Università degli Studi di Palermo
Computer Engineering

# Embedded Systems

## IR Receiver Project

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# Contents

# 1 Introduction

The proposed project consists of using an IR receiver to capture commands sent by a remote controller and displaying them on an LCD display, along with the name of the pressed buttons.
This document is organized as follows:

- Firstly, I will discuss the hardware used for the implementation, by describing the physical architecture where the software will run and the external necessary harware components that will interact with it;
- Then, I will explain the environment used for project development and how to obtain the parameters needed for the project to function properly;
- Lastly, I will illustate how the code was designed and organized.

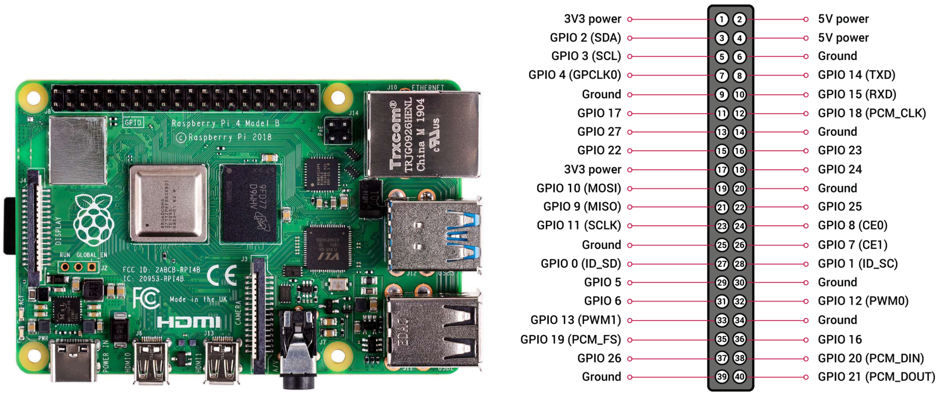
On the last pages you can find the entire code. It can also be found online using GitHub (insert link).

# 2 Hardware

## 2.1 Raspberry Pi 4 Model B

The target of this project is a general-purpose Single-Board Computer (SBC): the Raspberry Pi 4 Model B.

It is a member of a series of products, which are developed in the United Kingdom by the Raspberry Pi Foundation in association with Broadcom.
It was released in June 2019[1] and replaced the well-known **Raspberry Pi 3 Model B** and **Raspberry Pi 3 Model B+**.




(a) (b)

Figure 1: Raspberry Pi 4 Model B

It is built with the following specifications[2]:

- Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz;
- 1GB, 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model);

- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE;
- Gigabit Ethernet;
- 2 USB 3.0 ports; 2 USB 2.0 ports;
- Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards);
- 2 × micro-HDMI ports (up to 4kp60 supported);
- 2-lane MIPI DSI display port;
- 2-lane MIPI CSI camera port;
- 4-pole stereo audio and composite video port;
- H.265 (4kp60 decode);
- H264 (1080p60 decode, 1080p30 encode);
- OpenGL ES 3.1, Vulkan 1.0;
- Micro-SD card slot for loading operating system and data storage;
- 5V DC via USB-C connector (minimum 3A*);
- 5V DC via GPIO header (minimum 3A*);
- Power over Ethernet (PoE) enabled (requires separate PoE HAT);
- Operating temperature: 0 – 50 degrees C ambient.

The model I used comes with 4GB of RAM.

## 2.2 FTDI Adapter FT232RL

Since modern computers do not expose serial ports to program the SBC, a UART (Universal Asynchronous Receiver-Transmitter) serial adapter is required.

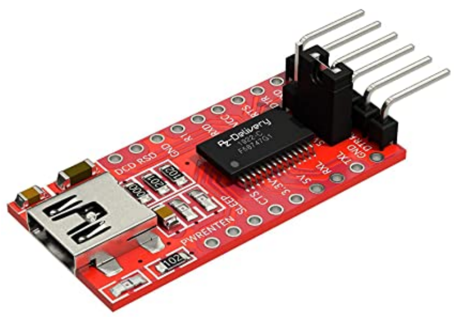


Figure 2: FTDI Adapter FT232RL from Mini-USB to TTL

I adopted the Mini-USB to TTL serial adapter provided by AZ-Delivery[4].
To avoid voltage problems power is supplied from the terminal used to develop the project and is shared between the Pi 4 and the FT232RL.
The connection is made in the following way:

- FT232RL RX pin is connected to GPIO 14 (TXD);
- FT232RL TX pin is connected to GPIO 15 (RXD);
- FT232RL GND pin is connected to the GND of the Pi 4.

## 2.3 KY-022 Infrared receiver module

IR detectors[5] are little microchips with a photocell that are tuned to listen to infrared light. They are almost always used for remote control detection - every TV and DVD player has one of these in the front to listen for the IR signal from the clicker. Inside the remote control is a matching IR LED, which emits IR pulses to tell the TV to turn on, off or change channels. IR light is not visible to the human eye, which means it takes a little more work to test a setup.


Figure 3: KY-022

The module is able to detect frequencies ranging from about 35 KHz to 41 KHz, but the peak frequency detection is at 38 KHz.

