GLOSSARY

Autonomous Mobile Robot(AMR): A mobile robot that possesses the ability to independently drive, navigate, localize, and map its surroundings with help of sensor.

Automated Guided Vehicle (AGV): A mobile robot that is capable of driving and navigating itself by utilizing static guides such as magnetic tapes, QR codes, and color lines.

Robot Operating System 2 (ROS2): A next-generation software framework specifically designed for robotics development that consists of libraries that provide a comprehensive and flexible platform for developing robotics.

Simultaneous Localization and Mapping (SLAM): A critical process in mobile robotics that involves simultaneously mapping the surrounding environment and determining the robot's position within that map.

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APPENDIX A – DATASHEETS

1. Teensy 4.0

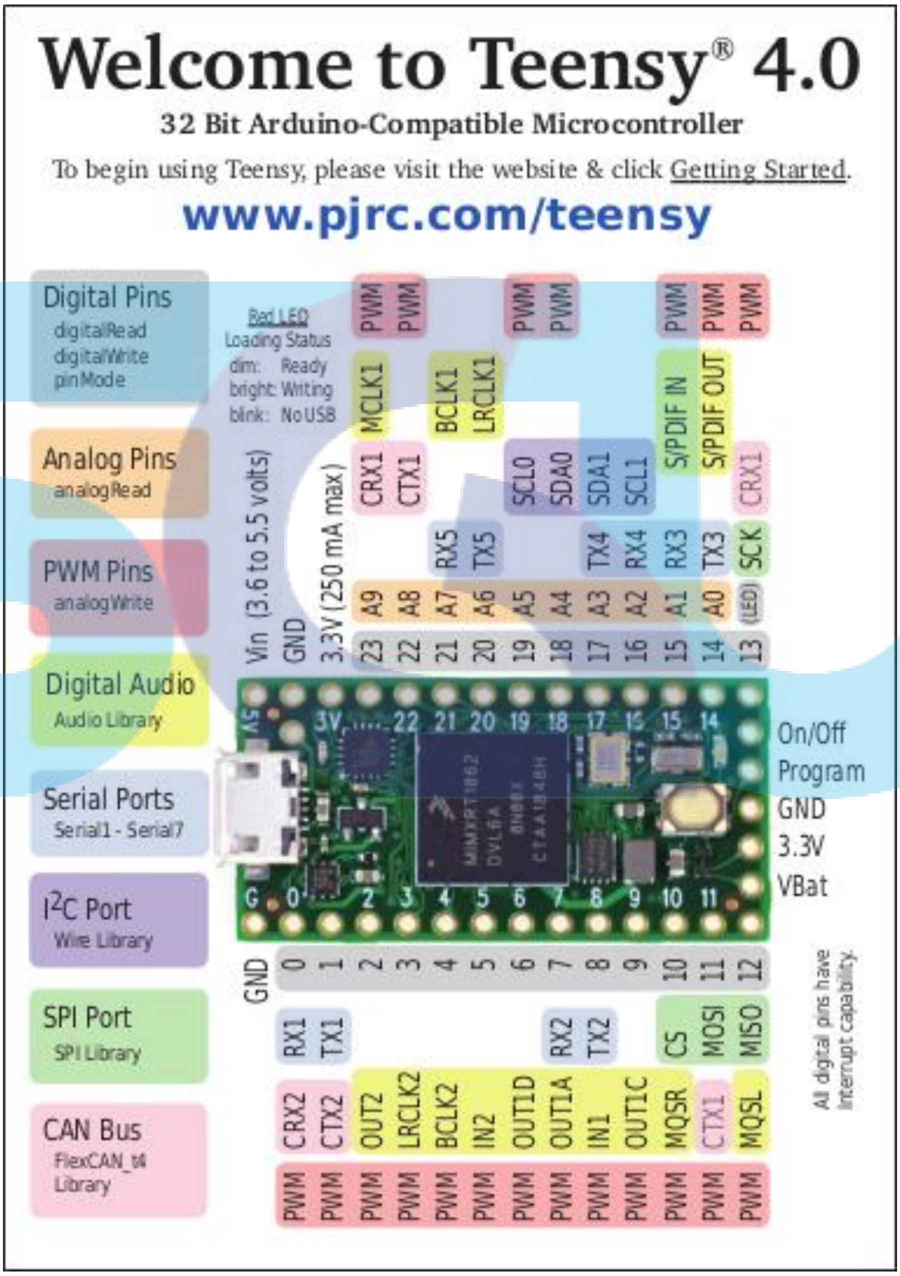


Figure A – 1 Teensy 4.0 Datasheet 1

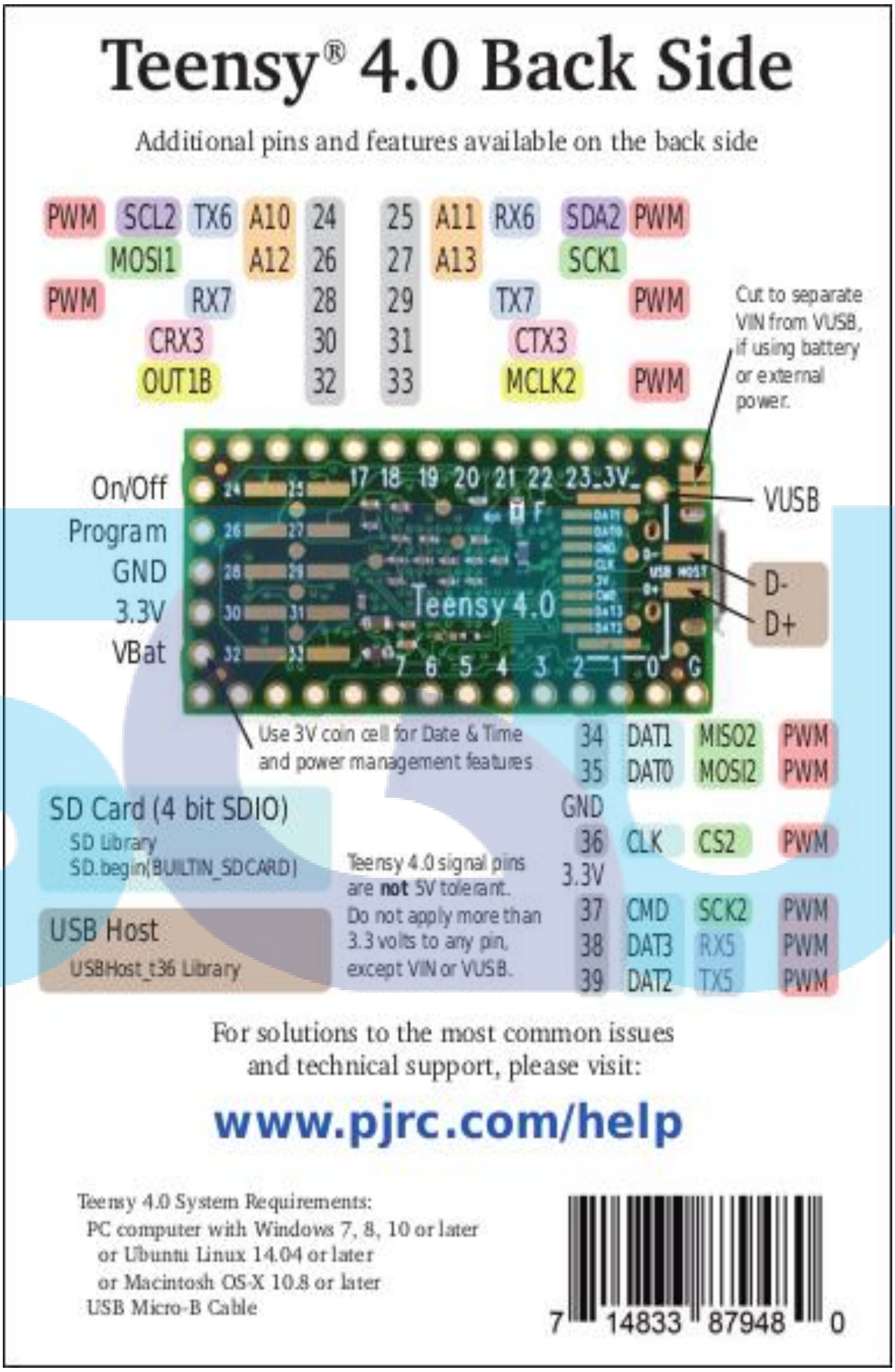


Figure A – 2 Teensy 4.0 Datasheet 2

2. MPU 9250

3 Electrical Characteristics

3.1 Gyroscope Specifications

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Full-Scale Range	FS_SEL=0		±250		°/s
	FS_SEL=1		±500		°/s
	FS_SEL=2		±1000		°/s
	FS_SEL=3		±2000		°/s
Gyroscope ADC Word Length			16		bits
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(°/s)
	FS_SEL=1		65.5		LSB/(°/s)
	FS_SEL=2		32.8		LSB/(°/s)
	FS_SEL=3		16.4		LSB/(°/s)
Sensitivity Scale Factor Tolerance	25°C		±3		%
Sensitivity Scale Factor Variation Over Temperature	-40°C to +85°C		±4		%
Nonlinearity	Best fit straight line; 25°C		±0.1		%
Cross-Axis Sensitivity			±2		%
Initial ZRO Tolerance	25°C		±5		°/s
