Robot Wiring Methodology

# Introduction

Every year during build season, we have to design the robot wiring from scratch. Depending on the competition task, the wiring may involve different number of I/O channels and configurations. Therefore, the wiring is customized differently every year. The problem with this approach is that the wiring process is error prone. The potential issues in the process include:

* **Wiring Time:** Wiring usually involves making wiring harnesses with connectors on both ends using a large number of individual cables. One end plugs into various I/O channels of the Robot Controller. The other end connects to various sensors such as encoders, gyros, accelerometers, sonic sensors, bumper switches, camera etc. and various controlled outputs such as PWM motors, servos, pneumatics and relays. Because of the number of wires to crimp on both ends, it takes a substantial amount of time to finish.
* **Wiring Correctness**: Usually, it is the programmers who decide on what I/O channels to use for different sensors and output controls. This information is communicated to the build team, who builds and wires the robot, either verbally or via ad-hoc written instructions. We have miscommunications in the past that resulted in damaged components and required tremendous amount of time to debug and fix.
* **Wiring Quality and Verification**: Since most of the connectors are crimped based and the number of wires that need crimping is huge, the quality of each crimped wire is not guaranteed. Some of them looked fine, but may in fact not be making good connections end-to-end. This resulted in things not working when the robot is first fired up. Debugging of wiring problem could take a long time if unaided. When the wiring is done, there usually isn’t any verification before the robot is fired up. Any mistakes in the wiring could damage some components. Part replacement cost aside, the amount of time to identify and debug the culprit could eat into precious build time.

# What improvements can we make to solve these issues?

* **Wiring Time**: Although the competition task is different every year, there are a lot of benefits in designing standardized wiring harnesses. A robot usually consists of three parts: the Robot Controller electronics, the Running Base and the Mechanical Attachment for the competition task. To make the build process more efficient, these three parts can be built by separate teams simultaneously in modular form. Then the three parts can fit together to form the final functional robot. Therefore, it is highly desirable to have detachable wiring harnesses where the robot controller electronics can be completely wired to a number of connectors (e.g. D-Sub 50-pin and D-Sub 25-pin connectors). Similarly, the Running Base and the Mechanical Attachment can also be wired to their own connectors. When the three parts are finally fit together, it is just a matter of connecting the connectors of the Running Base and the Mechanical Attachment to the connectors on the Robot Controller electronics. The connectors of the Robot Controller electronics can be standardized such that the wiring harness can be re-used year after year. Therefore, the only variables are on the Running Base and the Mechanical Attachment which need to be wired differently every year according to the competition task. This will certainly save a lot of the wiring time during build season.
* **Wiring Correctness**: When the robot design is completed, a formal specification must be written to document the design. Most importantly, the specification should include a wiring map. Creating a wiring map doesn’t have to be a tedious task. Since the wiring on the Robot Controller side is standardized, it is a matter of filling in the wiring map template with information on the Running Base and the Mechanical Attachment side (refer to Appendix B for the wiring map template). Once this specification is created, the build team will be able to wire the Running Base and the Mechanical Attachment parts according to the specification.
* **Wiring Quality and Verification**: Once all robot parts are fitted together, the wiring must be tested before the robot is fired up. To facilitate this task, the *Wiring Verification Tool* must be used to aid the verification and debugging of wiring correctness (refer to Appendix A for the details of how to use the *Wiring Verification Tool*). The robot will only be fired up after passing wiring verification.

# Wiring Harness Standardization on the Robot Controller Side

On the robot controller, there are the following groups of signals.

* **Analog Inputs**: There are 8 Analog Input channels (3 pins for each channel).
* **General Purpose I/O (GPIO)**: There are 14 digital GPIO channels. Each of the channels can be individually configured as either *input* or *output* channel (3 pins for each channel).
* **Relay Control**: There are 8 Relay Control channels (3 pins for each channel).
* **Pulse Width Modulation Control (PWM)**: There are 10 PWM channels (3 pins for each channel).
* **Pneumatic Control**: There are 8 Pneumatic Control channels (2 pins for each channel).
* **I2C Control**: This can be used to interface with Lego NXT peripherals (8 pins).
* **Robot Status**: This connects to the Robot Status Light (2 pins).
* **Network Connection**: This is for the network camera (8 pins).

