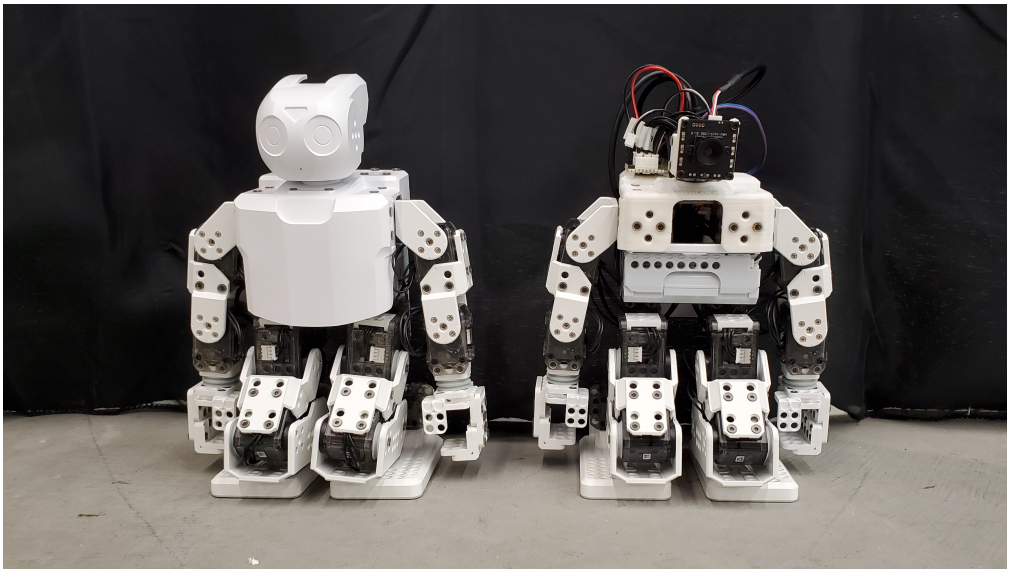
MINI Upgrade Kit Manual



Contributors: Kevin G. Gim, Junu Song, Joohyung Kim

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MINI Upgrade Kit Instruction

1 Assembly Instruction

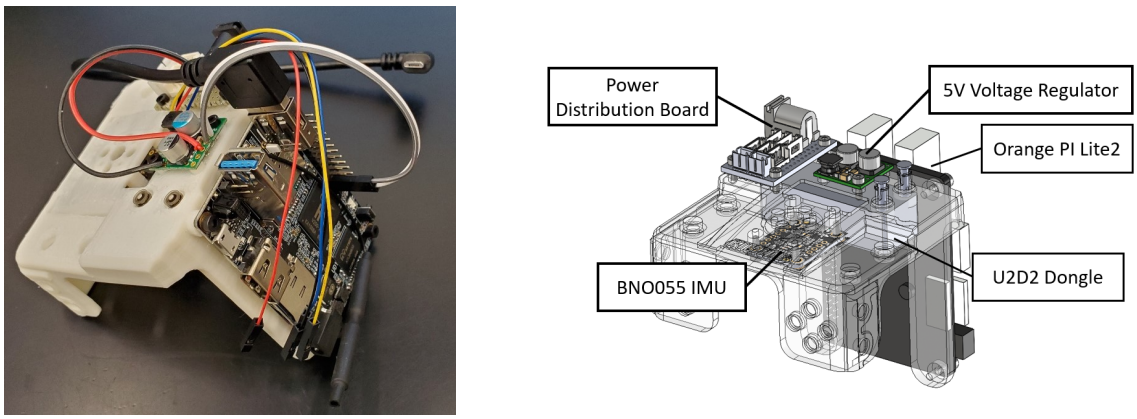
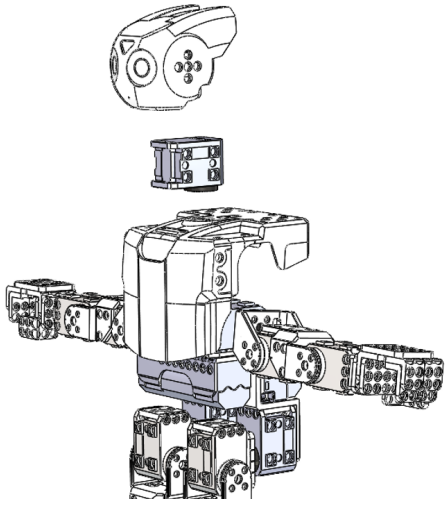


