ECG-HRM

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1 Module Index

1.1 Modules

Here is a list of all modules:

2 Data Structure Index

2.1 Data Structures

Here are the data structures with brief descriptions:

3 File Index

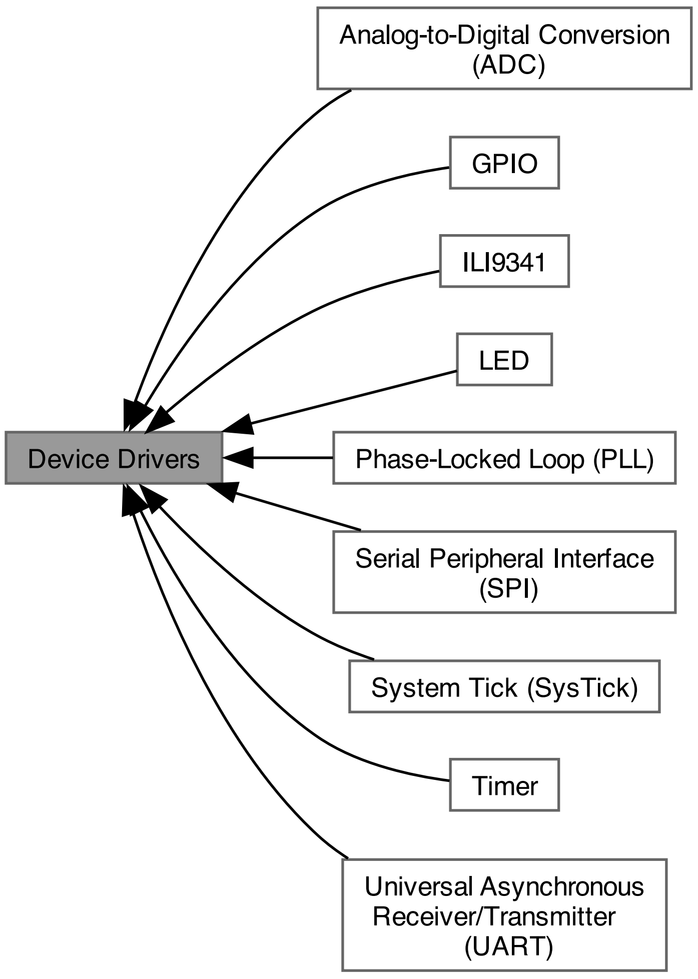
3.1 File List

Here is a list of all documented files with brief descriptions:

4 Module Documentation

4.1 Device Drivers

Collaboration diagram for Device Drivers:


Analog-to-Digital Conversion (ADC)
GPIO
ILI9341
LED
Device Drivers
Phase-Locked Loop (PLL)
Serial Peripheral Interface (SPI)
System Tick (SysTick)
Timer
Universal Asynchronous Receiver/Transmitter (UART)

Modules

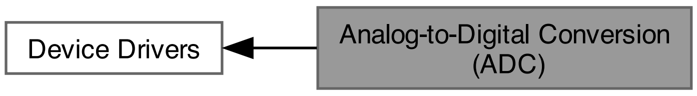
- Analog-to-Digital Conversion (ADC)
- GPIO
- ILI9341
- LED
- Phase-Locked Loop (PLL)
- Serial Peripheral Interface (SPI)
- System Tick (SysTick)
- Timer
- Universal Asynchronous Receiver/Transmitter (UART)

4.1.1 Detailed Description

Device driver modules.

4.1.2 Analog-to-Digital Conversion (ADC)

Collaboration diagram for Analog-to-Digital Conversion (ADC):



Files

- file ADC.c

    Source code for ADC module.
- file ADC.h

    Driver module for analog-to-digital conversion (ADC).
- file ADC_New.c

    Source code for ADC module.
- file ADC_New.h

    Driver module for analog-to-digital conversion (ADC).

Macros

- #define **GPIO_PIN_5** ((uint8_t) (1 << 5))

Functions

- void **ADC_Init** (void)

    Initialize ADC0 as a single-input analog-to-digital converter.
- void **ADC_InterruptEnable** (void)

    Enable the ADC interrupt.
- void **ADC_InterruptDisable** (void)

    Disable the ADC interrupt.
- volatile float32_t ADC_ConvertToVolts (uint16_t raw_sample)

    Convert a raw ADC sample to voltage in [mV].

4.1.2.1 Detailed Description

Functions for differential-input analog-to-digital conversion.

4.1.2.2 Function Documentation

ADC_ConvertToVolts()

```
volatile float32_t ADC_ConvertToVolts (
            uint16_t raw_sample )
```

Convert a raw ADC sample to voltage in [mV].

Parameters

raw_sample	12-bit unsigned ADC value. `sample = [0, 0xFFF]`

Returns

double Voltage value in range `[-5.5, 5.5) [mV]`.

Parameters

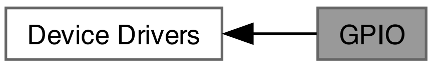
raw_sample	12-bit unsigned ADC value. `sample = [0, 0xFFF]`

Returns

double Voltage value in range `[-5.5, 5.5) [mV]`.

4.1.3 GPIO

Collaboration diagram for GPIO:



Files

- file GPIO.c

  Source code for GPIO module.
- file GPIO.h

  Driver module for using the LaunchPad's onboard switches and RGB LEDs for GPIO and interrupts.

Macros

- #define **LED_RED** (uint8_t) 0x02
- #define **LED_GREEN** (uint8_t) 0x08
- #define **LED_BLUE** (uint8_t) 0x04
- #define **LED_YELLOW** (LED_RED + LED_GREEN)
- #define **LED_CYAN** (LED_BLUE + LED_GREEN)
- #define **LED_PURPLE** (LED_RED + LED_BLUE)
- #define **LED_WHITE** (LED_RED + LED_BLUE + LED_GREEN)

Functions

- void GPIO_PF_Init (void)

  Initialize GPIO Port F.
- void GPIO_PF_LED_Init (void)

  Initialize PF1-3 to interface the LaunchPad's onboard RGB LED.
- void GPIO_PF_LED_Write (uint8_t color_mask, uint8_t on_or_off)

  Write a 1 or 0 to the selected LED(s).
- void GPIO_PF_LED_Toggle (uint8_t color_mask)

  Toggle the selected LED(s).
- void GPIO_PF_Sw_Init (void)

  Initialize PF0/4 to interface the LaunchPad's onboard switches. PF4 is Sw1, and PF0 is Sw2.
- void GPIO_PF_Interrupt_Init (void)

  Initialize GPIO Port F interrupts via Sw1 and Sw2.

4.1.3.1 Detailed Description

Functions for interfacing the LaunchPad's RGB LEDs (PF1-3) and switches (PF0/4).

4.1.3.2 Function Documentation

GPIO_PF_Init()

```
void GPIO_PF_Init (
            void  )
```

Initialize GPIO Port F.

GPIO_PF_Interrupt_Init()

```
void GPIO_PF_Interrupt_Init (
            void  )
```

Initialize GPIO Port F interrupts via Sw1 and Sw2.

GPIO_PF_LED_Init()

```
void GPIO_PF_LED_Init (
            void  )
```

Initialize PF1-3 to interface the LaunchPad's onboard RGB LED.

GPIO_PF_LED_Toggle()

```
void GPIO_PF_LED_Toggle (
            uint8_t color_mask )
```

Toggle the selected LED(s).

Parameters

color_mask	Hex. number of LED pin(s) to write to. 0x02 (PF1) – RED; 0x04 (PF2) – BLUE; 0x08 (PF3) – GREEN

GPIO_PF_LED_Write()

```
void GPIO_PF_LED_Write (
            uint8_t color_mask,
            uint8_t on_or_off )
```

Write a 1 or 0 to the selected LED(s).

Parameters

color_mask	Hex. number of LED pin(s) to write to. 0x02 (PF1) – RED; 0x04 (PF2) – BLUE; 0x08 (PF3) – GREEN
on_or_off	=0 for OFF, >=1 for ON

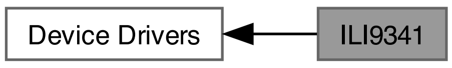
GPIO_PF_Sw_Init()

```
void GPIO_PF_Sw_Init (
            void  )
```

Initialize PF0/4 to interface the LaunchPad's onboard switches. PF4 is Sw1, and PF0 is Sw2.

4.1.4 ILI9341

Collaboration diagram for ILI9341:



Files

- file ILI9341.c

  Source code for ILI9341 module.
- file ILI9341.h

  Driver module for interfacing with an ILI9341 LCD driver.

Macros

- #define **CMD_NOP** (uint8_t) 0x00
- #define **CMD_SWRESET** (uint8_t) 0x01
- #define **CMD_SPLIN** (uint8_t) 0x10
- #define **CMD_SPLOUT** (uint8_t) 0x11
- #define **CMD_PTLON** (uint8_t) 0x12
- #define **CMD_NORON** (uint8_t) 0x13
- #define **CMD_DINVOFF** (uint8_t) 0x20
- #define **CMD_DINVON** (uint8_t) 0x21
- #define **CMD_CASET** (uint8_t) 0x2A
- #define **CMD_PASET** (uint8_t) 0x2B
- #define **CMD_RAMWR** (uint8_t) 0x2C
- #define **CMD_DISPOFF** (uint8_t) 0x28
- #define **CMD_DISPON** (uint8_t) 0x29
- #define **CMD_PLTAR** (uint8_t) 0x30
- #define **CMD_VSCRDEF** (uint8_t) 0x33
- #define **CMD_MADCTL** (uint8_t) 0x36
- #define **CMD_VSCRSADD** (uint8_t) 0x37
- #define **CMD_IDMOFF** (uint8_t) 0x38
- #define **CMD_IDMON** (uint8_t) 0x39
- #define **CMD_PIXSET** (uint8_t) 0x3A
- #define **CMD_FRMCTR1** (uint8_t) 0xB1
- #define **CMD_FRMCTR2** (uint8_t) 0xB2
- #define **CMD_FRMCTR3** (uint8_t) 0xB3
- #define **CMD_PRCTR** (uint8_t) 0xB5
- #define **CMD_IFCTL** (uint8_t) 0xF6
- #define **NUM_COLS** (uint16_t) 240
- #define **NUM_ROWS** (uint16_t) 320

Functions

- void **ILI9341_Init** (void)

  Initialize the LCD driver, the SPI module, and Timer2A.
- void ILI9341_resetHard (void)

  Perform a hardware reset of the LCD driver.
- void ILI9341_resetSoft (void)

  Perform a software reset of the LCD driver.
- void ILI9341_setSleepMode (bool is_sleeping)

  Enter or exit sleep mode. The LCD driver is in sleep mode by default upon powering on or either kind of reset.
- void ILI9341_setDispMode (bool is_normal, bool is_full_colors)

  Set the display area and color expression.
- void ILI9341_setPartialArea (uint16_t rowStart, uint16_t rowEnd)

  Set the partial display area for partial mode. Call before activating partial mode via ILI9341_setDisplayMode().
- void ILI9341_setDispInversion (bool is_ON)

  Toggle display inversion. Turning `ON` causes colors to be inverted on the display.
- void ILI9341_setDispOutput (bool is_ON)

  Turn display output ON or OFF. This function clears the display and stops outputting to the display area, but does not affect frame memory or power.
- void ILI9341_setScrollArea (uint16_t topFixedArea, uint16_t vertScrollArea, uint16_t bottFixedArea)

  Set the vertical scrolling area of the display. The sum of the three parameters should be equal to the max number of rows `NUM_ROWS = 320`.
- void ILI9341_setScrollStart (uint16_t startRow)

Set the start row for vertical scrolling.
- void ILI9341_setMemAccessCtrl (bool areRowsFlipped, bool areColsFlipped, bool areRowsColsSwitched, bool isVertRefreshFlipped, bool isColorOrderFlipped, bool isHorRefreshFlipped)

  Set how data is converted from memory to display.
- void ILI9341_setColorDepth (bool is_16bit)

  Set the pixel format to be 16-bit (65K colors) or 18-bit (262K colors).
- void **ILI9341_NoOpCmd** (void)

  Send the ¨No Operation¨ command (`NOP = 0x00`) to the LCD driver. Can be used to terminate the ¨Memory Write¨ (`RAMWR`) and ¨Memory Read¨ (`RAMRD`) commands, but does nothing otherwise.
- void ILI9341_setFrameRateNorm (uint8_t div_ratio, uint8_t clocks_per_line)

  TODO: Write brief.
- void ILI9341_setFrameRateIdle (uint8_t div_ratio, uint8_t clocks_per_line)

  TODO: Write brief.
- void ILI9341_setBlankingPorch (uint8_t vpf, uint8_t vbp, uint8_t hfp, uint8_t hbp)

  TODO: Write.
- void ILI9341_setInterface (void)

  Sets the interface for the ILI9341. The parameters for this command are hard-coded, so it only needs to be called once upon initialization.
- void ILI9341_setRowAddress (uint16_t start_row, uint16_t end_row)

  not using backlight, so these aren't necessary
- void ILI9341_setColAddress (uint16_t start_col, uint16_t end_col)

  Sets the start/end rows to be written to.
- void ILI9341_writeMemCmd (void)

  Sends the ¨Write Memory¨ (`RAMWR`) command to the LCD driver, signalling that incoming data should be written to memory.
- void ILI9341_write1px (uint8_t red, uint8_t green, uint8_t blue, bool is_16bit)

  Write a single pixel to frame memory.

4.1.4.1 Detailed Description

Functions for interfacing an ILI9341-based 240RGBx320 LCD via Serial Peripheral Interface (SPI).

4.1.4.2 Function Documentation

ILI9341_resetHard()

```
void ILI9341_resetHard (
            void  )
```

Perform a hardware reset of the LCD driver.

The LCD driver's RESET pin requires a negative logic (i.e. active `LOW`) signal for >= 10 [us] and an additional 5 [ms] before further commands can be sent.

ILI9341_resetSoft()

```
void ILI9341_resetSoft (
            void  )
```

Perform a software reset of the LCD driver.

the driver needs 5 [ms] before another command

ILI9341_setBlankingPorch()

```
void ILI9341_setBlankingPorch (
            uint8_t vpf,
            uint8_t vbp,
            uint8_t hfp,
            uint8_t hbp )
```

TODO: Write.

TODO: Write

ILI9341_setColAddress()

```
void ILI9341_setColAddress (
            uint16_t start_col,
            uint16_t end_col )
```

Sets the start/end rows to be written to.

```
Should be called along with `ILI9341_setRowAddress()` and
before `ILI9341_writeMemCmd()`.
```

Parameters

start_col	0 <= `start_col` <= `end_col`
end_col	`start_col` <= `end_col` < 240

This function is simply an interface to ILI9341_setAddress(). To work correctly, `start_col` must be no greater than `end_col`, and `end_col` cannot be greater than the max column number (default 240).

