Sensor and safety circuit documentation

- P1 Sub-Project -

Project Sub-Report

ROB1 B332-b

Aalborg Universitet
The Technological Faculty for IT and Design
Department of electronic systems

AALBORG UNIVERSITY
STUDENT REPORT

The Technological Faculty for IT and Design
Department of electronic systems
Niels Jernes Vej 10, 9220 Aalborg Øst
http://www.aau.dk

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Participant(s):
Kasper M. Hytting
Kjartan N. Jespersen
Maiken C. Lanng
Jesper Poscholann Hammer

Supervisor(s):
Matthias Rehm

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Abstract:

Technical documentation regarding hardware, firmware and ROS support for inductive sensors as well as circuit safety features for demining robot.

Preface

Aalborg University, December 18, 2020

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Kasper M. Hytting
khytti19@student.aau.dk

x

Kjartan N. Jespersen
knje20@student.aau.dk

x

Maiken C. Lanng
mlanng19@student.aau.dk

x

Jesper P. Hammer
jhamme19@student.aau.dk

Contents

1 Introduction

The purpose of the hardware is the enable and ensure the operation of the inductive sensors during demining operations.
The system will handle power management as well as circuit safety measurements and analysis.
All data from safety circuits as well as sensors are compressed to ROS packages, which are published to any subscriber in the robots software system.

At the same time, all functions handled by this hardware will subscribe to relevant ROS PKG, allowing the robots central software and external units connected to the robot full control of the functionalities provided by this hardware.

The hardware is optimized for 12V operation, but will function fully in the range 10.1V-12V. The system can function can operate for a limited period of time on any voltage $>12V$ and $<15V$. This will however overheat the internal power supply[1] and will eventually cause this to fail, resulting in failure of the entire hardware section.

The system is designed around minimizing power consumption while still providing the best possible sensor resolution and refresh rate.

To accommodate this, sensors as well as safety circuit can be witched on and off at any time using commands via ROS. This allows for robot movement in zero-risk areas while keeping power consumption at ”no more than absolutely necessary”.

[1] Power supply is not actively cooled

2 Hardware

2.1 PCB

The PCB handles signal processing for the sensors as well as safety features for the circuit, ensuring detection of potential failures in operation.

The circuit is designed with three sections; primary signal processing and ROS handling, safety and sensors.

The primary signal processing section handles signal processing, voltage control, enabling and disabling of other sectors and ROS communication. ROS communication is both in- and outgoing, integrated through Arduino onto ATmega 2560 microcontroller using rosserial and connected to the ROS server via USB.

The safety section measures critical points throughout the circuit and decodes potential errors subsequently relaying these through the primary signal processing section.

The sensor section handles sensors, sensor voltage regulation, and sensor signal voltage regulation. This section also handles powering the sensors on and of when receiving corresponding commands via ROS.

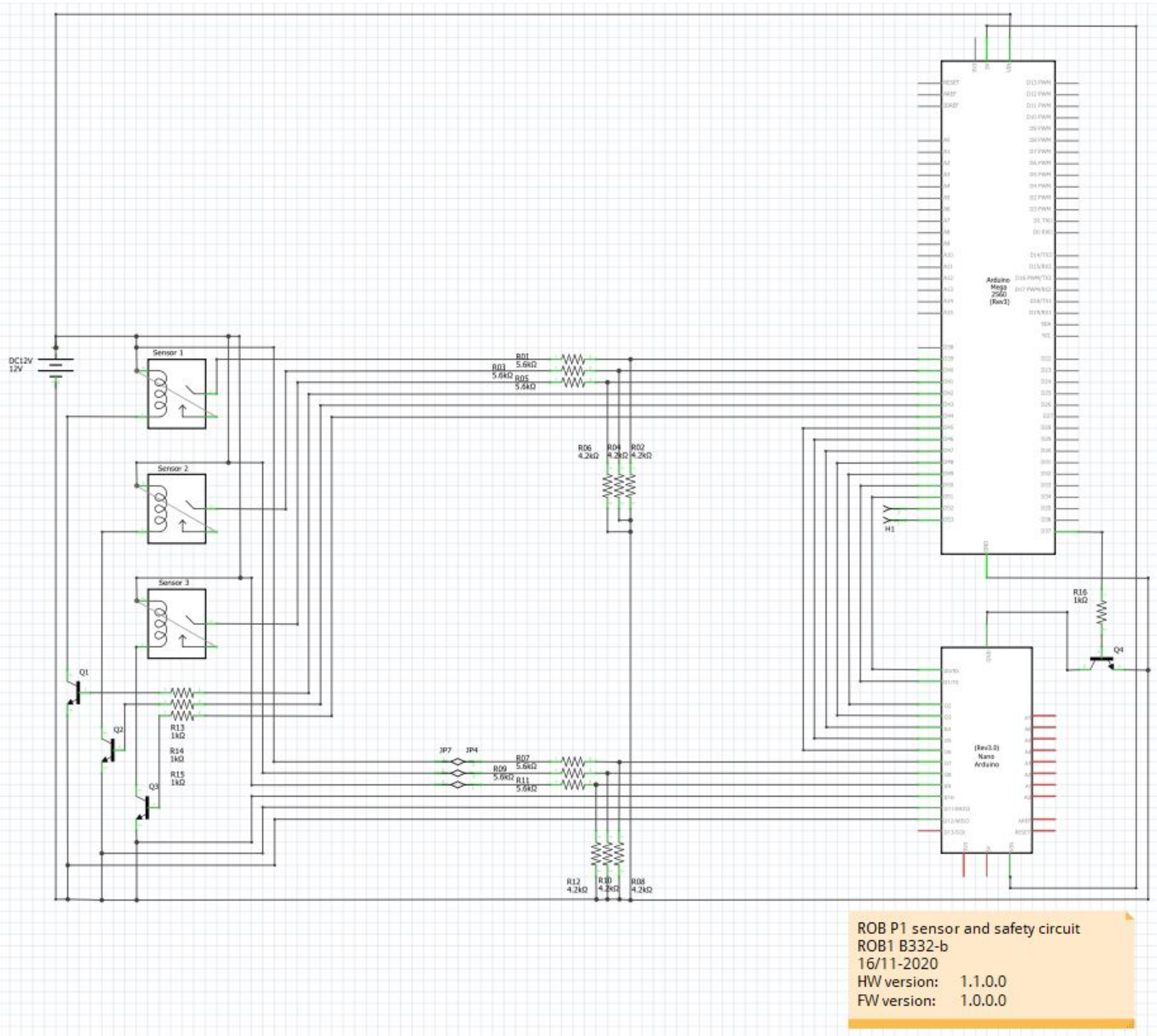
The safety circuit has a jumper bridge for the 12 VDC sensors. Removing the jumpers will disable the 12 VDC sensors[1] but will also lower power consumption in that subsection of the safety section and improve signal processing time in the safety microcontroller.

