V4L2 Sensor Driver Programming Guide

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Document Change History

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Version	Date	Authors	Description of Change
v1.0	13 Jul 2015	jbang/msum	Initial release.
v2.0	05 Oct 2015	jbang/hlang	Change in document title, other content updates.
v3.0	20 Jan 2016	jbang/gmead	Adds device tree and other BSP-integration information.
V4.0	21 Apr 2016	gigon bae/hlang	Added GNU licenses

Note: Apparent hyperlinks in this document are a legacy of the HTML version and may not operate as expected in the PDF version.

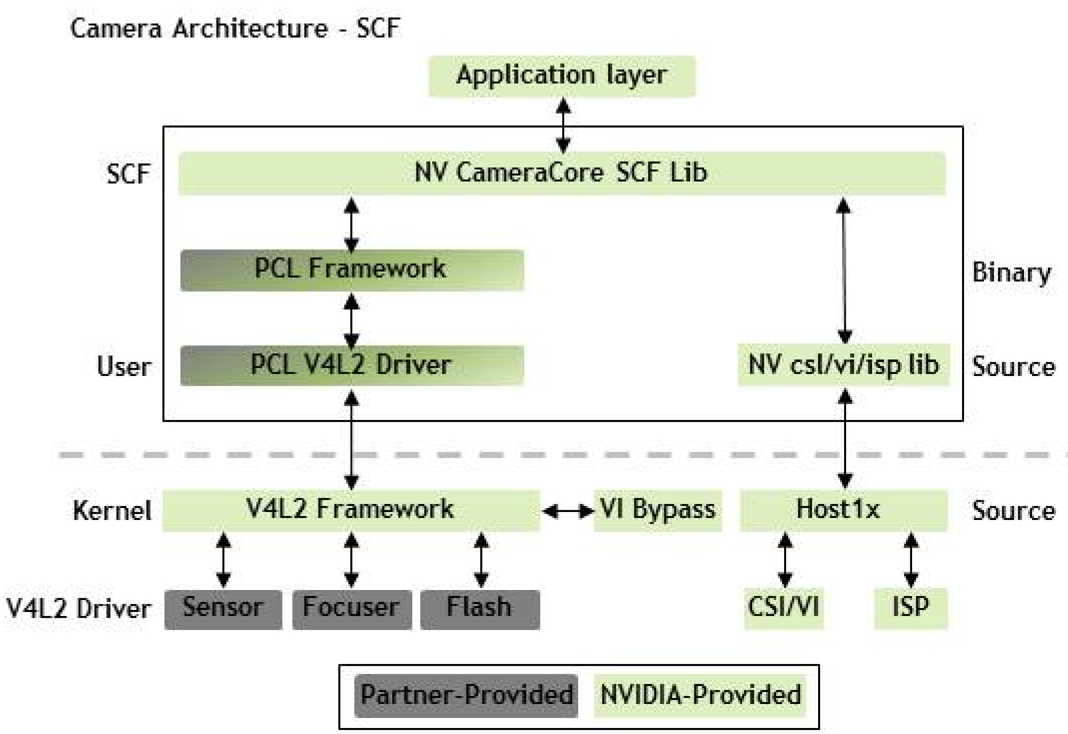
V4L2 Sensor Driver Programming Guide

This chapter provides advanced information for developing USB cameras and Bayer and YUV image sensor with NVIDIA® Tegra® Board Support Package (BSP) releases.

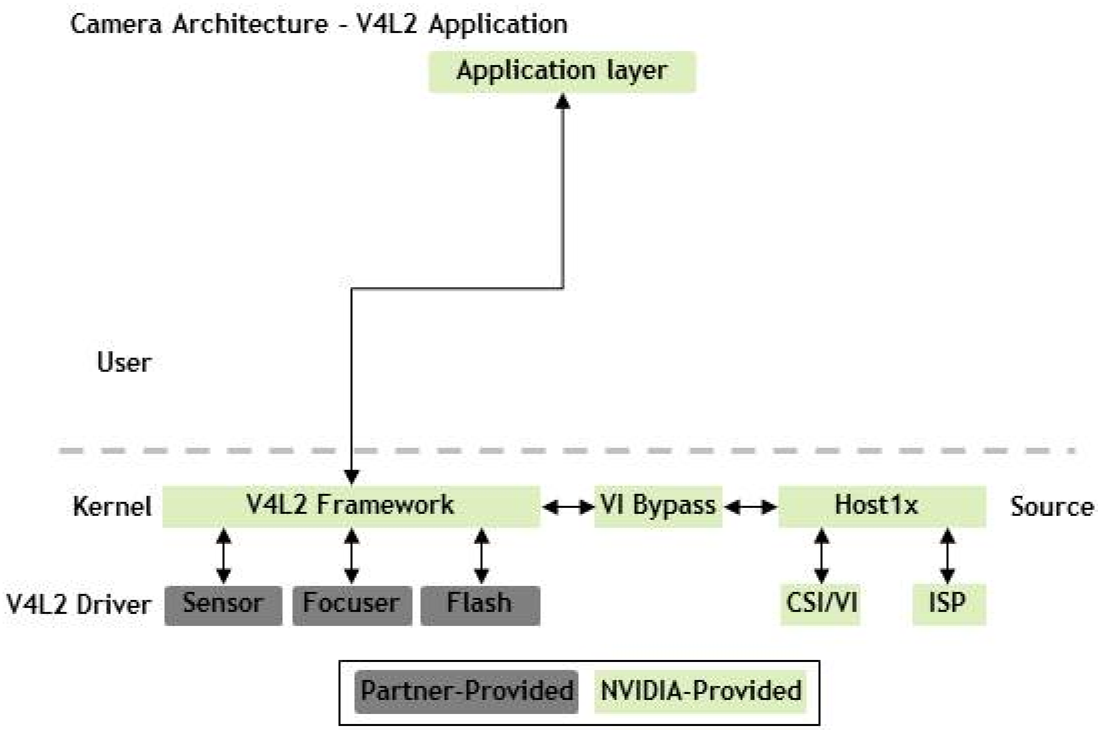
This document describes the sensor driver architecture required by Tegra® platform software, and provides guidance on the implementation of drivers suitable for use with this software release. Implementation of a camera sensor driver will enable acquisition of camera data over the CSI bus, in the native format provided by the sensor, and is intended for use in enabling sensors that contain an ISP (e.g. YUV output).