ILI9341_setColorDepth()

```
void ILI9341_setColorDepth (
            bool is_16bit )
```

Set the pixel format to be 16-bit (65K colors) or 18-bit (262K colors).

Parameters

is_16bit	

16-bit requires 2 transfers and allows for 65K colors. 18-bit requires 3 transfers and allows for 262K colors.

ILI9341_setDispInversion()

```
void ILI9341_setDispInversion (
            bool is_ON )
```

Toggle display inversion. Turning `ON` causes colors to be inverted on the display.

Parameters

is_ON	`true` to turn ON, `false` to turn OFF

TODO: Write description

ILI9341_setDispMode()

```
void ILI9341_setDispMode (
            bool is_normal,
            bool is_full_colors )
```

Set the display area and color expression.

```
Normal mode is the default and allows output to the full
display area. Partial mode should be activated after calling
`ILI9341_setPartialArea()`.

Setting `is_full_colors` to `false` restricts the color expression
to 8 colors, determined by the MSB of the R/G/B values.
```

Parameters

is_normal	`true` for normal mode, `false` for partial mode
is_full_colors	`true` for full colors, `false` for 8 colors

ILI9341_setDispOutput()

```
void ILI9341_setDispOutput (
            bool is_ON )
```

Turn display output ON or OFF. This function clears the display and stops outputting to the display area, but does not affect frame memory or power.

Parameters

is_ON	`true` to turn ON, `false` to turn OFF

TODO: Write description

ILI9341_setFrameRateIdle()

```
void ILI9341_setFrameRateIdle (
            uint8_t div_ratio,
            uint8_t clocks_per_line )
```

TODO: Write brief.

TODO: Write description

ILI9341_setFrameRateNorm()

```
void ILI9341_setFrameRateNorm (
            uint8_t div_ratio,
            uint8_t clocks_per_line )
```

TODO: Write brief.

TODO: Write description

ILI9341_setInterface()

```
void ILI9341_setInterface (
            void )
```

Sets the interface for the ILI9341. The parameters for this command are hard-coded, so it only needs to be called once upon initialization.

This function implements the ¨Interface Control¨ `CMD_IFCTL` command from p. 192-194 of the ILI9341 datasheet, which controls how the LCD driver handles 16-bit data and what interfaces (internal or external) are used.

Name	Bit #	Param #	Effect when set = 1
MY_EOR	7	0	flips value of corresponding CMD_MADCTL bit
MX_EOR	6		flips value of corresponding CMD_MADCTL bit
MV_EOR	5		flips value of corresponding CMD_MADCTL bit
BGR_EOR	3		flips value of corresponding CMD_MADCTL bit
WEMODE	0		overflowing pixel data is not ignored
EPF[1:0]	5:4	1	controls 16 to 18-bit pixel data conversion
MDT[1:0]	1:0		controls display data transfer method
ENDIAN	5	2	host sends LSB first
DM[1:0]	3:2		selects display operation mode
RM	1		selects GRAM interface mode
RIM	0		specifies RGB interface-specific details

The first param's bits are cleared so that the corresponding CMD_MADCTL bits (ILI9341_setMemoryAccessCtrl()) are unaffected and overflowing pixel data is ignored. The EPF bits are cleared so that the LSB of the R and B values is copied from the MSB when using 16-bit color depth. The TM4C123 sends the MSB first, so the ENDIAN bit is cleared. The other bits are cleared and/or irrelevant since the RGB and VSYNC interfaces aren't used.

ILI9341_setMemAccessCtrl()

```
void ILI9341_setMemAccessCtrl (
            bool areRowsFlipped,
            bool areColsFlipped,
            bool areRowsColsSwitched,
            bool isVertRefreshFlipped,
            bool isColorOrderFlipped,
            bool isHorRefreshFlipped )
```

Set how data is converted from memory to display.

Parameters

areRowsFlipped	
areColsFlipped	
areRowsColsSwitched	
isVertRefreshFlipped	
isColorOrderFlipped	
isHorRefreshFlipped	

This function implements the ¨Memory Access Control¨ (`CMD_MADCTL`) command from p. 127-128 of the ILI9341 datasheet, which controls how the LCD driver displays data upon writing to memory.

Name	Bit #	Effect when set = 1
MY	7	flip row (AKA ¨page¨) addresses
MX	6	flip column addresses
MV	5	exchange rows and column addresses
ML	4	reverse horizontal refresh order
BGR	3	reverse color input order (RGB -> BGR)
MH	2	reverse vertical refresh order

All bits are clear after powering on or `HWRESET`.

ILI9341_setPartialArea()

```
void ILI9341_setPartialArea (
            uint16_t rowStart,
            uint16_t rowEnd )
```

Set the partial display area for partial mode. Call before activating partial mode via ILI9341_setDisplayMode().

Parameters

rowStart	
rowEnd	

ILI9341_setRowAddress()

```
void ILI9341_setRowAddress (
            uint16_t start_row,
            uint16_t end_row )
```

not using backlight, so these aren't necessary

Sets the start/end rows to be written to.

```
Should be called along with `ILI9341_setColAddress()` and
before `ILI9341_writeMemCmd()`.
```

Parameters

start_row	0 <= `start_row` <= `end_row`
end_row	`start_row` <= `end_row` < 320

This function is simply an interface to ILI9341_setAddress(). To work correctly, `start_row` must be no greater than `end_row`, and `end_row` cannot be greater than the max row number (default 320).

ILI9341_setScrollArea()

```
void ILI9341_setScrollArea (
            uint16_t topFixedArea,
            uint16_t vertScrollArea,
            uint16_t bottFixedArea )
```

Set the vertical scrolling area of the display. The sum of the three parameters should be equal to the max number of rows `NUM_ROWS = 320`.

Parameters

topFixedArea	Number of rows fixed at the top of the screen.
vertScrollArea	Number of rows that scroll.
bottFixedArea	Number of rows fixed at the bottom of the screen.

ILI9341_setScrollStart()

```
void ILI9341_setScrollStart (
            uint16_t startRow )
```

Set the start row for vertical scrolling.

Parameters

startRow	Start row for scrolling. Should be >= `topFixedArea - 1`

ILI9341_setSleepMode()

```
void ILI9341_setSleepMode (
            bool is_sleeping )
```

Enter or exit sleep mode. The LCD driver is in sleep mode by default upon powering on or either kind of reset.

Parameters

is_sleeping	`true` to enter sleep mode, `false` to exit

This function turns sleep mode ON or OFF depending on the value of `is_sleeping`. Either way, the MCU must wait >= 5 [ms] before sending further commands.

It's also necessary to wait 120 [ms] before sending `CMD_SPLOUT` after sending `CMD_SPLIN` or a reset, so this function waits 120 [ms] regardless of the preceding event.

ILI9341_write1px()

```
void ILI9341_write1px (
            uint8_t red,
            uint8_t green,
            uint8_t blue,
            bool is_16bit )
```

Write a single pixel to frame memory.

```
Call `ILI9341_writeMemCmd()` before this one.
```

Parameters

red	5 or 6-bit `R` value
green	5 or 6-bit `G` value
blue	5 or 6-bit `B` value
is_16bit	`true` for 16-bit (65K colors, 2 transfers) color depth, `false` for 18-bit (262K colors, 3 transfer) color depth NOTE: set color depth via `ILI9341_setColorDepth()`

This function sends one pixel to the display. Because the serial interface (SPI) is used, each pixel requires 2 transfers in 16-bit mode and 3 transfers in 18-bit mode.

The following table (adapted from p. 63 of the datasheet) visualizes how the RGB data is sent to the display when using 16-bit color depth.

Transfer	**1**								**2**							
Bit #	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Value	R4	R3	R2	R1	R0	G5	G4	G3	G2	G1	G0	B4	B3	B2	B1	B0

The following table (adapted from p. 64 of the datasheet) visualizes how the RGB data is sent to the display when using 18-bit color depth.

Transfer	**1**								**2**		
Bit #	7	6	5	4	3	2	1	0	7	6	...
Value	R5	R4	R3	R2	R1	R0	0/1	0/1	G5	G4	...

ILI9341_writeMemCmd()

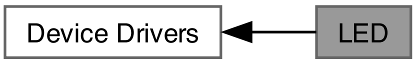
```
void ILI9341_writeMemCmd (
            void )
```

Sends the ¨Write Memory¨ (`RAMWR`) command to the LCD driver, signalling that incoming data should be written to memory.

Should be called after setting the row (`ILI9341_setRowAddress()`) and/or and/or column (`ILI9341_setRowAddress()`) addresses, but before writing image data (`ILI9341_write1px()`).

4.1.5 LED

Collaboration diagram for LED:



Files

- file Led.c

  Source code for LED module.
- file Led.h

  Interface for LED module.

Data Structures

- struct Led_t

Macros

- #define **LED_POOL_SIZE** 3

Functions

- Led_t ∗ Led_Init (GPIO_Port_t ∗gpioPort_ptr, GPIO_Pin_t pin)

  Initialize a light-emitting diode (LED) as an `Led_t`.
- GPIO_Port_t ∗ Led_GetPort (Led_t ∗led_ptr)

  Get the GPIO port associated with the LED.
- GPIO_Pin_t LED_GetPin (Led_t ∗led_ptr)

  Get the GPIO pin associated with the LED.
- bool Led_isOn (Led_t ∗led_ptr)

  Check the LED's status.
- void Led_TurnOn (Led_t ∗led_ptr)

  Turn the LED `ON`.
- void Led_TurnOff (Led_t ∗led_ptr)

  Turn the LED `OFF`.
- void Led_Toggle (Led_t ∗led_ptr)

  Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

4.1.5.1 Detailed Description

Functions for driving light-emitting diodes (LEDs) via GPIO.

4.1.5.2 Function Documentation

LED_GetPin()

```
GPIO_Pin_t LED_GetPin (
            Led_t * led_ptr )
```

Get the GPIO pin associated with the LED.

Parameters

in	*led_ptr*	Pointer to LED data structure.
out	*GPIO_↩ Pin_t*	GPIO pin associated with the LED.

Led_GetPort()

```
GPIO_Port_t * Led_GetPort (
            Led_t * led_ptr )
```

Get the GPIO port associated with the LED.

Parameters

in	*led_ptr*	Pointer to LED data structure.
out	*GPIO_Port↩ _t∗*	Pointer to a GPIO port data structure.

Led_Init()

```
Led_t * Led_Init (
            GPIO_Port_t * gpioPort_ptr,
            GPIO_Pin_t pin )
```

Initialize a light-emitting diode (LED) as an `Led_t`.

Parameters

in	*gpioPort_ptr*	Pointer to a `struct` representing a GPIO port.
in	*pin*	GPIO pin to use.
out	*Led_t∗*	Pointer to LED data structure.

Led_isOn()

```
bool Led_isOn (
            Led_t * led_ptr )
```

Check the LED's status.

Parameters

in	*led_ptr*	Pointer to LED data structure.
out	*true*	the LED is `ON`.
out	*false*	the LED is `OFF`.

Led_Toggle()

```
void Led_Toggle (
            Led_t * led_ptr )
```

Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

Parameters

in	*led_ptr*	Pointer to LED data structure.

Led_TurnOff()

```
void Led_TurnOff (
            Led_t * led_ptr )
```

Turn the LED `OFF`.

Parameters

in	*led_ptr*	Pointer to LED data structure.

Led_TurnOn()

```
void Led_TurnOn (
            Led_t * led_ptr )
```

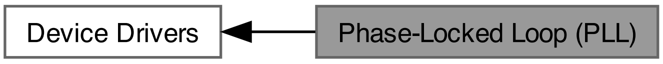
Turn the LED `ON`.

Parameters

in	*led_ptr*	Pointer to LED data structure.

4.1.6 Phase-Locked Loop (PLL)

Collaboration diagram for Phase-Locked Loop (PLL):



Files

- file PLL.c

  Implementation details for phase-lock-loop (PLL) functions.
- file PLL.h

  Driver module for activating the phase-locked-loop (PLL).

Functions

- void PLL_Init (void)

  Initializes the phase-locked-loop (PLL), allowing a bus frequency of 80[MHz].

4.1.6.1 Detailed Description

Function for initializing the phase-locked loop.

4.1.6.2 Function Documentation

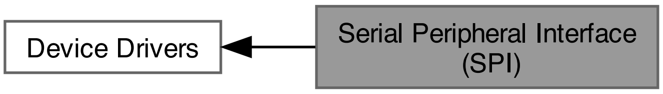
PLL_Init()

```
void PLL_Init (
            void  )
```

Initializes the phase-locked-loop (PLL), allowing a bus frequency of 80[MHz].

4.1.7 Serial Peripheral Interface (SPI)

Collaboration diagram for Serial Peripheral Interface (SPI):



Files

- file SPI.c

    Source code for SPI module.
- file SPI.h

    Driver module for using the serial peripheral interface (SPI) protocol.
- file SPI_New.c

    Source code for SPI module.
- file SPI_New.h

    Driver module for using the serial peripheral interface (SPI) protocol.

Macros

- #define NVIC_SSI0_NUM 7
- #define **SPI_INT_START**() (NVIC_SW_TRIG_R = (NVIC_SW_TRIG_R & ∼(0xFF)) | NVIC_SSI0_NUM)
- #define **SPI_SET_DC**() (GPIO_PORTA_DATA_R |= 0x40)
- #define **SPI_CLEAR_DC**() (GPIO_PORTA_DATA_R &= ∼(0x40))
- #define **SPI_IS_BUSY** (SSI0_SR_R & 0x10)
- #define **SPI_TX_ISNOTFULL** ((bool) (SSI0_SR_R & 0x02))
- #define **SPI_BUFFER_SIZE** 9
- #define NVIC_SSI0_NUM 7
- #define **SPI_INT_START**() (NVIC_SW_TRIG_R = (NVIC_SW_TRIG_R & ∼(0xFF)) | NVIC_SSI0_NUM)
- #define **SPI_SET_DC**() (GPIO_PORTA_DATA_R |= 0x40)
- #define **SPI_CLEAR_DC**() (GPIO_PORTA_DATA_R &= ∼(0x40))
- #define **SPI_IS_BUSY** (SSI0_SR_R & 0x10)
- #define **SPI_TX_ISNOTFULL** ((bool) (SSI0_SR_R & 0x02))
- #define **SPI_BUFFER_SIZE** 9

Enumerations

- enum {
  SPI_CLK_PIN = GPIO_PIN2 , **SPI_CS_PIN** = GPIO_PIN3 , **SPI_RX_PIN** = GPIO_PIN4 , **SPI_TX_PIN** = GPIO_PIN5 ,
  SPI_DC_PIN = GPIO_PIN6 , **SPI_RESET_PIN** = GPIO_PIN7 , **SPI_SSI0_PINS** = (SPI_CLK_PIN | SPI_↩ CS_PIN | SPI_RX_PIN | SPI_TX_PIN) , **SPI_GPIO_PINS** = (SPI_DC_PIN | SPI_RESET_PIN) ,
  SPI_ALL_PINS = (SPI_SSI0_PINS | SPI_GPIO_PINS) }

Functions

- void SPI_Init (void)

    Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.
- uint8_t SPI_Read (void)

    Read data from the peripheral.
- void SPI_WriteCmd (uint8_t cmd)

    Write an 8-bit command to the peripheral.
- void SPI_WriteData (uint8_t data)

    Write 8-bit data to the peripheral.
- void SPI_IRQ_WriteCmd (uint8_t cmd)

    Add an 8-bit command to the SPI queue. If no data or other command is written, should directly precede a call to `SPI_IRQ_StartWriting()`.
- void SPI_IRQ_WriteData (uint8_t data)

Add 8-bit data to the SPI queue. Should directly precede either another call to the same function or a call to `SPI_IRQ_StartWriting()`.