2.1.1 General characteristics

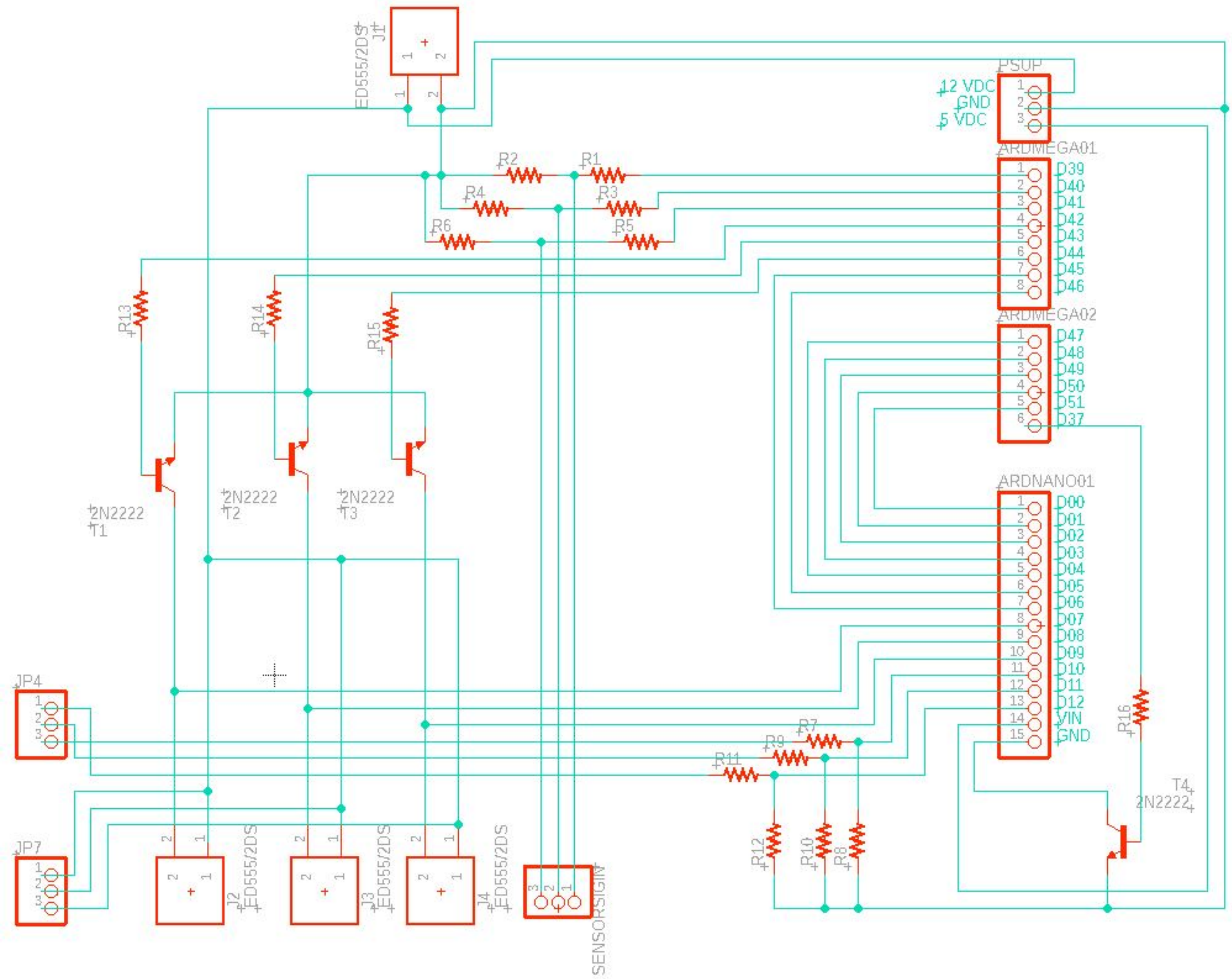
Operating voltage:	10.1 VDC to 12 VDC
Supply current (min):	0.3 A
Power consumption (max):	3.5 W
Operating temperature:	-25°C to 70°C
Standards:	IP00 after IEC 60529
Sensing range (horizontal):	33.69 mm
Sensing range (vertical):	17 mm
Sensor response frequency:	100 Hz
System update frequency:	10 Hz

[1] New firmware will have to be loaded to avoid system alerts caused by the lacking signal via the jumper bridge

2.1.2 System schematic



2.1.3 PCB schematic



2.1.3.1 Version note

Diodes D1-D3 blocks most redundant voltage (< 1 VDC) being passed through to the sensors, thus preventing the micro controller from functioning as GND to any considerable extent.[2] This applies in any case other than failure in the sensor.[3]

[2] This is due to the forward bias of diodes.

[3] Under normal operating conditions the redundant voltage from the sensors (5 mV) will not be sufficient to be read on the pin[1], and therefore the diodes does not protect against unintentionally triggering alarms in the safety micro controller.

2.1.4 Arduino pinout

Number	Name	State
D137	safetyCircuitHL	TX
D139	signal1HL	TX
D140	signal2HL	TX
D141	signal1HL	TX
D142	sensor1HL	RX
D143	sensor2HL	RX
D144	sensor3HL	RX
D145	sensorErrorType2	RX
D146	sensorErrorType1	RX
D147	sensorNumGRP3	RX
D148	sensorNumGRP2	RX
D149	sensorNumGRP1	RX
D150	imOkWire	RX
D151	rxTxMegaNano	TX
D152	testing1Tx	TX
D153	testing2Tx	TX
D200	rxTxMegaNano	RX
D201	imOkWire	TX
D202	sensorNumGRP1	TX
D203	sensorNumGRP2	TX
D204	sensorNumGRP3	TX
D205	sensorErrorType1	TX
D206	sensorErrorType2	TX
D207	sensor1Anode	RX
D208	sensor2Anode	RX
D209	sensor3Anode	RX
D210	sensor1Katode	RX
D211	sensor2Katode	RX
D212	sensor3Katode	RX

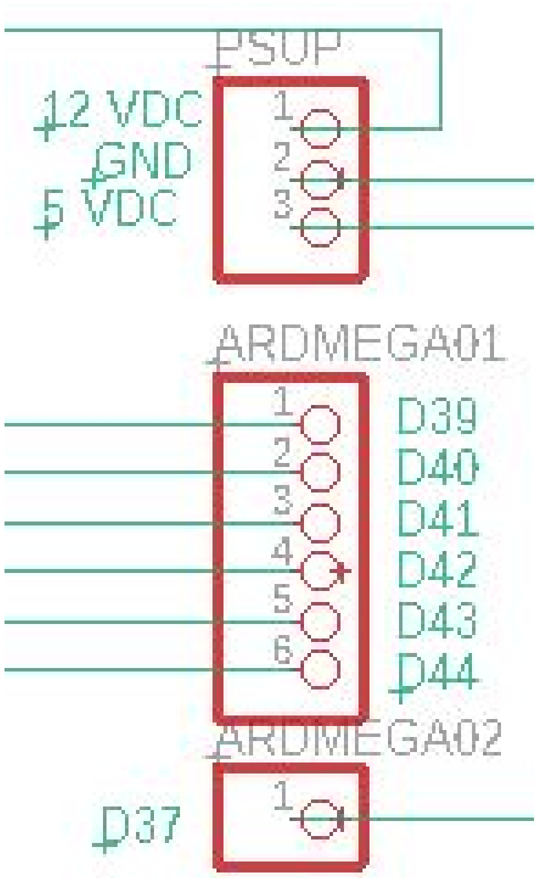
2.1.4.1 Legend

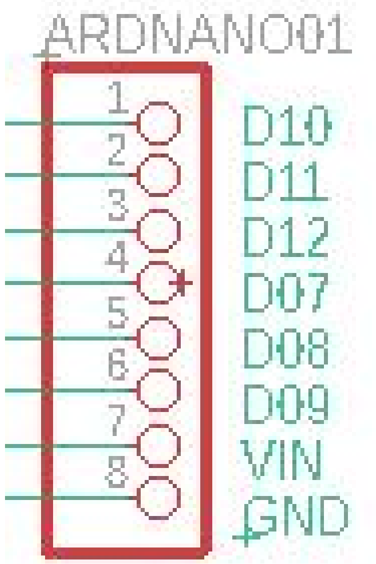
Number:
The pins are numbered using the format xyzz.
x is ether A (analog) or D (digital).
y is either 1 (Arduino mega 2560) or 2 (Arduino Nano).
zz is the corresponding pin number.