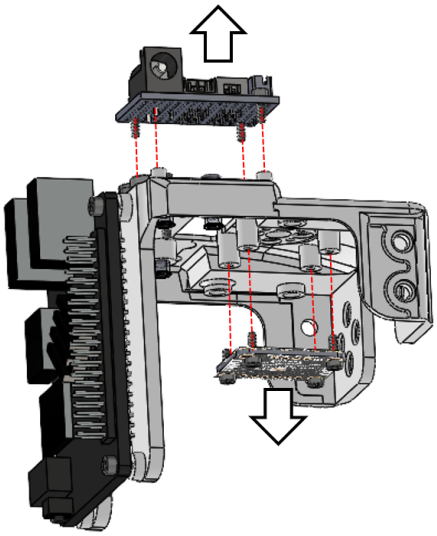
Figure 1: MINI upgrade Kit

MINI upgrade kit is an expansion kit for ROBOTIS MINI [1] humanoid robot for upgrading the capability of the robot. The upgrade kit is composed of a 3D printed frame, a single board computer, a power distribution board, a 5V voltage regulator, an IMU, and a camera as shown in Figure 1. You also need to assemble a U2D2 Serial Communication dongle. The following steps will explain how to upgrade your MINI robot with this upgrade KIT.

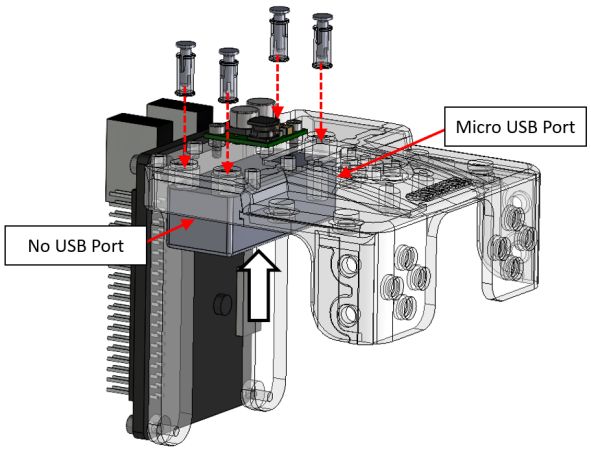
1. Take out the original frame from the body. Also, disassemble the head motor and head frame.

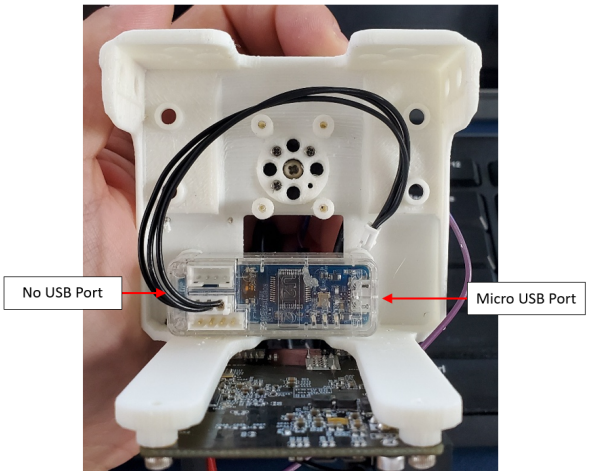


2. Unscrew the screws on the power distribution board and the IMU and detach the two boards out from the 3D printed frame.

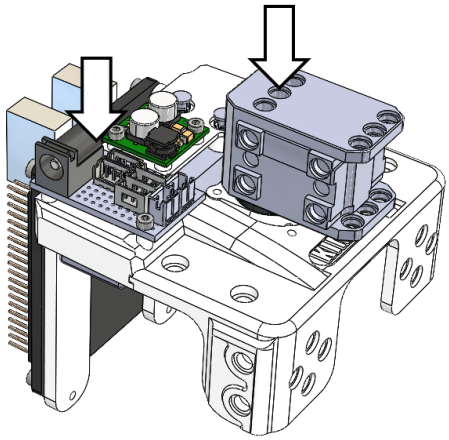


3. Place the U2D2 dongle at the bottom of the frame and secure it with long rivets. Make sure the micro USB port of the U2D2 dongle is pointing right side of the frame as shown in the Figure. Also, plug the 3-pin molex connector to the U2D2 dongle. The cable was also previously distributed with the MINI robot.