- void **SPI_IRQ_StartWriting** (void)

  Start writing data to the Tx FIFO. Should be used after 1+ calls to `SPI_IRQ_WriteCmd()` and/or `SPI_IRQ_WriteData()`. If unused, writing will start when the SPI queue is full.

- void SSI0_Handler (void)

  Sends parameters (data or commands) over SPI via SSI0.

4.1.7.1 Detailed Description

Functions for SPI-based communication via SSI0 peripheral.

4.1.7.2 Macro Definition Documentation

NVIC_SSI0_NUM `[1/2]`

```
#define NVIC_SSI0_NUM 7
```

TM4C Pin	Function	ILI9341 Pin	Description
PA2	SSI0Clk	CLK	Serial clock signal
PA3	SSI0Fss	CS	Chip select signal
PA4	SSI0Rx	MISO	TM4C (M) input, LCD (S) output
PA5	SSI0Tx	MOSI	TM4C (M) output, LCD (S) input
PA6	GPIO	D/C	Data = 1, Command = 0
PA7	GPIO	RESET	Reset the display (negative logic/active `LOW`)

Clk. Polarity = steady state low (0)
Clk. Phase = rising clock edge (0)

NVIC_SSI0_NUM `[2/2]`

```
#define NVIC_SSI0_NUM 7
```

TM4C Pin	Function	ILI9341 Pin	Description
PA2	SSI0Clk	CLK	Serial clock signal
PA3	SSI0Fss	CS	Chip select signal
PA4	SSI0Rx	MISO	TM4C (M) input, LCD (S) output
PA5	SSI0Tx	MOSI	TM4C (M) output, LCD (S) input
PA6	GPIO	D/C	Data = 1, Command = 0
PA7	GPIO	RESET	Reset the display (negative logic/active `LOW`)

Clk. Polarity = steady state low (0)
Clk. Phase = rising clock edge (0)

4.1.7.3 Function Documentation

SPI_Init()

```
void SPI_Init (
            void  )
```

Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.

The bit rate `BR` is set using the (positive, even-numbered) clock prescale divisor `CPSDVSR` and the `SCR` field in the SSI Control 0 (`CR0`) register:

$$BR = f_{bus} / (CPSDVSR * (1 + SCR))$$

The ILI9341 driver has a min. read cycle of 150 [ns] and a min. write cycle of 100 [ns], so the bit rate `BR` is set to be equal to the bus frequency ($f_{bus} = 80[MHz]$) divided by 8, allowing a bit rate of 10 [MHz], or a period of 100 [ns].

The bit rate `BR` is set using the (positive, even-numbered) clock prescale divisor `CPSDVSR` and the `SCR` field in the SSI Control 0 (`CR0`) register:

$$BR = f_{bus} / (CPSDVSR * (1 + SCR))$$

The ILI9341 driver has a min. read cycle of 150 [ns] and a min. write cycle of 100 [ns], so the bit rate `BR` is set to be equal to the bus frequency ($f_{bus} = 80[MHz]$) divided by 8, allowing a bit rate of 10 [MHz], or a period of 100 [ns].

SPI_IRQ_WriteCmd()

```
void SPI_IRQ_WriteCmd (
            uint8_t cmd )
```

Add an 8-bit command to the SPI queue. If no data or other command is written, should directly precede a call to `SPI_IRQ_StartWriting()`.

Parameters

cmd	command for peripheral

Parameters

cmd	command for peripheral

SPI_IRQ_WriteData()

```
void SPI_IRQ_WriteData (
            uint8_t data )
```

Add 8-bit data to the SPI queue. Should directly precede either another call to the same function or a call to `SPI_IRQ_StartWriting()`.

Parameters

data	input data for peripheral

Parameters

data	input data for peripheral

SPI_Read()

```
uint8_t SPI_Read (
             void  )
```

Read data from the peripheral.

Returns

uint8_t

Returns

uint8_t

SPI_WriteCmd()

```
void SPI_WriteCmd (
             uint8_t cmd )
```

Write an 8-bit command to the peripheral.

Parameters

cmd	command for peripheral

Parameters

cmd	command for peripheral

SPI_WriteData()

```
void SPI_WriteData (
             uint8_t data )
```

Write 8-bit data to the peripheral.

Parameters

data	input data for peripheral

Parameters

data	input data for peripheral

SSI0_Handler()

```
void SSI0_Handler (
            void  )
```

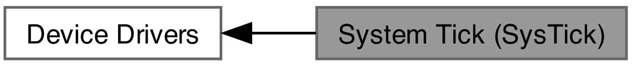
Sends parameters (data or commands) over SPI via SSI0.

```
The interrupt is enabled by the 'SPI_Init()' function and triggered by
a call to 'SPI_IRQ_StartWriting()'. The handler determines whether to
signal for data or a command via the D/C pin, and then writes to the data register.

The interrupt is unpended at the start of the function.
```

4.1.8 System Tick (SysTick)

Collaboration diagram for System Tick (SysTick):



Files

- file SysTick.c

  Implementation details for SysTick functions.
- file SysTick.h

  Driver module for using SysTick-based timing and/or interrupts.

Functions

- void SysTick_Timer_Init (void)

  Initialize SysTick for timing purposes.
- void **SysTick_Wait1ms** (uint32_t delay_ms)

  Delay for specified amount of time in [ms]. Assumes f_bus = 80[MHz].
- void SysTick_Interrupt_Init (uint32_t time_ms)

  Initialize SysTick for interrupts.

4.1.8.1 Detailed Description

Functions for timing and periodic interrupts via SysTick.

4.1.8.2 Function Documentation

SysTick_Interrupt_Init()

```
void SysTick_Interrupt_Init (
             uint32_t time_ms )
```

Initialize SysTick for interrupts.

Parameters

time_ms	Time in [ms] between interrupts. Cannot be more than 200[ms].

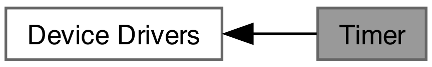
SysTick_Timer_Init()

```
void SysTick_Timer_Init (
             void  )
```

Initialize SysTick for timing purposes.

4.1.9 Timer

Collaboration diagram for Timer:



Files

- file Timer.c

  Implementation for timer module.
- file Timer.h

  Driver module for general-purpose timer modules.

Timer0A

- void Timer0A_Init (void)

  Initialize timer 0 as 32-bit, one-shot, countdown timer.
- void Timer0A_Start (uint32_t time_ms)

  Count down starting from the inputted value.
- uint8_t Timer0A_isCounting (void)

  Returns 1 if Timer0 is still counting and 0 if not.
- void Timer0A_Wait1ms (uint32_t time_ms)

  Wait for the specified amount of time in [ms].

Timer1A

- void Timer1A_Init (uint32_t time_ms)

  Initialize timer 1 as a 32-bit, periodic, countdown timer with interrupts.

Timer2A

- void Timer2A_Init (void)

  Initialize timer 2 as 32-bit, one-shot, countdown timer.
- void Timer2A_Start (uint32_t time_ms)

  Count down starting from the inputted value.
- uint8_t Timer2A_isCounting (void)

  Returns 1 if Timer2 is still counting and 0 if not.
- void Timer2A_Wait1ms (uint32_t time_ms)

  Wait for the specified amount of time in [ms].
- void Timer3A_Init (uint32_t time_ms)

  Initialize Timer3A as a 32-bit, periodic, countdown timer that triggers ADC sample capture.

4.1.9.1 Detailed Description

Functions for timing and periodic interrupts via general-purpose timer modules (GPTM).

4.1.9.2 Function Documentation

Timer0A_Init()

```
void Timer0A_Init (
             void  )
```

Initialize timer 0 as 32-bit, one-shot, countdown timer.

Timer0A_isCounting()

```
uint8_t Timer0A_isCounting (
             void  )
```

Returns 1 if Timer0 is still counting and 0 if not.

Returns

uint8_t status

Timer0A_Start()

```
void Timer0A_Start (
             uint32_t time_ms )
```

Count down starting from the inputted value.

Parameters

time_ms	Time in [ms] to load into Timer 0. Must be <= 53 seconds.

Timer0A_Wait1ms()

```
void Timer0A_Wait1ms (
             uint32_t time_ms )
```

Wait for the specified amount of time in [ms].

Parameters

time_ms	Time in [ms] to load into Timer 0. Must be <= 53 seconds.

Timer1A_Init()

```
void Timer1A_Init (
             uint32_t time_ms )
```

Initialize timer 1 as a 32-bit, periodic, countdown timer with interrupts.

Parameters

time_ms	Time in [ms] between interrupts. Must be <= 53 seconds.

Timer2A_Init()

```
void Timer2A_Init (
             void  )
```

Initialize timer 2 as 32-bit, one-shot, countdown timer.

Timer2A_isCounting()

```
uint8_t Timer2A_isCounting (
             void  )
```

Returns 1 if Timer2 is still counting and 0 if not.

Returns

uint8_t status

Timer2A_Start()

```
void Timer2A_Start (
            uint32_t time_ms )
```

Count down starting from the inputted value.

Parameters

time_ms	Time in [ms] to load into Timer 2. Must be <= 53 seconds.

Timer2A_Wait1ms()

```
void Timer2A_Wait1ms (
            uint32_t time_ms )
```

Wait for the specified amount of time in [ms].

Parameters

time_ms	Time in [ms] to load into Timer 2. Must be <= 53 seconds.

Timer3A_Init()

```
void Timer3A_Init (
            uint32_t time_ms )
```

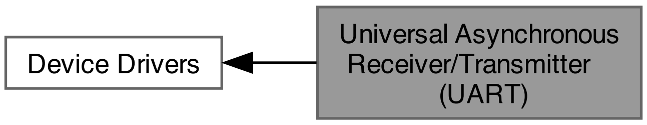
Initialize Timer3A as a 32-bit, periodic, countdown timer that triggers ADC sample capture.

Parameters

time_ms	Time in [ms] to load into Timer3A. Must be <= 53 seconds.

4.1.10 Universal Asynchronous Receiver/Transmitter (UART)

Collaboration diagram for Universal Asynchronous Receiver/Transmitter (UART):



Files

- file UART.c

  Source code for UART module.
- file UART.h

  Driver module for serial communication via UART0 and UART 1.
- file UART_New.c

  Source code for UART module.

Macros

- #define **ASCII_CONVERSION** 0x30
- #define **UART0_TX_FULL** (UART0_FR_R & 0x20)
- #define **UART0_BUFFER_SIZE** 16
- #define **UART0_INTERRUPT_NUM** 5
- #define **ASCII_CONVERSION** 0x30
- #define **UART0_TX_FULL** (UART0_FR_R & 0x20)
- #define **UART0_BUFFER_SIZE** 16
- #define **UART0_INTERRUPT_NUM** 5

Functions

- void UART0_Init (void)

  Initialize UART0 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART0_ReadChar (void)

  Read a single character from UART0.
- void UART0_WriteChar (unsigned char input_char)

  Write a single character to UART0.
- void UART0_WriteStr (void ∗input_str)

  Write a C string to UART0.
- void UART0_WriteInt (uint32_t n)

  Write a 32-bit unsigned integer to UART0.
- void UART0_WriteFloat (double n, uint8_t num_decimals)

  Write a floating-point number to UART0.
- void UART0_IRQ_AddChar (unsigned char input_char)

  Add a single character to UART0's FIFO.
- void UART0_IRQ_AddStr (void ∗input_str)

  Add a string to UART0's FIFO.
- void UART0_IRQ_AddInt (uint32_t n)

  Add an integer to UART0's FIFO.
- void UART0_IRQ_Start (void)

  Transmit the UART0's FIFO's contents via interrupt.
- void **UART0_Handler** (void)
- void UART1_Init (void)

  Initialize UART1 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART1_ReadChar (void)

  Read a single character from UART1.
- void UART1_WriteChar (unsigned char input_char)

  Write a single character to UART1.
- void UART1_WriteStr (void ∗input_str)

  Write a C string to UART1.

4.1.10.1 Detailed Description

Functions for UART-based communication.

4.1.10.2 Function Documentation

UART0_Init()

```
void UART0_Init (
            void  )
```

Initialize UART0 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.

Given the bus frequency (`f_bus`) and desired baud rate (`BR`), the baud rate divisor (`BRD`) can be calculated: $BRD = f_{bus}/(16 * BR)$

The integer BRD (`IBRD`) is simply the integer part of the BRD: $IBRD = int(BRD)$

The fractional BRD (`FBRD`) is calculated using the fractional part (`mod(BRD,1)`) of the BRD: $FBRD = int((mod(BRD,1) * 64) + 0.5)$

Given the bus frequency (`f_bus`) and desired baud rate (`BR`), the baud rate divisor (`BRD`) can be calculated: $BRD = f_{bus}/(16 * BR)$

The integer BRD (`IBRD`) is simply the integer part of the BRD: $IBRD = int(BRD)$

The fractional BRD (`FBRD`) is calculated using the fractional part (`mod(BRD,1)`) of the BRD: $FBRD = int((mod(BRD,1) * 64) + 0.5)$

UART0_IRQ_AddChar()

```
void UART0_IRQ_AddChar (
            unsigned char input_char )
```

Add a single character to UART0's FIFO.

Parameters

input_char	ASCII character.

Parameters

input_char	ASCII character.

UART0_IRQ_AddInt()

```
void UART0_IRQ_AddInt (
            uint32_t n )
```

Add an integer to UART0's FIFO.

Parameters

n	32-bit integer to be converted and transmitted.

Parameters

n	32-bit integer to be converted and transmitted.

UART0_IRQ_AddStr()

```
void UART0_IRQ_AddStr (
            void * input_str )
```

Add a string to UART0's FIFO.

Parameters

input_str	(Pointer to) array of ASCII characters.