ZRO Variation Over Temperature	-40°C to +85°C		±30		°/s
Total RMS Noise	DLPFCFG=2 (92 Hz)		0.1		°/s-rms
Rate Noise Spectral Density			0.01		°/s/√Hz
Gyroscope Mechanical Frequencies		25	27	29	KHz
Low Pass Filter Response	Programmable Range	5		250	Hz
Gyroscope Startup Time	From Sleep mode		35		ms
Output Data Rate	Programmable, Normal mode	4		8000	Hz

Table 1 Gyroscope Specifications

Figure A – 3 MPU 9250 Datasheet 1

3.2 Accelerometer Specifications

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Full-Scale Range	AFS_SEL=0		±2		*g*
	AFS_SEL=1		±4		*g*
	AFS_SEL=2		±8		*g*
	AFS_SEL=3		±16		*g*
ADC Word Length	Output in two's complement format		16		bits
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*
	AFS_SEL=1		8,192		LSB/*g*
	AFS_SEL=2		4,096		LSB/*g*
	AFS_SEL=3		2,048		LSB/*g*
Initial Tolerance	Component-Level		±3		%
Sensitivity Change vs. Temperature	-40°C to +85°C AFS_SEL=0 Component-level		±0.026		%/°C
Nonlinearity	Best Fit Straight Line		±0.5		%
Cross-Axis Sensitivity			±2		%
Zero-G Initial Calibration Tolerance	Component-level, X,Y		±60		mg
	Component-level, Z		±80		mg
Zero-G Level Change vs. Temperature	-40°C to +85°C		±1.5		mg/°C
Noise Power Spectral Density	Low noise mode		300		µg/√Hz
Total RMS Noise	DLPFCFG=2 (94Hz)			8	mg-rms
Low Pass Filter Response	Programmable Range	5		260	Hz
Intelligence Function Increment			4		mg/LSB
Accelerometer Startup Time	From Sleep mode		20		ms
	From Cold Start, 1ms V_{DD} ramp		30		ms
Output Data Rate	Low power (duty-cycled)	0.24		500	Hz
	Duty-cycled, over temp		±15		%
	Low noise (active)	4		4000	Hz

Table 2 Accelerometer Specifications

Figure A – 4 MPU 9250 Datasheet 2