The programming interfaces for the Tegra® ISP and associated image quality tuning are not covered in this document. NVIDIA provides a software implementation for supported camera modules. (For more information, refer to product documentation.)

The following block diagram show the overall architecture of NVIDIA camera software.



The Scalable Camera Framework (SCF) is the main camera user-mode library.If the application supports direct V4L2 interface, it communicates to the NVIDIA V4L2 driver without SCF. Typically, this path is used when the sensor is a YUV sensor since this sensor has a built-in ISP and frame does not need extra processing. For Bayer sensor, applications use the SCF library to convert RGB format to YUV format and to do various post processing tasks.



This chapter describes how to bring up a Bayer sensor with Tegra BSP. Bringing up the sensor requires customers to develop two things:

- Device Tree in the Linux kernel
- V4L2 sensor driver

Read the following sections to learn how to develop these; our examples use Omnivision OV5693 sensor, and the source code for OV5693 sensor is available to customers.

> **Note**: the examples in this document show Tegra® X1-based implementations. To implement for other Tegra® devices, contact your customer engineer.

Camera Modules

A camera module installed on the target platform can consist of one or more devices. A typical rear camera module includes a complementary metal-oxide semiconductor (CMOS) sensor, a Visual Computing Module (VCM) focuser, or both. A typical front camera module might include a single CMOS sensor only.

To add one or more camera modules to a device tree, find or create a tegra-camera-platform device node in the kernel source tree. Usually, that node is in the following directory:

```
arch/arm[64]/boot/dts
```

In a tegra-camera-platform device node, you must create a module table (modules) with one or more modules. Each module must contain its basic information and the definition of the devices that are inside that module.

> **Note**: Except for the ones that refer to other device nodes, all value fields in camera-related device nodes must use the string data type.

A typical device-tree node for a camera module looks like this:

```
tegra-camera-platform {
compatible = "nvidia, tegra-camera-platform";
modules {
module0 {
badge = "e3326_front_P5V27C";
position = "rear";
orientation = "1";
drivernode0 {
pcl_id = "v4l2_sensor";
proc-device-tree = "/proc/device-tree/host1x/i2c@546c0000/ov5693_c@36";
};
drivernode1 {
pcl_id = "v4l2_focuser_stub";
};
};
};
};
```

Module Properties

The following table shows the information for `moduleX: module` (or `moduleX: modules`).

Property	Value
badge	A unique name that identifies this module. Guidelines for naming the three parts of the `badge_info` property: • The first part is the camera board ID (`camera_board_id`) of the module. • The second part contains the position of the module, for example, rear or front. • The third part contains the last six characters of a part number, which you can find in the data sheet on the module from the vender.
position	The camera-facing information, either rear or front.
orientation	The orientation related to the display panel. Valid values: 0, 90, 180, or 270.
drivernodeX	The information on the driver node; the X: 0-based index.

Driver Properties

The following table shows the information for `drivernodeX: device` (or `drivernodeX: devices`).

Property	Value
pcl-id	A unique name that identifies this device.
proc-device-tree*	The device-tree file path for the device-specific data node. For example, details on the device GPIO, regulator, clock, mode, and so forth.

Individual Imaging Device

An imaging device (a component inside the camera module) can be a sensor, focuser, or flash. Be sure to add all the required information to the device-tree node to support the device operation.

For each device-tree node for a device, assign a device node that contains the name of the device, its slave address, and a compatible string that identifies the node.

> **Note**: Except for the ones that refer to other device nodes, all value fields in camera-related device nodes must use the string data type.