The IR receiver comes with 3 pins: the digital signal output pin (S) used to read the value of infrared light, the power pin (+) and the ground pin (-).

When it detects a 38KHz IR signal, the output is low. When it detects nothing, the output is high.
It requires a supply voltage in [2.7, 5.5]V, so it is powered by the Pi 4 using one of the 3V3 pins. Its GND pin is connected to the GND of the Pi 4.

Its output pin is connected to GPIO 25.

## 2.4 Samsung AA59-00584A

The TV remote controller I used is produced by Samsung.


Figure 4: Samsung AA59-00584A

After several timing trials, I observed that the implemented protocol conforms to the timings found online on the page cited in the references [9].

For convenience, I report the picture of the timings here:

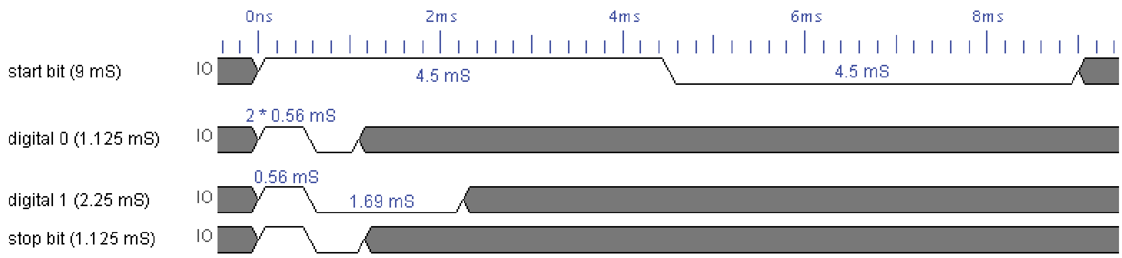



Figure 5: Samsung protocol

## 2.5 LCD1602

The LCD1602[6], [7] is an industrial character LCD that can display $16 \times 2$ or 32 characters at the same time, with a display font of $5 \times 8$ dots. The principle of the LCD1602 liquid crystal display is to use the physical characteristics of the liquid crystal to control the display area by voltage, that is, the graphic can be displayed.

Figure 6: LCD 1602

It is controlled through a parallel interface with:

- 8-bit/4-bit data bus;
- 3 control signals.

The interface signals reach the two controller chips that drive the LCD panel:

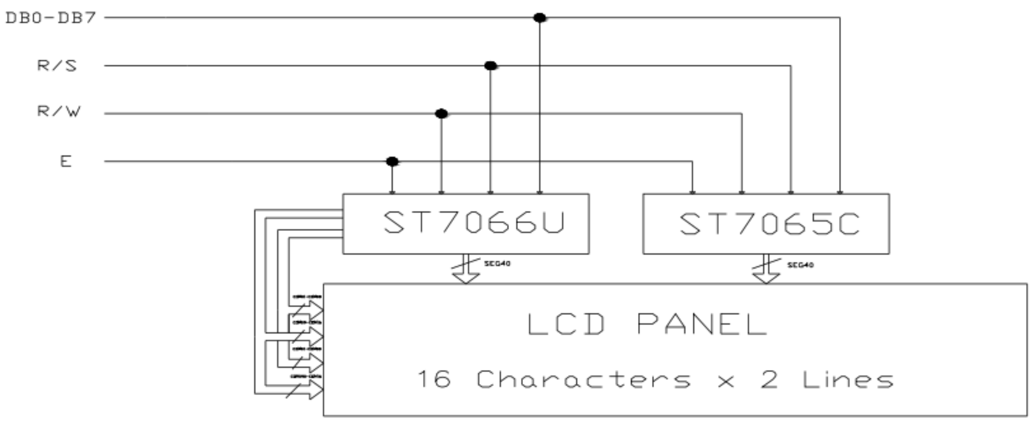



Figure 7: Block Diagram

Pin assignments are summarized in this table:

| No. | Symbol | Level | Function | |
|---|---|---|---|---|
| 1 | Vss | -- | 0V | Power Supply |
| 2 | Vdd | -- | +5V | |
| 3 | V0 | -- | for LCD | |
| 4 | RS | H/L | Register Select: H:Data Input L:Instruction Input | |
| 5 | R/W | H/L | H--Read L--Write | |
| 6 | E | H,H-L | Enable Signal | |
| 7 | DB0 | H/L | Data bus used in 8 bit transfer | |
| 8 | DB1 | H/L | | |
| 9 | DB2 | H/L | | |
| 10 | DB3 | H/L | | |
| 11 | DB4 | H/L | Data bus for both 4 and 8 bit transfer | |
| 12 | DB5 | H/L | | |
| 13 | DB6 | H/L | | |
| 14 | DB7 | H/L | | |
| 15 | BLA | -- | BLACKLIGHT +5V | |
| 16 | BLK | -- | BLACKLIGHT 0V- | |

Figure 8: LCD pin assignments

To properly read or write data, some timing constraints must be observed. Independently of whether we are reading or writing, the Enable signal must start its falling edge while DB0-DB7 are stable. If it is not, then erroneous data are sampled. The read or write mode is chosen only by the RW signal, so only one case of these modes can be represented.

