments, and the value of each argument was valid.

"NCK\r"
This not-acknowledgement string is sent after a command is received and the command was invalid, had an invalid number of arguments, or the value of an argument was invalid.

"ERR: ...\r"
Some commands send an "ACK" string before beginning a long running operation that can fail at any point – such as formatting the µSD card. If the operation fails, the "ERR:" string token is sent, followed by a human readable error message of the problem terminated by a carriage return. The "ERR: …\r" string is followed by the camera board returning to the idle state.

"MSG: …\r"
Some commands send an "ACK" string before beginning a long running operation that can fail at any point – such as formatting the µSD card. When a command wants to communicate intelligibly, the "MSG:" string token is sent, followed by a human readable message terminated by a carriage return. The "MSG: …\r" string should be ignored by any parsing system.

Type '**F**' data packet format:

Type 'F' packets contain non-ACSII viewable formatted data. They start with 0x46 followed by 0x20 ('F' followed by the space character) followed by 600 bytes of raw-data and a terminating carriage return.

The 600 bytes contain an 80x60 monochrome black and white (B&W) image. The 80x60 monochrome B&W image is 4,800 pixels where each white (1) pixel represents a tracked pixel and each black (0) pixel represents an untracked pixel. The image fits in 600 bytes by packing eight pixels into a single byte. The 600 bytes are sent organized in an unpadded pixel array 80x60 monochrome B&W image BMP file format.

Bit 7 in byte 0 = pixel 0.	**Row 0 = Bytes (0 – 9)**
Bit 6 in byte 0 = pixel 1.	**Row 1 = Bytes (10 – 19)**
…	**…**
Bit 0 in byte 0 = pixel 7.	**Row 59 = Bytes (590 – 599)**
…	
Bit 0 in byte 599 = pixel 4,799.	*(A column is the group of pixels with the same offset in all rows)*

Type '**H**' data packet format:

Type 'H' packets contain ACSII viewable formatted data. They start with 0x48 followed by 0x20 ('H' followed by the space character) followed by 1-64 packets of data and a terminating carriage return.

Each packet of data contains a decimal number separated from other packets by a space character.

H *bin0 bin1 … binN***r**

This is the packet returned by calling the "GH" (Get Histogram) command. Each bin contains a value ranging from 0 to 255 that represents the percentage of the total number of pixels that fell within a set range of values on a user-selected channel of the image. Where 0 represents 0% and 255 represents 100%. Due to integer-math-rounding-errors, the sum of all the bins may be less than 255 (100%).

Type '**S**' data packet format:

Type 'S' packets contain ACSII viewable formatted data. They start with 0x53 followed by 0x20 ('S' followed by the space character) followed by 12 packets of data and a terminating carriage return.

Each packet of data contains a decimal number separated from other packets by a space character.

S *RMean GMean BMean RMedian GMedian BMedian RMode GMode BMode RStDev GStDev BStDev***\r**

This is the packet normally returned by calling the "GM" (Get Mean) command.

RMean – The mean of the Red/V channel in the color-tracking window [0:255]
GMean – The mean of the Green/Y channel in the color-tracking window [0:255]
BMean – The mean of the Blue/U channel in the color-tracking window [0:255]

RMedian– The median of the Red/V channel in the color-tracking window [0:255]
GMedian – The median of the Green/Y channel in the color-tracking window [0:255]
BMedian – The median of the Blue/U channel in the color-tracking window [0:255]

RMode – The mode of the Red/V channel in the color-tracking window [0:255]
GMode – The mode of the Green/Y channel in the color-tracking window [0:255]
BMode – The mode of the Blue/U channel in the color-tracking window [0:255]

RStDev – The standard deviation of the Red/V channel in the color-tracking window [0:255]
GStDev – The standard deviation of the Green/Y channel in the color-tracking window [0:255]
BStDev – The standard deviation of the Blue/U channel in the color-tracking window [0:255]

Type '**T**' data packet format:

Type 'T' packets contain ACSII viewable formatted data. They start with 0x54 followed by 0x20 ('T' followed by the space character) followed by 8 packets of data and a terminating carriage return.

Each packet of data contains a decimal number separated from other packets by a space character.

