TEXAS INSTRUMENTS

Electronics Online Challenge 2020

iRobot Roomba 4220 Model Series

Team Name: MTSAC1
School: Mt. San Antonio College

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Table of Contents

I. Introduction

The team, as seen in Appendix F, has chosen the Roomba 4220 because it is analogous to robots built for VEX Robotics Competition. For more information on the Roomba, see Appendix A. The engineers at iRobot built this device to accomplish specific tasks using programming and hardware while following strict constraints. Thus, our team chose this device to learn how other engineers have designed the circuitry to complete these tasks. Further, to discover how different circuit blocks contribute to the overall system. The device has been disassembled (see Appendix B), and all the electrical components have been cataloged (Appendix C), and the quantities of which were then tabulated (see Appendix D).

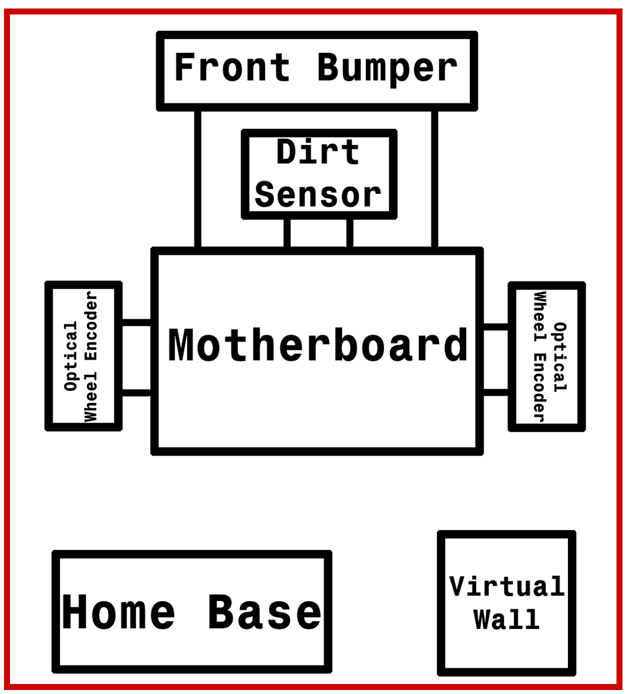


Fig. 1.1: Block Diagram showcasing how the six individual components connect to make up the Roomba.

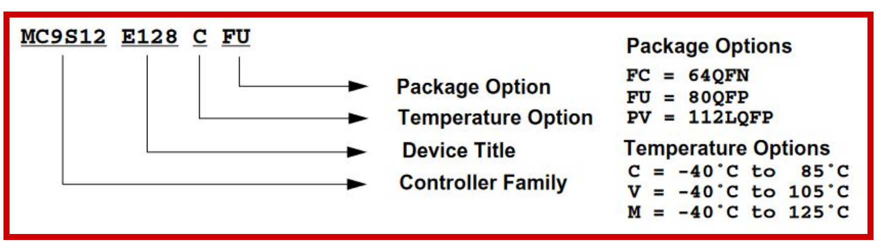
II. Research

MC9S12E128CPV Microcontroller - Overview

Fig. 2.1: image of the MC9S12E128CPV, microcontroller (MCU) for the Roomba 4220, manufactured by Freescale Semiconductor.

The MC9S12E128CPV is designed to be a low cost general purpose MCU equipped with a 16-bit central processing unit (HCS12 CPU). It also includes other fundamental circuit blocks (see Appendix E) like Memory, I/O peripherals, serial ports, etc. Its role is to process information from sensors, control movement, and execute programming instructions.

Operating Characteristics



Source: MC9S12E128CPV Datasheet

Fig. 2.2: Shows that the MC9S12E128CPV operates within -40C to 85C and that it is a 112-pin quad flat package.