An example device-tree node for the OV5693 V4L2 sensor driver:

```
ov5693_c@36 {
compatible = "nvidia,ov5693";
reg = <0x36>;
devnode = "video2";

physical_w = "3.674";
physical_h = "2.738";

avdd-reg = "vana";
iovdd-reg = "vif";

mode0 { // OV5693_MODE_2592X1944
mclk_khz = "24000";
num_lanes = "2";
tegra_sinterface = "serial_c";
discontinuous_clk = "no";
dpcm_enable = "false";
cil_settletime = "0";
```

```
active_w = "2592";
active_h = "1944";
pixel_t = "bayer_bggr";
readout_orientation = "90";
line_length = "2688";
inherent_gain = "1";
mclk_multiplier = "6.67";
pix_clk_hz = "160000000";

min_gain_val = "1.0";
max_gain_val = "16";
min_hdr_ratio = "1";
max_hdr_ratio = "64";
min_framerate = "1.816577";
max_framerate = "30";
min_exp_time = "34";
max_exp_time = "550385";
};
...
};
```

Device Properties

For the node of the V4L2 sensor-device, define the required hardware resource for the device, as shown in the following table.

Property	Value
compatible	Specifies the device identifier.
reg	Specifies the I2C slave address.
mclk	Specifies the input clock for the device.
XXX-gpio	Specifies the general-purpose input/output (GPIO) pins for the device.
XXX-supply	Specifies the regulator for the device, where XXX is the actual regulator name defined somewhere else in the device tree. The -supply suffix is mandatory.
XXX-reg	Specifies the name of the regulator, where XXX is the regulator name for the sensor driver. The value of this field is the regulator name with the suffix -reg.
physical_w	Specifies the physical width of the sensor.

physical_h	Specifies the physical height of the sensor.
devnode	Specifies a value used to derive the kernel device node. Android path: /dev/camera/<devnode> L4T path: /dev/<devnode>
formulaXXX	Specifies the predefined formula for calculating the parameters (pixel clock, frame rate, and so forth.) This formula is parsed and evaluated in the user space. Note these rules: • The variables in the formula can be numbers or any of the entries in the device tree. For example: `formulaPixelClk="(mclk*multiplier)/(pre_div*post_div)"` • The formula must contain only these operators: '*' '/' '+' '-' '(' ')' • At least one operator must be inside the parentheses. • No spaces are allowed in the formula.

Property-Value Pairs

The following table describes the property-value pairs that apply to the sensor mode for the V4L2 implementation.

Property	**Value**
modeX	Specifies the sensor-mode information, that is, the X: 0-based index.
Ports	Specifies the media controller graph binding info.
mclk_khz	Specifies the standard MIPI driving clock, which is typically 24MHz.
num_lanes	Specifies the number of lane channels the sensor is programmed to output.
tegra_sinterface	Specifies the base Tegra serial interface to which the lanes are connected.
discontinuous_clk	Specifies the indication that the sensor is programmed to use a discontinuous clock on MIPI lanes.
cil_settletime	Specifies the value of the settle time of the MIPI lane. A 0 value attempts to auto-calibrate according to the mclk_multiplier parameter.
active_w	Specifies the width of the pixel-active region.
active_h	Specifies the height of the pixel-active region.
pixel_t	Specifies the readout pixel pattern of the sensor.
readout_orientation	Specifies the readout orientation that is based on the orientation of the camera module. Change this property if you would like to program a different readout order for this mode.

line_length	Specifies the pixel line length (width) for sensor mode for calibrating the features in our camera stack.
mclk_multiplier	Specifies the multiplier to MCLK for timing the capture sequence of the hardware.
pix_clk_hz	Specifies the sensor pixel clock for calculating the exposure, frame rate, and so forth.
inherent_gain	Specifies the gain obtained inherently from the mode, that is, pixel binning.
min_gain_val	Specifies the minimum gain limit for the mode.
max_gain_val	Specifies the maximum gain limit for the mode.
min_exp_time	Specifies the minimum exposure time limit for the mode in microseconds.
max_exp_time	Specifies the maximum exposure time limit for the mode in microseconds.
min_hdr_ratio	Specifies the minimum high-dynamic-range (HDR) ratio limit for the mode (for HDR sensors).
max_hdr_ratio	Specifies the maximum HDR ratio limit for the mode (for HDR sensors).
min_framerat	Specifies the minimum frame-rate limit for the mode in frames per second (fps).
max_framerat	Specifies the maximum frame-rate limit for the mode in fps.

Example Focuser Driver Properties

The following table shows the required information for the example of the LC898212 focuser driver.

```
lc898212@72 {
compatible = "nvidia,lc898212";
reg = <0x72>;

devnode = "video6";
type = "default";
ports {
#address-cells = <1>;
#size-cells = <0>;
port@0 {
reg = <0>;
lc898212_out0: endpoint {
remote-endpoint = <&vi_in1>;
```

```
};
};
};
};
```

The following table describes the focuser driver properties.

Property	Value
compatible	Specifies the device identifier.
reg	Specifies the I2C slave address.
type	Specifies the focuser type: • default: VCM focuser. • steppermotor: Stepper motor focuser.
Ports	Media controller graph binding info.