T *mx my x1 y1 x2 y2 pixels confidence***\r**

This is the packet normally returned by calling the "TC" (Track Color) or "TW" (Track Window) command.

mx – The average of all X position coordinate values of all tracked pixels [0:159]
my – The average of all Y position coordinate values of all tracked pixels [0:119]

x1 – The X position coordinate value of the top left most corner of the bounding box [0:159]
y1 – The Y position coordinate value of the top left most corner of the bounding box [0:119]
x2 – The X position coordinate value of the bottom right most corner of the bounding box [0:159]
y2 – The Y position coordinate value of the bottom right most corner of the bounding box [0:119]

pixels – The percentage of the number of pixels tracked in the color-tracking window ranging from 0 to 255. Where 0 represents 0% and 255 represents 100%. 0 is returned if and only if no pixels are tracked at all within the color-tracking window.

confidence – The percentage of the number of pixels tracked in the bounding box ranging from 0 to 255. Where 0 represents 0% and 255 represents 100%. 0 is returned if and only if no pixels are tracked at all within the bounding box.

Error Message Descriptions

- **Camera Timeout Error**
  - o Receiving this error implies that the camera module's parallel video data bus is not working. This error should not be encountered under normal operation. The only time the camera board should respond with this error is if the camera module has been removed from the camera board or if the camera module has a bad connection to the camera board. If this is not the case then the camera module is damaged and most likely needs to be replaced.

- **Camera Connection Error**
  - o Receiving this error implies that the camera module's serial control data bus is not working. This error should not be encountered under normal operation. The only time the camera board should respond with this error is if the camera module has been removed from the camera board or if the camera module has a bad connection to the camera board. If this is not the case then the camera module is damaged and most likely needs to be replaced.

- **Disk IO Error**
  - o The μSD card either is inserted incorrectly in the camera board or was removed from the camera board improperly. Reinsert the μSD card to fix this problem. If this problem persists the camera board may not support the μSD card. Try another brand or type of μSD card to fix this problem.

- **File System Corrupted**
  - o This error is sent when the camera board's file system driver detects corruption of the FAT16 or FAT32 partition on the μSD card. Do a "non-quick" reformat of the μSD card to fix this problem.

- **File System Unsupported**
  - o This error is sent when the camera board's file system driver detects an unsupported partition on the μSD card. Do a "non-quick" reformat of the μSD card to fix this problem.

- **Card Not Detected**
  - o Insert a μSD card into the camera board to fix this problem.

- **Disk May Be Full**
  - o The FAT16 or FAT32 partition on the μSD card may be full. Execute the "DS" (Disk Space) to check if the FAT16 or FAT32 partition on the card is full. The error message is "Disk May Be Full" and not "Disk Is Full" because of the time it would take to verify the disk was completely full. Memory should be freed using the "RM" (Remove Entry) command if this error is received.

- **Directory Full**
  - o The target directory is completely full. NOTE: LFNs take up extra space. Use only 8.3 filenames.

- **Expected An Entry**
  - o The file system path string for a command was malformed. The command expected to see a file or directory name in some part of the file system path string supplied to it.

- **Expected A Directory**
  - The file system path string for a command was malformed. The command expected to see a directory name in some part of the file system path string supplied to it.

- **Entry Not Accessible**
  - A command tried to access and read or write the volume identification entry in the root directory. This is illegal behavior for accessing the file system.

- **Entry Not Modifiable**
  - A command tried to access and write a ".", "..", or read-only entry in the file system. This is illegal behavior for accessing the file system.

- **Entry Not Found**
  - A file or directory in the path string was not found.

- **Entry Already Exist**
  - The target file or directory to create in the path string already exist.

- **Directory Link Missing**
  - The ".." entry inside of a directory moved was missing when it was moved. This error should never be encountered. If this error is encountered, then the FAT16 or FAT32 partition on the µSD card may be corrupted.

- **Directory Not Empty**
  - The "RM" (Remove Entry) command can only delete empty directories.

- **Not A Directory**
  - The "CD" (Change Directory) command can only enter directories.

- **Not A File**
  - The "PR" (File Print) command can only print files. The "PL" (Print Line) command can only print to files.