LM339 Quad Differential Comparator

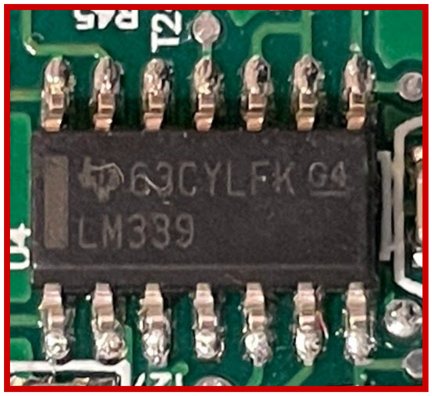
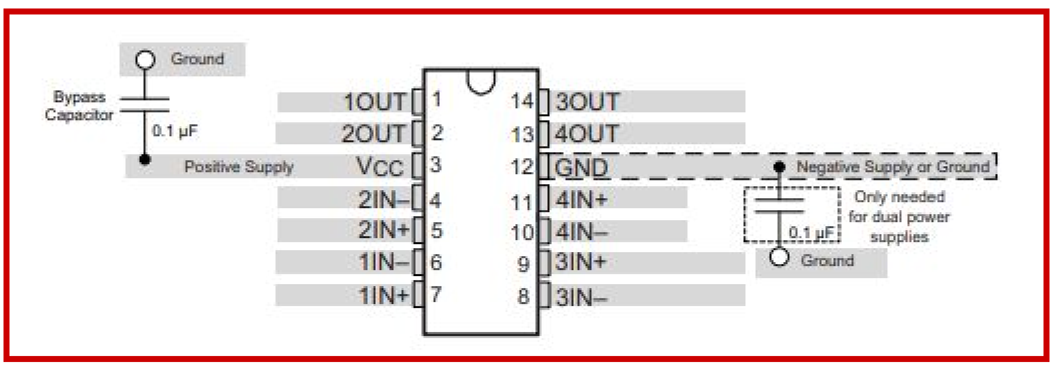


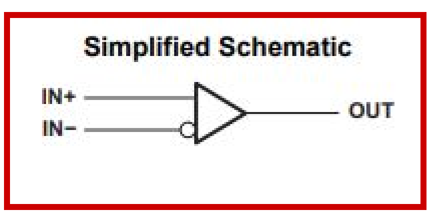
Fig. 2.3: The differential comparator, LM339, is a device used to compare four pairs of voltage signals at a time.

There are four op-amps that compare the voltages of the inverting (-) and non-inverting (+) inputs. If the inverting input is greater, the output is drawn to the VCC power pin. If the non-inverting input is greater, the output is drawn to the GND power pin. In the home base charging dock, it supervises the power distributed to the Roomba. This works in collaboration with other electronic components in the home base (See Appendix C).



Source: LM339 Quad Differential Comparator Data Sheet

Fig. 2.4: There are 4 op-amps with 3 pins each that compares inputs, 2 pins for power, VCC and GND, that gives power to the chip.



Source: LM339 Quad Differential Comparator Data Sheet

Fig. 2.5: Each op-amp has an inverting and noninverting terminal that compares the voltage. Once voltage goes above the reference voltage, the outputs will power on.

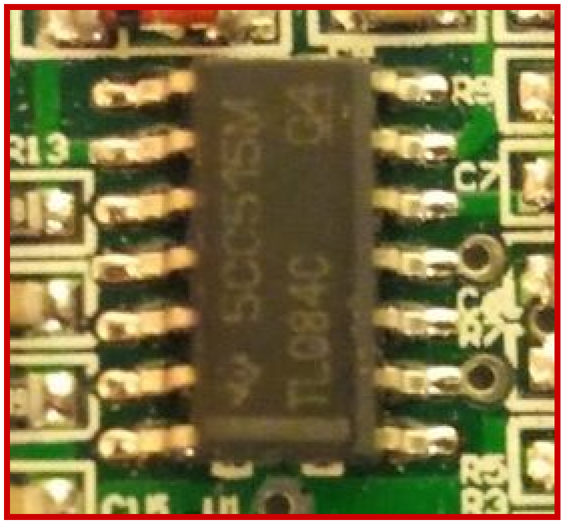
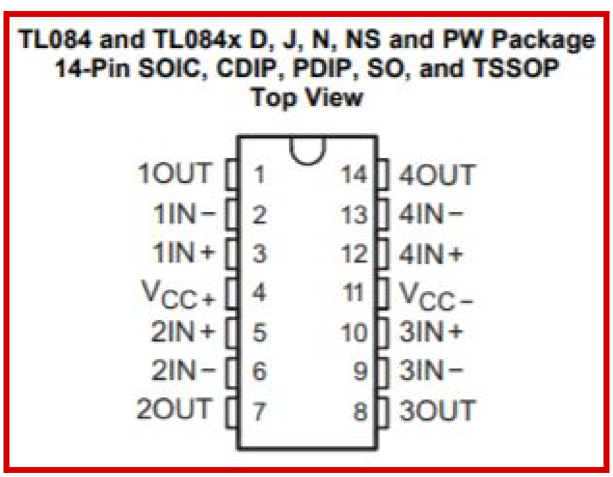
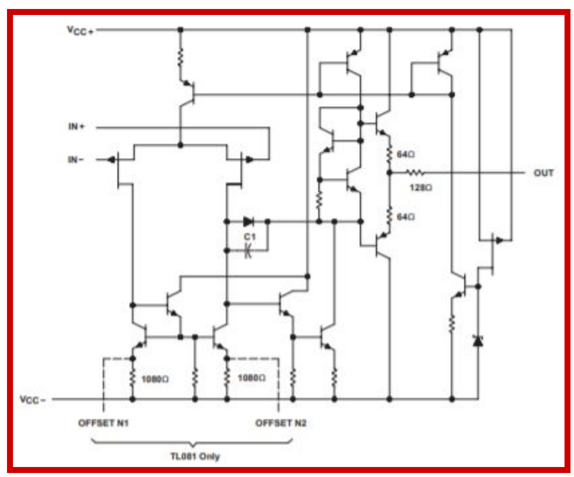