3.3 Magnetometer Specifications

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
MAGNETOMETER SENSITIVITY					
Full-Scale Range			±4800		µT
ADC Word Length			14		bits
Sensitivity Scale Factor			0.6		µT / LSB
ZERO-FIELD OUTPUT					
Initial Calibration Tolerance			±500		LSB

Figure A – 5 MPU 9250 Datasheet 3

3.4 Electrical Specifications

3.4.1 D.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SUPPLY VOLTAGES						
VDD		2.4	2.5	3.6	V	
VDDIO		1.71	1.8	VDD	V	
SUPPLY CURRENTS						
Normal Mode	9-axis (no DMP), 1 kHz gyro ODR, 4 kHz accel ODR, 8 Hz mag. repetition rate		3.7		mA	
	6-axis (accel + gyro, no DMP), 1 kHz gyro ODR, 4 kHz accel ODR		3.4		mA	
	3-axis Gyroscope only (no DMP), 1 kHz ODR		3.2		mA	
	6-axis (accel + magnetometer, no DMP), 4 kHz accel ODR, mag. repetition rate = 8 Hz		730		µA	
	3-Axis Accelerometer, 4kHz ODR (no DMP)		450		µA	
	3-axis Magnetometer only (no DMP), 8 Hz repetition rate		280		µA	
Accelerometer Low Power Mode (DMP, Gyroscope, Magnetometer disabled)	0.98 Hz update rate		8.4		µA	1
	31.25 Hz update rate		19.8		µA	1
Full Chip Idle Mode Supply Current			8		µA	
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	

Table 3 D.C. Electrical Characteristics

Notes:

1. Accelerometer Low Power Mode supports the following output data rates (ODRs): 0.24, 0.49, 0.98, 1.95, 3.91, 7.81, 15.63, 31.25, 62.50, 125, 250, 500Hz. Supply current for any update rate can be calculated as:

   Supply Current in µA = Sleep Current + Update Rate * 0.376

Figure A – 6 MPU 9250 Datasheet 4

3.4.2 A.C. Electrical Characteristics

Typical Operating Circuit of section 4.2, VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