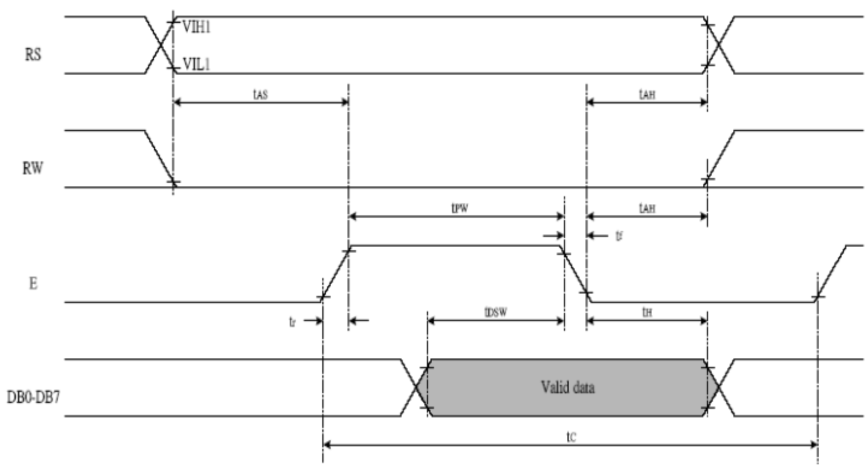



Figure 9: Writing timing characteristics

There are four categories of instructions that:

- set display format, data length, cursor move direction, display shift etc.;
- set internal RAM addresses;
- perform data transfer from/to internal RAM;

- others.

A detailed description of how they can be realized is as follows:

| Instruction | Instruction Code | | | | | | | | | | Description | Description Time (270KHz) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RS | R/W | DB7 | DB6 | DB5 | DB4 | DB3 | DB2 | DB1 | DB0 | | |
| Clear Display | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | Write "20H" to DDRAM. and set DDRAM address to "00H" from AC | 1.52 ms |
| Return Home | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | x | Set DDRAM address to "00H" from AC and return cursor to its original position if shifted. The contents of DDRAM are not changed. | 1.52 ms |
| Entry Mode Set | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | I/D | S | Sets cursor move direction and specifies display shift. These operations are performed during data write and read. | 37 us |
| Display ON/OFF | 0 | 0 | 0 | 0 | 0 | 0 | 1 | D | C | B | D=1:entire display on C=1:cursor on B=1:cursor position on | 37 us |
| Cursor or Display Shift | 0 | 0 | 0 | 0 | 0 | 1 | S/C | R/L | x | x | Set cursor moving and display shift control bit, and the direction, without changing DDRAM data. | 37 us |
| Function Set | 0 | 0 | 0 | 0 | 1 | DL | N | F | x | x | DL:interface data is 8/4 bits N:number of line is 2/1 F:font size is 5x11/5x8 | 37 us |
| Set CGRAM address | 0 | 0 | 0 | 1 | AC5 | AC4 | AC3 | AC2 | AC1 | AC0 | Set CGRAM address in address counter | 37 us |
| Set DDRAM address | 0 | 0 | 1 | AC6 | AC5 | AC4 | AC3 | AC2 | AC1 | AC0 | Set DDRAM address in address counter | 37 us |
| Read Busy flag and address | 0 | 1 | BF | AC6 | AC5 | AC4 | AC3 | AC2 | AC1 | AC0 | Whether during internal operation or not can be known by reading BF. The contents of address counter can also be read. | 0 us |
| Write data to RAM | 1 | 0 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Write data into internal RAM (DDRAM/CGRAM) | 37 us |
| Read data from RAM | 1 | 1 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | Read data from internal RAM (DDRAM/CGRAM) | 37 us |

Figure 10: Instruction Table

## 2.6 IIC PCF8574AT Interface

To ease the communication to the LCD display a serial $I^2C$ module[7], [8] has been used. The interface connects its serial input and parallel output to the LCD, so only 4 lines can be used to do the job.

The $I^2C$ bus was invented by Philips Semiconductor (now NXP Semiconductors). It can be described as:

- synchronous;
- multi-master;
- multi-slave;

- packet switched;
- single-ended.

Each device connected to the bus is software-addressable by a unique address.

Two wires carry data (SDA - Serial DAta) and clock signals (SCL - Serial CLock), with the bus clock generated by the master

It makes use of open-drain connections for bidirectional communication which allows us to transmit a logic low simply by activating a pull-down FET, which shorts the line to ground. To transmit a logic high, the line is left floating, and the pull-up resistor pulls the voltage up to the voltage rail.

The PCF8574AT I/O expander for $I^2C$-bus contains:

- 8-bit remote I/O pins (indicated as P0, P1, ..., P7) used to transfer data;
- 3 address pins (ndicated as A0, A1, A2) used to address the slave.

In this project, it is not necessary to read data from $I^2C$ LCD, so only the writing mechanism will be described.

### 2.6.1 Writing mechanism

To allow a master to send data to a slave device:

1. the master, which acts as the transmitter, initiates communication by sending a START condition and addressing the slave, which acts as the receiver;
2. the master sends data to the slave-receiver;
3. the master terminates the transfer by sending a STOP condition.