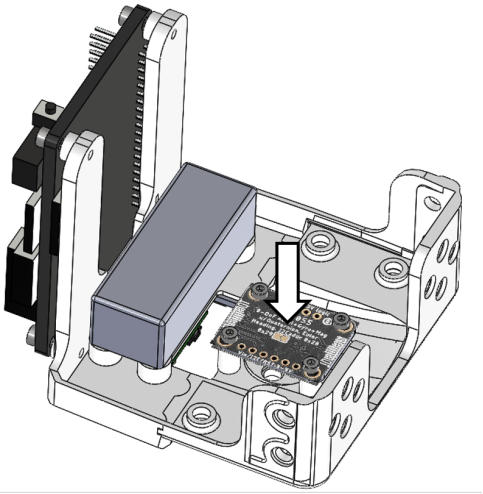


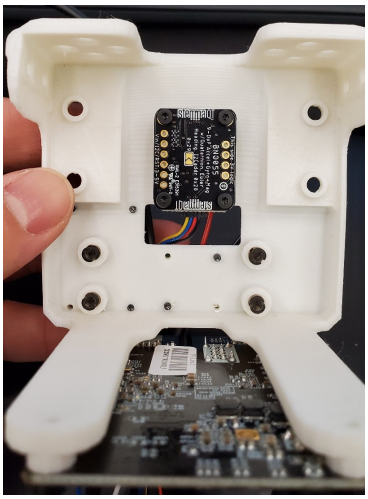


4. Attach the head motor and the power distribution board back to the upgrade kit frame

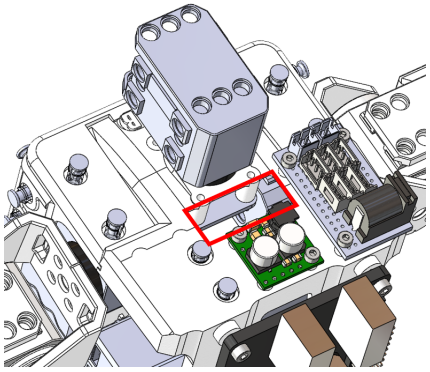


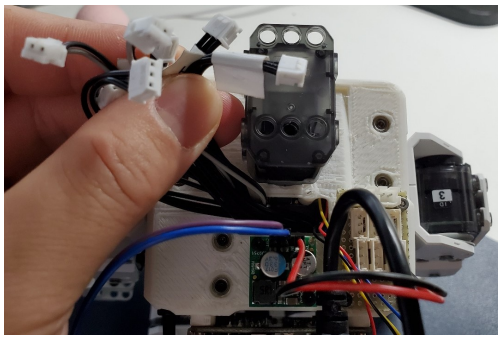
5. Assemble the BNO055 IMU back to the original place. Make sure the direction of the IMU is properly oriented as shown in the figure. The coordinate frame of the IMU is matched with the body's coordinate frame.



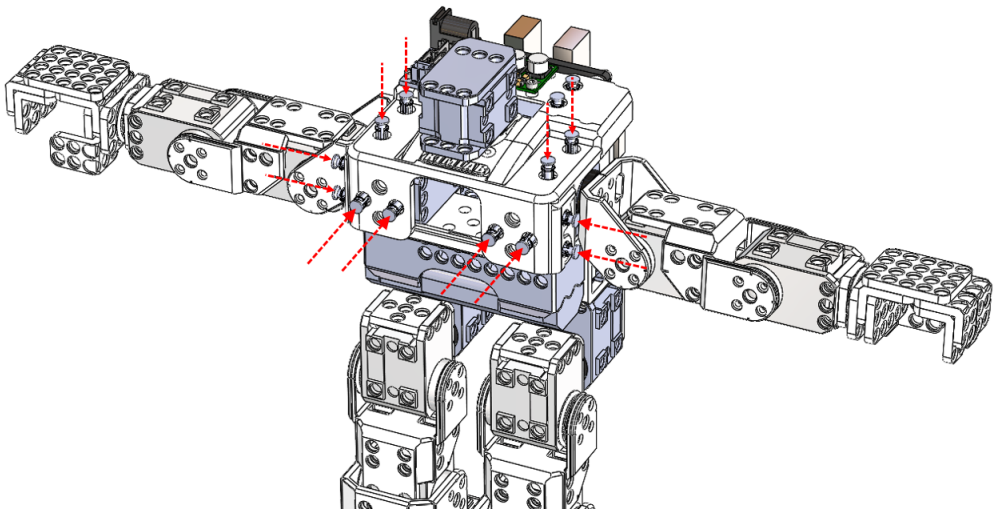


6. Bring the four motor cables, two battery cables, and a serial communication cable from U2D2 dongle to the outside of the frame through the window at the upgrade frame. Plug all the molex terminal into the power distribution board. There are no switch to power on/off the robot. To turn on the motors and the computer, plug both battery terminals to the power distribution board. You can also provide power by connecting 7.5V DC power to the adapter in the power distribution board.

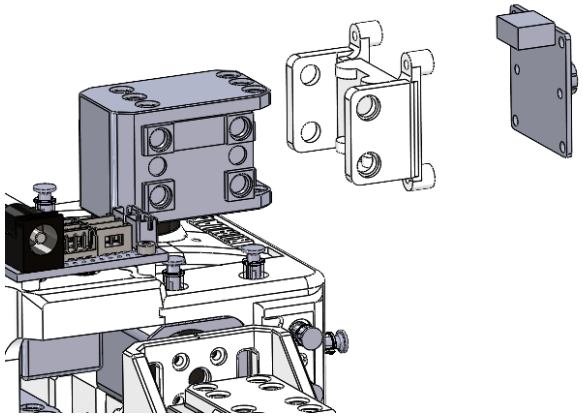




7. Assemble the upgraded frame to the MINI's body. Use long rivets to secure front side, and short rivets for other sides.



8. Assemble a camera frame and an USB camera to the head motor. Use M2 screw to secure the camera on to the camera frame.