Parameter	Conditions	MIN	TYP	MAX	Units
Supply Ramp Time	Monotonic ramp. Ramp rate is 10% to 90% of the final value	0.1		100	ms
Operating Range	Ambient	-40		85	°C
Sensitivity	Untrimmed		333.87		LSB/°C
Room Temp Offset	21°C		0		LSB
Supply Ramp Time (T_{RAMP})	Valid power-on RESET	0.01	20	100	ms
Start-up time for register read/write	From power-up		11	100	ms
I²C ADDRESS	AD0 = 0 AD0 = 1		1101000 1101001		
V_{IH}, High Level Input Voltage		0.7*VDDIO			V
V_{IL}, Low Level Input Voltage				0.3*VDDIO	V
C_I, Input Capacitance			< 10		pF
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ;	0.9*VDDIO			V
V_{OL1}, LOW-Level Output Voltage	R_{LOAD}=1MΩ;			0.1*VDDIO	V
$V_{OL.INT1}$, INT Low-Level Output Voltage	OPEN=1, 0.3mA sink Current			0.1	V
Output Leakage Current	OPEN=1		100		nA
t_{INT}, INT Pulse Width	LATCH_INT_EN=0		50		µs
V_{IL}, LOW Level Input Voltage		-0.5V		0.3*VDDIO	V
V_{IH}, HIGH-Level Input Voltage		0.7*VDDIO		VDDIO + 0.5V	V
V_{hys}, Hysteresis			0.1*VDDIO		V
V_{OL}, LOW-Level Output Voltage	3mA sink current	0		0.4	V
I_{OL}, LOW-Level Output Current	V_{OL}=0.4V V_{OL}=0.6V		3 6		mA mA
Output Leakage Current			100		nA
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pf	20+0.1C_b		250	ns
V_{IL}, LOW-Level Input Voltage		-0.5V		0.3*VDDIO	V
V_{IH}, HIGH-Level Input Voltage		0.7* VDDIO		VDDIO + 0.5V	V
V_{hys}, Hysteresis			0.1* VDDIO		V
V_{OL1}, LOW-Level Output Voltage	VDDIO > 2V; 1mA sink current	0		0.4	V
V_{OL3}, LOW-Level Output Voltage	VDDIO < 2V; 1mA sink current	0		0.2* VDDIO	V
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V V_{OL} = 0.6V		3 6		mA mA
Output Leakage Current			100		nA
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	20+0.1C_b		250	ns
Sample Rate	Fchoice=0,1,2 SMPLRT_DIV=0		32		kHz
	Fchoice=3; DLPFCFG=0 or 7 SMPLRT_DIV=0		8		kHz
	Fchoice=3; DLPFCFG=1,2,3,4,5,6; SMPLRT_DIV=0		1		kHz
Clock Frequency Initial Tolerance	CLK_SEL=0, 6; 25°C	-2		+2	%
	CLK_SEL=1,2,3,4,5; 25°C	-1		+1	%
Frequency Variation over Temperature	CLK_SEL=0,6	-10		+10	%
	CLK_SEL=1,2,3,4,5		±1		%

Table 4 A.C. Electrical Characteristics

Figure A – 7 MPU 9250 Datasheet 5

3.5 I2C Timing Characterization

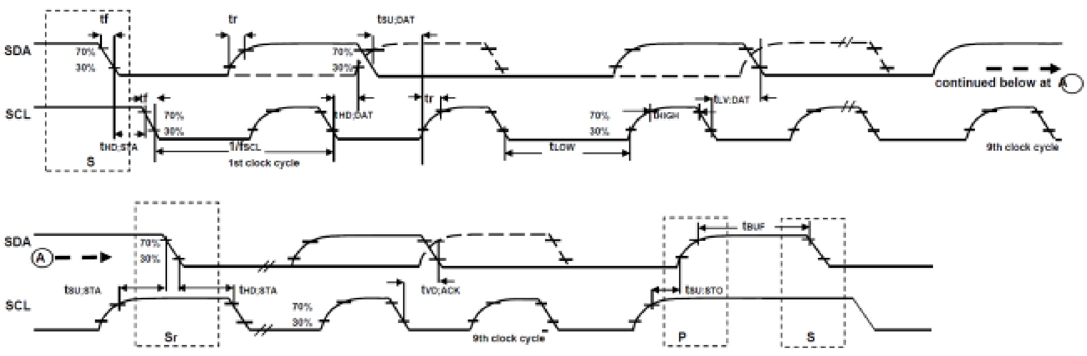
Typical Operating Circuit of section 4.2, VDD = 2.4V to 3.6V, VDDIO = 1.71 to VDD, T_A=25°C, unless otherwise noted.