A high-to-low transition on the SDA line while the SCL is high is interpreted as a START condition.
In a reverse manner, a low-to-high transition on the SDA line while the SCL is high is interpreted as a STOP condition.

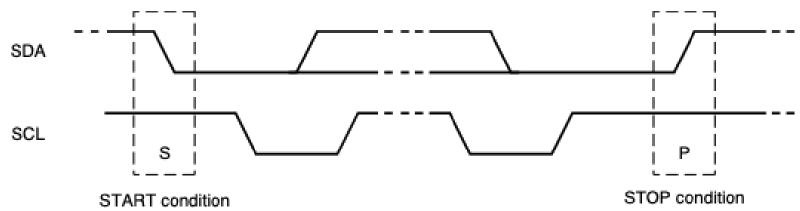



Figure 11: START and STOP conditions

A byte may either be a device address, register address, or data written a slave.

One data bit is transferred during each clock pulse. The data on the SDA line must remain stable during the HIGH period of the clock pulse as changes in the data line at this time will be interpreted as control signals.
Any number of data bytes can be transferred from the master to slave between the

START and STOP conditions.
Data is transferred starting from the MSB (Most Significant Bit).

After each byte of data is transmitted, the master releases the SDA line to allow the slave-receiver to signal a successful transfer with an ACK (Acknowledge) or a failed transfer with a NACK (Not Acknowledge).
The receiver sends an ACK bit if it pulls down the SDA line during the low phase of period 9 of SCL. If the SDA line remains high, a NACK is sent.

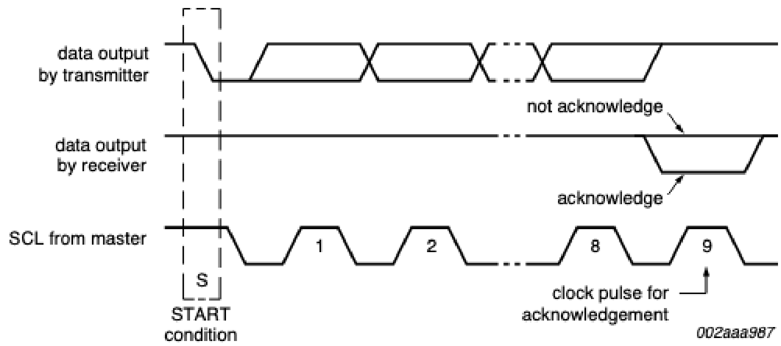



Figure 12: Acknowledgements

Thus, there are 6 steps for the writing mechanism:

1. the master sends the START condition and slave address setting the last bit of the address byte to logic 0 for the write mode;
2. the slave sends an ACK bit;
3. the master sends the register address of the register it wishes to write to;
4. the slave possibly acknowledges again;
5. the master starts sending data;
6. the master terminates the transmission with a STOP condition.

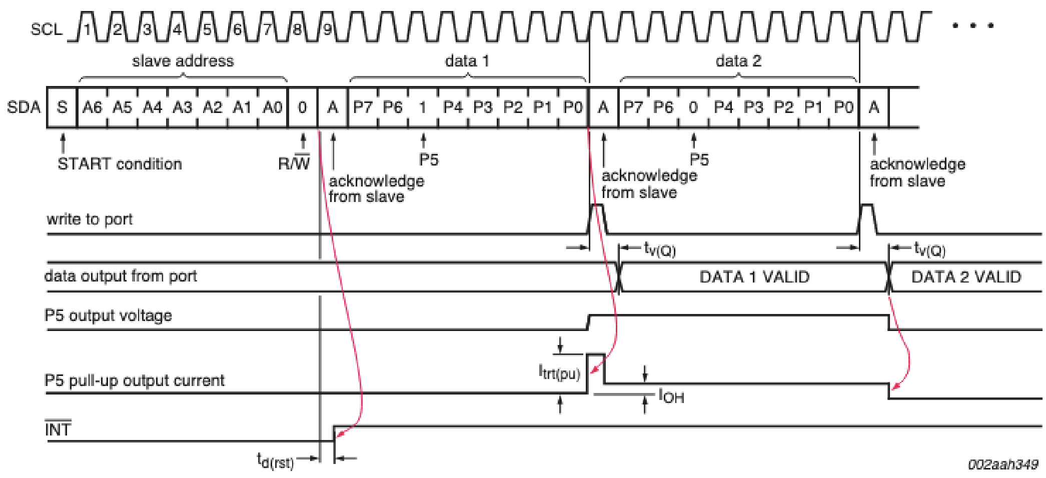



Figure 13: Write mode (output)

All this work is done by the PCF8574AT interface. All we need to do is to send the data byte for pins P7 to P0.