V4L2 Kernel Driver

The content of this chapter is based on the Video for Linux 2 (V4L2) driver for the OmniVision OV5693 sensor (`ov5693.c`) at:

```
kernel/drivers/media/i2c/ov5693.c
```

NVIDIA suggests that you look at that source before reading this the rest of this chapter.

Macro Definitions

Following are the sensor-specific macro values:

- The minimum and maximum values for each control.
- The default value for each control.
- The macro values that is required for sensor timing or general functionality.

Sensor-Private Data

The following structure contains the private data that are specific to the sensor:

```
struct ov5693 {
struct camera_common_power_rail power;
int numctrls;
struct v4l2_ctrl_handler ctrl_handler;
struct camera_common_eeprom_data eeprom[OV5693_EEPROM_NUM_BLOCKS];
u8 eeprom_buf[OV5693_EEPROM_SIZE];
struct i2c_client *i2c_client;
```

```
struct v4l2_subdev *subdev;
struct media_pad pad;
s32 group_hold_prev;
bool group_hold_en;
struct regmap *regmap;
struct camera_common_data *s_data;
struct camera_common_pdata *pdata;
struct v4l2_ctrl *ctrls[];
};
```

The following table describes the sensor properties.

Property	Value
power	Holds generic power controls, include regulators,clks, and GPIOs.
numctrls	Holds the number of v4l2 controls for the sensor.
ctrl_handlerr	Holds the required v4l2 handler to controls, needed for v4l2 control init.
i2c_client	Holds a handle to i2c_client, used to access to sensor i2c client instance.
subdev	Holds a handle for v4l2 sub-device, needed to run subdev operations (ops).
eeprom	Holds common EEPROM device data.
eeprom_buf	Holds eeprom buffer storage.
pad	Holds media pad used for media controller initialization for a device to work as SINK or SOURCE.
group_hold_prev	Holds previous state use by group hold control handler to check for change of state.
group_hold_en	Holds group hold enable flag directly related to group hold control.
reg_map	Holds a register map setup for I2C read and write.
s_data	Holds a handle to common data, see documentation for camera_common_data.
pdata	Holds a handle to common platform data, populated by read Device Tree.
ctrls	Holds handles to initialized v4l2 controls, dynamic array, MUST BE LAST FIELD.

Configuring Regmap

Depending on the I2C interface of the sensor, you should update the values of `reg_bits` and `val_bits`.

```
regmap_config {
reg_bits = 16;
val_bits = 8;
};
```

The following table describes the `regmap_config` properties.

Property	Value
`reg_bits`	Specifies the number of bits needed to represent the I2C register offset.
`val_bits`	Specifies the number of bits in the buffer to store data to be transferred over I2C.

Check the vendor register programming table of your sensor to determine the size of `reg_bits` and `val_bits`.

Configuring Controls

To link the controls to their control handlers, set up the function pointers:

- Point `g_volatile_ctrl` to the internal `get` volatile control handler of the sensor.
- Point `s_ctrl` to the internal `set` control handler of the sensor.

```
static const struct v4l2_ctrl_ops ov5693_ctrl_ops = {
.g_volatile_ctrl = ov5693_g_volatile_ctrl,
.s_ctrl = ov5693_s_ctrl,
};
```

The following code-snippet lists the controls and their initialized values. This list is looped through during the `ctrls_init` call to initialize each of the controls. Each control is then accessible through the `ctrls` handler in the private data. The set of controls defined for OV5693 are the standard ones used by the user-mode PCL V4L2 driver.

> **Note**: Additional controls require a change in the PCL driver.

Three types of controls are defined for the OV5693 sensor.

```
static struct v4l2_ctrl_config ctrl_config_list[] = {
/* Integer Control: setting integer values such as gain, coarse
* time, *and frame length.
*/
{
```

```
.ops = &ov5693_ctrl_ops, //pointer to control ops
//function

.id = V4L2_CID_GAIN, //id, defined in
//camera_common.h

.name = "Gain", //string name of control
.type = V4L2_CTRL_TYPE_INTEGER, //type of control
.flags = V4L2_CTRL_FLAG_SLIDER, //control flags

// The following three are the value most likely
// needs changing
.min = OV5693_MIN_GAIN, //control value lower bound
.max = OV5693_MAX_GAIN, //control value upper bound
.def = OV5693_DEFAULT_GAIN, //default control value
.step = 1, //increment step size for
//value
},
...
/* String Data Control: converts data to string format then
* send to PCL
* drivers, used for EEPROM, OTP, and fuse id.
*/
{
.ops = &ov5693_ctrl_ops,
.id = V4L2_CID_EEPROM_DATA,
.name = "EEPROM Data",
.type = V4L2_CTRL_TYPE_STRING,
.flags = V4L2_CTRL_FLAG_VOLATILE,
.min = 0,
/* the following one is the value that likely needs
* changing, the string size is 2 times actual
* buffer size
*/
.max = OV5693_EEPROM_STR_SIZE,
.step = 2,
},
```

```
...

/* Menu Control: used as on/off switch for group hold and HDR.
* switch_ctrl_qmenu is used to define the states on/off there
* shouldn't be a need to change these controls, unless a
* completely new one is being added.
*/
{
.ops = &ov5693_ctrl_ops,
.id = V4L2_CID_GROUP_HOLD,
.name = "Group Hold",
.type = V4L2_CTRL_TYPE_INTEGER_MENU,
.min = 0,
.max = ARRAY_SIZE(switch_ctrl_qmenu) - 1,
.menu_skip_mask = 0,
.def = 0,
.qmenu_int = switch_ctrl_qmenu,
},
};
```