Parameters	Conditions	Min	Typical	Max	Units	Notes
I²C TIMING	**I²C FAST-MODE**					
f_{SCL}, SCL Clock Frequency				400	kHz	
$t_{HD.STA}$, (Repeated) START Condition Hold Time		0.6			µs	
t_{LOW}, SCL Low Period		1.3			µs	
t_{HIGH}, SCL High Period		0.6			µs	
$t_{SU.STA}$, Repeated START Condition Setup Time		0.6			µs	
$t_{HD.DAT}$, SDA Data Hold Time		0			µs	
$t_{SU.DAT}$, SDA Data Setup Time		100			ns	
t_r, SDA and SCL Rise Time	C_b bus cap. from 10 to 400pF	20+0.1C_b		300	ns	
t_f, SDA and SCL Fall Time	C_b bus cap. from 10 to 400pF	20+0.1C_b		300	ns	
$t_{SU.STO}$, STOP Condition Setup Time		0.6			µs	
t_{BUF}, Bus Free Time Between STOP and START Condition		1.3			µs	
C_b, Capacitive Load for each Bus Line			< 400		pF	
$t_{VD.DAT}$, Data Valid Time				0.9	µs	
$t_{VD.ACK}$, Data Valid Acknowledge Time				0.9	µs	

Table 6 I²C Timing Characteristics

Notes:

- Timing Characteristics apply to both Primary and Auxiliary I2C Bus
- Based on characterization of 5 parts over temperature and voltage as mounted on evaluation board or in sockets



I²C Bus Timing Diagram

Figure A – 8 MPU 9250 Datasheet 6

3.6 SPI Timing Characterization

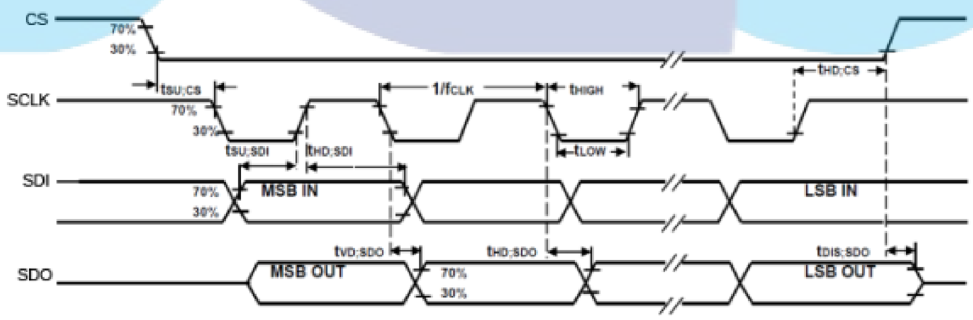
Typical Operating Circuit of section 4.2, VDD = 2.4V to 3.6V, VDDIO = 1.71V to VDD, T_A=25°C, unless otherwise noted.

Parameters	Conditions	Min	Typical	Max	Units	Notes
SPI TIMING						
f_{SCLK}, SCLK Clock Frequency				1	MHz	
t_{LOW}, SCLK Low Period		400			ns	
t_{HIGH}, SCLK High Period		400			ns	
$t_{SU.CS}$, CS Setup Time		8			ns	
$t_{HD.CS}$, CS Hold Time		500			ns	
$t_{SU.SDI}$, SDI Setup Time		11			ns	
$t_{HD.SDI}$, SDI Hold Time		7			ns	
$t_{VD.SDO}$, SDO Valid Time	C_{load} = 20pF			100	ns	
$t_{HD.SDO}$, SDO Hold Time	C_{load} = 20pF	4			ns	
$t_{DIS.SDO}$, SDO Output Disable Time				50	ns	

Table 7 SPI Timing Characteristics

Notes:

1. Based on characterization of 5 parts over temperature and voltage as mounted on evaluation board or in sockets



SPI Bus Timing Diagram

Figure A –9 MPU 9250 Datasheet 7

3. RPLIDAR A2

Items in the Development Kit

RPLIDAR Development Kit contains:

- RPLIDAR (PWM motor driver embedded)
- USB Adapter

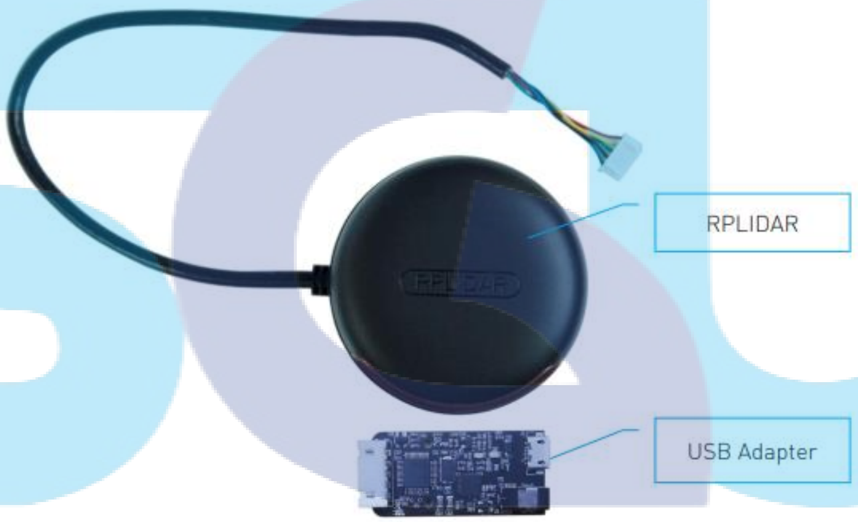


Figure 1-1 Items in the RPLIDAR Development Kit

Figure A –10 RPLIDAR A2 Datasheet 1

RPLIDAR A2 Pin Definition and Specification

RPLIDAR A2 is using XH2.54-5P specification plug. Please use it with socket that meet the specification of XH2.54-5P. The detailed pin definition is shown as below:

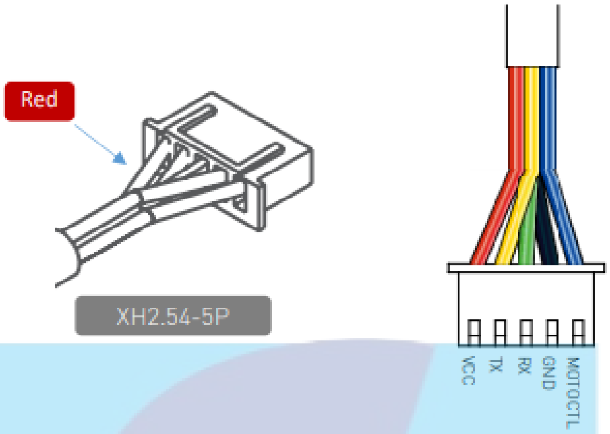


Figure 3-1 RPLIDAR A2 Pins

Figure A –11 RPLIDAR A2 Datasheet 2

Color	Signal name	Type	Description	Minimum	Typical	Maximum
Red	VCC	Power	Power supply for the whole RPLIDAR	4.9V	5V	5.5V
Yellow	TX	Output	Serial output for RPLIDAR scan core	0V	3.3V	3.5V
Green	RX	Input	Serial input for RPLIDAR scan core	0V	3.3V	3.5V
Black	GND	Power	GND	0V	0V	0V
Blue	MOTOCTL	Input (pull down)	Enable pin for RPLIDAR scan motor/PWM control signal (active high)	0V	3.3V	5V

Figure 3-2 RPLIDAR Pin Definition and Specification

RPLIDAR A2 uses the one 5V DC power supply for powering the scan motor and the scan core at the same time. No extra power is required.

With build-in and speed-adjustable motor driver, RPLIDAR A2 can control the start, the stop and the rotating speed of the motor via the MOTOCTL signal.

Figure A –12 RPLIDAR A2 Datasheet 3

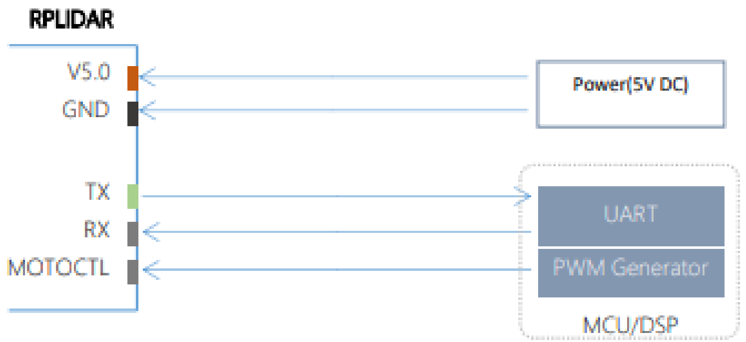


Figure 3-3 RPLIDAR A2 Pins Reference Design

Figure A –13 RPLIDAR A2 Datasheet 4

Pin Definition for the USB Adapter

The USB adapter is also using XH2.54-5P specification socket, and it can be connected with RPLIDAR A2 directly. The pin definition is the same as the RPLIDAR A2.

Configure RPLIDAR A2 Scan Frequency

The motor speed control signal MOTOCTL can be configured directly via the USB adapter of RPLIDAR A2. Therefore, the RPLIDAR A2's scan frequency can be modified by invoking the related functions in the SDK to configure the motor speed.