Because of the large number of pins, we must use multiple connectors to accommodate all possible signals. Since we can potentially have a separate modular Running Base and Mechanical Attachment, it is desirable to have two groups of almost identical connectors, one goes to the Running Base (e.g. Connectors A and B) and the other goes to the Mechanical Attachment (e.g. Connectors C and D). With the above consideration, the signals are grouped into the following connectors.

### Connector A: Sensor I/O-1 (D-Sub 50-pin Female)

* Analog Input channels 1-4 (12 pins).
* Relay Control channels 1-4 (12 pins).
* GPIO channels 1-7 (21 pins).
* Robot Status: Light+ and Light- (2 pins).
* Unused (3 pins).

|  |  |  |  |
| --- | --- | --- | --- |
| **Connector A: Sensor I/O-1 (D-Sub 50-pin Female)** | | | |
| **Name** | **Function** | **Pin** | **Wiring ID** |
| Analog-1 | Ainput | 18 | FA1: White/Blue |
| 5V | 2 | FA1: White/Brown |
| GND | 34 | FA1: Blue |
| Analog-2 | Ainput | 19 | FA1: White/Orange |
| 5V | 3 | FA1: Brown |
| GND | 35 | FA1: Orange |
| Analog-3 | Ainput | 20 | FA1: White/Green |
| 5V | 4 | FA2: White/Brown |
| GND | 36 | FA1: Green |
| Analog-4 | Ainput | 21 | FA2: White/Blue |
| 5V | 5 | FA2: Brown |
| GND | 37 | FA2: Blue |
| Relay-1 | FWD | 22 | FA2: White/Orange |
| REV | 6 | FA3: White/Green |
| GND | 38 | FA2: Orange |
| Relay-2 | FWD | 23 | FA2: White/Green |
| REV | 7 | FA3: Green |
| GND | 39 | FA2: Green |
| Relay-3 | FWD | 24 | FA3: White/Blue |
| REV | 8 | FA3: White/Brown |
| GND | 40 | FA3: Blue |
| Relay-4 | FWD | 25 | FA3: White/Orange |
| REV | 9 | FA3: Brown |
| GND | 41 | FA3: Orange |
| Digital-1 | GPIO | 26 | FA4: White/Blue |
| 5V | 10 | FA4: White/Brown |
| GND | 42 | FA4: Blue |
| Digital-2 | GPIO | 27 | FA4: White/Orange |
| 5V | 11 | FA4: Brown |
| GND | 43 | FA4: Orange |
| Digital-3 | GPIO | 28 | FA4: White/Green |
| 5V | 12 | FA5: White/Brown |
| GND | 44 | FA4: Green |
| Digital-4 | GPIO | 29 | FA5: White/Blue |
| 5V | 13 | FA5: Brown |
| GND | 45 | FA5: Blue |
| Digital-5 | GPIO | 30 | FA5: White/Orange |
| 5V | 14 | FA6: White/Green |
| GND | 46 | FA5: Orange |
| Digital-6 | GPIO | 31 | FA5: White/Green |
| 5V | 15 | FA6: Green |
| GND | 47 | FA5: Green |
| Digital-7 | GPIO | 32 | FA6: White/Blue |
| 5V | 16 | FA6: White/Brown |
| GND | 48 | FA6: Blue |
| Misc | Reserved | 33 | FA6: White/Orange |
| Robot Status | Light + | 17 | FA6: Brown |
| Light - | 49 | FA6: Orange |
|  | Unused | 1 |  |
|  | Unused | 50 |  |