### 2.6.2 PCF8574AT to LCD connection

The PCF8574AT expander is soldered to the LCD pins according to the following scheme:

| PCF8574AT pins | LCD pins |
|---|---|
| P0 | RS |
| P1 | R/W |
| P2 | E |
| P3 | Backlight |
| P4 | D4 |
| P5 | D5 |
| P6 | D6 |
| P7 | D7 |

Table 1: PCF8574AT to LCD pin connections

Hence, the first time the LCD is turned on, it must be set to operate in 4 bit mode by sending the sequence:

| D7 | D6 | D5 | D4 | Backlight | E | R/W | RS |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |

| D7 | D6 | D5 | D4 | Backlight | E | R/W | RS |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |

Table 2: FUNCTION SET for 4 bit mode

After this setting, instructions can be sent by transmitting the most significant nibble first.
As an example, suppose you want to display an E, whose ASCII code is 0x45. To accomplish this task, the sequence to be sent is as follows:

| D7 | D6 | D5 | D4 | Backlight | E | R/W | RS |
|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |

| D7 | D6 | D5 | D4 | Backlight | E | R/W | RS |
|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |

Table 3: Sending an ASCII E

which means that the sequence to transmit is: 0x4D, 0x49, 0x5D, 0x59.

Command instructions are sent in the same way, except for the RS bit, which must be set to zero.

## 2.7 Schematics

All the hardware components shown in the previous sections have been connected with a breadboard to the Pi 4 as follows:

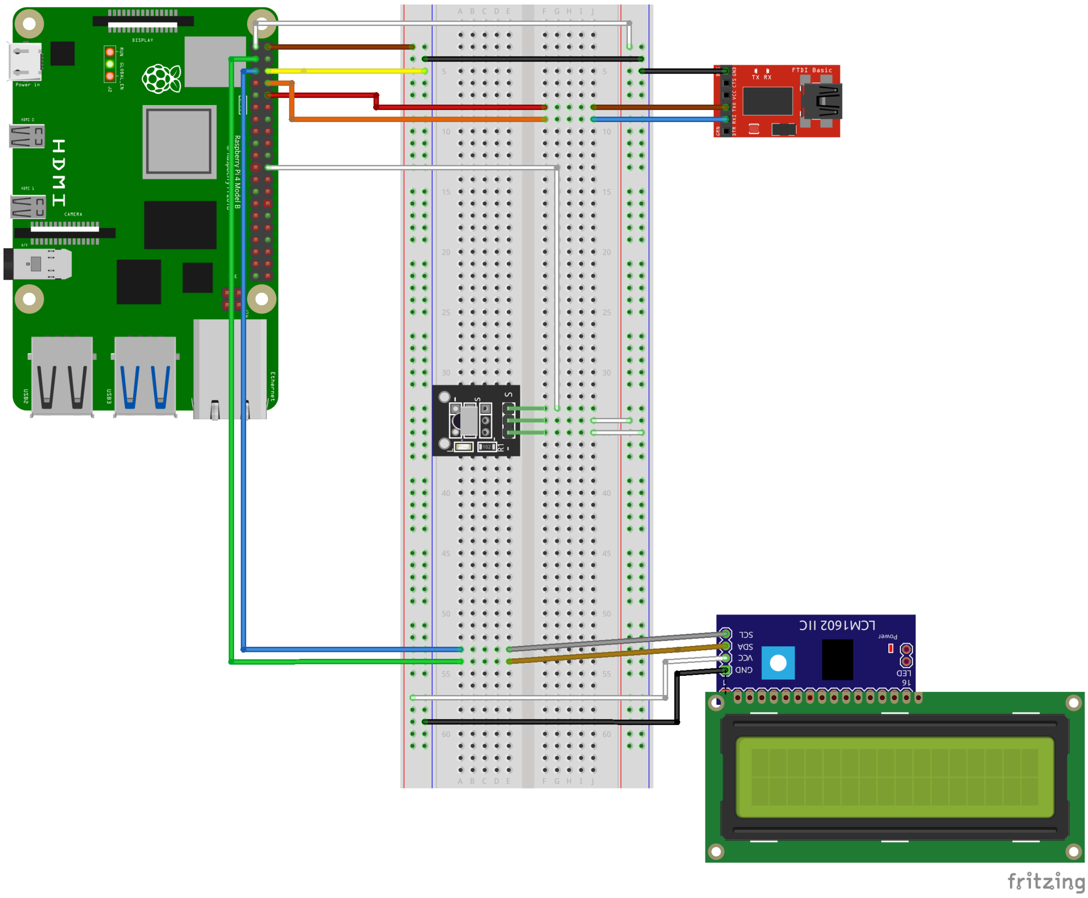



Figure 14: Schematics

The following table summarizes all the connections between them and the Pi:

| Pi 4 Model B | KY-022 | FT232RL | IIC PCF8574T |
|---|---|---|---|
| GPIO 25 | S | | |
| 3V3 power | + | | |
| GPIO 14 (TXD) | | RX | |
| GPIO 15 (RXD) | | TX | |
| 5V power | | | VCC |
| GPIO 2 (SDA) | | | SDA |
| GPIO 3 (SCL) | | | SCL |
| Ground | - | GND | GND |

# 3 Environment

## 3.1 pijFORTHos

Forth is a programming language designed by *Charles H. "Chuck" Moore* which can be implemented easily for resource-constrained machines due to its semplicity.
It is a procedural language heavely based on the use of the stack.

There are several dialects, each with its own definitions. The development involves the definition of new words, which added to the pre-existing vocabulary, can create the final application incrementally and naturally.

pijFORTHos[11] is a bare-metal FORTH interpreter for the Raspberry Pi, based on Jonesforth-ARM[10].