Fig. 2.6: TL084C JFET-Input operational amplifier (op-amp) developed by Texas Instruments (TI) found upon disassembly of the Vacuum Intake. (See Appendix B for disassembly details)

The TL084C JFET-Input op-amp is an integrated circuit developed by Texas Instruments(TI) consisting of Junction-Gate Field Effect Transistors(JFETs) and Bipolar Transistors to change the input voltages into the desired output voltage. This op-amp boasts a high slew rate to allow minimal lag between the change in the input voltage and the resulting change for the output. For this reason, the op-amp is used in high precision applications such as the dust sensor module found in the Roomba.



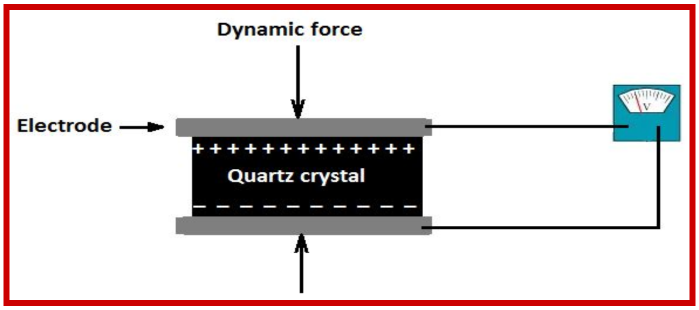


Source: TL084C Datasheet

Fig. 2.7: TL084 Pin Layout along with circuit schematic showcasing the Operational amplifier.

Fig. 2.8: A picture of the dirt sensor (circular gold plate).

The dirt sensor controls the Roomba's vacuum intake. When driving over a dirty section of ground, the robot signals the brush roller motor to start spinning and pick up the dirt. This is possible because of the dirt sensor's piezoelectric properties.



Source: Piezoelectric Property Explained
Fig. 2.9: Materials with piezoelectric properties generate small amounts of electricity when pressure is applied to them.

Source: Roomba Brush Roller
Fig. 2.10:Vacuum brush roller.

When enough dirt particles hit the sensor, a current is generated and sent to the robot. If it's above a certain threshold the Roomba can assume that dirt is present, triggering the brush roller and starting the vacuum.

III. Conclusion

We learned that the Roomba implements the MC9S12E128CPV as the microcontroller, which enables it to interface with its sensors, motors, as well as execute program instructions. The LM339 regulates the charging of the Roomba via the home base. The dirt sensor detects dust particles, which informs the Roomba where to concentrate, thus making the machine more intelligent. Due to the vital role that electronic components play to provide efficient and optimal functionality, they are hand-picked during the engineering process. Thus, the meticulous planning displayed by the Roomba is a goal that we will match in our future work.