### Connector B: Control Output-1 (D-Sub 25-pin Female)

* PWM channels 1-5 (15 pins).
* Pneumatic Control channels 1-4 (8 pins).
* Unused (2 pins)

|  |  |  |  |
| --- | --- | --- | --- |
| **Connector B: Control Output (D-Sub 25-pin Female)** | | | |
| **Name** | **Function** | **Pin** | **Wiring ID** |
| PWM-1 | PWM | 2 | FB1: White/Blue |
| 6V | 14 | FB1: White/Brown |
| GND | 15 | FB1: Blue |
| PWM-2 | PWM | 16 | FB1: White/Orange |
| 6V | 3 | FB1: Brown |
| GND | 4 | FB1: Orange |
| PWM-3 | PWM | 5 | FB1: White/Green |
| 6V | 17 | FB2: White/Green |
| GND | 18 | FB1: Green |
| PWM-4 | PWM | 19 | FB2: White/Blue |
| 6V | 6 | FB2: Green |
| GND | 7 | FB2: Blue |
| PWM-5 | PWM | 8 | FB2: White/Orange |
| 6V | 20 | FB2: White/Brown |
| GND | 21 | FB2: Orange |
| DO-1 | OUT | 9 | FB3: White/Blue |
| GND | 22 | FB3: Blue |
| DO-2 | OUT | 10 | FB3: White/Orange |
| GND | 23 | FB3: Orange |
| DO-3 | OUT | 11 | FB3: White/Green |
| GND | 24 | FB3: Green |
| DO-4 | OUT | 12 | FB3: White/Brown |
| GND | 25 | FB3: Brown |
| Misc | Reserved | 1 | FB2: Brown |
|  | Unused | 13 |  |

### Connector C: Senor I/O-2 (D-Sub 50-pin Female)

* Analog Input channels 5-8 (12 pins).
* Relay Control channels 5-8 (12 pins).
* GPIO channels 8-14 (21 pins).
* Power: 5V and GND (2 pins).
* Unused (3 pins).

|  |  |  |  |
| --- | --- | --- | --- |
| **Connector C: Sensor I/O-2 (D-Sub 50-pin Female)** | | | |
| **Name** | **Function** | **Pin** | **Wiring ID** |
| Analog-5 | Ainput | 18 | FC1: White/Blue |
| 5V | 2 | FC1: White/Brown |
| GND | 34 | FC1: Blue |
| Analog-6 | Ainput | 19 | FC1: White/Orange |
| 5V | 3 | FC1: Brown |
| GND | 35 | FC1: Orange |
| Analog-7 | Ainput | 20 | FC1: White/Green |
| 5V | 4 | FC2: White/Brown |
| GND | 36 | FC1: Green |
| Analog-8 | Ainput | 21 | FC2: White/Blue |
| 5V | 5 | FC2: Brown |
| GND | 37 | FC2: Blue |
| Relay-5 | FWD | 22 | FC2: White/Orange |
| REV | 6 | FC3: White/Green |
| GND | 38 | FC2: Orange |
| Relay-6 | FWD | 23 | FC2: White/Green |
| REV | 7 | FC3: Green |
| GND | 39 | FC2: Green |
| Relay-7 | FWD | 24 | FC3: White/Blue |
| REV | 8 | FC3: White/Brown |
| GND | 40 | FC3: Blue |
| Relay-8 | FWD | 25 | FC3: White/Orange |
| REV | 9 | FC3: Brown |
| GND | 41 | FC3: Orange |
| Digital-8 | GPIO | 26 | FC4: White/Blue |
| 5V | 10 | FC4: White/Brown |
| GND | 42 | FC4: Blue |
| Digital-9 | GPIO | 27 | FC4: White/Orange |
| 5V | 11 | FC4: Brown |
| GND | 43 | FC4: Orange |
| Digital-10 | GPIO | 28 | FC4: White/Green |
| 5V | 12 | FC5: White/Brown |
| GND | 44 | FC4: Green |
| Digital-11 | GPIO | 29 | FC5: White/Blue |
| 5V | 13 | FC5: Brown |
| GND | 45 | FC5: Blue |
| Digital-12 | GPIO | 30 | FC5: White/Orange |
| 5V | 14 | FC6: White/Green |
| GND | 46 | FC5: Orange |
| Digital-13 | GPIO | 31 | FC5: White/Green |
| 5V | 15 | FC6: Green |
| GND | 47 | FC5: Green |
| Digital-14 | GPIO | 32 | FC6: White/Blue |
| 5V | 16 | FC6: White/Brown |
| GND | 48 | FC6: Blue |
| Misc | Reserved | 33 | FC6: White/Orange |
| Power | 5V | 17 | FC6: Brown |
| GND | 49 | FC6: Orange |
|  | Unused | 1 |  |
|  | Unused | 50 |  |