Parameters

input_str	(Pointer to) array of ASCII characters.

UART0_IRQ_Start()

```
void UART0_IRQ_Start (
            void )
```

Transmit the UART0's FIFO's contents via interrupt.

This function writes to the Software Trigger Interrupt (`SWTRIG`) register to activate the `UART0_Handler()` function rather than relying on the TM4C123's built-in UART0 interrupt sources.

This function writes to the Software Trigger Interrupt (`SWTRIG`) register to activate the `UART0_Handler()` function rather than relying on the TM4C123's built-in UART0 interrupt sources.

UART0_ReadChar()

```
unsigned char UART0_ReadChar (
            void )
```

Read a single character from UART0.

Returns

input_char

Returns

input_char

This function uses busy-wait synchronization to read a character from UART0.

This function uses busy-wait synchronization to read a character from UART0.

UART0_WriteChar()

```
void UART0_WriteChar (
            unsigned char input_char )
```

Write a single character to UART0.

Parameters

input_char	

Parameters

input_char	

This function uses busy-wait synchronization to write a character to UART0.

This function uses busy-wait synchronization to write a character to UART0.

UART0_WriteFloat()

```
void UART0_WriteFloat (
            double n,
            uint8_t num_decimals )
```

Write a floating-point number to UART0.

Parameters

n	Floating-point number to be converted and transmitted.
num_decimals	Number of digits after the decimal point to include.

Parameters

n	Floating-point number to be converted and transmitted.
num_decimals	Number of digits after the decimal point to include.

UART0_WriteInt()

```
void UART0_WriteInt (
            uint32_t n )
```

Write a 32-bit unsigned integer to UART0.

Parameters

n	32-bit unsigned integer to be converted and transmitted

Parameters

n	32-bit unsigned integer to be converted and transmitted

UART0_WriteStr()

```
void UART0_WriteStr (
            void * input_str )
```

Write a C string to UART0.

Parameters

input_str	(Pointer to) array of ASCII characters.

Parameters

input_str	(Pointer to) array of ASCII characters.

This function uses UART0_WriteChar() function to write a C string to UART0. The function writes until either the entire string has been written or a null-terminated character has been reached.

This function uses UART0_WriteChar() function to write a C string to UART0. The function writes until either the entire string has been written or a null-terminated character has been reached.

UART1_Init()

```
void UART1_Init (
            void )
```

Initialize UART1 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.

Given the bus frequency (`f_bus`) and desired baud rate (`BR`), the baud rate divisor (`BRD`) can be calculated: $BRD = f_{bus}/(16 * BR)$

The integer BRD (`IBRD`) is simply the integer part of the BRD: $IBRD = int(BRD)$

The fractional BRD (`FBRD`) is calculated using the fractional part (`mod(BRD,1)`) of the BRD: $FBRD = int((mod(BRD, 1) * 64) + 0.5)$

NOTE: LCRH must be accessed *AFTER* setting the `BRD` register

Given the bus frequency (`f_bus`) and desired baud rate (`BR`), the baud rate divisor (`BRD`) can be calculated: $BRD = f_{bus}/(16 * BR)$

The integer BRD (`IBRD`) is simply the integer part of the BRD: $IBRD = int(BRD)$

The fractional BRD (`FBRD`) is calculated using the fractional part (`mod(BRD,1)`) of the BRD: $FBRD = int((mod(BRD, 1) * 64) + 0.5)$

NOTE: LCRH must be accessed *AFTER* setting the `BRD` register

UART1_ReadChar()

```
unsigned char UART1_ReadChar (
            void )
```

Read a single character from UART1.

Returns

input_char

Returns

input_char

This function uses busy-wait synchronization to read a character from UART1.

This function uses busy-wait synchronization to read a character from UART1.

UART1_WriteChar()

```
void UART1_WriteChar (
            unsigned char input_char )
```

Write a single character to UART1.

Parameters

input_char	

Parameters

input_char	

This function uses busy-wait synchronization to write a character to UART1.

This function uses busy-wait synchronization to write a character to UART1.

UART1_WriteStr()

```
void UART1_WriteStr (
            void * input_str )
```

Write a C string to UART1.

Parameters

input_str	C string

Parameters

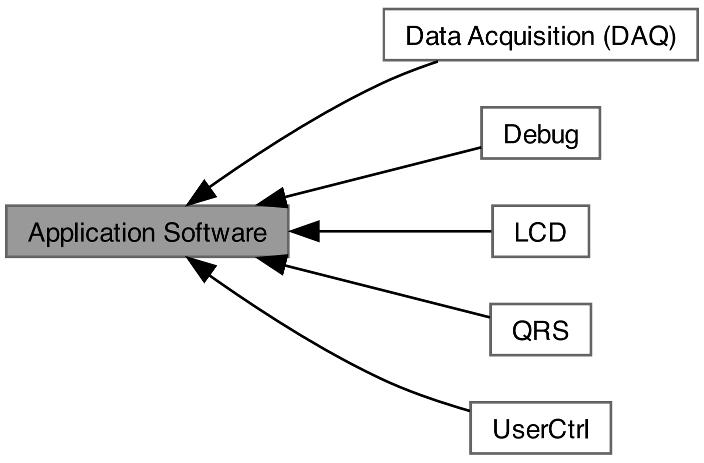
input_str	C string

This function uses UART1_WriteChar() function to write a C string to UART1. The function writes until either the entire string has been written or a null-terminated character has been reached.

This function uses UART1_WriteChar() function to write a C string to UART1. The function writes until either the entire string has been written or a null-terminated character has been reached.

4.2 Application Software

Collaboration diagram for Application Software:



Modules

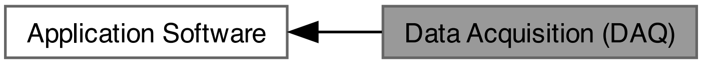
- Data Acquisition (DAQ)
- Debug
- LCD
- QRS
- UserCtrl

4.2.1 Detailed Description

Application-specific software modules.

4.2.2 Data Acquisition (DAQ)

Collaboration diagram for Data Acquisition (DAQ):



Files

- file DAQ.c

  Source code for DAQ module.
- file DAQ.h

  Application software for handling data acquision (DAQ) functions.

Macros

- #define **SAMPLING_PERIOD_MS** 5

  sampling period in ms ($T_s = 1/f_s$)

Typedefs

- typedef arm_biquad_casd_df1_inst_f32 **filt_t**

Functions

- void **DAQ_Init** (void)
- volatile float32_t **DAQ_Filter** (volatile float32_t inputSample)

4.2.2.1 Detailed Description

Module for managing data acquisition (DAQ) functions.

4.2.3 Debug

Collaboration diagram for Debug:

Application Software
Debug

Module for debugging functions, including serial output and assertion.

4.2.4 LCD

Collaboration diagram for LCD:

Application Software
LCD

Files

- file LCD.c

  Source code for LCD module.
- file LCD.h

  Module for outputting the ECG waveform and HR to a liquid crystal display (LCD).

Macros

- #define **X_MAX** NUM_ROWS
- #define **Y_MAX** NUM_COLS
- #define **LCD_BLACK** (uint8_t) 0x00
- #define **LCD_RED** (uint8_t) 0x04
- #define **LCD_GREEN** (uint8_t) 0x02
- #define **LCD_BLUE** (uint8_t) 0x01
- #define **LCD_YELLOW** (uint8_t) 0x06
- #define **LCD_CYAN** (uint8_t) 0x03
- #define **LCD_PURPLE** (uint8_t) 0x05
- #define **LCD_WHITE** (uint8_t) 0x07
- #define **LCD_BLACK_INV** (uint8_t) LCD_WHITE
- #define **LCD_RED_INV** (uint8_t) LCD_CYAN
- #define **LCD_GREEN_INV** (uint8_t) LCD_PURPLE
- #define **LCD_BLUE_INV** (uint8_t) LCD_YELLOW
- #define **LCD_YELLOW_INV** (uint8_t) LCD_BLUE
- #define **LCD_CYAN_INV** (uint8_t) LCD_RED
- #define **LCD_PURPLE_INV** (uint8_t) LCD_GREEN
- #define **LCD_WHITE_INV** (uint8_t) LCD_BLACK

Init./Config. Functions

- void LCD_Init (void)

  Initialize the LCD driver and its internal independencies.
- void **LCD_toggleOutput** (void)

  Toggle display output `ON` or `OFF` (`OFF` by default). Turning output `OFF` prevents the LCD driver from refreshing the display, which can prevent abnormalities like screen tearing while attempting to update the image.
- void **LCD_toggleInversion** (void)

  Toggle color inversion `ON` or `OFF` (`OFF` by default).
- void **LCD_toggleColorDepth** (void)

  Toggle 16-bit or 18-bit color depth (16-bit by default).

Drawing Area Definition Functions

- void LCD_setArea (uint16_t x1_new, uint16_t x2_new, uint16_t y1_new, uint16_t y2_new)

  Set the area of the display to be written to. `0 <= x1 <= x2 < X_MAX 0 <= y1 <= y2 < Y_MAX`
- void LCD_setX (uint16_t x1_new, uint16_t x2_new)

  Set only new x-coordinates to be written to. `0 <= x1 <= x2 < X_MAX`
- void LCD_setY (uint16_t y1_new, uint16_t y2_new)

  Set only new y-coordinates to be written to. `0 <= y1 <= y2 < Y_MAX`

Color Setting Functions

- void LCD_setColor (uint8_t R_val, uint8_t G_val, uint8_t B_val)

  Set the current color value for the display. Only the first 5-6 bits of each inputted value are used.
- void LCD_setColor_3bit (uint8_t color_code)

  Set the color value via a 3-bit code.

Drawing Functions

- void LCD_draw (void)

  Draw on the LCD display. Call this function after setting the drawable area via `LCD_setArea()`*, or after individually calling* `LCD_setX()` *and/or* `LCD_setY()`*.*
- void **LCD_fill** (void)

  Fill the display with a single color.
- void LCD_drawHLine (uint16_t yCenter, uint16_t lineWidth)

  Draw a horizontal line across the entire display.
- void LCD_drawVLine (uint16_t xCenter, uint16_t lineWidth)

  Draw a vertical line across the entire display.
- void LCD_drawRectangle (uint16_t x1, uint16_t dx, uint16_t y1, uint16_t dy, bool is_filled)

  Draw a rectangle of size `dx` *x* `dy` *onto the display. The bottom-left corner will be located at* `(x1, y1)`*.*
- void LCD_graphSample (uint16_t x1, uint16_t dx, uint16_t y1, uint16_t dy, uint16_t y_min, uint16_t y_max, uint16_t color_code)

  Draw a rectangle of size `dx` *x* `dy` *and blank out all other pixels between* `y_min` *and* `y_max`*.*

4.2.4.1 Detailed Description

Module for displaying graphs on an LCD via the ILI9341 module.

4.2.4.2 Function Documentation

LCD_draw()

```
void LCD_draw (
            void  )
```

Draw on the LCD display. Call this function after setting the drawable area via `LCD_setArea()`, or after individually calling `LCD_setX()` and/or `LCD_setY()`.

References LCD_t::B_val, LCD_t::G_val, ILI9341_write1px(), ILI9341_writeMemCmd(), LCD_t::is_16bit, LCD_t::numPixels, and LCD_t::R_val.

LCD_drawHLine()

```
void LCD_drawHLine (
            uint16_t yCenter,
            uint16_t lineWidth )
```

Draw a horizontal line across the entire display.

Parameters

yCenter	y-coordinate to center the line on
lineWidth	width of the line; should be a positive, odd number

LCD_drawRectangle()

```
void LCD_drawRectangle (
            uint16_t x1,
            uint16_t dx,
            uint16_t y1,
            uint16_t dy,
            bool is_filled )
```

Draw a rectangle of size `dx` x `dy` onto the display. The bottom-left corner will be located at `(x1, y1)`.

Parameters

x1	lowest (left-most) x-coordinate
dx	length (horizontal distance) of the rectangle
y1	lowest (bottom-most) y-coordinate
dy	height (vertical distance) of the rectangle
is_filled	`true` to fill the rectangle, `false` to leave it unfilled

LCD_drawVLine()

```
void LCD_drawVLine (
            uint16_t xCenter,
            uint16_t lineWidth )
```

Draw a vertical line across the entire display.

Parameters

xCenter	x-coordinate to center the line on
lineWidth	width of the line; should be a positive, odd number

LCD_graphSample()

```
void LCD_graphSample (
            uint16_t x1,
            uint16_t dx,
            uint16_t y1,
            uint16_t dy,
            uint16_t y_min,
            uint16_t y_max,
            uint16_t color_code )
```

Draw a rectangle of size `dx` x `dy` and blank out all other pixels between `y_min` and `y_max`.

Parameters

x1	lowest (left-most) x-coordinate
dx	length (horizontal distance) of the column
y1	y-coordinate of the pixel's bottom side
dy	height (vertical distance) of the pixel
y_min	lowest (bottom-most) y-coordinate
y_max	highest (top-most) y-coordinate
color_code	3-bit color code

TODO: Write description

LCD_Init()

```
void LCD_Init (
             void  )
```

Initialize the LCD driver and its internal independencies.

LCD_setArea()

```
void LCD_setArea (
             uint16_t x1_new,
             uint16_t x2_new,
             uint16_t y1_new,
             uint16_t y2_new )
```

Set the area of the display to be written to. `0 <= x1 <= x2 < X_MAX` `0 <= y1 <= y2 < Y_MAX`

Parameters

x1_new	left-most x-coordinate
x2_new	right-most x-coordinate
y1_new	lowest y-coordinate
y2_new	highest y-coordinate

LCD_setColor()

```
void LCD_setColor (
             uint8_t R_val,
             uint8_t G_val,
             uint8_t B_val )
```

Set the current color value for the display. Only the first 5-6 bits of each inputted value are used.

Parameters

R_val	5-bit (`[0-31]`) R value; 6-bit (`[0-63]`) if color depth is 18-bit
G_val	6-bit (`[0-63]`) G value
B_val	5-bit (`[0-31]`) B value; 6-bit (`[0-63]`) if color depth is 18-bit

LCD_setColor_3bit()

```
void LCD_setColor_3bit (
            uint8_t color_code )
```

Set the color value via a 3-bit code.

Parameters

color_code	3-bit color value to use. Bits 2, 1, 0 correspond to R, G, and B values, respectively.