Setting Up Control Registers

Set up register writes for integer controls with the following functions. `addr` depends on the sensor being used; `val` is the source from the control handler. These functions are called by each control handler to set up register writes for each of the controls.

- ov5693_get_frame_length_regs
- ov5693_get_coarse_time_regs
- ov5693_get_coarse_time_short_regs
- ov5693_get_gain_reg
- ov5693_get_gain_short_reg

Read-Write Wrapper in the Register

The following functions are wrappers for the read-write interface of the I2C register. For OV5693, use the `regmap` interface. However, you can modify these functions for other interfaces.

- ov5693_read_reg
- ov5693_write_reg
- ov5693_write_table

Power Functions

The following table describes the functions for power-related controls.

Function	Description
ov5693_power_on	Contains the power-on sequence. You must modify this function according to the specification sheets. Note the usage of controls from common power rail, including regulators and GPIOs.
ov5693_power_off	Contains the power-off sequence. You must modify this function according to the specification sheets. Note the usage of controls from common power rail, including regulators and GPIOs.
ov5693_power_put	Calls `regulator_put` on all regulators.
ov5693_power_get	Calls `regulator_get` on all regulators.

Setting Up V4L2 Subdevice and Camera Common

The `ov5693_s_stream` function is mainly for writing mode tables by making calls to register the `write_table` function. You set up mode tables in the `ov5693_mode_tbls.h` file. For details, see Mode Tables in this chapter.

In addition to writing mode tables and enabling the stream through stream-enable register writes, `ov5693_s_stream` also writes the initial integer-control values to the register through direct calls to the integer-control handlers. For details, see the section Control Handlers.

```
control.id = V4L2_CID_GAIN;
err = v4l2_g_ctrl(&priv->ctrl_handler, &control);
err |= ov5693_set_gain(priv, control.value);
…
```

If a test pattern is supported by the sensor and you can create a register table for that pattern, you can add a `test_mode` flag to write the test-mode table here.

Camera common is a set of functions that are common to camera drivers of the NVIDIA kernel, to which this driver refers. Camera common sets up most of the V4L2 framework, requiring linkage from the driver in the form of the following:

```
struct camera_common_sensor_ops
struct camera_common_data
```

For details on modifying and adding new modes, see Mode Tables in this chapter.

The following code snippets set up the V4L2 subdevices and camera common for registering the sensor driver with the V4L2 framework. The `s_stream` pointer must point to the internal `s_stream` function of the sensor; you can leave the other pointers as is.

```
static struct v4l2_subdev_video_ops ov5693_subdev_video_ops = {
.s_stream = ov5693_s_stream,
...
};
```

You need not modify this structure:

```
static struct v4l2_subdev_core_ops ov5693_subdev_core_ops = {
...
};
```

Match the name for the pointer for the `core` and `video` operations function with the two from above, as follows:

```
static struct v4l2_subdev_ops ov5693_subdev_ops = {
.core = &ov5693_subdev_core_ops,
.video = &ov5693_subdev_video_ops,
};
```

During the parsing of the device tree, `of_device_id` matches the compatible field with the one in the Device Tree.

```
static struct of_device_id ov5693_of_match[] = {
{ .compatible = "nvidia,ov5693", },
{ },
};
```

This structure is required for camera common and you must set up the function pointers appropriately. Link the `power_on`, `power_off`, `write_reg`, and `read_reg` functions here:

```
static struct camera_common_sensor_ops ov5693_common_ops = {
.power_on = ov5693_power_on,
.power_off = ov5693_power_off,
.write_reg = ov5693_write_reg,
.read_reg = ov5693_read_reg,
};
```

Control Handlers

This section describes the control handlers.

Set Control

The two subsections describe the handlers for set control.

V4L2 Set-Control Operation

The V4L2 set-control function contains a `switch` statement to redirect set-control calls to their appropriate control handlers.

> **Note**: Read-only controls, such as `fuse_id` and One-Time Programmable Read-Only Memory (OTP ROM), do not have a case statement in the control ID `switch` statement.

```
ov5693_s_ctrl {
...
switch (ctrl->id) {
case V4L2_CID_GAIN:
...
case V4L2_CID_EEPROM_DATA:
...
case V4L2_CID_HDR_EN:
...
}
...
}
```

> **Note**: For EEPROM_DATA, the string control must have a preallocated string passed in. Hence, a null check is necessary before passing the string to the control handler.
>
> HDR_EN is a pure software control. No control handler writes to the hardware so simply break out of the switch statement.