(Total Word Count: 493)

IV. References and Citations

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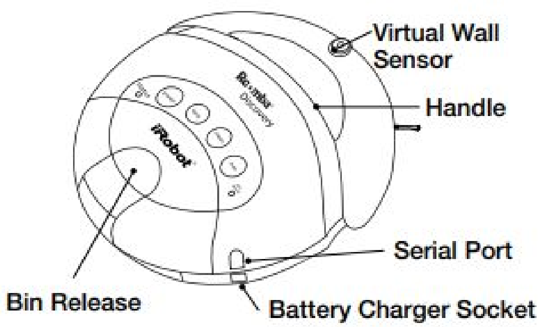
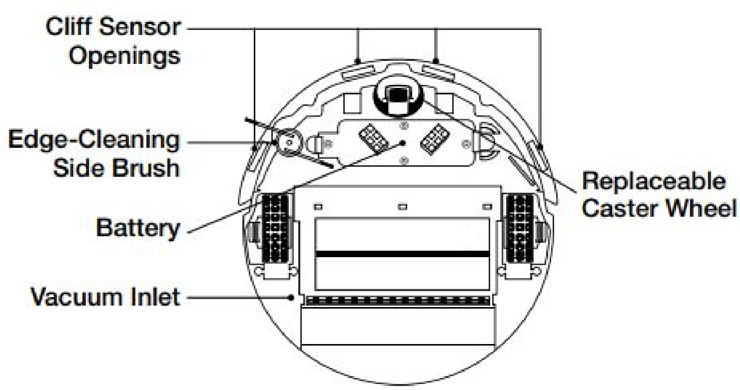
Appendix A: iRobot Roomba Overview



Source: Roomba Manual

Fig. A1: This is an autonomous robotic vacuum cleaner. It uses sensors and motors to maneuver itself to pick up debris.



Source: Roomba Manual

Fig. A2: It boasts a larger dust bin, greatly improved software and room detection, faster charging, and more.

<table>
<tr>
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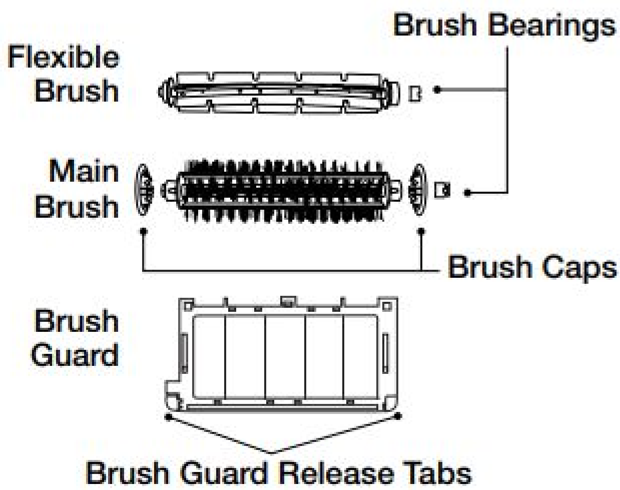