Name:
The name is the name of the handler variable in the respective Arduino units.

State:
State refers to the set state of each pin in the corresponding Arduino unit.
RX-pins can only receive signals and, TX-pins can only transmit signals.

2.1.5 PCB pin list




ARDNANO01
1
2
3
4
5
6
7
8
D10
D11
D12
D07
D08
D09
VIN
GND

2.1.6 Part list

Ref.	P/N	Properties	Description
U1	- None -	VCC5V	Arduino Mega 2560
U2	- None -	VCC5V	Arduino Nano
U3	Omron E2B-M30LN30-WP-B1 2M	30 mm range, 10-30 VDC, max. 200 mA	Inductive sensor
U4	Omron E2B-M30LN30-WP-B1 2M	30 mm range, 10-30 VDC, max. 200 mA	Inductive sensor
U5	Omron E2B-M30LN30-WP-B1 2M	30 mm range, 10-30 VDC, max. 200 mA	Inductive sensor
R1	5k62	5.62KΩ, max. effect: 1/4 W	Resistor
R2	4k22	4.22kΩ, max. effect: 1/4 W	Resistor
R3	5k62	5.62KΩ, max. effect: 1/4 W	Resistor
R4	4k22	4.22kΩ, max. effect: 1/4 W	Resistor
R5	5k62	5.62KΩ, max. effect: 1/4 W	Resistor
R6	4k22	4.22kΩ, max. effect: 1/4 W	Resistor
R7	5k62	5.62KΩ, max. effect: 1/4 W	Resistor
R8	4k22	4.22kΩ, max. effect: 1/4 W	Resistor
R9	5k62	5.62KΩ, max. effect: 1/4 W	Resistor
R10	4k22	4.22kΩ, max. effect: 1/4 W	Resistor
R11	5k62	5.62KΩ, max. effect: 1/4 W	Resistor
R12	4k22	4.22kΩ, max. effect: 1/4 W	Resistor
R13	1k00	1KΩ, max. effect: 1/4 W	Resistor
R14	1k00	1kΩ, max. effect: 1/4 W	Resistor
R15	1k00	1KΩ, max. effect: 1/4 W	Resistor
R16	1k00	1kΩ, max. effect: 1/4 W	Resistor
Q1	BC547	NPN, max. effect: 625 mW	Transistor
Q2	BC547	NPN, max. effect: 625 mW	Transistor
Q3	BC547	NPN, max. effect: 625 mW	Transistor
Q4	BC547	NPN, max. effect: 625 mW	Transistor
D1	1N4001	V_F: 1 V, max. strøm: 1 A	Diode
D2	1N4001	V_F: 1 V, max. strøm: 1 A	Diode
D3	1N4001	V_F: 1 V, max. strøm: 1 A	Diode

2.1.7 Electrical characteristics

The system is designed to operate on battery power and therefore levels are listed for both highest and lowest operable battery-state.

2.1.7.1 System current draw under various conditions

Condition	10.1V	12V
System on, safety off, sensors off, not detecting	170.00 mA	200.00 mA
System on, safety on, sensors on, not detecting	224.04 mA	256.65 mA
System on, safety on, sensors on, 1 sensor detecting	225.07 mA	288.07 mA
System on, safety on, sensors on, 2 sensors detecting	226.10 mA	289.31 mA
System on, safety on, sensors on, 3 sensors detecting	227.13 mA	290.64 mA

2.1.7.2 System power consumption under various conditions

Condition	10.1V	12V
System on, safety off, sensors off, not detecting	1.8 W	2.4 W
System on, safety on, sensors on, not detecting	2.3 W	3.1 W
System on, safety on, sensors on, 1 sensor detecting	2.3 W	3.5 W
System on, safety on, sensors on, 2 sensors detecting	2.3 W	3.5 W
System on, safety on, sensors on, 3 sensors detecting	2.3 W	3.5 W

2.1.7.3 Sub-system current draw

Sub-system	10.1V	12V
12/5V converter	160 mA	190 mA
Arduino Mega 2560	10 mA	10 mA
Arduino Nano	19 mA	19 mA
Sensor power on/off transistors	10.86 mA	12.90 mA
Power rail status safety	3.09 mA	3.66 mA
Sensor short-circuit safety	3.09 mA	3.66 mA
Sensor	10 mA	10 mA
Sensor signal voltage reduction	1.03 mA	1.33 mA

2.2 Arduino Mega 2560

Arduino Mega 2560 using ATmega 2560 microcontroller[2]

2.2.1 Specs

Operating Voltage	5 VDC
Input Voltage (recommended)	7 to 12 VDC
Input Voltage (limit)	6 to 20 VDC
Digital I/O Pins	54
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 kB of which 8 kB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
Length	101.52 mm
Width	53.3 mm
Weight	37 g

Source: Arduino.cc[3]

2.2.2 Pinout

See appendix A - Arduino Mega 2560 pinout

2.3 Arduino Nano

Arduino Nano using ATmega328 microcontroller[4]

2.3.1 Specs

Operating Voltage	5 VDC
Input Voltage (recommended)	7 to 12 VDC
Digital I/O Pins	22
Analog Input Pins	8
DC Current per I/O Pin	40 mA
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 kB
EEPROM	1 kB
Clock Speed	16 MHz
Length	45 mm
Width	18 mm
Weight	7 g

Source: Arduino.cc[1]

2.3.2 Pinout

See appendix B - Arduino Nano pinout

2.4 Censor

2.4.1 Specs

Operating Voltage range	10 to 32VDC
Current consumption (max)	10 mA
Output load current (max)	200 mA
Operation mode	NO
Operating temperature	-25°C to 70°C
Ambient humidity	35% to 95%
Sensor head diameter	27.8 mm
Standards	IP67 after IEC 60529

Source: Omron.eu[5]

2.4.2 Schematic

See appendix C - Omron - E2B-M30x-xBx Schematic

2.4.3 Sensor coverage

Sensor coverage at 8 mm distance from ground while system at 10.1 VDC. Coverage calculations have been done assuming a 10.1 VDC system voltage as well as a 12 VDC system voltage to ensure safe operations in the entire voltage range.

Note that the sensor spacing is calculated based on 12 VDC system voltage to avoid interference from the housing of neighbouring sensors.

The sensors have complete coverage in an area 15.87 mm in front of the sensors center point and similarly 15.87 mm to the outward side of the sensors center point in the extreme sides. Consequently; the sensors have complete coverage at up to 2.02 mm in front of the sensor housing and at least 33.69 mm in front of the part of the robot which is closets to the sensors.

The calculations are done with CAS

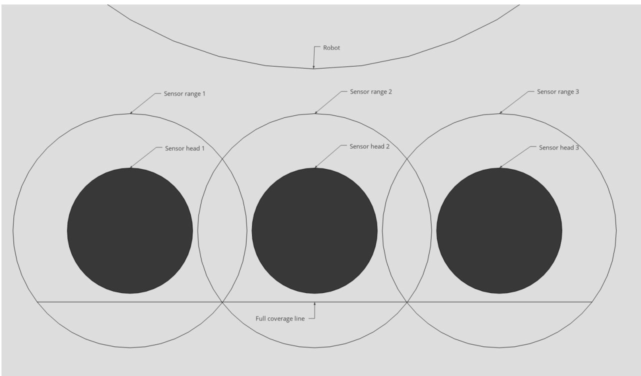


Figure 2.1: Sensor coverage sketch

3 Software

3.1 Firmware

The primary function of the firmware is to enable the micro controllers to take in signals from the circuits and translate these to communicable data in an effective and precise manner.