Setter-Control Handlers (Writes)

Setter-control handlers are the control handlers called by `s_ctrl`. They perform additional control-handling operations, such as writes to registers. The majority of these controls make calls to the control register setup functions (see the section Setting Up Control Registers). The exception is `write_eeprom`, which acts as a separate I2C device with its own I2C write interface.

- ov5693_set_group_hold
- ov5693_set_gain
- ov5693_set_frame_length
- ov5693_set_coarse_time
- ov5693_set_coarse_time_short
- ov5693_write_eeprom

Note a special case for the gain-control handler, which contains a function call to:

```
ov5693_calculate_gain(val, OV5693_GAIN_SHIFT);
```

The function takes a binary-coded decimal from user space as input and computes the gain-register value according to the vendor-provided gain-calculation formula. Because that formula can vary from sensor to sensor, you must rewrite this function in the V4L2 sensor driver for each of the sensors.

The input of this function is the gain value passed in from user space. The value is a binary-coded decimal ranging from 1 to 16. The binary-coded decimal is divided into a six-byte integer representation and a two-byte decimal representation. The most significant six bytes of `val` is the integer representation. The least significant two bytes is the decimal representation, which is actually the numerator of a fraction over the maximum decimal representation of 0xFF.

The output of this function is the actual gain-register value programmed over I2C. That value depends on the gain-calculation formula provided by the sensor vendor (usually found in the data sheets on the sensor). The goal of this function is to convert the decimal `val` input into the gain-register value with as little truncation as possible.

For the OV5693 formula on which the `ov5693_calculate_gain` (or _`to_gain`) function is based, see the *OV5693 Software Reference Manual*.

Get-Volatile Control

Following are the get-volatile controls:

- **V4L2 get-volatile control operation**: The `ov5693_g_volatile_ctrl` function contains a switch statement for redirecting get-control calls to their appropriate control handlers.

  Note: For non-volatile controls, get-control simply returns the previously written value stored in the control handler.

- **Get-control handler (reads)**: The `ov5693_read_eeprom` control handler is an example of a get-volatile control handler. This handler reads the volatile value directly from the EEPROM register and updates the value that is read back every time get is called on this control.

Other Control-Related Functions

Following are two other control-related functions:

- **EPROM device-related controls**: These two functions are for setting up EEPROM as a separate I2C device with its own `regmap` interface:

  ```
  ov5693_eeprom_device_init
  ov5693_eeprom_device_release
  ```

- **Handlers called only on `ctrls_init`**: These control handlers are called only once from the `ctrls_init` function (see the section Boot-Time Initialization). That is because OTP and `fuse_id` controls are read-only and their values only need to be read once during boot time.

Boot-Time Initialization

This section describes the functions for initializing boot time.

Control Initialization

The `ov5693_ctrls_init` function iterates through `ctrl_config_list` (see Configuration Controls) and registers each control as a new custom control with the V4L2 framework. `s_ctrl` is also called for each control to set it to its default value defined in `ctrl_config_list`.

You need not modify the function except for the calls for initializing the value for the read-only controls. See the calls to `otp_setup` and `fuse_id_setup` in the section Control Handlers.

```
ov5693_ctrls_init {
...
err = ov5693_otp_setup(priv);
...
err = ov5693_fuse_id_setup(priv);
...
}
```

Device Tree Parser

The `ov5693_parse_dt` function, which parses device trees, takes the Device Tree node and looks for the parameters (according to the sensor-related private data) required by the sensor driver.

The values include but are not limited to the following:

```
mclk
pwdn-gpios
reset-gpios
af-gpios
avdd-reg
dvdd-reg
iovdd-reg
```

For details on how to set up device trees with the appropriate values, see the documentation. You must match the name list with the names in the Device Tree for their respective name-value pairs.

Port binding

```
vi {
ports {
port@0 {
reg = <0>;
vi_in0: endpoint {
bus-width = <2>;
remote-endpoint = <&ov5693_out0>;
};
};
};
};
```

```
ov5693_c@36 {
ports {
port@0 {
reg = <0>;
ov5693_out0: endpoint {
csi-port = <2>;
bus-width = <2>;
remote-endpoint = <&vi_in0>;
};
};
};
};
```

The following table describes the port binding properties.

Function	Description
port	Specifies the mediapad that the port is connected. All imager devices will have only one media pad for binding the connection with VI.
csi-port	This value defines the CSI port sensor is connected. For imager devices like focuser or flash this field is not required.
bus-width	Bus width defines the number of CSI lanes connected to sensor.
remote-endpoint	Remote end point is the label used for binding two ports. The binding expects one port is the sink and the other one is the source.

Media Controller Setup

A few additional components are needed to setup the media controller for V4L2 use. The open call is a placeholder operation for satisfying the V4L2 sub device internal operation requirements. The setup likely will not need to be change besides a name change to match the devices.

```
ov5693_open
```

Sub device function ops need to link to an the open operation:

```
static const struct v4l2_subdev_internal_ops ov5693_subdev_internal_ops = {
.open = ov5693_open,
};
```

Media entity function ops need to link to the V4L2 sub device link validation method:

```
static const struct media_entity_operations ov5693_media_ops = {
.link_validate = v4l2_subdev_link_validate,
};
```

Sensor-Driver Probing

The following subsections explain the probe function of the sensor driver.