Source: [Roomba Manual]
</td>
<td>**Fig. A3**: Shows the brushes used to pick up debris.</td>
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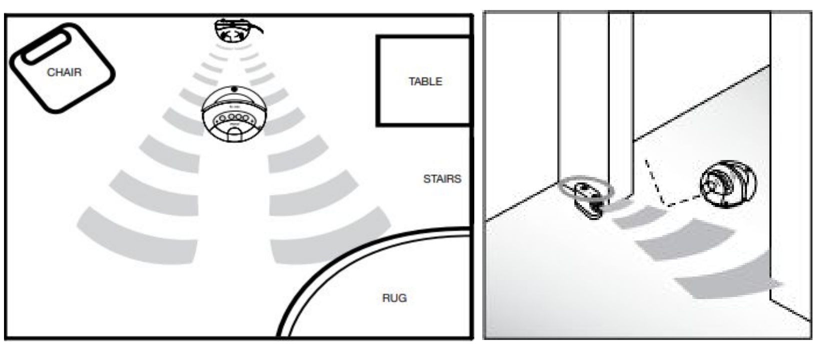
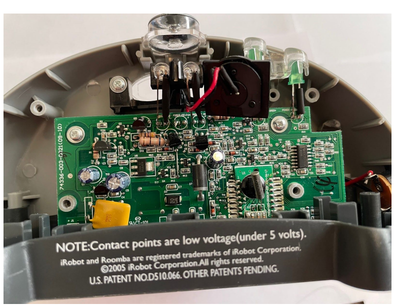
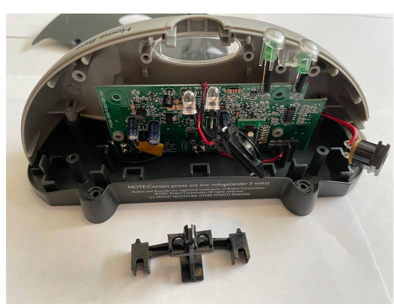
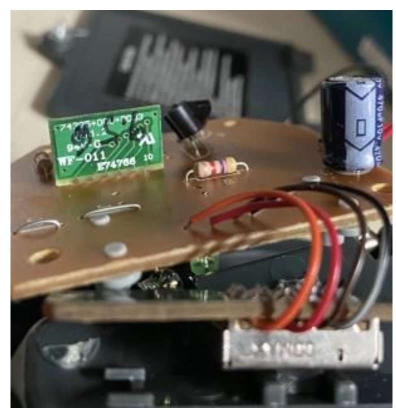
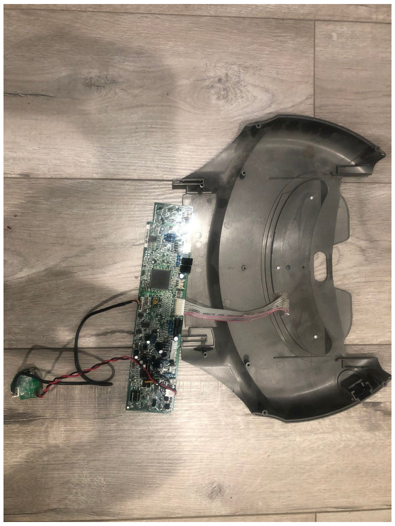
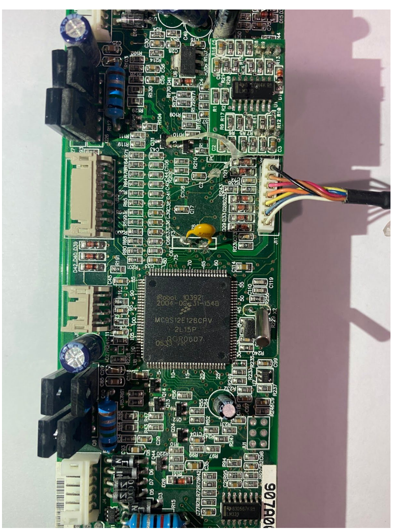
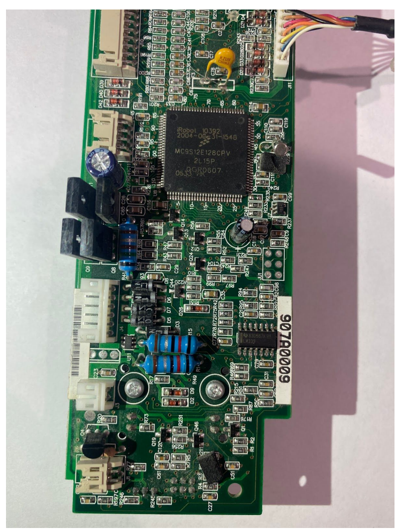
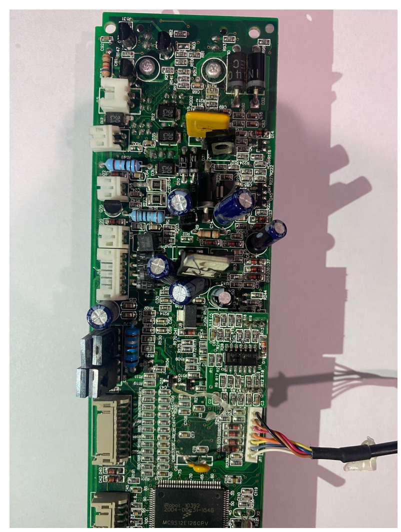
<td>