### Connector D: Control Output-2 (D-Sub 25-pin female)

* PWM channels 6-10 (15 pins).
* Pneumatic Control channels 1-4 (8 pins).
* Unused (2 pins).

|  |  |  |  |
| --- | --- | --- | --- |
| **Connector D: Control Output (D-Sub 25-pin Female)** | | | |
| **Name** | **Function** | **Pin** | **Wiring ID** |
| PWM-6 | PWM | 2 | FD1: White/Blue |
| 6V | 14 | FD1: White/Brown |
| GND | 15 | FD1: Blue |
| PWM-7 | PWM | 16 | FD1: White/Orange |
| 6V | 3 | FD1: Brown |
| GND | 4 | FD1: Orange |
| PWM-8 | PWM | 5 | FD1: White/Green |
| 6V | 17 | FD2: White/Green |
| GND | 18 | FD1: Green |
| PWM-9 | PWM | 19 | FD2: White/Blue |
| 6V | 6 | FD2: Green |
| GND | 7 | FD2: Blue |
| PWM-10 | PWM | 8 | FD2: White/Orange |
| 6V | 20 | FD2: White/Brown |
| GND | 21 | FD2: Orange |
| DO-5 | OUT | 9 | FD3: White/Blue |
| GND | 22 | FD3: Blue |
| DO-6 | OUT | 10 | FD3: White/Orange |
| GND | 23 | FD3: Orange |
| DO-7 | OUT | 11 | FD3: White/Green |
| GND | 24 | FD3: Green |
| DO-8 | OUT | 12 | FD3: White/Brown |
| GND | 25 | FD3: Brown |
| Misc | Reserved | 1 | FD2: Brown |
|  | Unused | 13 |  |

### Connector E: I2C/NXT (D-Sub 9-pin female)

* NXT I2C (4 pins).
* I2C Spare (4 pins).
* Unused (1 pin).

|  |  |  |
| --- | --- | --- |
| **Connector E: I2C/NXT (D-Sub 9-pin Female)** | | |
| **Function** | **Pin** | **Wiring ID** |
| Unused | 1 |  |
| I2C-SDA | 2 | FE1: White/Green |
| I2C-SCL | 3 | FE1: White/Orange |
| I2C-5V | 4 | FE1: Orange |
| I2C-GND | 5 | FE1: Green |
| SpareOut-1 | 6 | FE1: White/Blue |
| SpareOut-2 | 7 | FE1: Blue |
| SpareOut-3 | 8 | FE1: White/Brown |
| SpareOut-4 | 9 | FE1: Brown |

### Connector F: Network Camera (RJ-45 Jack)

* Network connection wired as cross-over (8 pins).

|  |  |  |
| --- | --- | --- |
| **Connector F: Camera (RJ-45 Jack)** | | |
| **RJ-45 Plug (A)** | **Pin** | **RJ-45 Jack (B)** |
| White/Green | 1 | White/Orange |
| Green | 2 | Orange |
| White/Orange | 3 | White/Green |
| Blue | 4 | Blue |
| White/Blue | 5 | White/Blue |
| Orange | 6 | Green |
| White/Brown | 7 | White/Brown |
| Brown | 8 | Brown |