Entry Point for Initialization During Boot

The `ov5693_probe` function is the entry point of the driver. The function starts off by allocating memory for common data and sensor-private data (see the section Sensor-Private Data).

```
common_data = devm_kzalloc(&client->dev,
sizeof(struct camera_common_data), GFP_KERNEL);

priv = devm_kzalloc(&client->dev,
sizeof(struct ov5693) + sizeof(struct v4l2_ctrl *) *
ARRAY_SIZE(ctrl_config_list),
GFP_KERNEL);
```

The function then initializes `regmap`:

```
priv->regmap = devm_regmap_init_i2c(client, &sensor_regmap_config);
```

Next, the function calls the other initialization functions, including the following:

```
// See the section Parser for Device Trees: stored in private
// data pdata field.
ov5693_parse_dt(client);

// See the section Power Functions.
ov5693_power_get(priv);



// Link the appropriate subdev ops (see the section
// Setting Up V4L2 Subdevice and Camera Common.
v4l2_i2c_subdev_init(&common_data->subdev, client, &subdev_ops);

// See the section Initialization of Controls.
ov5693_ctrls_init(priv);
```

```
// See the section Other Control-Related Functions.
ov5693_eeprom_device_init(priv);
```

Next, the function links the common data and sensor-private values:

```
// Link to ops. See Setting Up V4L2 Subdevice and Camera Common.
common_data->ops = &ov5693_common_ops;

// Control handler linking
common_data->ctrl_handler = &priv->ctrl_handler;

// I2C client passed in to probe
common_data->i2c_client = client;

// Default to frame format 0. See Mode Tables in this chapter.
common_data->frmfmt = &ov5693_frmfmt[0];

// Based on default data format definition, generally defaults
// to the same format. See the section Macro Definitions.
common_data->colorfmt = camera_common_find_datafmt(
OV5693_DEFAULT_DATAFMT);

// Power-handler linking
common_data->power = &priv->power;

// Sensor-private data linking
common_data->priv = (void *)priv;


// Number of format is frame format. See the section Macro Definitions.
common_data->numfmts = ARRAY_SIZE(ov5693_frmfmt);
```

```
// Set up of port information for device
camera_common_parse_ports(...)
// Port information is also used to create the name for debugfs node setup
sprintf(debugfs_name, "ov5693_%c", common_data->csi_port + 'a');
```

```
camera_common_create_debugfs(common_data, debugfs_name);
```

Setup of Default Values for Common Data

See the section Macro Definitions.

```
common_data->def_mode = OV5693_DEFAULT_MODE;
common_data->def_width = OV5693_DEFAULT_WIDTH;
common_data->def_height = OV5693_DEFAULT_HEIGHT;
common_data->def_clk_freq = OV5693_DEFAULT_CLK_FREQ;
debugfs_name

// I2C client passed in to probe
priv->i2c_client = client;

// Link to common data above
priv->s_data = common_data;

// Link to V4L2 subdevice handler
priv->subdev = &common_data->subdev;
// Link to subdevice dev to i2c_client dev (for media controller usage)
priv->subdev->dev = &client->dev;

// Initialize previous group hold state to 0
priv->group_hold_prev = 0;
```

Setup of for Media Controller

```
// Link subdevice internal and media entity operations
priv->subdev->internal_ops = &ov5693_subdev_internal_ops;
priv->subdev->entity.ops = &ov5693_media_ops;

// Setup subdevice flags and media entity type
priv->subdev->flags |= V4L2_SUBDEV_FL_HAS_DEVNODE | V4L2_SUBDEV_FL_HAS_EVENTS;
priv->subdev->entity.type = MEDIA_ENT_T_V4L2_SUBDEV_SENSOR;

// Setup media controller pad flags
priv->pad.flags = MEDIA_PAD_FL_SOURCE;
```

```
// Initialize and register subdevice and media entity with media controller
framework.
media_entity_init(&priv->subdev->entity, 1, &priv->pad, 0);
v4l2_async_register_subdev(priv->subdev);
```

All imager devices must register themselves as sub devices to media controller framework. VI acts as the master device which controls the binding, parsing the DT and establish the media links once all the sub devices are registered.

Each sub device can register to media controller framework by defining the entity and pads information.

Entity: Media entity is the unit device represented by media controller framework for establishing connections. Each media entity can have multiple pads. Framework provides a list of known entity types and the corresponding media operations.

Pad: Pad represents the device behaves as SINK or SOURCE port. Imager device must have a SOURCE port which gets binded to VI. If imager device has a SINK port then the SOURCE port which is getting binded the device SINK port must be represented in DT to complete the binding.

Removal of Sensor Drivers

The `ov5693_remove` function removes the sensor-device instance and calls on a device shutdown.