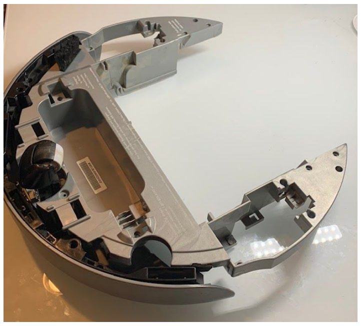
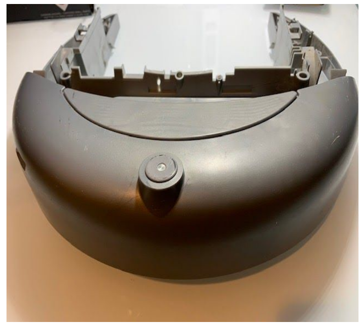
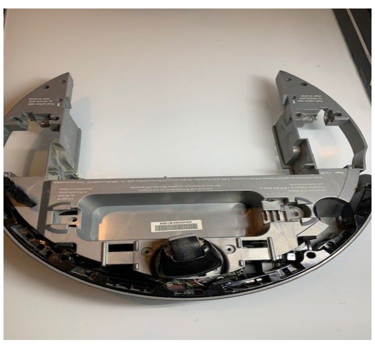
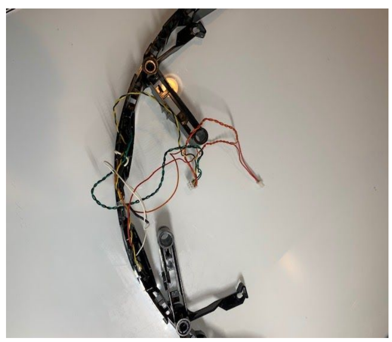
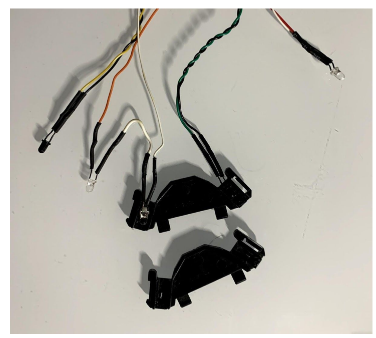
Source: [Roomba Manual]
</td>
<td>**Fig. A4:** Demonstrates how external peripherals are used to navigate around the room.</td>
</tr>
</table>

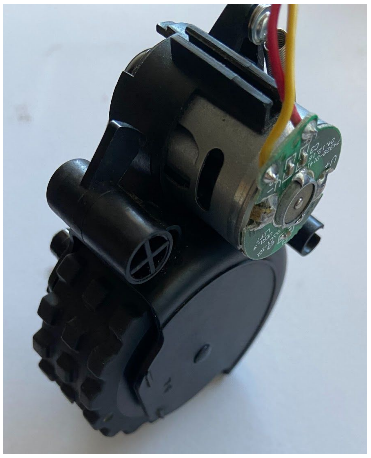
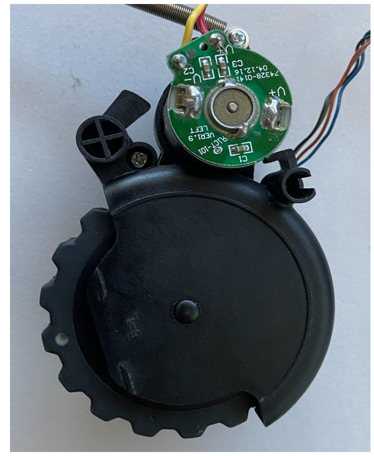
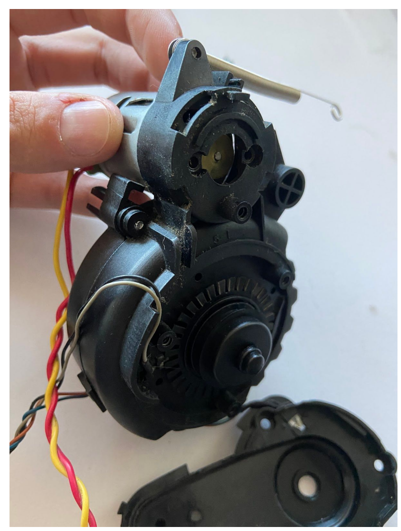
Appendix B: Disassembly and Outer Anatomy