# Good Wiring Practices

* Since we have a very large number of pins for the connectors, using high conductor count cable may be too expensive (e.g. 50-conductor cable). Cat-5 cable may be a good compromise because it provides 4 twisted pair of wires and can minimize cross talk between signals. Besides, on the Running Base or the Mechanical Attachment side, the wires may need to run to different directions, a single bundle of 50 wires is a lot less flexible than 6 Cat-5 cables where one Cat-5 can run up the left side of the robot and another Cat-5 can run up the right side of the robot. There is however a down side to Cat-5 cables. Each conductor is a single strand solid copper wire. It could mean if the robot movement is causing the cable to bend back and forth at high frequency, the solid copper wire may break. This is unlikely unless the movement is at high frequency and the cable routing has very tight turns. In case this is a concern for a certain cable routing scenario, inexpensive 9-conductor cables could be used instead.
* All connectors must be clearly labeled on both ends (e.g. A, B, C, … etc.).
* All cables must be clearly labeled on both ends (e.g. FA1, MB2, FD3, … etc.).
* All header connectors must be clearly labeled with the designated signal channel of the Robot Controller (e.g. AI-1, AI-2, DI-1, DI-2, DO-3, NM-1, PWM-3, … etc.).
* Each wire should be uniquely identifiable by the triplet (Connector Number, Cable Number, and Wire Color). For example, the signal pin of Analog Input 1 should be (FA1: White/Blue, which means Female Connector A, cable 1, White/Blue wire).
* After crimping a pin, check the crimping quality (e.g. is it secured?) and continuity between the two ends before inserting the pin into the D-Sub shell. Double check the D-Sub pin number, cable number and wire colors on the wiring map before inserting the pin into the D-Sub shell.
* After wiring is done, have another team member check your work.
* Before plugging the header connectors to various sensors and output controls on the robot, plug them to the *Wiring Verification Tool* first to verify the correctness.

# Appendix A: Wiring Verification Tool

The *Wiring Verification Tool* is designed to verify the wiring correctness end-to-end. The tool consists of two components: a circuit board (shown in the schematic diagram at the end of this appendix) and a testing program running on the Robot Controller. To verify the correctness of the wiring, follow the instructions below.

* Complete all the connections on the robot controller side (i.e. plug in all the header connectors from Connectors A through F into various I/O channels of the Robot Controller).
* Connect the Running Base and the Mechanical Attachment to the Robot Controller by connecting Connectors A through D. If the robot does not use some of the I/O channels, you may not need all the connectors. For example, if the robot is using less than or equal to 4 channels of Analog Input, 4 channels of Relay Control, 7 channels of Digital GPIO, 5 channels of PWM and 4 channels of Pneumatic Control, then you may want to use only Connectors A, B and skip Connectors C, D.
* Make sure all the input sensors and output controls are **NOT** connected on the Running Base and the Mechanical Attachment.
* On the Running Base and Mechanical Attachment side, plug in the header connectors to the verification tool circuit board. The circuit board is designed to test up to 8 channels of Digital GPIO, 4 channels of Analog Input, 4 channels of Relay Control, 4 channels of PWM and 4 channels of Pneumatic Control simultaneously. If the robot is using more than this capacity, you may need to do this multiple times with different sets of channels. The sections below will describe the details on how to test each type of I/O channels.
* Once the verification circuit board is connected, run the test program on the Robot Controller. The test program will display various controls and status indicators on the Control Panel. The details on how to use the test program and interpret the result on each type of I/O channels are also included in the below sections.

### Verifying Digital GPIO Channels

Verifying the Digital GPIO channels should be the first test. This is because testing other channels such as PWM involves using some Digital GPIO channels as input channels.