3.1.1 Signal processing micro controller

The signal processing micro controller (also referred to as primary IC) collects signals from the entire circuit - including the circuit safety micro controller. These signals are read as either high or low state on each port and the state is translated to a 1 or a 0, which is then transmitted via ROS onto the network of nodes.

The signal processing micro controller also takes instructions from the ROS network of nodes and translates these to these to signals and outputs these to the circuit by setting corresponding ports to either high or low.

3.1.1.1 Code

The described translations are handled in the code as follows:

```
// Contact 1
if (digitalRead (39) == HIGH)
{
  msg1.contact1 = 1;
  saspub.publish( &msg1);
}
```

All transmissions out of the micro controller are handled as shown above. A signal input is read if present and the result is published to the ROS network. Note that the publisher is only activated, if the port has a relevant state.

```
//Switch sensor 1 ON and advertise state to safety circuit
if(sensorIO.sensor1IO == 1)
{
  digitalWrite (42, HIGH);
  digitalWrite (51, LOW);
}
```

All transmissions in to the micro controller are handled in an equally simple manner. If a transmission is received from the ROS network, the contents are translated to states on the relevant ports and thus processed into a signal in the circuit.

3.1.2 Circuit safety micro controller

The circuit safety micro controller monitors the sensors and key points in the circuit. The purpose is to ensure quality of messages from the circuit. If there are one or more errors in the circuit preventing the sensors from detecting, the data sent from the circuit will be of very low quality.

The circuit safety controller transmits its data as high/low signals directly to the signal processing microcontroller. Practically this means that the safety micro controller translates the state of one or more ports into a more simple set of signals, which can be easily and accurately processed by the signal processing micro controller.

3.1.2.1 Code

```
  //No power at sensor 1
  if digitalRead (D7) = LOW {
    digitalWrite (D1, LOW);
    digitalWrite (D2, HIGH);
    digitalWrite (D5, HIGH);
  }
```

The above code gets an input from port D7 and translates that into i clear instruction for the signal processing micro controller. D1 low means there is an error in the system, D2 high means that the error is at sensor 1 and D5 high means that it is an error type 1 which is a ”no power at ... ” error.

In the circuit safety micro controller all signals are translated into clear instructions in this manner.

3.2 Software

There are two primary purposes of the software: to receive orders from the user and to translate data from the signal processing micro controller into human readable text.

3.2.1 System monitor

The system monitor is used to output statuses for all systems to the screen. It is a read only function intended to provide the user with a quick overview of the entire system enable general monitoring or error handling if needed.

The system monitor receives data from the ROS network and translates it into text strings and prints this to the screen.

3.2.1.1 Command interfaces

The command interfaces are simple terminal-text based interfaces allowing the user to give orders to the system which are the translated to data and transmitted via the ROS network.

3.2.1.2 Code

3.2.1.3 Subscribers

```
void chatterCallback (const sensor_mannager::sensorIO::ConstPtr& msg)
{
// Copy message content to var
c_s1io = msg -> sensor1IO;
c_s2io = msg -> sensor2IO;
c_s3io = msg -> sensor3IO;
}
```

Firstly the contend of the message is de-referenced and the value is stored in a corresponding variable, in this case c_sXio variables that handle sensor on or off information.

```
if(h_s1co == 1)
    {
        s1status = "Contact";
    }
    else if(c_s1io == 0)
    {
        s1status = "OFF";
    }
    else if(c_s1io == 1)
    {
        s1status = "ON";

        ...
```

Secondly the variables are used to interpret the meaning of the data. In this case a set of variables are used to determine if sensor 1 is in ”contact condition”, ”OFF” or ”ON”. The result of the is/else function is stored in a string variable and can be printed to the screen at the users command.
The function continues in the same pattern beyond what is shown here.

```
std::cout << "␣---␣SYSTEM␣STATUS␣---" << std::endl;
    std::cout << "Client␣<=>␣ROS␣communication:␣␣␣␣␣␣␣␣␣␣␣" <<
       ROSComStr << std::endl;
    std::cout << "Client␣<=>␣Sensor␣communication:␣␣␣␣␣␣␣␣" <<
       sensorComStr << std::endl;
    std::cout << "Safety␣circuit␣=>␣client␣communication:␣" <<
       safetyComStr << std::endl;
    std::cout << "Sensor␣IC␣status:␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣" <<
       sensorICStr << std::endl;
    std::cout << "Safety␣IC␣status:␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣" <<
       safetyICStr << std::endl;
    std::cout << "Sensor␣1␣status:␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣" <<
       s1status << std::endl;
    std::cout << "Sensor␣2␣status:␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣" <<
       s2status << std::endl;
    std::cout << "Sensor␣3␣status:␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣" <<
       s3status << std::endl;
```

Finally the strings generated are printed to the screen in a simple display.

3.2.1.4 Publishers

```
    case 1:
            msg.safetyState = 1;

            systemHandling_pub.publish(msg);
            ros::spinOnce;
            std::cout << "Published!" << std::endl;
            std::cout << "Press any key + enter to return to menu" <<
               std::endl;
            std::cin >> selection;
            break;
            case 2:
            msg.safetyState = 0;

            ...
```

Commands from the user are taken in via the terminal and sorted through a switch with each possible command triggering a corresponding publish.

In this case an input of ”1” will set the message content ”safetyState” to one and publish the message using *systemHandling_pub* which publishes on the safetyStateTopic.

3.2.2 ROS node communication

Communication between the ROS nodes (including the Arduino node) is handled in three message types.

They are all predefined as 8 bit integers variables, but all just carry i single integer, which is interpreted as described above.

msg	Mesage type	Topic	Var type
contact1	sensorData	sensorStateTopic	Int8
contact2	-	-	-
contact3	-	-	-
saftyNotOK	-	-	-
sensor1Error1	-	-	-
sensor1Error2	-	-	-
sensor2Error1	-	-	-
sensor2Error2	-	-	-
sensor3Error1	-	-	-
sensor3Error2	-	-	-
safetyState	-	-	-
SensorICStatus	-	-	-
safetyOff	-	-	-
safetyOk	-	-	-
safetyState	safetyIO	safetyStateTopic	Int8
sensor1IO	sensorIO	sensorStateTopic	Int8
sensor2IO	-	-	-
sensor3IO	-	-	-

4 Error types

4.1 No power on sensor(s)

4.1.1 Condition

Pin:sensor[1,2,3]Anode remains low.

4.1.2 Possible error(s)

Sensor(s) not receiving power from 12v power source.[1]

If all three pins are in low state, it is likely, that the main 12 VDC source or route has failed.

4.2 Short circuit in sensor(s)

4.2.1 Condition

Pin:sensor[1,2,3]Cathode goes high.
Pin:sensor[1,2,3]HL must have been in high state prior to error. Pin:sensor[1,2,3]HL may be either high or low during the error.

4.2.2 Possible error(s)

Internal short circuit in sensor(s) resulting in $>$3.0V leaking from the sensor(s).