2 Wiring guide

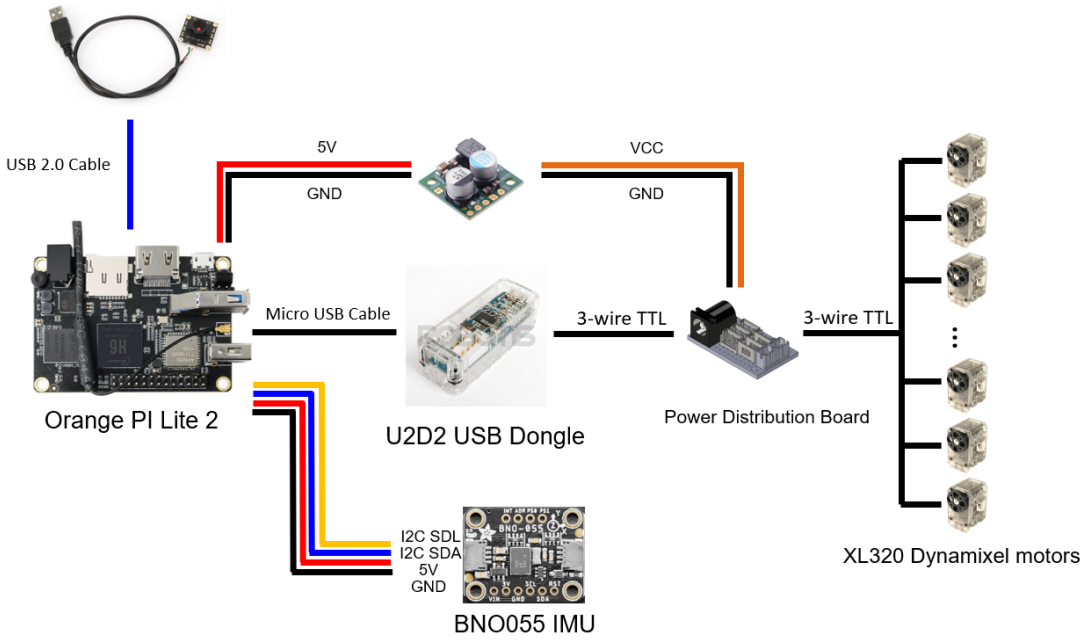
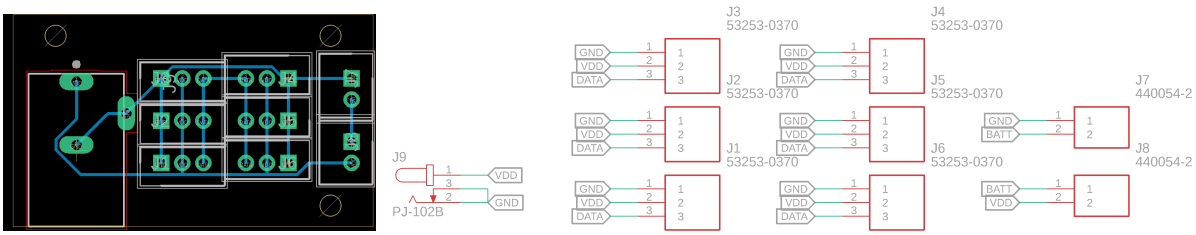


Figure 5: Upgraded MINI Communication Configuration

The schematic of the upgraded MINI system is presented in Figure 5. An Orange PI Lite 2 single-board computer is used to operate the robot [2]. A U2D2 USB serial dongle is connected to the power distribution board [3]. The XL320 Dynamixel servo motors are plugged into the power distribution board, so the U2D2 dongle and all the motors are connected in serial for a TTL 3-wire serial communication bus. The servo motors take 7.5V. Then a voltage regulator is regulating 7.5V Vcc voltage to 5V for powering the Orange PI Lite 2 computer. There is an IMU connected to the computer through I2C communication and 5V power.



(a) (b)

Figure 6: (a) Power distribution board drawing (b) Citcuit schematics

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The upgraded MINI can be powered by an external 7.5V DC power or the MINI's batteries. The single battery has specifications of 3.7V 1300mAh and the full charge voltage is 4.2V. The two batteries are connected in serial to supply voltage between 6.8V to 8.2V. When the voltage of single battery goes lower than 3.4V, the protection circuit inside of the battery package automatically cut the power to protect the battery from irreversible damage. The external power can be also used to power the robot by using a 2.5 x 5.5mm power adaptor with 7.5V DC supply voltage.

Only one of the power source (batteries or external power) should be connected to the power distribution board to provide power to the robot. Since there is no switch for the power, please connect the power source to turn on the system and plug out to turn off. In the power distribution board, there are six 3-pin molex male connectors. Since the all the motors in the MINI are connected together in a serial bus, all the motors share the same ground, VCC, and data line. The U2D2 dongle should be connected to one of the molex connectors as well to connect the motors to the serial bus.