This is simply a convenience function for setting the color using the macros defined in the header file. The ones with the `_INV` suffix should used when the display colors are inverted.

hex	binary	macro
0x00	000	LCD_BLACK
0x01	001	LCD_BLUE
0x02	010	LCD_GREEN
0x03	011	LCD_CYAN
0x04	100	LCD_RED
0x05	101	LCD_PURPLE
0x06	110	LCD_YELLOW
0x07	111	LCD_WHITE

LCD_setX()

```
void LCD_setX (
            uint16_t x1_new,
            uint16_t x2_new )
```

Set only new x-coordinates to be written to. `0 <= x1 <= x2 < X_MAX`

Parameters

x1_new	left-most x-coordinate
x2_new	right-most x-coordinate

LCD_setY()

```
void LCD_setY (
            uint16_t y1_new,
            uint16_t y2_new )
```

Set only new y-coordinates to be written to. `0 <= y1 <= y2 < Y_MAX`

Parameters

y1_new	lowest y-coordinate
y2_new	highest y-coordinate

4.2.5 QRS

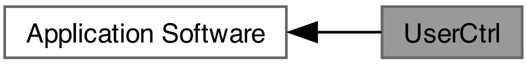
Collaboration diagram for QRS:

Application Software
QRS

Module for analyzing ECG data to determine heart rate.

4.2.6 UserCtrl

Collaboration diagram for UserCtrl:



User control module.

4.3 Program Threads

Functions

- int **main** (void)
- void GPIO_PortF_Handler (void)

  Interrupt service routine (ISR) for the UserCtrl module via GPIO Port F.
- void ADC0_SS3_Handler (void)

  Interrupt service routine (ISR) for collecting ADC samples.
- void Timer1A_Handler (void)

  Interrupt service routine (ISR) for outputting data to the LCD.

4.3.1 Detailed Description

Primary threads of execution.

4.3.2 Function Documentation

ADC0_SS3_Handler()

```
void ADC0_SS3_Handler (
             void  )
```

Interrupt service routine (ISR) for collecting ADC samples.

GPIO_PortF_Handler()

```
void GPIO_PortF_Handler (
             void  )
```

Interrupt service routine (ISR) for the UserCtrl module via GPIO Port F.

Timer1A_Handler()

```
void Timer1A_Handler (
             void  )
```

Interrupt service routine (ISR) for outputting data to the LCD.

4.4 Fifo

Files

- file FIFO.c

  Source code for FIFO buffer module.
- file FIFO.h

  FIFO buffer data structure.

Data Structures

- struct FIFO_t

Macros

- #define **FIFO_POOL_SIZE** 5

Functions

- volatile FIFO_t $*$ FIFO_Init (volatile uint32_t buffer[ ], const uint32_t N)

  Initialize a FIFO buffer of length N.

Basic Operations

- void FIFO_Put (volatile FIFO_t ∗fifo_ptr, const uint32_t val)

  Add a value to the end of the buffer.
- volatile uint32_t FIFO_Get (volatile FIFO_t ∗fifo_ptr)

  Remove the first value of the buffer.
- void FIFO_TransferOne (volatile FIFO_t ∗src_fifo_ptr, volatile FIFO_t ∗dest_fifo_ptr)

  Transfer a value from one FIFO buffer to another.

Bulk Removal

- void FIFO_Flush (volatile FIFO_t ∗fifo_ptr, uint32_t output_buffer[ ])

  Empty the FIFO buffer's contents into an array.
- void FIFO_TransferAll (volatile FIFO_t ∗src_fifo_ptr, volatile FIFO_t ∗dest_fifo_ptr)

  Transfer the contents of one FIFO buffer to another.

Status Checks

- uint32_t FIFO_PeekOne (volatile FIFO_t ∗fifo_ptr)

  See the first element in the FIFO without removing it.
- void FIFO_PeekAll (volatile FIFO_t ∗fifo_ptr, uint32_t output_buffer[ ])

  See the FIFO buffer's contents without removing them.
- bool FIFO_isFull (volatile FIFO_t ∗fifo_ptr)

  Check if the FIFO buffer is full.
- bool FIFO_isEmpty (volatile FIFO_t ∗fifo_ptr)

  Check if the FIFO buffer is empty.
- uint32_t FIFO_getCurrSize (volatile FIFO_t ∗fifo_ptr)

  Get the current size of the FIFO buffer.

4.4.1 Detailed Description

4.4.2 Function Documentation

FIFO_Flush()

```
void FIFO_Flush (
            volatile FIFO_t ∗ fifo_ptr,
            uint32_t output_buffer[ ] )
```

Empty the FIFO buffer's contents into an array.

Parameters

fifo_ptr	Pointer to source FIFO buffer.
output_buffer	Array to output values to. Should be the same length as the FIFO buffer.

FIFO_Get()

```
volatile uint32_t FIFO_Get (
             volatile FIFO_t * fifo_ptr )
```

Remove the first value of the buffer.

Parameters

fifo_ptr	Pointer to FIFO object

Returns

First sample in the FIFO.

FIFO_getCurrSize()

```
uint32_t FIFO_getCurrSize (
             volatile FIFO_t * fifo_ptr )
```

Get the current size of the FIFO buffer.

Parameters

fifo_ptr	Pointer to the FIFO buffer.

FIFO_Init()

```
volatile FIFO_t * FIFO_Init (
             volatile uint32_t buffer[],
             const uint32_t N )
```

Initialize a FIFO buffer of length `N`.

Parameters

buffer	Array of size `N` to be used as FIFO buffer
N	Length of `buffer`. Usable length is `N - 1`.

Returns

pointer to the FIFO buffer

TODO: Add details

FIFO_isEmpty()

```
bool FIFO_isEmpty (
             volatile FIFO_t * fifo_ptr )
```

Check if the FIFO buffer is empty.

Parameters

fifo_ptr	Pointer to the FIFO buffer.

Return values

true	The buffer is empty.
false	The buffer is not empty.

FIFO_isFull()

```
bool FIFO_isFull (
             volatile FIFO_t * fifo_ptr )
```

Check if the FIFO buffer is full.

Parameters

fifo_ptr	Pointer to the FIFO buffer.

Return values

true	The buffer is full.
false	The buffer is not full.

FIFO_PeekAll()

```
void FIFO_PeekAll (
             volatile FIFO_t * fifo_ptr,
             uint32_t output_buffer[] )
```

See the FIFO buffer's contents without removing them.

Parameters

fifo_ptr	Pointer to FIFO object
output_buffer	Array to output values to. Should be the same length as the FIFO buffer.

FIFO_PeekOne()

```
uint32_t FIFO_PeekOne (
             volatile FIFO_t * fifo_ptr )
```

See the first element in the FIFO without removing it.

Parameters

fifo_ptr	Pointer to FIFO object

Returns

First sample in the FIFO.

FIFO_Put()

```
void FIFO_Put (
            volatile FIFO_t * fifo_ptr,
            const uint32_t val )
```

Add a value to the end of the buffer.

Parameters

fifo_ptr	Pointer to FIFO object
val	last value in the buffer

FIFO_TransferAll()

```
void FIFO_TransferAll (
            volatile FIFO_t * src_fifo_ptr,
            volatile FIFO_t * dest_fifo_ptr )
```

Transfer the contents of one FIFO buffer to another.

Parameters

src_fifo_ptr	Pointer to source FIFO buffer.
dest_fifo_ptr	Pointer to destination FIFO buffer.

FIFO_TransferOne()

```
void FIFO_TransferOne (
            volatile FIFO_t * src_fifo_ptr,
            volatile FIFO_t * dest_fifo_ptr )
```

Transfer a value from one FIFO buffer to another.

Parameters

src_fifo_ptr	Pointer to source FIFO buffer.
dest_fifo_ptr	Pointer to destination FIFO buffer.

5 Data Structure Documentation

5.1 FIFO_t Struct Reference

Data Fields

- volatile uint32_t * **buffer**

  (pointer to) array to use as FIFO buffer
- volatile uint32_t **N**

  length of `buffer`
- volatile uint32_t **front_idx**

  idx of front of FIFO
- volatile uint32_t **back_idx**

  idx of back of FIFO

The documentation for this struct was generated from the following file:

- FIFO.c

5.2 GPIO_Port_t Struct Reference

Data Fields

- const uint32_t **BASE_ADDRESS**
- bool **isInit**

The documentation for this struct was generated from the following file:

- GPIO_New.c

5.3 LCD_t Struct Reference

Data Fields

- uint16_t **x1**

  starting x-value in range [0, x2]
- uint16_t **x2**

  ending x-value in range [0, NUM_ROWS)
- uint16_t **y1**

  starting y-value in range [0, y2]
- uint16_t **y2**

  ending x-value in range [0, NUM_COLS)
- uint32_t **numPixels**

  number of pixels to write to; `= (x2 - x1 + 1) * (y2 - y1 + 1)`
- uint8_t **R_val**

  5 or 6-bit R value
- uint8_t **G_val**

6-bit G value
- uint8_t **B_val**

  5 or 6-bit B value
- bool **is_outputON**

  if `true`, the LCD driver is writing from its memory to display
- bool **is_inverted**

  if `true`, the display's colors are inverted
- bool **is_16bit**

  `true` for 16-bit color depth (65K colors, 2 transfers), `false` for 18-bit
- bool **is_init**

  if `true`, LCD has been initialized

The documentation for this struct was generated from the following file:

- LCD.c

5.4 Led_t Struct Reference

Data Fields

- GPIO_Port_t ∗ **GPIO_PORT_PTR**

  pointer to GPIO port data structure
- GPIO_Pin_t **GPIO_PIN**

  GPIO pin number.
- bool **is_ON**

  state indicator

The documentation for this struct was generated from the following file:

- Led.c

6 File Documentation

6.1 DAQ.c File Reference

Source code for DAQ module.

```
#include "DAQ.h"
#include "ADC.h"
#include "Timer.h"
#include "arm_math_types.h"
#include "dsp/filtering_functions.h"
#include "FIFO.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Macros

- #define **SAMPLING_PERIOD_MS** 5
  sampling period in ms ($T_s = 1/f_s$)

Typedefs

- typedef arm_biquad_casd_df1_inst_f32 **filt_t**

Functions

- void **DAQ_Init** (void)
- volatile float32_t **DAQ_Filter** (volatile float32_t inputSample)

6.1.1 Detailed Description

Source code for DAQ module.

Author

Bryan McElvy

6.2 DAQ.h File Reference

Application software for handling data acquision (DAQ) functions.

```
#include "ADC.h"
#include "Timer.h"
#include "arm_math_types.h"
#include "dsp/filtering_functions.h"
#include "FIFO.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void **DAQ_Init** (void)
- volatile float32_t **DAQ_Filter** (volatile float32_t inputSample)

6.2.1 Detailed Description

Application software for handling data acquision (DAQ) functions.

Author

Bryan McElvy

6.3 Debug.h File Reference

Functions to output debugging information to a serial port via UART.

```
#include "UART.h"
#include "arm_math_types.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Enumerations

- enum **messages** {
  START_MSG , **DAQ_INIT** , **QRS_INIT** , **LCD_INIT** ,
  ASSERT_FALSE }

Functions

- void Debug_Init (void)

  Initialize the Debug module and send a start message to the serial port.
- void Debug_SendMsg (void ∗message)

  Send a message to the serial port.
- void **Debug_SendFromList** (uint8_t msg_idx)
- void **Debug_WriteFloat** (float64_t value)
- void Debug_Assert (bool condition)

  Stops program if `condition` is `true`. Useful for bug detection during debugging.

6.3.1 Detailed Description

Functions to output debugging information to a serial port via UART.

Author

Bryan McElvy

6.3.2 Function Documentation

Debug_Assert()

```
void Debug_Assert (
            bool condition )
```

Stops program if `condition` is `true`. Useful for bug detection during debugging.

Parameters

condition	

Debug_Init()

```
void Debug_Init (
             void  )
```

Initialize the Debug module and send a start message to the serial port.

Debug_SendMsg()

```
void Debug_SendMsg (
             void * message )
```

Send a message to the serial port.

Parameters

message	(Pointer to) array of ASCII characters.

6.4 LCD.c File Reference

Source code for LCD module.

```
#include "LCD.h"
#include "ILI9341.h"
#include "SPI.h"
#include "Timer.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
#include <stdbool.h>
```

Data Structures

- struct LCD_t

Functions

- void LCD_Init (void)

  Initialize the LCD driver and its internal independencies.
- void **LCD_toggleOutput** (void)

  Toggle display output `ON` or `OFF` (`OFF` by default). Turning output `OFF` prevents the LCD driver from refreshing the display, which can prevent abnormalities like screen tearing while attempting to update the image.
- void **LCD_toggleInversion** (void)

  Toggle color inversion `ON` or `OFF` (`OFF` by default).
- void **LCD_toggleColorDepth** (void)

  Toggle 16-bit or 18-bit color depth (16-bit by default).
- void LCD_setArea (uint16_t x1, uint16_t x2, uint16_t y1, uint16_t y2)

  Set the area of the display to be written to. `0 <= x1 <= x2 < X_MAX 0 <= y1 <= y2 < Y_MAX`

- void LCD_setX (uint16_t x1, uint16_t x2)

  Set only new x-coordinates to be written to. `0 <= x1 <= x2 < X_MAX`
- void LCD_setY (uint16_t y1, uint16_t y2)

  Set only new y-coordinates to be written to. `0 <= y1 <= y2 < Y_MAX`
- void LCD_setColor (uint8_t R_val, uint8_t G_val, uint8_t B_val)

  Set the current color value for the display. Only the first 5-6 bits of each inputted value are used.
- void LCD_setColor_3bit (uint8_t color_code)

  Set the color value via a 3-bit code.
- void LCD_draw (void)

  Draw on the LCD display. Call this function after setting the drawable area via `LCD_setArea()`*, or after individually calling* `LCD_setX()` *and/or* `LCD_setY()`*.*
- void **LCD_fill** (void)

  Fill the display with a single color.
- void LCD_drawHLine (uint16_t yCenter, uint16_t lineWidth)

  Draw a horizontal line across the entire display.
- void LCD_drawVLine (uint16_t xCenter, uint16_t lineWidth)

  Draw a vertical line across the entire display.
- void LCD_drawRectangle (uint16_t x1, uint16_t dx, uint16_t y1, uint16_t dy, bool is_filled)

  Draw a rectangle of size `dx` *x* `dy` *onto the display. The bottom-left corner will be located at* `(x1, y1)`*.*
- void LCD_graphSample (uint16_t x1, uint16_t dx, uint16_t y1, uint16_t dy, uint16_t y_min, uint16_t y_max, uint16_t color_code)

  Draw a rectangle of size `dx` *x* `dy` *and blank out all other pixels between* `y_min` *and* `y_max`*.*

6.4.1 Detailed Description

Source code for LCD module.

Author

Bryan McElvy

6.5 LCD.h File Reference

Module for outputting the ECG waveform and HR to a liquid crystal display (LCD).