If the leak is in the range 1.5-3.0V, pin:sensor[1,2,3]Cathode may be in either high or low with probability trending toward high as potential rises and probability trending towards low as potential drops.

If the leak is $<$1.5V pin:sensor[1,2,3]Cathode will be in low state.

If the potential across the transistor(s) is $>$0.7V, the transistor(s) will not be able to transition from closed to open state.

[1] In theory this could also indicate a potential $<$4.18V across the 12V power rail, but the system is set to disable sensor at battery-potential $<$10.1V, so this should not occur

4.3 Transistor(s) not closing

4.3.1 Condition

Pin:sensor[1,2,3]HL is set high and Pin:sensor[1,2,3]Anode is in high state, sensor(s) do not respond to metal at any range.

4.3.2 Possible error(s)

If the transistor(s) does not close, the sensor(s) will not be connected to GND and will therefore not conduct electricity.

5 Experiments

5.1 Inductive sensors

5.1.1 Detection range at various voltages

The purpose of this test, is to map the sensing range of the inductive sensors at various voltages.

5.1.1.1 Setup

Temperature: 20,1 °C
Medium: Athmospheric air
Power fed from PSU via power-bridge through each sensor to common GND-rail.

Secondarily from sensor through voltage-limiter - optimized for 25/5 v conversion - to 5v LED, colored respectively red, blue and green and connected individually to common GND-rail.

Plastic ruler mounted as an extension to the sensor, directly in front of it.

5.1.1.2 Method

A straight edged metal object is moved along the ruler, toward the sensor. The distance between the metal object and the sensor is recorded from the ruler.

5.1.1.3 Results

Detection range in mm, directly in front of the sensor, measured at the center of the sensor.

Voltage	Sensor 1	Sensor 2	Sensor 3	Average
30	16	17	17	17
25	16	17	17	17
20	17	17	17	17
15	16	17	17	17
10	17	17	17	17

5.1.1.4 Precision

Ruler: $\pm$ 1 mm deviation
Power supply: $> 99\%$

5.1.1.5 Conclusion

Seeing that the sensor-sensitivity (except from that of sensor 1, which we suspect has a minor defect, given that it deviates a little from the other two sensors in all experiments at low voltages) is the same at the low end as well as high end of the sensors' voltage range, we choose the energy-efficient approach and choose to operate in the low end of the voltage range.

Combining the above with the voltage potential of the power source (12V) and the expected voltage drop in the power source as power is consumed, it is clear that the most practical solution is to design the system around a 12V power source, while accounting for voltage drops down to 10.1V. The sensors will have as good as full effect in this entire voltage range.

5.1.1.6 Follow-up tests

- None -

5.1.2 Perpendicular detection range at various voltages and 15 mm spacing

The purpose of this test, is to map the sensing range perpendicular to the inductive sensors at various voltages.

5.1.2.1 Setup

Temperature: 20,1 °C
Medium: Athmospheric air
Power fed from PSU via power-bridge through each sensor to common GND-rail.

Secondarily from sensor through voltage-limiter - optimized for 25/5 v conversion - to 5v LED, colored respectively red, blue and green and connected individually to common GND-rail.

Plastic ruler mounted perpendicularly, at a position elevated 15 mm from the tip of the active end of the sensor.

5.1.2.2 Method

A straight edged metal object is moved along the ruler, toward the sensor. The distance between the metal object and the sensor is recorded from the ruler.

5.1.2.3 Results

Detection range in mm, perpendicular to and 15 mm from the edge of the sensor.

Voltage	Sensor 1	Sensor 2	Sensor 3	Average
30	8	8	8	8
25	8	8	8	8
20	8	8	8	8
15	8	8	8	8
12	6	6	6	6
10	6	6	6	6

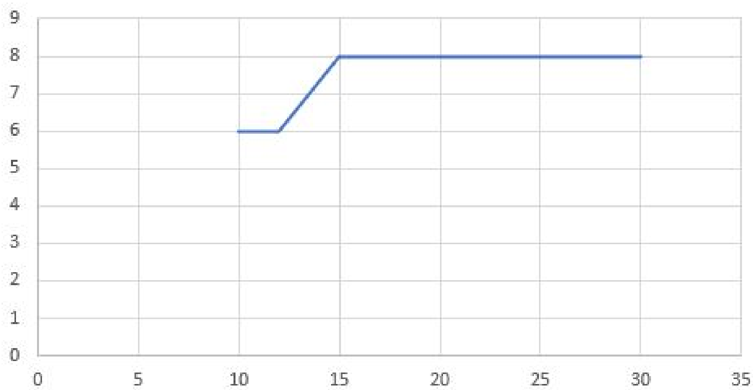


Figure 5.1: Detection ranges at 15 mm distance

5.1.2.4 Precision

Ruler: $\pm$ 1 mm deviation
Power supply: $> 99\%$

5.1.2.5 Conclusion

Seeing that the sensor-sensitivity (except from that of sensor 1, which we suspect has a minor defect, given that it deviates a little from the other two sensors in all experiments at low voltages) is equally low throughout the sensors' entire voltage range at this distance, we decide to use the sensors at 8 mm distance, which yielded much better results (see below).

5.1.2.6 Follow-up tests

Perpendicular detection range at various voltages and 8 mm spacing

5.1.3 Perpendicular detection range at various voltages and 8 mm spacing

The purpose of this test, is to map the sensing range perpendicular to the inductive sensors at various voltages.

5.1.3.1 Setup

Temperature: 20,1 °C
Medium: Athmospheric air
Power fed from PSU via power-bridge through each sensor to common GND-rail.

Secondarily from sensor through voltage-limiter - optimized for 25/5 v conversion - to 5v LED, colored respectively red, blue and green and connected individually to common GND-rail.

Plastic ruler mounted perpendicularly, at a position elevated 8 mm from the tip of the active end of the sensor.

5.1.3.2 Method

A straight edged metal object is moved along the ruler, toward the sensor. The distance between the metal object and the sensor is recorded from the ruler.

5.1.3.3 Results

Detection range in mm, perpendicular to and 8 mm from the edge of the sensor.

Voltage	Sensor 1	Sensor 2	Sensor 3	Average
30	14	14	14	14
25	14	14	14	14
20	14	14	14	14
15	13	14	14	14
12	13	13	13	13
10	12	13	13	13

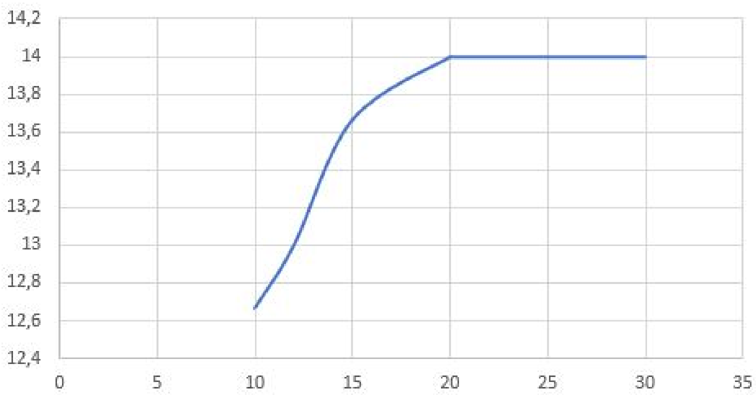


Figure 5.2: Detection ranges at 8 mm distance

5.1.3.4 Precision

Ruler: $\pm$ 1 mm deviation
Power supply: $> 99\%$

5.1.3.5 Conclusion

This distance provided much better detection range than the experiment at 15 mm did. The pattern with slight increase in range as the voltage potential rose from 10 to 15 volt and nearly similar results for all voltages above repeated itself, though with less of a difference in range[1].