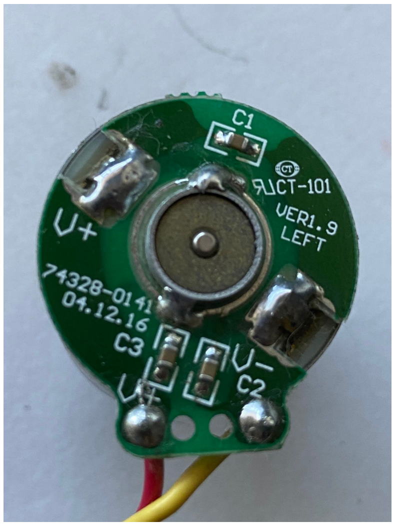
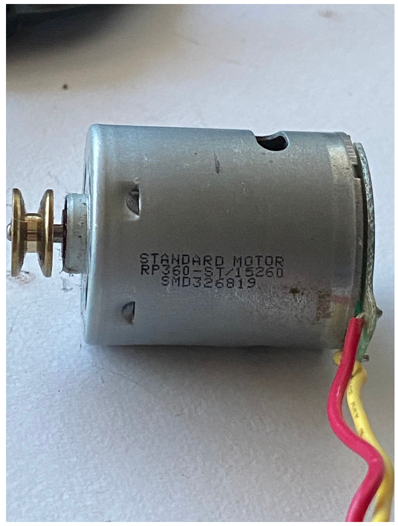
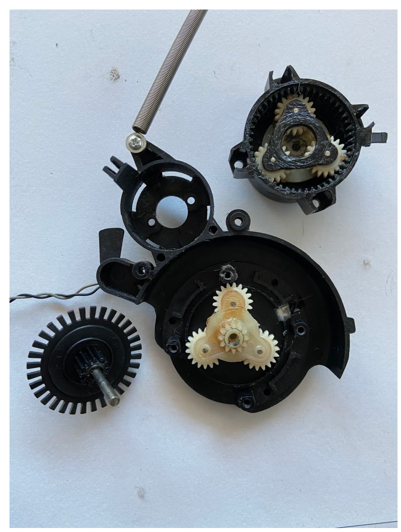
Home Base Disassembly		
Isometric View	**Front View**	**Top-Down View**
		
Step 1: Use a screwdriver to loosen screws.	**Step 2:** Once screws are removed, pull up the top plastic piece.	**Step 3:** Remove loose screws from back grey piece, and pull grey plastic piece off to expose the interior.
		
Step 4: Unscrew around circuit board.	**Step 5:** Remove surrounding parts anchoring circuit board.	**Step 6:** Gently pull the circuit board out.
		

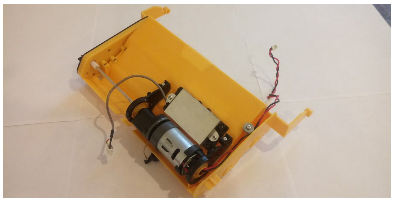
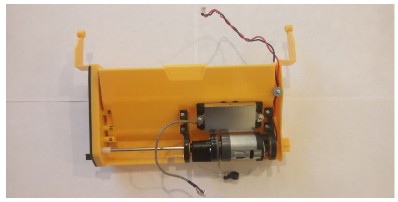
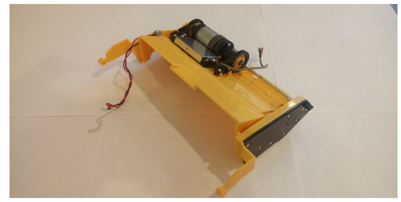
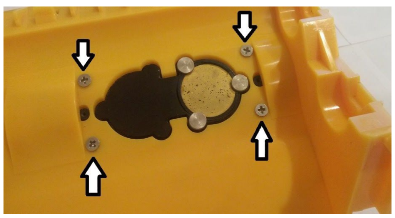
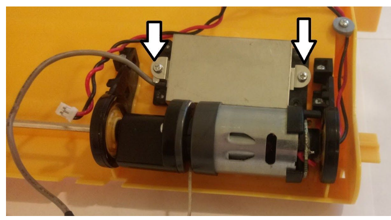
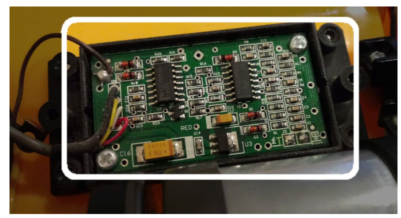
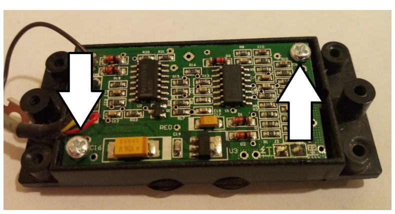
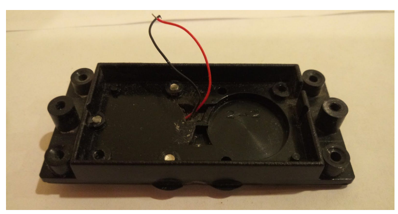
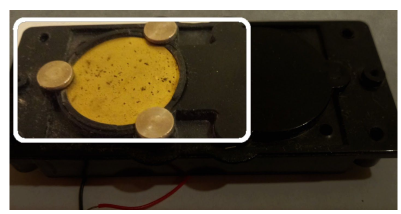
Virtual Wall		
Isometric View	**Bottom View**	**Battery Storage View**
	 	
Step 1: The virtual wall unit consists of an On/Off button, range selection and infrared light.	**Step 2:** Remove one screw to open the battery storage.	**Step 3:** Take out the four rubber stands and unscrew four nuts to look at the interior unit.
		