Jonesforth-ARM is an ARM port of x86 JonesForth, which is a Linux-hosted FORTH presented in a Literate Programming style by *Richard W.M. Jones.*

pijFORTHos represents the base on which the application is built.

## 3.2 Minicom and Picocom

**Minicom**[12] is a terminal emulation program for Unix-like operating systems, used for communication and typically to set up a remote serial console.

**Picocom**[13] is, in principle, very much like minicom. It was designed to serve as a simple, manual, modem configuration, testing, and debugging tool.

**ASCII-XFR**[14] transfers files in ASCII mode. It is used to send the source file to the Raspberry because it allows a delay between each character and line sent.
Given that the UART is asynchronous, this is a needed feature because it avoids overrun errors and lost characters if the receiver is busy while executing or compiing FORTH words.

Picocom is launched on the development machine through the command:

```
picocom --b 115200 /dev/cu.usbserial-A50285BI --send "ascii-xfr
↪  -sv -l100 -c10" --imap delbs
```

It is launched with the same VCP (Virtual COM Port) parameters as the Pi UART:

- `--b 115200`: 9600 bit/s bit rate;
- `/dev/cu.usbserial-A50285BI`: the serial UART device;
- `--send "ascii-xfr -sv -l100 -c10"`:

  specifies ascii-xfr as the external command to use for transmitting files.
  The options used are:

  - `-sv`: verbose send mode;

  - `-l100`: sets a 100 milliseconds delay after each line is sent, this usually gives enough time to run a command and be ready for the next line in time
  - `-c10`: waits 10 milliseconds between each character sent.
- `--imap delbs`: : allows the use of backspace to delete a character.

## 3.3 Script

Since the serial UART has a limited operating speed, one way to speed up the loading of the entire project is to delete all comments and merge the files into a single file.

As not everyone has a Unix-like system operating, the first part of the script (`create_program.sh`) is made for Zsh, but can be easily changed to other shelsl because it simply prints the files to the stdout.

```
#! /bin/zsh

rm program.f 2> /dev/null
cat jonesforth.f    \
    se-ans.f        \
    utils.f         \
    timer.f         \
    i2c.f           \
    lcd.f           \
    ir_receiver.f   \
    lookup_table.f  \
    main.f          \
    | ./unify_and_uncomment.py
```

The second part (`unify_and_uncomment.py`) is done in Python, because today almost everyone has a Python interpreter in their system. It reads from stdin, deleting comments and joining all words by separating them with a single space.

```
#! /usr/bin/python3

import sys
import re

with open('program.f', 'a') as f:
    for line in sys.stdin:
        # delete leading and trailing extra spaces
        line = line.strip()
        # skip comment lines
        if line and line[0] != '\\':
            # delete inline comments such as ( i1 i2 ... -- o1 o2 ... )
            reg = re.search("\s+\(\s+[^-]*--[^-]*\s+\)", line)
            if hasattr(reg, 'start') and hasattr(reg, 'end'):
                idx1 = reg.start()
                idx2 = reg.end()
                line = line[:idx1] + line[idx2:]
            # delete inline comments such as \ ...
            line = line[: line.find('\\') - 1 ] if line.find('\\') != -1 else line
```

```python
            # unify line by deleting extra spaces and skipping
            # empty strings or strings containing only whitespaces
            skip_whitespaces = lambda x: x and not x.isspace()
            line = ' '.join( filter( skip_whitespaces,  re.split('\s+', line) ) )
            print(line, file=f, end=' ')
```

Script files must have execution permissions to run. If you are using a Unix-like operating system you can grant them by typing in a terminal window (assuming you are in the project folder):

```
chmod u+x unify_and_uncomment.py
chmod u+x create_program.sh
```

and then build the project by simply writing (assuming that you have changed the shell and python interpreter):

```
./create_program.sh
```

# 4 Software

## 4.1 Prerequisites

The files needed to be placed in the micro SD card to run the software are as follows:

- `bootcode.bin`;
- `config.txt`;
- `fixup.dat`;
- `start4.elf`;
- `kernel7.img` (which contains pijFORTHos);
- `bcm2711-rpi-4-b.dtb`.

In an equivalent manner, you can format the micro SD card for the Pi 4 using the official software called Raspberry Pi Imager[1], released by Raspberry Pi.
When you open the program, you are asked to choose an operating system. You can select Raspberry Pi OS (32 bit) and continue with formatting.

Once the formatting is complete[2], you need to remove the `kernel*.img` and insert the `kernel7.img` that contains pijFORTHos.

Your `config.txt` file must contain the following uncommented options:

```
dtparam=i2c_arm=on

dtparam=audio=on

dtoverlay=vc4-fkms-v3d
```

[1] `https://www.raspberrypi.com/software/`
[2] Please read the following subsection first

```
max_framebuffers=2
enable_uart=1
dtoverlay=w1-gpio,gpiopin=26

enable_uart=1
dtoverlay=w1-gpio,gpiopin=26
```

#### 4.1.1 How to get IIC LCD slave address

For the project to work, it is important to know the correct slave address.