Based on the experiments it is clear ti see, that distance from the ground matters considerably more that the voltage. Practically this means, that we can work in our desired voltage range (10.1V-12V) and mount the sensors in a way where they are elevated 8 mm of the ground.

5.1.3.6 Follow-up tests

Current at various voltages Sensitivity at various voltages

[1]At 8 mm distance, the increase in range only had about one quarter of the effect seen in the 15 mm experiment

5.1.4 Redundant voltage from sensors under normal operating conditions

The purpose of this test, is to determine the redundant voltage potential on the GND side of the sensors.

5.1.4.1 Setup

Temperature: 20,4 °C
Medium: Copper
DC12V fed from PSU to power rail connecting to sensors.
Secondarily from sensors through transistor directly to GND rail connecting to PSU GND.

5.1.4.2 Method

Voltage potential measured between sensor GND pin and PSU GND using probes on Tenma 72-7730A multi-meter.

5.1.4.3 Results

Voltage potential in mV.

Repetition	Sensor 1	Sensor 2	Sensor 3	Average
1	5	5	5	5
2	5	5	5	5
3	5	5	5	5
4	5	5	5	5
5	5	5	5	5

5.1.4.4 Precision

Tenma 72-7730A: $\pm 0.05\%$
Power supply: $> 99\%$

5.1.4.5 Conclusion

The redundant voltage on the GND side of the sensors is consistently DC5mV.

5.1.4.6 Follow-up tests

- None -

Bibliografi

[1] Arduino. ARDUINO NANO. URL: `https://store.arduino.cc/arduino-nano` (visited on 11/22/2020).

[2] ATmega640/V-1280/V-1281/V-2560/V-2561/V. 2020.

[3] Arduino. ARDUINO MEGA 2560 REV3. URL: `https://store.arduino.cc/arduino-mega-2560-rev3` (visited on 11/20/2020).

[4] ATmega48A/PA/88A/PA/168A/PA/328/P. 2020.

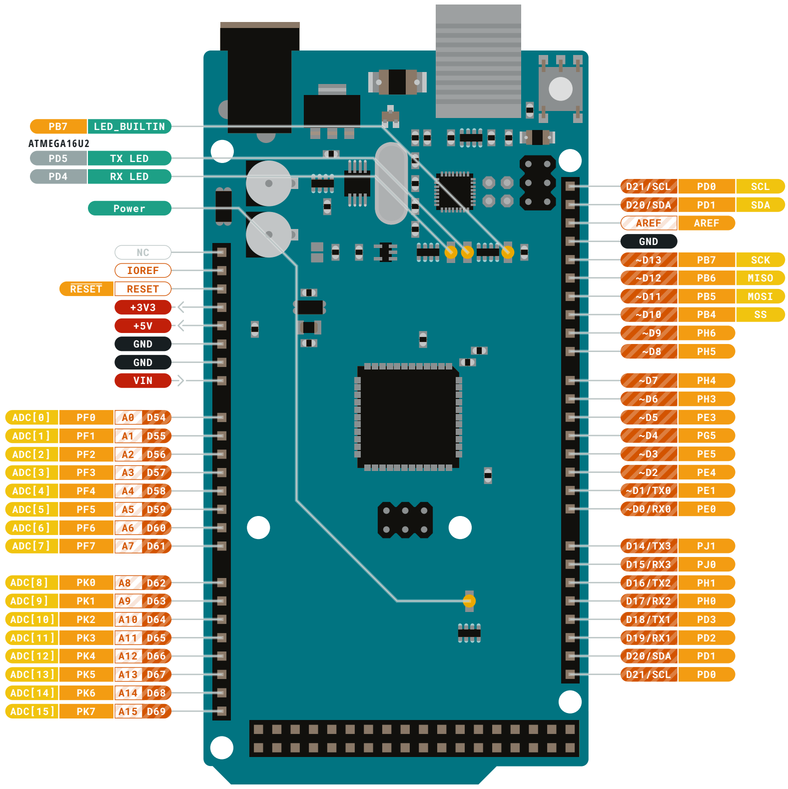
[5] Omron. E2B. URL: `https://assets.omron.eu/downloads/datasheet/en/v3/d116_e2b_cylindrical_proximity_sensor_datasheet_en.pdf` (visited on 11/22/2020).

A Arduino Mega 2560 Pinout

ARDUINO

MEGA 2560 REV3

STORE.ARDUINO.CC/MEGA-2560-REV3



- Ground
- Power
- LED
- Internal Pin
- SWD Pin
- Digital Pin
- Analog Pin
- Other Pin
- Microcontroller's Port
- Default

MAXIMUM current per I/O pin is 20mA

MAXIMUM current per +3.3V pin is 50mA

VIN 6-20 V input to the board.