* Make sure the 10KΩ resistor array is removed from the Digital Input/PWM Tester. This resistor array is only needed when using it as Digital Input switches for the Driver Station. It acts as pull-up resistors for the Digital Input channels on the Driver Station.
* Connect all Digital GPIO channels (up to 8 channels at a time) to the Digital Input/PWM Tester (DI-A through DI-H connectors) on the verification circuit board.
* Make sure the jumpers JP-A through JP-H are in place.
* Run the test program and watch the Digital Input lights turn on and off when flipping the corresponding Digital Input channel DIP switches on and off on the verification circuit board.
* If the lights behave as expected, all Digital GPIO channel wirings are good.
* If some channels are not behaving as expected, check the wiring of that channel and correct the problem if necessary.
* This test only confirms whether the Digital GPIO pins and the GND pins are wired correctly. It doesn’t confirm if the +5V pins are good. Therefore, you need to remove the Digital GPIO headers from the DI-x terminals of the Digital Input/PWM Tester and plug them into the DO-x terminals of the Digital Output/Relay Tester instead. If the +5V pins are wired correctly, you should see only the RED LEDs lighting up.

### Verifying Analog Input Channels

Analog Input channels are used for sensors such as gyros and accelerometers. The Analog Input Tester on the verification circuit board tests it by connecting the channel to a potentiometer so that you can adjust the voltage to the Analog Input pin.

* Connect all Analog Input channels (up to 4 channels at a time) to the Analog Input Tester (AI-A through AI-D connectors) on the verification circuit board.
* Run the test program and watch the Analog signal meters when adjusting the potentiometers on the circuit board up and down. If the meters behave as expected, the Analog channel wirings are good.
* If some channels are not behaving as expected, check the wiring of that channel and correct the problem if necessary.

### Verifying Relay Control Channels

Relay Control channels are similar to Digital Outputs except that they can have two states: Forward (FWD) and Reverse (REV) instead of just ON and OFF.

* Connect all Relay Control channels (up to 4 channels at a time) to the Digital Output/Relay Tester (FWD-A through FWD-D connectors) on the verification circuit board.
* Run the test program and flip each of the Relay controls to FWD or REV. Watch the RED and GREEN LEDs for the corresponding channel on the verification circuit board. Make sure RED lights up when on REV and GREEN lights up on FWD. If they do, the Relay Output wirings are good.
* If some channels are not behaving as expected, check the wiring of that channel and correct the problem if necessary.

### Verifying Pneumatic Control Channels

Pneumatic Control channels are similar to Digital Outputs except that they have higher voltage, usually 12V instead of 5V. Therefore, you cannot plug the Pneumatic Control channels to the Digital Output Tester or you may damage the LEDs on the tester.

* Connect all Pneumatic Control channels (up to 4 channels at a time) to the Pneumatic Control Tester (NM-A through NM-D connectors) on the verification circuit board.
* Run the test program and flip each of the Pneumatic controls ON and OFF. Watch the YELLOW LEDs for the corresponding channel and make sure they come ON and OFF as expected. If they do, the Pneumatic Control wirings are good.
* If some channels are not behaving as expected, check the wiring of that channel and correct the problem if necessary.

### Verifying PWM Channels

PWM channels are like Digital Outputs except that the signals on these outputs are not simple ON and OFF but square wave pulses with different widths according to the values programmed into the channels. Since the pulse widths are in the order of milliseconds, it is very hard to monitor those using LEDs. To simplify the tester circuit, it is decided to feed the PWM signals into the Digital Input Tester so that the Digital Input graphs on the test program will capture the wave forms of the signal.

* Make sure the 10KΩ resistor array is removed from the Digital Input/PWM Tester. This resistor array is only needed when using it as Digital Input switches for the Driver Station. It acts as pull-up resistors for the Digital Input channels on the Driver Station.
* Connect all Digital GPIO channels (up to 8 channels at a time) to the Digital Input/PWM Tester (DI-A through DI-H connectors) on the verification circuit board.
* Remove the jumpers JP-A through JP-H.
* Connect all PWM channels (up to 8 channels at a time) to the Digital Input/PWM Tester (PWM-A through PWM-H connectors) on the verification circuit board.
* Run the test program and adjust the PWM value of each channel up and down. Watch the corresponding Digital Input graphs for pulse width changes.
* If the pulse widths changed as expected, the PWM wirings are good.
* If some channels are not behaving as expected, check the wiring of that channel and correct the problem if necessary.