```
#include "ILI9341.h"
#include "SPI.h"
#include "Timer.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
#include <stdbool.h>
```

Macros

- #define **X_MAX** NUM_ROWS
- #define **Y_MAX** NUM_COLS
- #define **LCD_BLACK** (uint8_t) 0x00
- #define **LCD_RED** (uint8_t) 0x04
- #define **LCD_GREEN** (uint8_t) 0x02
- #define **LCD_BLUE** (uint8_t) 0x01
- #define **LCD_YELLOW** (uint8_t) 0x06
- #define **LCD_CYAN** (uint8_t) 0x03
- #define **LCD_PURPLE** (uint8_t) 0x05
- #define **LCD_WHITE** (uint8_t) 0x07
- #define **LCD_BLACK_INV** (uint8_t) LCD_WHITE
- #define **LCD_RED_INV** (uint8_t) LCD_CYAN
- #define **LCD_GREEN_INV** (uint8_t) LCD_PURPLE
- #define **LCD_BLUE_INV** (uint8_t) LCD_YELLOW
- #define **LCD_YELLOW_INV** (uint8_t) LCD_BLUE
- #define **LCD_CYAN_INV** (uint8_t) LCD_RED
- #define **LCD_PURPLE_INV** (uint8_t) LCD_GREEN
- #define **LCD_WHITE_INV** (uint8_t) LCD_BLACK

Functions

Init./Config. Functions

- void LCD_Init (void)

  Initialize the LCD driver and its internal independencies.
- void **LCD_toggleOutput** (void)

  Toggle display output `ON` or `OFF` (`OFF` by default). Turning output `OFF` prevents the LCD driver from refreshing the display, which can prevent abnormalities like screen tearing while attempting to update the image.
- void **LCD_toggleInversion** (void)

  Toggle color inversion `ON` or `OFF` (`OFF` by default).
- void **LCD_toggleColorDepth** (void)

  Toggle 16-bit or 18-bit color depth (16-bit by default).

Drawing Area Definition Functions

- void LCD_setArea (uint16_t x1_new, uint16_t x2_new, uint16_t y1_new, uint16_t y2_new)

  Set the area of the display to be written to. `0 <= x1 <= x2 < X_MAX 0 <= y1 <= y2 < Y_MAX`
- void LCD_setX (uint16_t x1_new, uint16_t x2_new)

  Set only new x-coordinates to be written to. `0 <= x1 <= x2 < X_MAX`
- void LCD_setY (uint16_t y1_new, uint16_t y2_new)

  Set only new y-coordinates to be written to. `0 <= y1 <= y2 < Y_MAX`

Color Setting Functions

- void LCD_setColor (uint8_t R_val, uint8_t G_val, uint8_t B_val)

  Set the current color value for the display. Only the first 5-6 bits of each inputted value are used.
- void LCD_setColor_3bit (uint8_t color_code)

  Set the color value via a 3-bit code.

Drawing Functions

- void LCD_draw (void)

Draw on the LCD display. Call this function after setting the drawable area via `LCD_setArea()`, or after individually calling `LCD_setX()` and/or `LCD_setY()`.

- void **LCD_fill** (void)

  Fill the display with a single color.
- void LCD_drawHLine (uint16_t yCenter, uint16_t lineWidth)

  Draw a horizontal line across the entire display.
- void LCD_drawVLine (uint16_t xCenter, uint16_t lineWidth)

  Draw a vertical line across the entire display.
- void LCD_drawRectangle (uint16_t x1, uint16_t dx, uint16_t y1, uint16_t dy, bool is_filled)

  Draw a rectangle of size `dx` x `dy` onto the display. The bottom-left corner will be located at `(x1, y1)`.
- void LCD_graphSample (uint16_t x1, uint16_t dx, uint16_t y1, uint16_t dy, uint16_t y_min, uint16_t y_max, uint16_t color_code)

  Draw a rectangle of size `dx` x `dy` and blank out all other pixels between `y_min` and `y_max`.

6.5.1 Detailed Description

Module for outputting the ECG waveform and HR to a liquid crystal display (LCD).

Author

Bryan McElvy

6.6 QRS.h File Reference

QRS detection algorithm functions.

```
#include "dsp/filtering_functions_f16.h"
```

6.6.1 Detailed Description

QRS detection algorithm functions.

Author

Bryan McElvy

This module contains functions for detecting heart rate (`HR`) using a simplified version of the Pan-Tompkins algorithm.

6.7 UserCtrl.h File Reference

Interface for user control module.

```
#include "GPIO.h"
#include "Timer.h"
```

Functions

- void UserCtrl_Init ()
  Initializes the UserCtrl module and its dependencies (Timer0B and GPIO_PortF)

6.7.1 Detailed Description

Interface for user control module.

Author

Bryan McElvy

6.7.2 Function Documentation

UserCtrl_Init()

```
void UserCtrl_Init ( )
```

Initializes the UserCtrl module and its dependencies (Timer0B and GPIO_PortF)

6.8 FIFO.c File Reference

Source code for FIFO buffer module.

```
#include "FIFO.h"
#include <stdint.h>
#include <stdbool.h>
```

Data Structures

- struct FIFO_t

Functions

- volatile FIFO_t ∗ FIFO_Init (volatile uint32_t buffer[ ], const uint32_t N)
  Initialize a FIFO buffer of length N.

Basic Operations

- void FIFO_Put (volatile FIFO_t ∗fifo_ptr, const uint32_t val)
  Add a value to the end of the buffer.
- volatile uint32_t FIFO_Get (volatile FIFO_t ∗fifo_ptr)
  Remove the first value of the buffer.
- void FIFO_TransferOne (volatile FIFO_t ∗src_fifo_ptr, volatile FIFO_t ∗dest_fifo_ptr)
  Transfer a value from one FIFO buffer to another.

Bulk Removal

- void FIFO_Flush (volatile FIFO_t ∗fifo_ptr, uint32_t output_buffer[ ])
  Empty the FIFO buffer's contents into an array.
- void FIFO_TransferAll (volatile FIFO_t ∗src_fifo_ptr, volatile FIFO_t ∗dest_fifo_ptr)
  Transfer the contents of one FIFO buffer to another.

Status Checks

- uint32_t FIFO_PeekOne (volatile FIFO_t ∗fifo_ptr)
  See the first element in the FIFO without removing it.
- void FIFO_PeekAll (volatile FIFO_t ∗fifo_ptr, uint32_t output_buffer[ ])
  See the FIFO buffer's contents without removing them.
- bool FIFO_isFull (volatile FIFO_t ∗fifo_ptr)
  Check if the FIFO buffer is full.
- bool FIFO_isEmpty (volatile FIFO_t ∗fifo_ptr)
  Check if the FIFO buffer is empty.
- uint32_t FIFO_getCurrSize (volatile FIFO_t ∗fifo_ptr)
  Get the current size of the FIFO buffer.

6.8.1 Detailed Description

Source code for FIFO buffer module.

Author

Bryan McElvy

6.9 FIFO.h File Reference

FIFO buffer data structure.

```
#include <stdint.h>
#include <stdbool.h>
```

Macros

- #define **FIFO_POOL_SIZE** 5

Functions

- volatile FIFO_t ∗ FIFO_Init (volatile uint32_t buffer[ ], const uint32_t N)
  Initialize a FIFO buffer of length `N`.

Basic Operations

- void FIFO_Put (volatile FIFO_t ∗fifo_ptr, const uint32_t val)
  Add a value to the end of the buffer.
- volatile uint32_t FIFO_Get (volatile FIFO_t ∗fifo_ptr)
  Remove the first value of the buffer.
- void FIFO_TransferOne (volatile FIFO_t ∗src_fifo_ptr, volatile FIFO_t ∗dest_fifo_ptr)
  Transfer a value from one FIFO buffer to another.

Bulk Removal

- void FIFO_Flush (volatile FIFO_t ∗fifo_ptr, uint32_t output_buffer[ ])
    Empty the FIFO buffer's contents into an array.
- void FIFO_TransferAll (volatile FIFO_t ∗src_fifo_ptr, volatile FIFO_t ∗dest_fifo_ptr)
    Transfer the contents of one FIFO buffer to another.

Status Checks

- uint32_t FIFO_PeekOne (volatile FIFO_t ∗fifo_ptr)
    See the first element in the FIFO without removing it.
- void FIFO_PeekAll (volatile FIFO_t ∗fifo_ptr, uint32_t output_buffer[ ])
    See the FIFO buffer's contents without removing them.
- bool FIFO_isFull (volatile FIFO_t ∗fifo_ptr)
    Check if the FIFO buffer is full.
- bool FIFO_isEmpty (volatile FIFO_t ∗fifo_ptr)
    Check if the FIFO buffer is empty.
- uint32_t FIFO_getCurrSize (volatile FIFO_t ∗fifo_ptr)
    Get the current size of the FIFO buffer.

6.9.1 Detailed Description

FIFO buffer data structure.

Author

Bryan McElvy

6.10 lookup.c File Reference

Lookup table source code.

```
#include "lookup.h"
#include "arm_math_types.h"
```

Functions

- const float32_t ∗ Lookup_GetPtr_ADC (void)
    Return a pointer to the ADC lookup table.

6.10.1 Detailed Description

Lookup table source code.

Author

Bryan McElvy

6.10.2 Function Documentation

Lookup_GetPtr_ADC()

```
const float32_t * Lookup_GetPtr_ADC (
            void  )
```

Return a pointer to the ADC lookup table.

Returns

const float32_t∗

6.11 lookup.h File Reference

Lookup table API.

```
#include "arm_math_types.h"
```

Macros

- #define **LOOKUP_ADC_MAX** (float32_t) 5.5

Functions

- const float32_t ∗ Lookup_GetPtr_ADC (void)

  Return a pointer to the ADC lookup table.

6.11.1 Detailed Description

Lookup table API.

Author

Bryan McElvy

6.11.2 Function Documentation

Lookup_GetPtr_ADC()

```
const float32_t * Lookup_GetPtr_ADC (
            void  )
```

Return a pointer to the ADC lookup table.

Returns

const float32_t∗

6.12 ADC.c File Reference

Source code for ADC module.

```
#include "lookup.h"
#include "Timer.h"
#include "arm_math_types.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Macros

- #define **GPIO_PIN_5** ((uint8_t) (1 << 5))

Functions

- void **ADC_Init** (void)

  Initialize ADC0 as a single-input analog-to-digital converter.
- void **ADC_InterruptEnable** (void)

  Enable the ADC interrupt.
- void **ADC_InterruptDisable** (void)

  Disable the ADC interrupt.
- volatile float32_t ADC_ConvertToVolts (uint16_t raw_sample)

  Convert a raw ADC sample to voltage in [mV].

6.12.1 Detailed Description

Source code for ADC module.

Author

Bryan McElvy

6.13 ADC.h File Reference

Driver module for analog-to-digital conversion (ADC).

```
#include "lookup.h"
#include "Timer.h"
#include "arm_math_types.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void **ADC_Init** (void)

  Initialize ADC0 as a single-input analog-to-digital converter.
- void **ADC_InterruptEnable** (void)

  Enable the ADC interrupt.
- void **ADC_InterruptDisable** (void)

  Disable the ADC interrupt.
- volatile float32_t ADC_ConvertToVolts (uint16_t raw_sample)

  Convert a raw ADC sample to voltage in [mV].

6.13.1 Detailed Description

Driver module for analog-to-digital conversion (ADC).

Author

Bryan McElvy

6.14 ADC_New.c File Reference

Source code for ADC module.

```
#include "ADC.h"
#include "lookup.h"
#include "GPIO_New.h"
#include "Timer.h"
#include "arm_math_types.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void **ADC_Init** (void)

  Initialize ADC0 as a single-input analog-to-digital converter.
- void **ADC_InterruptEnable** (void)

  Enable the ADC interrupt.
- void **ADC_InterruptDisable** (void)

  Disable the ADC interrupt.
- volatile float32_t ADC_ConvertToVolts (uint16_t raw_sample)

  Convert a raw ADC sample to voltage in [mV].

6.14.1 Detailed Description

Source code for ADC module.

Author

Bryan McElvy

6.15 ADC_New.h File Reference

Driver module for analog-to-digital conversion (ADC).

```
#include "lookup.h"
#include "GPIO_New.h"
#include "Timer.h"
#include "arm_math_types.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void **ADC_Init** (void)

    Initialize ADC0 as a single-input analog-to-digital converter.
- void **ADC_InterruptEnable** (void)

    Enable the ADC interrupt.
- void **ADC_InterruptDisable** (void)

    Disable the ADC interrupt.
- volatile float32_t ADC_ConvertToVolts (uint16_t raw_sample)

    Convert a raw ADC sample to voltage in [mV].

6.15.1 Detailed Description

Driver module for analog-to-digital conversion (ADC).

Author

Bryan McElvy

6.16 GPIO.c File Reference

Source code for GPIO module.

```
#include "GPIO.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void GPIO_PF_Init (void)

    Initialize GPIO Port F.
- void GPIO_PF_LED_Init (void)

    Initialize PF1-3 to interface the LaunchPad's onboard RGB LED.
- void GPIO_PF_LED_Write (uint8_t color_mask, uint8_t on_or_off)

    Write a 1 or 0 to the selected LED(s).
- void GPIO_PF_LED_Toggle (uint8_t color_mask)

    Toggle the selected LED(s).
- void GPIO_PF_Sw_Init (void)

    Initialize PF0/4 to interface the LaunchPad's onboard switches. PF4 is Sw1, and PF0 is Sw2.
- void GPIO_PF_Interrupt_Init (void)

    Initialize GPIO Port F interrupts via Sw1 and Sw2.

6.16.1 Detailed Description

Source code for GPIO module.

Author

Bryan McElvy

6.17 GPIO.h File Reference

Driver module for using the LaunchPad's onboard switches and RGB LEDs for GPIO and interrupts.

```
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Macros

- #define **LED_RED** (uint8_t) 0x02
- #define **LED_GREEN** (uint8_t) 0x08
- #define **LED_BLUE** (uint8_t) 0x04
- #define **LED_YELLOW** (LED_RED + LED_GREEN)
- #define **LED_CYAN** (LED_BLUE + LED_GREEN)
- #define **LED_PURPLE** (LED_RED + LED_BLUE)
- #define **LED_WHITE** (LED_RED + LED_BLUE + LED_GREEN)

Functions

- void GPIO_PF_Init (void)

  Initialize GPIO Port F.
- void GPIO_PF_LED_Init (void)

  Initialize PF1-3 to interface the LaunchPad's onboard RGB LED.
- void GPIO_PF_LED_Write (uint8_t color_mask, uint8_t on_or_off)

  Write a 1 or 0 to the selected LED(s).
- void GPIO_PF_LED_Toggle (uint8_t color_mask)

  Toggle the selected LED(s).
- void GPIO_PF_Sw_Init (void)

  Initialize PF0/4 to interface the LaunchPad's onboard switches. PF4 is Sw1, and PF0 is Sw2.
- void GPIO_PF_Interrupt_Init (void)

  Initialize GPIO Port F interrupts via Sw1 and Sw2.

6.17.1 Detailed Description

Driver module for using the LaunchPad's onboard switches and RGB LEDs for GPIO and interrupts.

Author

Bryan McElvy

6.18 ILI9341.c File Reference

Source code for ILI9341 module.