Without the USB adapter, users can also control the speed by setting the PWM duty cycle of MOTOCTL. Please note that the PWM frequency is 20kHz. For more detailed parameter and index, please refer to the datasheet.

Please refer to the RPLIDAR protocol and application note for more information and the SDK for the sample code on RPLIDAR scan frequency.

Figure A –14 RPLIDAR A2 Datasheet 5

APPENDIX B – INSTALLATION PROCEDURE

1. RPLIDAR A2 ROS 2 :

https://github.com/babakhani/rplidar_ros2

- mkdir p ~/rplidara2_ws/src
- cd ~/ros2_ws/src/
- git clone https://github.com/babakhani/rplidar_ros2.git
- colcon build
- source install/setup.bash

2. Linorobot2 :

Robot Computer

- source /opt/ros/<ros_distro>/setup.bash
- cd /tmp
- wget https://raw.githubusercontent.com/linorobot/linorobot2/${ROS_DISTRO}/install_linorobot2.bash
- bash install_linorobot2.bash <robot_type> <laser_sensor> <depth_sensor>
- source ~/.bashrc

Host Machine

- cd <host_machine_ws>

- git clone -b $ROS_DISTRO https://github.com/linorobot/linorobot2 src/linorobot2
- rosdep update && rosdep install --from-path src --ignore-src -y --skip-keys microxrcedds_agent --skip-keys micro_ros_agent
- colcon build
- source install/setup.bash
- echo "export LINOROBOT2_BASE=2wd" >> ~/.bashrc
- source ~/.bashrc
- cd <host_machine_ws>
- git clone https://github.com/linorobot/linorobot2_viz src/linorobot2_viz
- rosdep update && rosdep install --from-path src --ignore-src -y
- colcon build
- source install/setup.bash

3. Turtlebot3 :

- sudo apt install ros-humble-gazebo-*
- sudo apt install ros-humble-cartographer
- sudo apt install ros-humble-cartographer-ros
- sudo apt install ros-humble-navigation2
- sudo apt install ros-humble-nav2-bringup
- source ~/.bashrc
- sudo apt install ros-humble-dynamixel-sdk

- sudo apt install ros-humble-turtlebot3-msgs
- sudo apt install ros-humble-turtlebot3
- echo 'export ROS_DOMAIN_ID=30 #TURTLEBOT3' >> ~/.bashrc
- source ~/.bashrc

or

- mkdir p ~/turtlebot3_ws/src
- cd ~/turtlebot3_ws/src/
- git clone https://github.com/ROBOTIS-GIT/turtlebot3.git
- colcon build