# Appendix B: Wiring Map for Running Base and Mechanical Attachment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Connector A: Sensor I/O-1 (D-Sub 50-pin Male)** | | | | |
| **Name** | **Function** | **Pin** | **Wiring ID** | **Robot Function** |
| Analog-1 | Ainput | 18 | MA |  |
| 5V | 2 | MA |
| GND | 34 | MA |
| Analog-2 | Ainput | 19 | MA |  |
| 5V | 3 | MA |
| GND | 35 | MA |
| Analog-3 | Ainput | 20 | MA |  |
| 5V | 4 | MA |
| GND | 36 | MA |
| Analog-4 | Ainput | 21 | MA |  |
| 5V | 5 | MA |
| GND | 37 | MA |
| Relay-1 | FWD | 22 | MA |  |
| REV | 6 | MA |
| GND | 38 | MA |
| Relay-2 | FWD | 23 | MA |  |
| REV | 7 | MA |
| GND | 39 | MA |
| Relay-3 | FWD | 24 | MA |  |
| REV | 8 | MA |
| GND | 40 | MA |
| Relay-4 | FWD | 25 | MA |  |
| REV | 9 | MA |
| GND | 41 | MA |
| Digital-1 | GPIO | 26 | MA |  |
| 5V | 10 | MA |
| GND | 42 | MA |
| Digital-2 | GPIO | 27 | MA |  |
| 5V | 11 | MA |
| GND | 43 | MA |
| Digital-3 | GPIO | 28 | MA |  |
| 5V | 12 | MA |
| GND | 44 | MA |
| Digital-4 | GPIO | 29 | MA |  |
| 5V | 13 | MA |
| GND | 45 | MA |
| Digital-5 | GPIO | 30 | MA |  |
| 5V | 14 | MA |
| GND | 46 | MA |
| Digital-6 | GPIO | 31 | MA |  |
| 5V | 15 | MA |
| GND | 47 | MA |
| Digital-7 | GPIO | 32 | MA |  |
| 5V | 16 | MA |
| GND | 48 | MA |
| Misc | Reserved | 33 | MA |  |
| Robot Status | Light + | 17 | MA |  |
| Light - | 49 | MA |
|  | Unused | 1 | MA |  |
|  | Unused | 50 | MA |  |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Connector B: Control Output (D-Sub 25-pin Male)** | | | | | | | | | |
| **Name** | **Function** | | **Pin** | | **Wiring ID** | | **Robot Function** | | |
| PWM-1 | PWM | | 2 | | MB | |  | | |
| 6V | | 14 | | MB | |
| GND | | 15 | | MB | |
| PWM-2 | PWM | | 16 | | MB | |  | | |
| 6V | | 3 | | MB | |
| GND | | 4 | | MB | |
| PWM-3 | PWM | | 5 | | MB | |  | | |
| 6V | | 17 | | MB | |
| GND | | 18 | | MB | |
| PWM-4 | PWM | | 19 | | MB | |  | | |
| 6V | | 6 | | MB | |
| GND | | 7 | | MB | |
| PWM-5 | PWM | | 8 | | MB | |  | | |
| 6V | | 20 | | MB | |
| GND | | 21 | | MB | |
| DO-1 | OUT | | 9 | | MB | |  | | |
| GND | | 22 | | MB | |
| DO-2 | OUT | | 10 | | MB | |  | | |
| GND | | 23 | | MB | |
| DO-3 | OUT | | 11 | | MB | |  | | |
| GND | | 24 | | MB | |
| DO-4 | OUT | | 12 | | MB | |  | | |
| GND | | 25 | | MB | |
| Misc | Reserved | | 1 | | MB | |  | | |
|  | Unused | | 13 | | MB | |  | | |