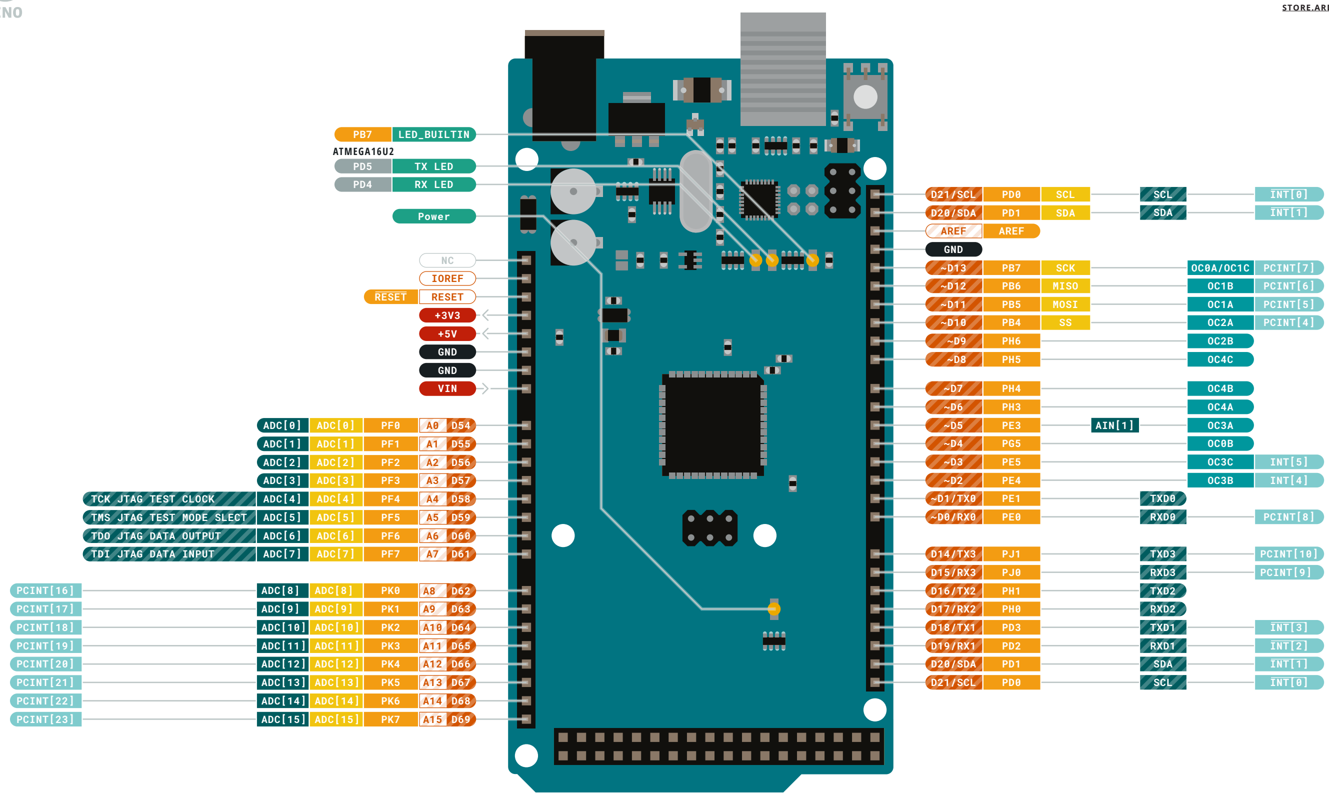
ARDUINO.CC

Last update: 26/10/2020

ARDUINO

ARDUINO
MEGA 2560 REV3

STORE.ARDUINO.CC/MEGA-2560-REV3



- Ground
- Power
- LED
- Internal Pin
- SWD Pin
- Digital Pin
- Analog Pin
- Other Pin
- Microcontroller's Port
- Default
- Analog
- Communication
- Timer
- Interrupt
- Sercom

MAXIMUM current per I/O pin is 20mA

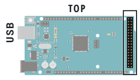
MAXIMUM current per +3.3V pin is 50mA

VIN 6-20 V input to the board.

ARDUINO.CC

Last update: 26/10/2020

ARDUINO



Digital pins D22-D53

ARDUINO
MEGA 2560 REV3
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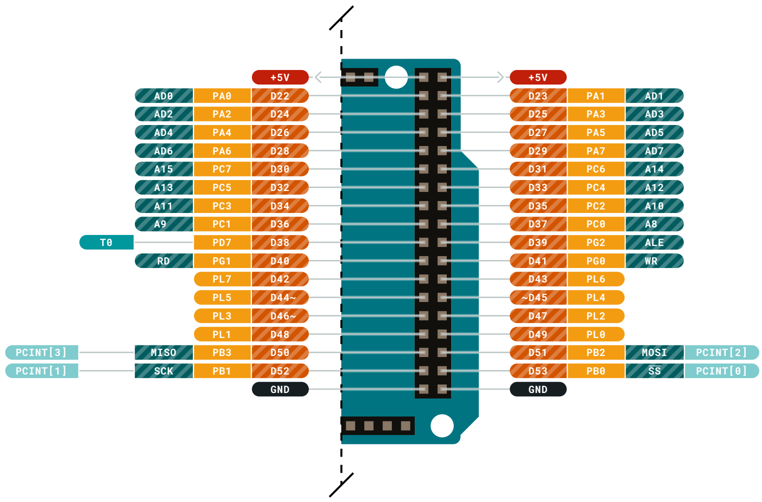


Ground
Power
LED
Internal Pin
SWD Pin

Digital Pin
Analog Pin
Other Pin
Microcontroller's Port
Default

Analog
Communication
Timer
Interrupt
Sercom

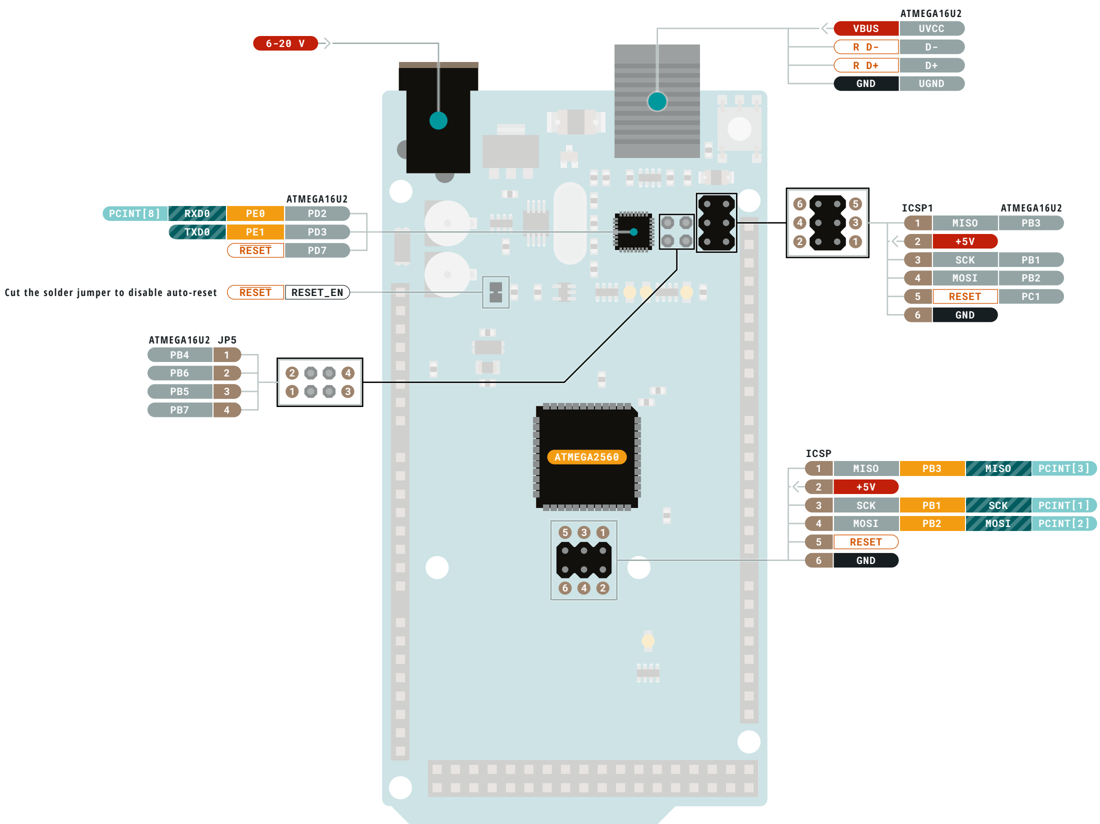
MAXIMUM current per I/O pin is 20mA

MAXIMUM current per +3.3V pin is 50mA

VIN 6-20 V input to the board.

ARDUINO.CC

Last update: 26/10/2020



ARDUINO
MEGA 2560 REV3
STORE.ARDUINO.CC/MEGA-2560-REV3

Ground
Power
LED
Internal Pin
SWD Pin

Digital Pin
Analog Pin
Other Pin
Microcontroller's Port
Default

Analog
Communication
Timer
Interrupt
Sercom

MAXIMUM current per I/O pin is 20mA

MAXIMUM current per +3.3V pin is 50mA

VIN 6-20 V input to the board.

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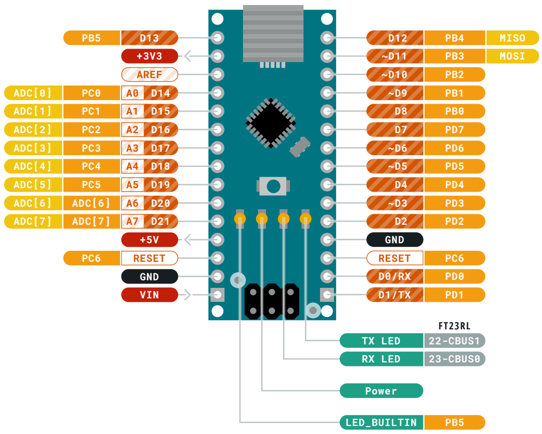
Last update: 26/10/2020

B Arduino Nano Pinout

ARDUINO
NANO

STORE.ARDUINO.CC/NANO



Ground
Power
LED
Internal Pin
SWD Pin

Digital Pin
Analog Pin
Other Pin
Microcontroller's Port
Default

MAXIMUM current per I/O pin is 20mA

MAXIMUM current per +3.3V pin is 50mA

VIN 6-20 V input to the board.