Next to the power distribution board, there is a Pololu 5V voltage regulator [4]. The input voltage lines are connected to one of the molex connectors in the power distribution board. The voltage regulator takes the VCC voltage and drops down to 5V. The 5V and GND wires come out from the voltage regulator are connected to the Orange PI Lite 2 to power the computer. The board can be also powered by micro USB cable or a 5V/2A power jack.

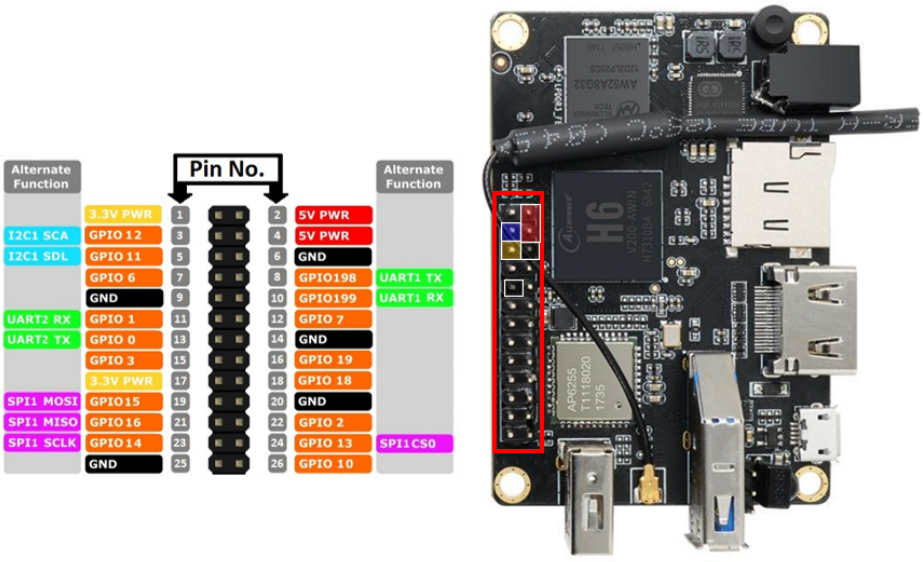

Figure 7: GPIO pinout map of Orange PI Lite 2. 5V: red, GND: black, SDA: Blue, SDL: Yellow.

There is a 9-DOF BNO055 IMU measuring the robot's acceleration, absolute orientation and magnetic field [5]. The sensor fusion algorithm is embedded on the board allowing a stable

three-axis orientation output. The IMU can output the following sensor data:

- Absolute Orientation (Euler Vector, 100Hz) Three axis orientation data based on a 360° sphere
- Absolute Orientation (Quatenrion, 100Hz) Four point quaternion output for more accurate data manipulation
- Absolute Orientation (Quatenrion, 100Hz) Four point quaternion output for more accurate data manipulation
- Angular Velocity Vector (100Hz) Three axis of 'rotation speed' in rad/s
- Acceleration Vector (100Hz) Three axis of acceleration (gravity + linear motion) in m/s^2
- Magnetic Field Strength Vector (20Hz) Three axis of magnetic field sensing in micro Tesla (uT)
- Linear Acceleration Vector (100Hz) Three axis of linear acceleration data (acceleration minus gravity) in m/s^2
- Gravity Vector (100Hz) Three axis of gravitational acceleration (minus any movement) in m/s^2
- Temperature (1Hz) Ambient temperature in degrees celsius

The IMU is connected to the computer with I2C communication. There are 4 wires coming out from the IMU. Red wire is for 5V, Black wire is for GND, Blue wire is I2C SDA Data, and Yellow wire is I2C SDL Clock. Please refer to Figure 7 which shows the GPIO pinout map of Orange Pi Lite 2 Board to properly connect the wires to the GPIO pins at the computer.

Finally, a HBV-1615-1355 USB camera is attached at the head motor. The USB camera is connected to the computer with USB 2.0 line. Please refer to the table below for the specification of the camera.

Model No.	HBV-1615
Size	28mm x 28mm x 11.5mm
Interface	USB2.0
Supply Voltage	5V
Maximum Power Consumption	500mW
Sensor	HM1355 (1/6")
Pixel Size	1.75μm x 1.75μm
Image Transfer Rage	YUY2 160x120 30 FPS YUY2 320x240 30 FPS YUY2 640x480 30 FPS YUY2 800x600 7 FPS YUY2 1280x1024 7 FPS
FOV	55°

3 System setup

This section will explain how to configure the operating system of the Upgrade MINI such as imaging a SD card and set up an network and I2C communication in the system configuration.