A visual method to recognize the address is to analyze the expander structure as follows[7]:

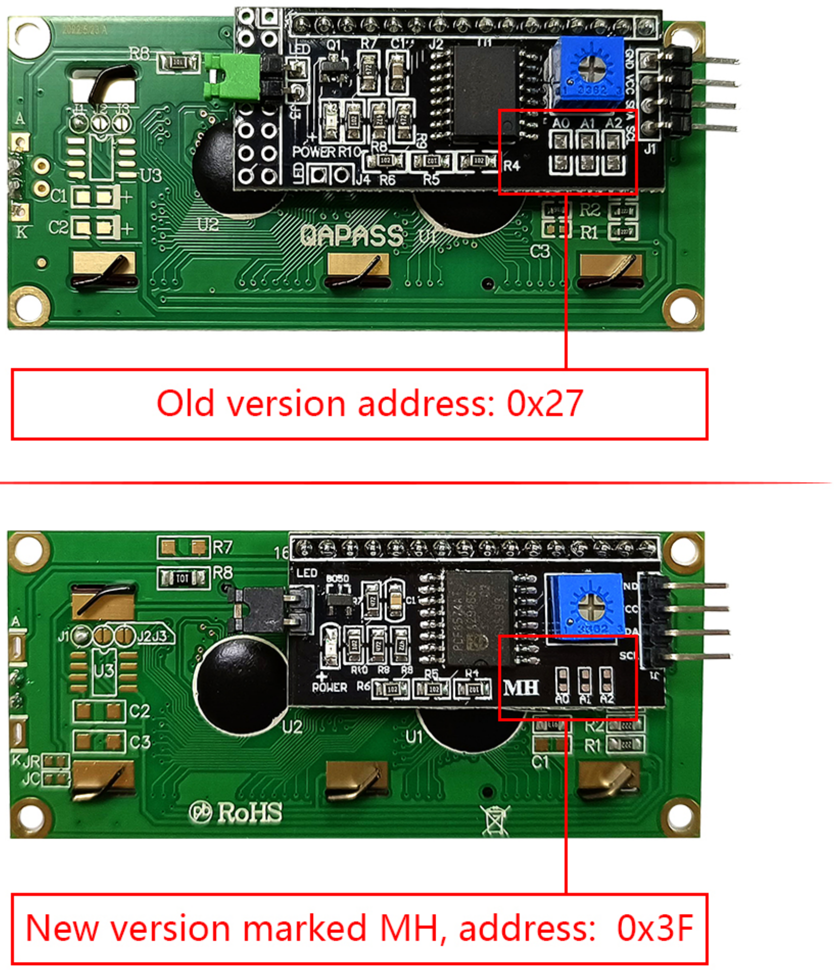



Figure 15: PCF8574AT I/O expander

If it doesn't work and you still can't figure out what the address is you can operate using Raspbian.
Open a terminal window and install `i2c-tools`:

```
sudo apt-get install i2c-tools
```

Once the download is complete, you can simply type:

```
i2cdetect -y 1
```

Now, if the connection on the breadboard is correct, you should see the slave address in the center of the array.
In my case, the I2C slave address is 0x27.