This function makes calls to various `free`, `put`, and `destroy` functions that match up with several calls in probe. It must remain largely the same.

```
// See the section Initialization of Controls for details on
// freeing the control handler.
v4l2_ctrl_handler free(&priv->ctrl_handler);

// See the section Power Functions.
ov5693_power_put(priv);
```

Debugging Tips

When the driver is complete, your primary goal is then to get the driver to probe and register the `/dev/camera/video#` node for the driver. That node is the file I/O interface with which the user-space driver accesses the driver.

Problems might occur in the probing process and require debugging. Typically, problems occur in the clock, GPIO, and regulator setup. See below for a few tips.

Verify that names match the Device Tree

To debug those problems, first verify that the names that are being read through the `parse_dt` function matches those in the Device Tree.

Verify that Device-Tree values match the hardware

Ensure that the values assigned to the Device Tree fields match the hardware they describe. Oftentimes, regulator names, GPIO numbers, and clock names are out-of-date in the Device Tree, causing probing to fail.

Verify that functions run to completion

Ensure that the `power_get` calls runs to completion. For details, see the sections Power Functions and Boot-Time Initialization.

Anther common problem that occurs during probe is in `control init`.

Verify that default values are correctly linked

Verify that default values are all linked correctly in the control configuration (see the section Sensor-Private Data) and that the default macros (see the section Macro Definitions) are updated appropriately with the values in the mode table of the sensor.

If new controls have been added to the control configuration list (on rare occasions), ensure that they contain the appropriate control handlers and default values.

After probing succeeds, problems could still occur with the control setting. A common problem is in the values of the register writes.

Verify that control-register values are correct

Ensure that the control-register setup (see the section Setting Up Control Registers) contains the correct register address and formats according to the mode table and data sheets.

For gain control, be sure to create a new `calculate_gain (to_gain)` function for calculating the gain value according to the gain formula in the data sheets.

Verify that mode-specific settings are correct

Double-check the mode-specific settings in the Device Tree. Update them if necessary. Problems might arise from the minimum and maximum values, potentially resulting in timing issues and sync-point timeouts.

Mode Tables

This topic explains mode tables and describes the procedure for adding them.

The modes tables of the register reside in a separate header file called `sensor_mode_tbls.h` and are included by the main driver. Those tables can be a list of `reg_8` or `reg_16` address-value pairs. Mode tables are separated by resolution. For the `ov5693`driver, a common mode table also exists, which contains the common register values among all the resolutions.

```
static ov5693_reg mode_table_common[] = {
...
};
```

The `start` and `stop` stream-register values must be in a separate mode table. When you separate them, delete the `start` stream-register values at the end of the resolution mode tables.

```
static ov5693_reg ov5693_start[] = {
```

```
{ 0x0100, 0x01 }, /* mode select streaming on */
{ OV5693_TABLE_END, 0x00 }
};

static ov5693_reg ov5693_stop[] = {
{ 0x0100, 0x00 }, /* mode select streaming off */
{ OV5693_TABLE_END, 0x00 }
};
```

Also, a table for the color bars of the test pattern is used if the `test_mode` flag is enabled, activating the test-pattern mode of the sensor. That table is required only if test pattern is supported by the sensor.

```
static ov5693_reg tp_colorbars[] = {
...
};
```

At the end of the header of the mode tables is an enumeration of all the mode tables, as well as a list that maps the enumeration to table pointers.

```
enum {
OV5693_MODE_4096X3072,
...
};
static ov5693_reg *mode_table[] = {
[OV5693_MODE_2593X1944] = mode_2593X1944,
...
};
```

The `camera_common_frmfmt` array list is a required table that sets up the format for the V4L2 framework. Each of the elements on that list contains the resolutions, the `is_hdr` flag, and the enumeration for the mode.

```
static const struct camera_common_frmfmt ov5693_frmfmt[] = {
{{2592, 1944}, 0, OV5693_MODE_2593X1944},
...
};
```

Adding a register mode table is a relatively simple and straightforward process.

To add a register mode table

1. Obtain the address-value pairs for the mode table you would like to add.

   Note: If separate stream-on and stream-off mode tables exist, you can omit them from the mode table.

2. Format the pairs according to the register structure and initialize a static array with the mode resolution as part of the name. For example:

```
static ov5693_reg mode_####x####[] = {
{ 0x0100, 0x01 }, /* mode select streaming on */
...
/* your addr and val pairs */
};
```

The mode table is now in place. Be sure to end the table array with the following:

```
{ OV5693_TABLE_END, 0x00 }
```

3. Create a new enumeration in the list of enumerations and add it to the array of mode tables:

```
enum {
...
OV5693_MODE_####X####,
}

static ov5693_reg *mode_table[] = {
...
[OV5693_MODE_####X####] = mode_####x####,
};
```

4. Add the new mode to the camera_common frmfmt array:

```
static const struct camera_common_frmfmt ov5693_frmfmt[] = {
...
{{####, ####}, 0, OV5693_MODE_####X####},
};
```

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This option is useful when you wish to copy part of the code of the Library into a program that is not a library.

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