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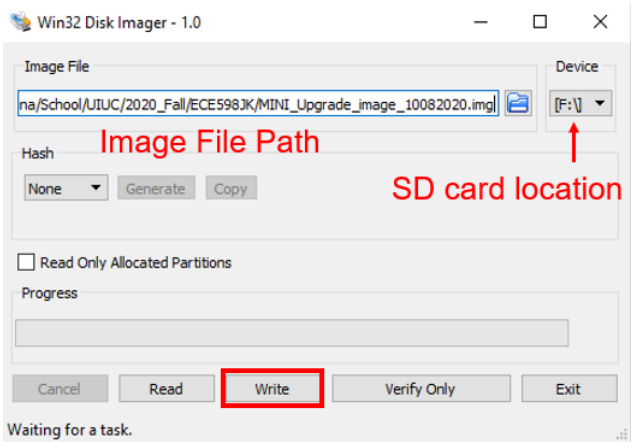
1) Image OS

The system image for MINI can be downloaded in the following link:
https://uofi.box.com/s/pz7chnnekmoqi1l691u9w1nzvsp027o8.

By writing the image file to a SD card, an operation system and the necessary software components to run the hardware can be ready at once.

To write the image to an SD card, you can use an imaging software. I recommend to use "Win32 Disk Imager" for Windows computers [6].



Open "Win32 Disk Imager" and insert the SD card into your PC. Then put the path of the image file and SD card location in the software. After pressing "write" and waiting for a while, your SD card will be ready.

The image has Armbian Bionic Linux Operation System. Armbian Bionic is an Ubuntu bionic based operating system for ARM development boards. For the upgrade MINI, armbian bionic 21.02.1 version with linux 5.10.60-sunxi64 version is installed. In the provided image, ROS Melodic, OpenCV and Dynamixel SDK are already installed. Dynamixel SDK is a software development kit that provides control function for Dynamixel servo using packet communication. It supports C, C++, C#, Java, MATLAB, Labview, Python and ROS. Please refer to the e-manual to get more information and tutorials for Dynamixel SDK [7].

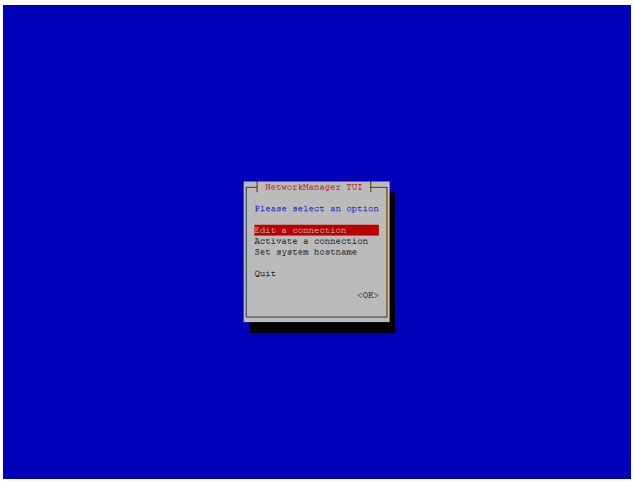
Please use **"mini"** for the username and **"1234"** for the password. Now, let's get started with setting up the network and I2C communication.

2) Network Setup

First, let's connect the computer to a WIFI network. If the computer is connected to a network, you don't need to connect a monitor and keyboard to the Orange Pi Lite 2 directly,

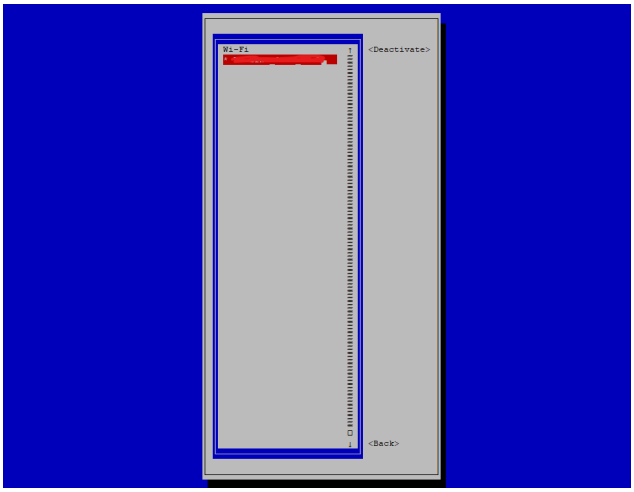
but you can use a SSH communication to remotely access to the Orange PI Lite 2 more conveniently. Please follow the steps for the network setting.

1. type `sudo nmtui` to open Network Manager Text User Interface



2. Select Activate Connection

3. You will see a list of available WIFI names. Select the one you want to connect.



4. When the computer is successfully connected to the WIFI, an asterisk mark (*) next to the WIFI's name.

5. Press "ESC" to exit Network Manager Text User Interface.

6. type `sudo ifconfig` to see the current network information.