APPENDIX C– RQT GRAPH

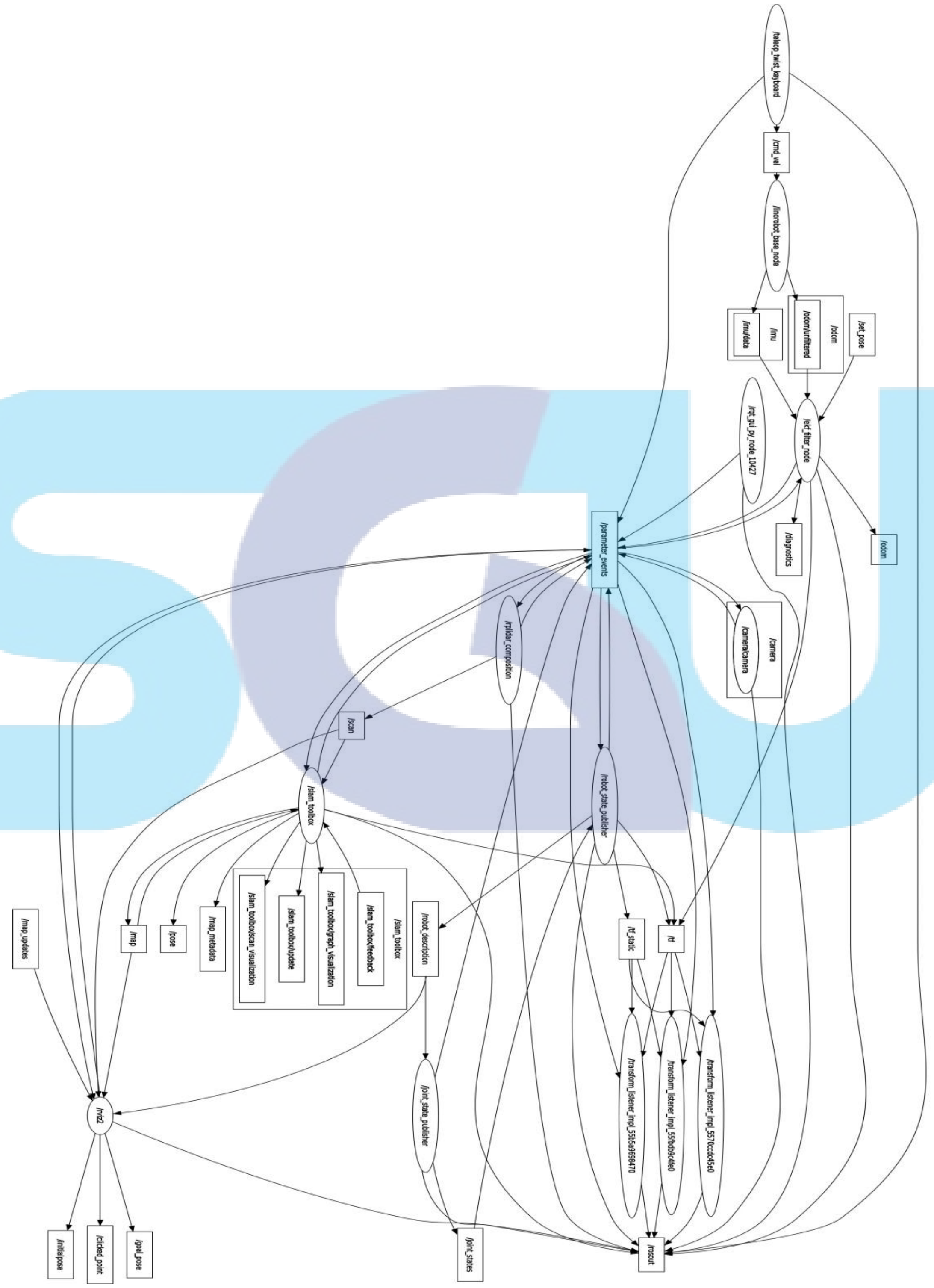


Figure C – 15 RQT Graph of SLAM using Hardware

CURRICULUM VITAE

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STUDIES

- 2019 - 2023 Swiss German University Jakarta
  Bachelor's Degree Mechatronics Engineering

SCHOOL EDUCATION

- 2016 - 2019 High School (SMA Negeri 49 Jakarta)
- 2013 - 2016 Junior High School (SMP Negeri 68 Jakarta)
- 2007 - 2013 Elementary School (SDI Dwi Matra Jakarta)

INTERNSHIP SEMESTER

- May - July 2021

  Intern at PT. Parama Spekta Infinindo,
  a Machine modification and repair companies
  Activities: Research technology in modification and repair

  - Research and development fiberglass motor box for SIKLUS REFILL INDONESIA
  - Responsible for the new product line of portable fitness equipment for PT.Infinitude Indonesia
  - Disassembly and evaluation of Screw Cap Plastic Injection Mold

- November 2021 - January 2022

  Training at Akademi Teknik Mesin Industri (ATMI)

  - Received a industrial training such as milling, turning, drilling, welding, learning technical drawing, PCB design, and building power supply units.

- March - August 2022

  Intern at Siemens AG Schaltanlagenwerk Frankfurt,
  a Siemens switch gear factory in Germany
  Activites: Mechanical Engineering and Electrical Engineering in the customer center for all Switch Gear products and learning as FAT test Engineering

- Electrical wiring
- Electrical troubleshooting
- Quality control for FAT and before shipping
- Reparation
- Protective relays assembler
- Assembly processes

KURS

- 2016 - 2019 German course at the Goethe Institute Jakarta

SOFTWARE SKILLS

- CAD
    - Solidworks
    - Fusion 360
- Simulation
    - Multisim (simple electrical circuit design)
    - Psim (simple electrical circuit design)
    - Fluidsim (simple pneumatics circuit design)
- Programming
    - C ++ Lerning phase (basic)
    - ROS 2 (basic)
- MS Office

LANGUAGE SKILLS

- Indonesisch (native)
- Englisch (spoken and written)
- Deutsch (level B2)
- Japanisch (basic knowledge)

INTERESTS

- Basketball
    - Winner in second place in the basketball tournament in the Charithy High School (2018)
    - Third Place Winner in Sumbangsih High School Basketball Tournament (2018)
- Karate brown belt
- Music, Playing Guitar

ORGANISATION EXPERIENCE

- Chairman of the karate club in high school from 2018 to 2019
- Member of the Mechatronics Student Association
- Member of the sponsorship department for the "Mechatronics Day" event

Jakarta, 18.06.2023

Tengku Pascal Alamsyah