## 4.2 Code structure

The project is composed of

```
\ There are 8 Broadcom Serial Control (BSC) controllers, numbered from 0 to 7
\ Only 6 of these masters can be used, because BSC masters 2 and 7 are not
↪  user-accessible.
\ Since GPIO pins 2 and 3 are used, BSC1 is the reference master.
804000 CONSTANT BSC1

\ There are 8 I2C registers, each of which is at an address obtained by applying
↪  an
\ offset to BSC1 (this process is the same for all BSCs).
\ I2C registers are:
\ - C register          The control register is used to enable interrupts, clear
↪  the FIFO,
\                       define a read or write operation and start a transfer;
\ - S register          The status register is used to record activity status,
↪  errors
\                       and interrupt requests;
\ - DLEN register       The data length register defines the number of bytes of
↪  data
\                       to transmit or receive in the I2C transfer. Reading the
\                       register gives the number of bytes remaining in the
↪  current
\                       transfer;
\ - A register          The slave address register specifies the slave address
↪  and cycle type.
\                       The address register can be left across multiple
↪  transfers;
\ - FIFO register       The Data FIFO register is used to access the FIFO. Write
↪  cycles
\                       to this address place data in the 16-byte FIFO, ready to
\                       transmit on the BSC bus. Read cycles access data received
↪  from
\                       the bus;
\ - DIV register        The clock divider register is used to define the clock
↪  speed of the
\                       BSC peripheral;
\ - DEL register        The data delay register provides fine control over the
\                       sampling/launch point of the data;
\ - CLKT Register       The clock stretch timeout register provides a timeout on
↪  how long the
\                       master waits for the slave to stretch the clock before
↪  deciding that
\                       the slave has hung.
```

```
\ The following constants are defined to point to the registers above.
\ DIV, DEL and CLKT can be left without changes.
BSC1 PERI_BASE +            CONSTANT CTRL
BSC1 PERI_BASE + 04 +       CONSTANT STATUS
BSC1 PERI_BASE + 08 +       CONSTANT DLEN
BSC1 PERI_BASE + 0C +       CONSTANT SLAVE
BSC1 PERI_BASE + 10 +       CONSTANT FIFO
BSC1 PERI_BASE + 14 +       CONSTANT DIV
BSC1 PERI_BASE + 18 +       CONSTANT DEL
BSC1 PERI_BASE + 1C +       CONSTANT CLKT

\ Sets slave address.
\ It can be left across multiple transfers.
: SET_SLAVE ( slave_address -- )
    SLAVE ! ;

\ Sets number of data bytes to transfer.
: SET_DLEN ( length -- )
    DLEN ! ;

\ Places 8 bits at a time in FIFO in order to transmit them on the BSC bus.
: APPEND ( 8_bit_data -- )
    FIFO ! ;

\ Resets the control register without touching the reserved bits.
\ Reserved bits are in positions: 31:16, 14:11, 6 and 3:1.
\ Interrupts are disabled.
: RESET_CTRL ( -- )
    CTRL @ 87B1 BIC CTRL ! ;

\ Resets status for subsequent transfers without touching the reserved bits.
\ Only CLKT (9), ERR (8) and DONE (1) can be cleared (W1C type), all other flags
↪  are read-only (RO).
\ Reserved bits are in positions: 31:10.
: RESET_STATUS ( -- )
    STATUS @ 302 OR STATUS ! ;

\ Clears FIFO without touching the reserved bits.
\ - CLEAR (5:4) set to X1 or 1X in order to clear the FIFO before the new frame
↪  is started.
\ Interrupts are disabled.
: CLEAR_FIFO ( -- )
    CTRL @ 10 OR CTRL ! ;

\ Modifies control register to trigger a transfer.
\ To start a new transfer, all bits are zero except for:
\ - I2CEN (15) set to 1 to enable the BSC controller;
\ - ST (7) set to 1 to start a new transfer (one-shot operation).
\ Interrupts are disabled.
: TRANSFER ( -- )
    CTRL @ 8080 OR CTRL ! ;

\ Transfers data through the I2C bus interface.
\ Since communication is established to the LCD panel, 8 bits at a time are sent.
: >I2C
```

```
    RESET_STATUS
    RESET_CTRL
    CLEAR_FIFO
    01 SET_DLEN
    APPEND
    TRANSFER ;

\ Sets up the I2C bus interface and the slave address.
\ Configures GPIO pin 2 for Serial Data Line.
\ Configures GPIO pin 3 for Serial Clock Line.
\ Sets the slave address to 0x27.
: INIT_I2C
    02 ALT0 CONFIGURE
    03 ALT0 CONFIGURE
    27 SET_SLAVE ;

\ Consider the following structure of data transfer:
\           D7 D6 D5 D4 Backlight Enable Read/Write Register-Select
\ equivalently:
\           D7 D6 D5 D4 BL EN RW RS
\ In order to send a byte, it must be decomposed in two nibbles, upper nibble and
↪  lower
\ nibble. Each nibble represented by D7 D6 D5 D4 must be followed by a
↪  combination of
\ BL EN RW RS.
\ For each data or command to transfer RW = 0.
\ Given a byte B = HIGH LOW (upper-nibble lower-nibble), if it is part of a
↪  command,
\ then transfer is obtained by sending:
\   HIGH 1 1 0 0 -> HIGH 1 0 0 0 -> LOW 1 1 0 0 -> LOW 1 0 0 0
\ If it part of a data transfer then:
\   HIGH 1 1 0 1 -> HIGH 1 0 0 1 -> LOW 1 1 0 1 -> LOW 1 0 0 1
\ RS is equal to 0 for command input and it is equal to 1 for data input.


\ Returns setting parts to be sent based on a truth value that indicates whether
↪  the input
\ is part of a command or data.
: SETTINGS ( truth_value -- first_setting second_setting )
    IF
        0C 08                      \ Setting parts for a command
    ELSE
        0D 09                      \ Setting parts for data
    THEN ;

\ Returns a nibble aggregated with the first setting part and the second setting
↪  part.
: AGGREGATE ( first_setting second_setting nibble -- nibble_second_setting
↪  nibble_first_setting )
    04 LSHIFT DUP                  \ first_setting second_setting byte byte
    ROT OR                         \ first_setting byte nibble_second_setting
    -ROT OR ;

\ Divides a byte into two nibbles.
: BYTE>NIBBLES ( byte -- lower_nibble upper_nibble )
    DUP 0F AND                     \ Gets lower_nibble
```

```
    SWAP 04 RSHIFT OF AND ;         \ Gets upper_nibble

\ Sends a nibble to LCD aggregated with settings.
: SEND_NIBBLE ( nibble truth_value -- )
    SETTINGS ROT
    AGGREGATE                       \ Gets the 2 bytes to send
    >I2C 1000 DELAY
    >I2C 1000 DELAY ;

\ Transmits input to LCD given an instruction or data.
: >LCD ( input -- )
    DUP 08 WORD>BIT >R              \ Stores the command/data bit in the return
    ↪  stack
    BYTE>NIBBLES R@                 \ Creates the two nibbles to be sent
    SEND_NIBBLE R>                  \ Sends the most significant nibble
    SEND_NIBBLE ;                   \ Sends the least significant nibble
```

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