```
#include "ILI9341.h"
#include "SPI.h"
#include "Timer.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
#include <stdbool.h>
```

Macros

- #define **CMD_NOP** (uint8_t) 0x00
- #define **CMD_SWRESET** (uint8_t) 0x01
- #define **CMD_SPLIN** (uint8_t) 0x10
- #define **CMD_SPLOUT** (uint8_t) 0x11
- #define **CMD_PTLON** (uint8_t) 0x12
- #define **CMD_NORON** (uint8_t) 0x13
- #define **CMD_DINVOFF** (uint8_t) 0x20
- #define **CMD_DINVON** (uint8_t) 0x21
- #define **CMD_CASET** (uint8_t) 0x2A
- #define **CMD_PASET** (uint8_t) 0x2B
- #define **CMD_RAMWR** (uint8_t) 0x2C
- #define **CMD_DISPOFF** (uint8_t) 0x28
- #define **CMD_DISPON** (uint8_t) 0x29
- #define **CMD_PLTAR** (uint8_t) 0x30
- #define **CMD_VSCRDEF** (uint8_t) 0x33
- #define **CMD_MADCTL** (uint8_t) 0x36
- #define **CMD_VSCRSADD** (uint8_t) 0x37
- #define **CMD_IDMOFF** (uint8_t) 0x38
- #define **CMD_IDMON** (uint8_t) 0x39
- #define **CMD_PIXSET** (uint8_t) 0x3A
- #define **CMD_FRMCTR1** (uint8_t) 0xB1
- #define **CMD_FRMCTR2** (uint8_t) 0xB2
- #define **CMD_FRMCTR3** (uint8_t) 0xB3
- #define **CMD_PRCTR** (uint8_t) 0xB5
- #define **CMD_IFCTL** (uint8_t) 0xF6

Functions

- void **ILI9341_Init** (void)

  Initialize the LCD driver, the SPI module, and Timer2A.
- void ILI9341_resetHard (void)

  Perform a hardware reset of the LCD driver.
- void ILI9341_resetSoft (void)

  Perform a software reset of the LCD driver.
- void ILI9341_setSleepMode (bool is_sleeping)

  Enter or exit sleep mode. The LCD driver is in sleep mode by default upon powering on or either kind of reset.
- void ILI9341_setDispMode (bool is_normal, bool is_full_colors)

  Set the display area and color expression.

- void ILI9341_setPartialArea (uint16_t rowStart, uint16_t rowEnd)

    Set the partial display area for partial mode. Call before activating partial mode via ILI9341_setDisplayMode().
- void ILI9341_setDispInversion (bool is_ON)

    Toggle display inversion. Turning `ON` causes colors to be inverted on the display.
- void ILI9341_setDispOutput (bool is_ON)

    Turn display output ON or OFF. This function clears the display and stops outputting to the display area, but does not affect frame memory or power.
- void ILI9341_setScrollArea (uint16_t topFixedArea, uint16_t vertScrollArea, uint16_t bottFixedArea)

    Set the vertical scrolling area of the display. The sum of the three parameters should be equal to the max number of rows `NUM_ROWS = 320`.
- void ILI9341_setScrollStart (uint16_t startRow)

    Set the start row for vertical scrolling.
- void ILI9341_setMemAccessCtrl (bool areRowsFlipped, bool areColsFlipped, bool areRowsColsSwitched, bool isVertRefreshFlipped, bool isColorOrderFlipped, bool isHorRefreshFlipped)

    Set how data is converted from memory to display.
- void ILI9341_setColorDepth (bool is_16bit)

    Set the pixel format to be 16-bit (65K colors) or 18-bit (262K colors).
- void **ILI9341_NoOpCmd** (void)

    Send the ¨No Operation¨ command (`NOP = 0x00`) to the LCD driver. Can be used to terminate the ¨Memory Write¨ (`RAMWR`) and ¨Memory Read¨ (`RAMRD`) commands, but does nothing otherwise.
- void ILI9341_setFrameRateNorm (uint8_t div_ratio, uint8_t clocks_per_line)

    TODO: Write brief.
- void ILI9341_setFrameRateIdle (uint8_t div_ratio, uint8_t clocks_per_line)

    TODO: Write brief.
- void ILI9341_setBlankingPorch (uint8_t vpf, uint8_t vbp, uint8_t hfp, uint8_t hbp)

    TODO: Write.
- void ILI9341_setInterface (void)

    Sets the interface for the ILI9341. The parameters for this command are hard-coded, so it only needs to be called once upon initialization.
- void ILI9341_setRowAddress (uint16_t start_row, uint16_t end_row)

    not using backlight, so these aren't necessary
- void ILI9341_setColAddress (uint16_t start_col, uint16_t end_col)

    Sets the start/end rows to be written to.
- void ILI9341_writeMemCmd (void)

    Sends the ¨Write Memory¨ (`RAMWR`) command to the LCD driver, signalling that incoming data should be written to memory.
- void ILI9341_write1px (uint8_t red, uint8_t green, uint8_t blue, bool is_16bit)

    Write a single pixel to frame memory.

6.18.1 Detailed Description

Source code for ILI9341 module.

Author

Bryan McElvy

6.19 ILI9341.h File Reference

Driver module for interfacing with an ILI9341 LCD driver.

```
#include "SPI.h"
#include "Timer.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
#include <stdbool.h>
```

Macros

- #define **NUM_COLS** (uint16_t) 240
- #define **NUM_ROWS** (uint16_t) 320

Functions

- void **ILI9341_Init** (void)

    Initialize the LCD driver, the SPI module, and Timer2A.
- void ILI9341_resetHard (void)

    Perform a hardware reset of the LCD driver.
- void ILI9341_resetSoft (void)

    Perform a software reset of the LCD driver.
- void ILI9341_setSleepMode (bool is_sleeping)

    Enter or exit sleep mode. The LCD driver is in sleep mode by default upon powering on or either kind of reset.
- void ILI9341_setDispMode (bool is_normal, bool is_full_colors)

    Set the display area and color expression.
- void ILI9341_setPartialArea (uint16_t rowStart, uint16_t rowEnd)

    Set the partial display area for partial mode. Call before activating partial mode via ILI9341_setDisplayMode().
- void ILI9341_setDispInversion (bool is_ON)

    Toggle display inversion. Turning `ON` causes colors to be inverted on the display.
- void ILI9341_setDispOutput (bool is_ON)

    Turn display output ON or OFF. This function clears the display and stops outputting to the display area, but does not affect frame memory or power.
- void ILI9341_setScrollArea (uint16_t topFixedArea, uint16_t vertScrollArea, uint16_t bottFixedArea)

    Set the vertical scrolling area of the display. The sum of the three parameters should be equal to the max number of rows `NUM_ROWS = 320`.
- void ILI9341_setScrollStart (uint16_t startRow)

    Set the start row for vertical scrolling.
- void ILI9341_setMemAccessCtrl (bool areRowsFlipped, bool areColsFlipped, bool areRowsColsSwitched, bool isVertRefreshFlipped, bool isColorOrderFlipped, bool isHorRefreshFlipped)

    Set how data is converted from memory to display.
- void ILI9341_setColorDepth (bool is_16bit)

    Set the pixel format to be 16-bit (65K colors) or 18-bit (262K colors).
- void **ILI9341_NoOpCmd** (void)

    Send the "No Operation" command (`NOP = 0x00`) to the LCD driver. Can be used to terminate the "Memory Write" (`RAMWR`) and "Memory Read" (`RAMRD`) commands, but does nothing otherwise.
- void ILI9341_setFrameRateNorm (uint8_t div_ratio, uint8_t clocks_per_line)

    TODO: Write brief.
- void ILI9341_setFrameRateIdle (uint8_t div_ratio, uint8_t clocks_per_line)

TODO: Write brief.

- void ILI9341_setBlankingPorch (uint8_t vpf, uint8_t vbp, uint8_t hfp, uint8_t hbp)

  TODO: Write.
- void ILI9341_setInterface (void)

  Sets the interface for the ILI9341. The parameters for this command are hard-coded, so it only needs to be called once upon initialization.
- void ILI9341_setRowAddress (uint16_t start_row, uint16_t end_row)

  not using backlight, so these aren't necessary
- void ILI9341_setColAddress (uint16_t start_col, uint16_t end_col)

  Sets the start/end rows to be written to.
- void ILI9341_writeMemCmd (void)

  Sends the "Write Memory" (`RAMWR`) command to the LCD driver, signalling that incoming data should be written to memory.
- void ILI9341_write1px (uint8_t red, uint8_t green, uint8_t blue, bool is_16bit)

  Write a single pixel to frame memory.

6.19.1 Detailed Description

Driver module for interfacing with an ILI9341 LCD driver.

Author

Bryan McElvy

This module contains functions for initializing and outputting graphical data to a 240RGBx320 resolution, 262K color-depth liquid crystal display (LCD). The module interfaces the LaunchPad (or any other board featuring the TM4C123GH6PM microcontroller) with an ILI9341 LCD driver chip via the SPI (serial peripheral interface) protocol.

6.20 Led.c File Reference

Source code for LED module.

```
#include "Led.h"
#include "GPIO_New.h"
#include "NewAssert.h"
#include <stdbool.h>
#include <stdint.h>
```

Data Structures

- struct Led_t

Functions

- Led_t ∗ Led_Init (GPIO_Port_t ∗gpioPort_ptr, GPIO_Pin_t pin)

    Initialize a light-emitting diode (LED) as an `Led_t`.
- GPIO_Port_t ∗ Led_GetPort (Led_t ∗led_ptr)

    Get the GPIO port associated with the LED.
- GPIO_Pin_t LED_GetPin (Led_t ∗led_ptr)

    Get the GPIO pin associated with the LED.
- bool Led_isOn (Led_t ∗led_ptr)

    Check the LED's status.
- void Led_TurnOn (Led_t ∗led_ptr)

    Turn the LED `ON`.
- void Led_TurnOff (Led_t ∗led_ptr)

    Turn the LED `OFF`.
- void Led_Toggle (Led_t ∗led_ptr)

    Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

6.20.1 Detailed Description

Source code for LED module.

Author

Bryan McElvy

6.21 Led.h File Reference

Interface for LED module.

```
#include "GPIO_New.h"
#include "NewAssert.h"
#include <stdbool.h>
#include <stdint.h>
```

Macros

- #define **LED_POOL_SIZE** 3

Functions

- Led_t ∗ Led_Init (GPIO_Port_t ∗gpioPort_ptr, GPIO_Pin_t pin)

    Initialize a light-emitting diode (LED) as an `Led_t`.
- GPIO_Port_t ∗ Led_GetPort (Led_t ∗led_ptr)

    Get the GPIO port associated with the LED.
- GPIO_Pin_t LED_GetPin (Led_t ∗led_ptr)

    Get the GPIO pin associated with the LED.
- bool Led_isOn (Led_t ∗led_ptr)

    Check the LED's status.
- void Led_TurnOn (Led_t ∗led_ptr)

    Turn the LED `ON`.
- void Led_TurnOff (Led_t ∗led_ptr)

    Turn the LED `OFF`.
- void Led_Toggle (Led_t ∗led_ptr)

    Toggle the LED (i.e. `OFF` -> `ON` or `ON` -> `OFF`).

6.21.1 Detailed Description

Interface for LED module.

Author

Bryan McElvy

6.22 PLL.c File Reference

Implementation details for phase-lock-loop (PLL) functions.

```
#include "PLL.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void PLL_Init (void)

  Initializes the phase-locked-loop (PLL), allowing a bus frequency of 80[MHz].

6.22.1 Detailed Description

Implementation details for phase-lock-loop (PLL) functions.

Author

Bryan McElvy

6.23 PLL.h File Reference

Driver module for activating the phase-locked-loop (PLL).

```
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void PLL_Init (void)

  Initializes the phase-locked-loop (PLL), allowing a bus frequency of 80[MHz].

6.23.1 Detailed Description

Driver module for activating the phase-locked-loop (PLL).

Author

Bryan McElvy

6.24 SPI.c File Reference

Source code for SPI module.

```
#include "SPI.h"
#include "FIFO.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Macros

- #define NVIC_SSI0_NUM 7
- #define **SPI_INT_START**() (NVIC_SW_TRIG_R = (NVIC_SW_TRIG_R & ∼(0xFF)) | NVIC_SSI0_NUM)
- #define **SPI_SET_DC**() (GPIO_PORTA_DATA_R |= 0x40)
- #define **SPI_CLEAR_DC**() (GPIO_PORTA_DATA_R &= ∼(0x40))
- #define **SPI_IS_BUSY** (SSI0_SR_R & 0x10)
- #define **SPI_TX_ISNOTFULL** ((bool) (SSI0_SR_R & 0x02))
- #define **SPI_BUFFER_SIZE** 9

Functions

- void SPI_Init (void)

  Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.
- uint8_t SPI_Read (void)

  Read data from the peripheral.
- void SPI_WriteCmd (uint8_t cmd)

  Write an 8-bit command to the peripheral.
- void SPI_WriteData (uint8_t data)

  Write 8-bit data to the peripheral.
- void SPI_IRQ_WriteCmd (uint8_t cmd)

  Add an 8-bit command to the SPI queue. If no data or other command is written, should directly precede a call to `SPI_IRQ_StartWriting()`.
- void SPI_IRQ_WriteData (uint8_t data)

  Add 8-bit data to the SPI queue. Should directly precede either another call to the same function or a call to `SPI_IRQ_StartWriting()`.
- void **SPI_IRQ_StartWriting** (void)

  Start writing data to the Tx FIFO. Should be used after 1+ calls to `SPI_IRQ_WriteCmd()` and/or `SPI_IRQ_WriteData()`. If unused, writing will start when the SPI queue is full.
- void SSI0_Handler (void)

  Sends parameters (data or commands) over SPI via SSI0.

6.24.1 Detailed Description

Source code for SPI module.