| **Connector C: Sensor I/O-2 (D-Sub 50-pin Male)** | | | | | | | | |
| **Name** | | **Function** | | **Pin** | | **Wiring ID** | | **Robot Function** |
| Analog-1 | | Ainput | | 18 | | MC | |  |
| 5V | | 2 | | MC | |
| GND | | 34 | | MC | |
| Analog-2 | | Ainput | | 19 | | MC | |  |
| 5V | | 3 | | MC | |
| GND | | 35 | | MC | |
| Analog-3 | | Ainput | | 20 | | MC | |  |
| 5V | | 4 | | MC | |
| GND | | 36 | | MC | |
| Analog-4 | | Ainput | | 21 | | MC | |  |
| 5V | | 5 | | MC | |
| GND | | 37 | | MC | |
| Relay-1 | | FWD | | 22 | | MC | |  |
| REV | | 6 | | MC | |
| GND | | 38 | | MC | |
| Relay-2 | | FWD | | 23 | | MC | |  |
| REV | | 7 | | MC | |
| GND | | 39 | | MC | |
| Relay-3 | | FWD | | 24 | | MC | |  |
| REV | | 8 | | MC | |
| GND | | 40 | | MC | |
| Relay-4 | | FWD | | 25 | | MC | |  |
| REV | | 9 | | MC | |
| GND | | 41 | | MC | |
| Digital-1 | | GPIO | | 26 | | MC | |  |
| 5V | | 10 | | MC | |
| GND | | 42 | | MC | |
| Digital-2 | | GPIO | | 27 | | MC | |  |
| 5V | | 11 | | MC | |
| GND | | 43 | | MC | |
| Digital-3 | | GPIO | | 28 | | MC | |  |
| 5V | | 12 | | MC | |
| GND | | 44 | | MC | |
| Digital-4 | | GPIO | | 29 | | MC | |  |
| 5V | | 13 | | MC | |
| GND | | 45 | | MC | |
| Digital-5 | | GPIO | | 30 | | MC | |  |
| 5V | | 14 | | MC | |
| GND | | 46 | | MC | |
| Digital-6 | | GPIO | | 31 | | MC | |  |
| 5V | | 15 | | MC | |
| GND | | 47 | | MC | |
| Digital-7 | | GPIO | | 32 | | MC | |  |
| 5V | | 16 | | MC | |
| GND | | 48 | | MC | |
| Misc | | Reserved | | 33 | | MC | |  |
| Power | | 5V | | 17 | | MC | |  |
| GND | | 49 | | MC | |
|  | | Unused | | 1 | | MC | |  |
|  | | Unused | | 50 | | MC | |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Connector D: Control Output (D-Sub 25-pin Male)** | | | | |
| **Name** | **Function** | **Pin** | **Wiring ID** | **Robot Function** |
| PWM-6 | PWM | 2 | MD |  |
| 6V | 14 | MD |
| GND | 15 | MD |
| PWM-7 | PWM | 16 | MD |  |
| 6V | 3 | MD |
| GND | 4 | MD |
| PWM-8 | PWM | 5 | MD |  |
| 6V | 17 | MD |
| GND | 18 | MD |
| PWM-9 | PWM | 19 | MD |  |
| 6V | 6 | MD |
| GND | 7 | MD |
| PWM-10 | PWM | 8 | MD |  |
| 6V | 20 | MD |
| GND | 21 | MD |
| DO-5 | OUT | 9 | MD |  |
| GND | 22 | MD |
| DO-6 | OUT | 10 | MD |  |
| GND | 23 | MD |
| DO-7 | OUT | 11 | MD |  |
| GND | 24 | MD |
| DO-8 | OUT | 12 | MD |  |
| GND | 25 | MD |
| Misc | Reserved | 1 | MD |  |
|  | Unused | 13 | MD |  |