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Last update: 7/07/2020

ARDUINO

ARDUINO NANO

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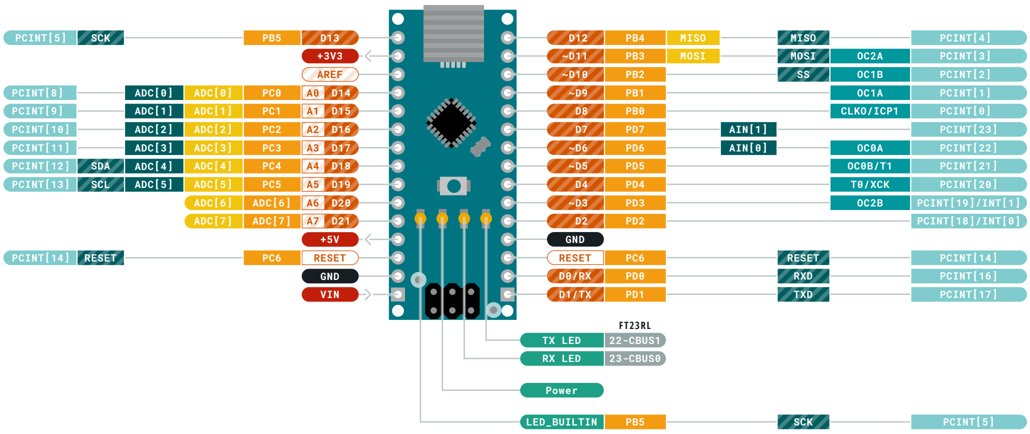


Ground	Digital Pin	Analog
Power	Analog Pin	Communication
LED	Other Pin	Timer
Internal Pin	Microcontroller's Port	Interrupt
SWD Pin	Default	Sercom

MAXIMUM current per I/O pin is 20mA

MAXIMUM current per +3.3V pin is 50mA

VIN 6-20 V input to the board.

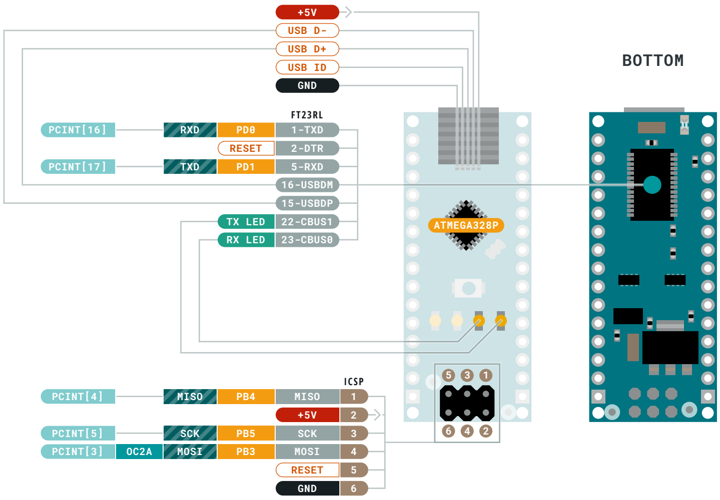
ARDUINO.CC

Last update: 7/07/2020

ARDUINO

ARDUINO NANO

STORE.ARDUINO.CC/NANO



Ground	Digital Pin	Analog
Power	Analog Pin	Communication
LED	Other Pin	Timer
Internal Pin	Microcontroller's Port	Interrupt
SWD Pin	Default	Sercom

MAXIMUM current per I/O pin is 20mA

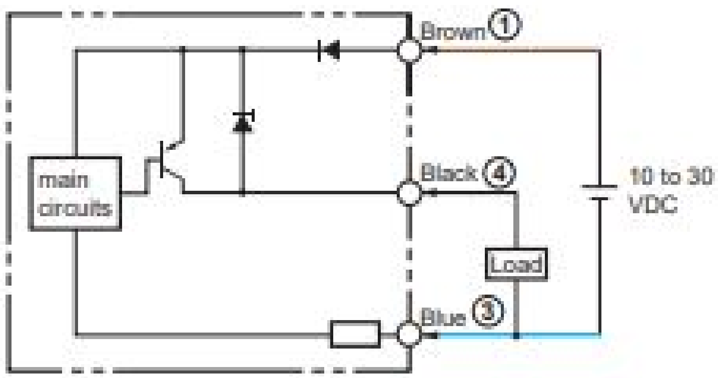
MAXIMUM current per +3.3V pin is 50mA

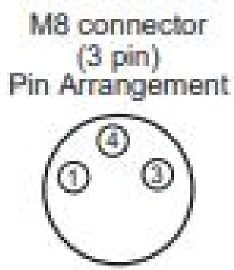
VIN 6-20 V input to the board.

ARDUINO.CC

Last update: 7/07/2020

C Omron - E2B-M30x-xBx Schemat





D Sensor coverage calculation (CAS)

Circles form: $(x\text{-}a)^2 + (y\text{-}b)^2 = r^2$

Circle 1:	$(x - 20.4)^2 + (y - 0)^2 = 25.85^2$ pow
Circle 2:	$(x - -20.4)^2 + (y - 0)^2 = 25.85^2$ pow

Circles form: $x^2 + y^2 + Ax + By + C = 0$

Circle 1:	$x^2 + y^2 + -40.8\,x + 0\,y + -252.063 = 0$
Circle 2:	$x^2 + y^2 + 40.8\,x + 0\,y + -252.063 = 0$

-0.0 +0.00 Clear All Clear Circle 1 Clear Circle 2 Ex1 Ex2 Ex3 Ex4 Ex5

Two circles intersects.

Intersection coordinates (x , y):	(0 , -15.876)	(0 , 15.876)
Line passing through intersection points:	$x = 0$	
Distance between circles centers:	40.8	
Equation of the line passing circles centers:	$y = 0$	
Common area between circles:	236.088	
Circle 1 - x and y axis intercepts:	x: (46.25 , 0) (-5.45 , 0)	y: (0 , 15.876) (0 , -15.876)
Circle 2 - x and y axis intercepts:	x: (5.45 , 0) (-46.25 , 0)	y: (0 , 15.876) (0 , -15.876)

E Bill of Materials

Bill Of Materials

Project:	Sensor and safecircuit, ROB P1
Hardware version:	1.0.0.0
Date:	14-11-2020
Contact(s):	Jesper P. Hammer & Maiken C. Lanng

Item	P/N	Properties	Quantity	Inventory status
Resistor	4k22	4.22kΩ @ 1/4W	12	AAU-V
Resistor	5k62	5.62kΩ @ 1/4W	6	AAU-V
Resistor	1k00	1.00kΩ @ 1/4W	4	AAU-V
Transistor	BC547	NPN, 5V	4	AAU-V
PCB	-	SchematicSensorRobP1	1	AAU-E
Arduino Mega2560	-		1	LOK
Arduino Nano	-		1	LOK
Inductive sensor	Omron - E2B-M30LN30-WP-B1	Range: 30 mm @ 10-30 V	3	LOK