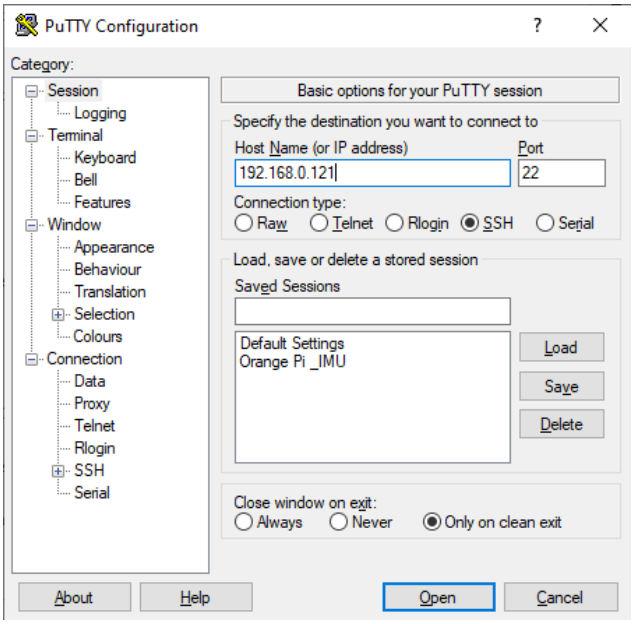
```
root@orangepilite2:~# sudo ifconfig
lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1  prefixlen 128  scopeid 0x10<host>
        loop  txqueuelen 1000  (Local Loopback)
        RX packets 0  bytes 0 (0.0 B)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 0  bytes 0 (0.0 B)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

wlan0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet 192.168.0.121  netmask 255.255.255.0  broadcast 192.168.0.255
        inet6 fe80::c16:4902:f11a:6e5  prefixlen 64  scopeid 0x20<link>
        ether 10:2c:6b:06:c1:5a  txqueuelen 1000  (Ethernet)
        RX packets 481  bytes 38573 (38.5 KB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 410  bytes 126832 (126.8 KB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

7. Please remember the inet IP address which is the IP of your computer. You will need this address to open SSH connection.

8. Now, Let's try to use SSH connection to remotely access to the Orange Pi Lite 2. Download and run "Putty". Putty is one of the most popular client for SSH connection.

9. In the configuration window, type in the inet IP address as a Host name and press "Open"



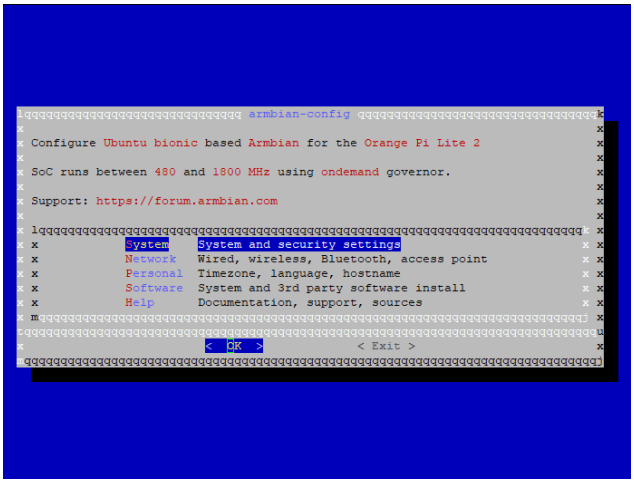
10. If you see a prompt asking a credential, you are all set!

3) I2C Setup

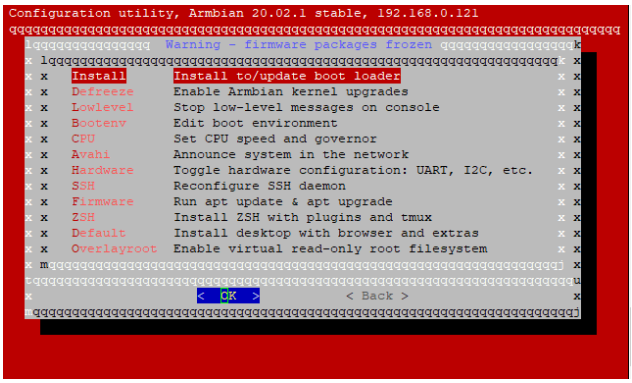
Since the IMU is connected over I2C communication, we need to make sure the I2C is enabled in the system configuration. The I2C channel 0 and 1 are enabled by default but if you have some problem with I2C communication with the IMU, you can go through the following steps for troubleshooting. Armbian operating system provides Armbian configuration utility which is a convenient tool to manage the system setting. Please proceed with the following steps after the network is connected. The network connection is required for Armbian configuration utility to work properly.

1. Type `sudo armbian-config` in the terminal. The tool needs root privilege, so don't forget to enter `sudo` in front of `armbian-config` command.

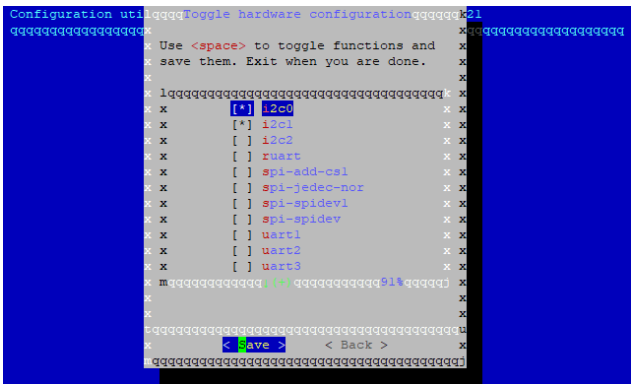
2. Go to the "System" tab



3. Select the "Hardware" tab to setup I2C communication



4. Arrow down to I2C 0 and I2C 1 and press the space bar to enable (*) both. Press enter to save



Select "Back" to exit the configuration utility and type `sudo reboot` to reboot the system.

4 Example Code

1) Squat Demonstration

- location: ~/MINI-Upgrade/
- Execute file: ~/MINI-Upgrade/Squat_Example
- Execution command: sudo ./Squat_Example
- source file: squat.c, Kinematics.c, dxl_driver.c
- description: Squat Example is a sample code for demonstrating a squat motion on a MINI robot. By running this example, your robot will do repeated squat motion!

You can adjust motion by changing the hand and foot positions. This code is a good example of how to control the Upgraded MINI robot with an Orange PI Lite 2. "mini.c" is a main source file containing the limb position command part. "Kinematics.c" is for inverse kinematics of MINI robot, and "dxl_driver.c" includes various functions regarding reading/writing to Dynamixel motors.

2) Camera Snapshot

- location: ∼/MINI-Upgrade/
- Execute file: ∼/MINI-Upgrade/bmpCapture
- Execution command: sudo ./bmpCapture filename
- source file: bmpCapture.c
- description: This is an example for a USB camera taking a snapshot in a bmp format.

3) IMU Read

- location: ∼/MINI-Upgrade/BNO055_testcode
- Execute file: ∼/MINI-Upgrade/BNO055_Read