Author

Bryan McElvy

6.25 SPI.h File Reference

Driver module for using the serial peripheral interface (SPI) protocol.

```
#include "tm4c123gh6pm.h"
#include "FIFO.h"
#include <stdbool.h>
#include <stdint.h>
```

Functions

- void SPI_Init (void)

  Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.
- uint8_t SPI_Read (void)

  Read data from the peripheral.
- void SPI_WriteCmd (uint8_t cmd)

  Write an 8-bit command to the peripheral.
- void SPI_WriteData (uint8_t data)

  Write 8-bit data to the peripheral.
- void SPI_IRQ_WriteCmd (uint8_t cmd)

  Add an 8-bit command to the SPI queue. If no data or other command is written, should directly precede a call to `SPI_IRQ_StartWriting()`.
- void SPI_IRQ_WriteData (uint8_t data)

  Add 8-bit data to the SPI queue. Should directly precede either another call to the same function or a call to `SPI_IRQ_StartWriting()`.
- void **SPI_IRQ_StartWriting** (void)

  Start writing data to the Tx FIFO. Should be used after 1+ calls to `SPI_IRQ_WriteCmd()` and/or `SPI_IRQ_WriteData()`. If unused, writing will start when the SPI queue is full.

6.25.1 Detailed Description

Driver module for using the serial peripheral interface (SPI) protocol.

Author

Bryan McElvy

6.26 SPI_New.c File Reference

Source code for SPI module.

```
#include "SPI.h"
#include "GPIO_New.h"
#include "FIFO.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Macros

- #define NVIC_SSI0_NUM 7
- #define **SPI_INT_START**() (NVIC_SW_TRIG_R = (NVIC_SW_TRIG_R & ∼(0xFF)) | NVIC_SSI0_NUM)
- #define **SPI_SET_DC**() (GPIO_PORTA_DATA_R |= 0x40)
- #define **SPI_CLEAR_DC**() (GPIO_PORTA_DATA_R &= ∼(0x40))
- #define **SPI_IS_BUSY** (SSI0_SR_R & 0x10)
- #define **SPI_TX_ISNOTFULL** ((bool) (SSI0_SR_R & 0x02))
- #define **SPI_BUFFER_SIZE** 9

Enumerations

- enum {
  SPI_CLK_PIN = GPIO_PIN2 , **SPI_CS_PIN** = GPIO_PIN3 , **SPI_RX_PIN** = GPIO_PIN4 , **SPI_TX_PIN** = GPIO_PIN5 ,
  SPI_DC_PIN = GPIO_PIN6 , **SPI_RESET_PIN** = GPIO_PIN7 , **SPI_SSI0_PINS** = (SPI_CLK_PIN | SPI_↩ CS_PIN | SPI_RX_PIN | SPI_TX_PIN) , **SPI_GPIO_PINS** = (SPI_DC_PIN | SPI_RESET_PIN) ,
  SPI_ALL_PINS = (SPI_SSI0_PINS | SPI_GPIO_PINS) }

Functions

- void SPI_Init (void)

  Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.
- uint8_t SPI_Read (void)

  Read data from the peripheral.
- void SPI_WriteCmd (uint8_t cmd)

  Write an 8-bit command to the peripheral.
- void SPI_WriteData (uint8_t data)

  Write 8-bit data to the peripheral.
- void SPI_IRQ_WriteCmd (uint8_t cmd)

  Add an 8-bit command to the SPI queue. If no data or other command is written, should directly precede a call to `SPI_IRQ_StartWriting()`.
- void SPI_IRQ_WriteData (uint8_t data)

  Add 8-bit data to the SPI queue. Should directly precede either another call to the same function or a call to `SPI_IRQ_StartWriting()`.
- void **SPI_IRQ_StartWriting** (void)

  Start writing data to the Tx FIFO. Should be used after 1+ calls to `SPI_IRQ_WriteCmd()` and/or `SPI_IRQ_WriteData()`. If unused, writing will start when the SPI queue is full.
- void SSI0_Handler (void)

  Sends parameters (data or commands) over SPI via SSI0.

6.26.1 Detailed Description

Source code for SPI module.

Author

Bryan McElvy

6.27 SPI_New.h File Reference

Driver module for using the serial peripheral interface (SPI) protocol.

```
#include "GPIO_New.h"
#include "FIFO.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Functions

- void SPI_Init (void)

  Initialize SSI0 to act as an SPI Controller (AKA Master) in mode 0.
- uint8_t SPI_Read (void)

  Read data from the peripheral.
- void SPI_WriteCmd (uint8_t cmd)

  Write an 8-bit command to the peripheral.
- void SPI_WriteData (uint8_t data)

  Write 8-bit data to the peripheral.
- void SPI_IRQ_WriteCmd (uint8_t cmd)

  Add an 8-bit command to the SPI queue. If no data or other command is written, should directly precede a call to `SPI_IRQ_StartWriting()`.
- void SPI_IRQ_WriteData (uint8_t data)

  Add 8-bit data to the SPI queue. Should directly precede either another call to the same function or a call to `SPI_IRQ_StartWriting()`.
- void **SPI_IRQ_StartWriting** (void)

  Start writing data to the Tx FIFO. Should be used after 1+ calls to `SPI_IRQ_WriteCmd()` and/or `SPI_IRQ_WriteData()`. If unused, writing will start when the SPI queue is full.

6.27.1 Detailed Description

Driver module for using the serial peripheral interface (SPI) protocol.

Author

Bryan McElvy

6.28 SysTick.c File Reference

Implementation details for SysTick functions.

```
#include "SysTick.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void SysTick_Timer_Init (void)

  Initialize SysTick for timing purposes.
- void **SysTick_Wait1ms** (uint32_t delay_ms)

  Delay for specified amount of time in [ms]. Assumes f_bus = 80[MHz].
- void SysTick_Interrupt_Init (uint32_t time_ms)

  Initialize SysTick for interrupts.

6.28.1 Detailed Description

Implementation details for SysTick functions.

Author

Bryan McElvy

6.29 SysTick.h File Reference

Driver module for using SysTick-based timing and/or interrupts.

```
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

- void SysTick_Timer_Init (void)

  Initialize SysTick for timing purposes.
- void **SysTick_Wait1ms** (uint32_t delay_ms)

  Delay for specified amount of time in [ms]. Assumes f_bus = 80[MHz].
- void SysTick_Interrupt_Init (uint32_t time_ms)

  Initialize SysTick for interrupts.

6.29.1 Detailed Description

Driver module for using SysTick-based timing and/or interrupts.

Author

Bryan McElvy

6.30 Timer.c File Reference

Implementation for timer module.

```
#include "Timer.h"
#include "tm4c123gh6pm.h"
#include <stdint.h>
```

Functions

Timer0A

- void Timer0A_Init (void)
  Initialize timer 0 as 32-bit, one-shot, countdown timer.
- void Timer0A_Start (uint32_t time_ms)
  Count down starting from the inputted value.
- uint8_t Timer0A_isCounting (void)
  Returns 1 if Timer0 is still counting and 0 if not.
- void Timer0A_Wait1ms (uint32_t time_ms)
  Wait for the specified amount of time in [ms].

Timer1A

- void Timer1A_Init (uint32_t time_ms)
  Initialize timer 1 as a 32-bit, periodic, countdown timer with interrupts.

Timer2A

- void Timer2A_Init (void)
  Initialize timer 2 as 32-bit, one-shot, countdown timer.
- void Timer2A_Start (uint32_t time_ms)
  Count down starting from the inputted value.
- uint8_t Timer2A_isCounting (void)
  Returns 1 if Timer2 is still counting and 0 if not.
- void Timer2A_Wait1ms (uint32_t time_ms)
  Wait for the specified amount of time in [ms].
- void Timer3A_Init (uint32_t time_ms)
  Initialize Timer3A as a 32-bit, periodic, countdown timer that triggers ADC sample capture.

6.30.1 Detailed Description

Implementation for timer module.

Author

Bryan McElvy

6.31 Timer.h File Reference

Driver module for general-purpose timer modules.

```
#include ¨tm4c123gh6pm.h¨
#include <stdint.h>
```

Functions

Timer0A

- void Timer0A_Init (void)
  Initialize timer 0 as 32-bit, one-shot, countdown timer.
- void Timer0A_Start (uint32_t time_ms)
  Count down starting from the inputted value.
- uint8_t Timer0A_isCounting (void)
  Returns 1 if Timer0 is still counting and 0 if not.
- void Timer0A_Wait1ms (uint32_t time_ms)
  Wait for the specified amount of time in [ms].

Timer1A

- void Timer1A_Init (uint32_t time_ms)
  Initialize timer 1 as a 32-bit, periodic, countdown timer with interrupts.

Timer2A

- void Timer2A_Init (void)
  Initialize timer 2 as 32-bit, one-shot, countdown timer.
- void Timer2A_Start (uint32_t time_ms)
  Count down starting from the inputted value.
- uint8_t Timer2A_isCounting (void)
  Returns 1 if Timer2 is still counting and 0 if not.
- void Timer2A_Wait1ms (uint32_t time_ms)
  Wait for the specified amount of time in [ms].
- void Timer3A_Init (uint32_t time_ms)
  Initialize Timer3A as a 32-bit, periodic, countdown timer that triggers ADC sample capture.

6.31.1 Detailed Description

Driver module for general-purpose timer modules.

Author

Bryan McElvy

```
Timer | Function
----------------------
0A      Debouncing
1A      LCD Interrupts
2A      ILI9341 Resets
3A      ADC Interrupts
```

6.32 UART.c File Reference

Source code for UART module.

```
#include "UART.h"
#include "FIFO.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Macros

- #define **ASCII_CONVERSION** 0x30
- #define **UART0_TX_FULL** (UART0_FR_R & 0x20)
- #define **UART0_BUFFER_SIZE** 16
- #define **UART0_INTERRUPT_NUM** 5

Functions

- void UART0_Init (void)

  Initialize UART0 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART0_ReadChar (void)

  Read a single character from UART0.
- void UART0_WriteChar (unsigned char input_char)

  Write a single character to UART0.
- void UART0_WriteStr (void ∗input_str)

  Write a C string to UART0.
- void UART0_WriteInt (uint32_t n)

  Write a 32-bit unsigned integer to UART0.
- void UART0_WriteFloat (double n, uint8_t num_decimals)

  Write a floating-point number to UART0.
- void UART0_IRQ_AddChar (unsigned char input_char)

  Add a single character to UART0's FIFO.
- void UART0_IRQ_AddStr (void ∗input_str)

  Add a string to UART0's FIFO.
- void UART0_IRQ_AddInt (uint32_t n)

  Add an integer to UART0's FIFO.
- void UART0_IRQ_Start (void)

  Transmit the UART0's FIFO's contents via interrupt.
- void **UART0_Handler** (void)
- void UART1_Init (void)

  Initialize UART1 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART1_ReadChar (void)

  Read a single character from UART1.
- void UART1_WriteChar (unsigned char input_char)

  Write a single character to UART1.
- void UART1_WriteStr (void ∗input_str)

  Write a C string to UART1.

6.32.1 Detailed Description

Source code for UART module.

Author

Bryan McElvy

6.33 UART.h File Reference

Driver module for serial communication via UART0 and UART 1.

```
#include "FIFO.h"
#include "tm4c123gh6pm.h"
```

Functions

- void UART0_Init (void)

    Initialize UART0 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART0_ReadChar (void)

    Read a single character from UART0.
- void UART0_WriteChar (unsigned char input_char)

    Write a single character to UART0.
- void UART0_WriteStr (void ∗input_str)

    Write a C string to UART0.
- void UART0_WriteInt (uint32_t n)

    Write a 32-bit unsigned integer to UART0.
- void UART0_WriteFloat (double n, uint8_t num_decimals)

    Write a floating-point number to UART0.
- void UART0_IRQ_AddChar (unsigned char input_char)

    Add a single character to UART0's FIFO.
- void UART0_IRQ_AddStr (void ∗input_str)

    Add a string to UART0's FIFO.
- void UART0_IRQ_AddInt (uint32_t n)

    Add an integer to UART0's FIFO.
- void UART0_IRQ_Start (void)

    Transmit the UART0's FIFO's contents via interrupt.
- void UART1_Init (void)

    Initialize UART1 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART1_ReadChar (void)

    Read a single character from UART1.
- void UART1_WriteChar (unsigned char input_char)

    Write a single character to UART1.
- void UART1_WriteStr (void ∗input_str)

    Write a C string to UART1.

6.33.1 Detailed Description

Driver module for serial communication via UART0 and UART 1.

Author

Bryan McElvy

```
UART0 uses PA0 and PA1, which are not broken out but can connect
to a PC's serial port via USB.

UART1 uses PB0 (Rx) and PB1 (Tx), which are broken out but
do not connect to a serial port.
```

6.34 UART_New.c File Reference

Source code for UART module.

```
#include "UART.h"
#include "GPIO_New.h"
#include "FIFO.h"
#include "tm4c123gh6pm.h"
#include <stdbool.h>
#include <stdint.h>
```

Macros

- #define **ASCII_CONVERSION** 0x30
- #define **UART0_TX_FULL** (UART0_FR_R & 0x20)
- #define **UART0_BUFFER_SIZE** 16
- #define **UART0_INTERRUPT_NUM** 5

Functions

- void UART0_Init (void)

  Initialize UART0 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART0_ReadChar (void)

  Read a single character from UART0.
- void UART0_WriteChar (unsigned char input_char)

  Write a single character to UART0.
- void UART0_WriteStr (void ∗input_str)

  Write a C string to UART0.
- void UART0_WriteInt (uint32_t n)

  Write a 32-bit unsigned integer to UART0.
- void UART0_WriteFloat (double n, uint8_t num_decimals)

  Write a floating-point number to UART0.
- void UART0_IRQ_AddChar (unsigned char input_char)

  Add a single character to UART0's FIFO.
- void UART0_IRQ_AddStr (void ∗input_str)

  Add a string to UART0's FIFO.
- void UART0_IRQ_AddInt (uint32_t n)

  Add an integer to UART0's FIFO.
- void UART0_IRQ_Start (void)

  Transmit the UART0's FIFO's contents via interrupt.
- void **UART0_Handler** (void)
- void UART1_Init (void)

  Initialize UART1 to a baud rate of 115200, 8-bit data length, 1 start bit, and 1 stop bit.
- unsigned char UART1_ReadChar (void)

  Read a single character from UART1.
- void UART1_WriteChar (unsigned char input_char)

  Write a single character to UART1.
- void UART1_WriteStr (void ∗input_str)

  Write a C string to UART1.

6.34.1 Detailed Description

Source code for UART module.

Author

Bryan McElvy

6.35 main.c File Reference

Main program file for ECG-HRM.

```
#include "ADC.h"
#include "ILI9341.h"
#include "PLL.h"
#include "DAQ.h"
#include "Debug.h"
#include "QRS.h"
#include "UserCtrl.h"
```

Functions

- int **main** (void)
- void GPIO_PortF_Handler (void)

  Interrupt service routine (ISR) for the UserCtrl module via GPIO Port F.
- void ADC0_SS3_Handler (void)

  Interrupt service routine (ISR) for collecting ADC samples.
- void Timer1A_Handler (void)

  Interrupt service routine (ISR) for outputting data to the LCD.

6.35.1 Detailed Description

Main program file for ECG-HRM.

Author

Bryan McElvy

Index