- Execution command: sudo ./BNO055_Read
- source file: getbno055.c, i2c_bno055.c
- description: This is an example to display IMU sensor readings. When you run the example, 3-axis accelerometer data, 3-axis raw gyroscope data and 3-axis Euler angle values which was calculated by the embedded sensor fusion. "BNO055_test_prompt" is another sample code can read/write to the IMU using the prompt.

5 ROS

ROS melodic is installed in the provided image. `/catkin_ws/src` folder contains the packages. Dynamixel SDK package, BNO055 IMU driver, and MINI ROS packages are already installed. The Dynamixel SDK package is a necessary package for running the XL320 servo motors. It will generate the library reference that can be used by other ROS packages. There are no nodes generated for Dynamixel SDK package.

1) imu_bno055 package

imu_bno055 package is used to read the bno055 9-DOF imu included in the Upgrade MINI though I2C communication. By executing `roslaunch imu_bno055 imu.launch`, you can start to read the fused imu data, raw accelerometer data, raw magnetic field data. For more information, please refer to the package github [8].

2) MINI ROS package

This package incorporates the upgraded ROBOTIS MINI with ROS.

- Inplace walking node

'inplace_walking.cpp' uses inverse kinematic equations to make the MINI walk, and uses DynamixelSDK's Sync Write instruction to write motor positions all at once.

The inverse kinematic functions for right hand, left hand, right foot, and left foot (IK_RH, IK_LH, IK_RF, IK_LF) are all provided in the same file. These functions update a vector of motor positions that will be synchronously written to the motors.

The `walk(long loops)` function will loop for the input amount of ticks, and one tick is set to 8ms. The `initPose()` function sets the MINI to its initial standing pose.

- ball_chasing_node

'ball_chasing.cpp' provides a rudimentary pose-based movements for the MINI. An array of motor positions sets each of the MINI's joints individually for each frame.

It is subscribed to the 'ball_pos' topic, and receives the x and y coordinates, and size of a ball detected by the perception node. Based on the ball's coordinates and size, the robot will attempt to turn and walk towards the ball and kick it.

The motion of the robot is not very consistent, and it may fail to reach the ball, especially as the ball disappears from the camera's FOV the closer it gets to the ball.

- perception node

'perception.py' uses OpenCV to take in a video feed from the USB camera on the MINI and performs image processing to detect blue balls. It will publish the detected ball's x and y coordinates and size to the 'ball_pos' topic.

- **mini.launch**

mini.launch run the ball chasing node and perception node together, so the robot can see and move toward the ball.

References

[1] "Robotis mini e-manual, https://emanual.robotis.com/docs/en/edu/mini/."

[2] "Orange pi lite 2, http://www.orangepi.org/Orange%20Pi%20Lite%202/."

[3] "U2d2 e-manual, https://emanual.robotis.com/docs/en/parts/interface/u2d2/."

[4] "2858 pololu voltage regulator, https://www.digikey.com/en/products/detail/pololu-corporation/2858/10451183."

[5] "Adafruit bno055 9-dof imu, https://www.adafruit.com/product/4646."

[6] "Win32 disk imager, https://win32diskimager.org/."

[7] "Dynamixel sdk e-manual, https://emanual.robotis.com/docs/en/software/dynamixel/dynamixel_sdk/overview."

[8] "Bno055 ros package github, https://github.com/dheera/ros-imu-bno055."