Step 4: Unscrew 6 more screws that are connected to the PCB.	**Step 5:** Turn the circuit board over to view the bottom portion.	**Step 6:** Rotate the bottom circuit board to access the side components.

Motherboard		
Top-Down View	**Underside View**	**Top-Down View**
		
Step 1: When removing the top, disconnect all ribbon cables that connect to the motherboard.	**Step 2:** Remove 4 screws that strap down the motherboard to the chassis.	**Step 3:** Push the back bumper in and lift to remove it.
		

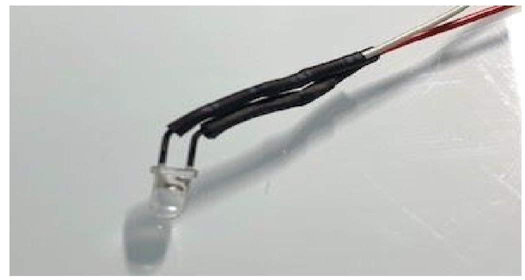
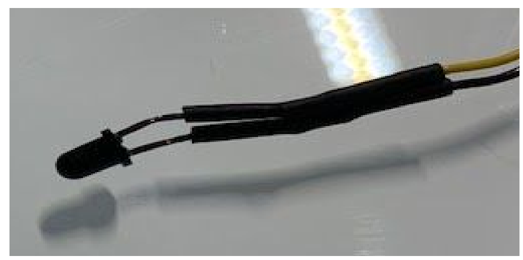
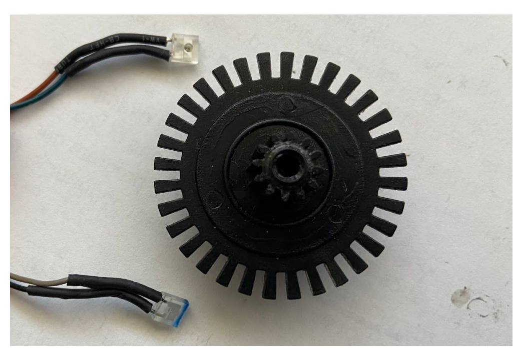
Front Bumper		
Isometric View	**Front View**	**Top-Down View**
		
Step 1: Remove 2 screws and take off springs to detach the bumper off of the enclosure.	**Step 2:** Remove the 4 enclosures within the bumper which are holding in the IR proximity sensors.	**Step 3:** IR emitter and receiver can be isolated by pulling the 2 plastic enclosures apart.
		

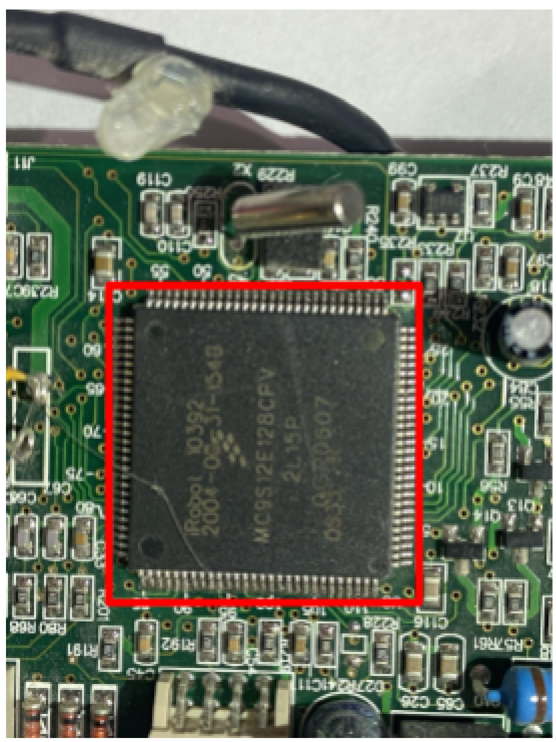
Motor Encoder		
Isometric View	**Front View**	**Outer-Side View**
		
Step 1: Remove back plate cover.	**Step 2:** Unscrew pins holding DC Motor in place**.**	**Step 3:** Remove DC Motor.
		

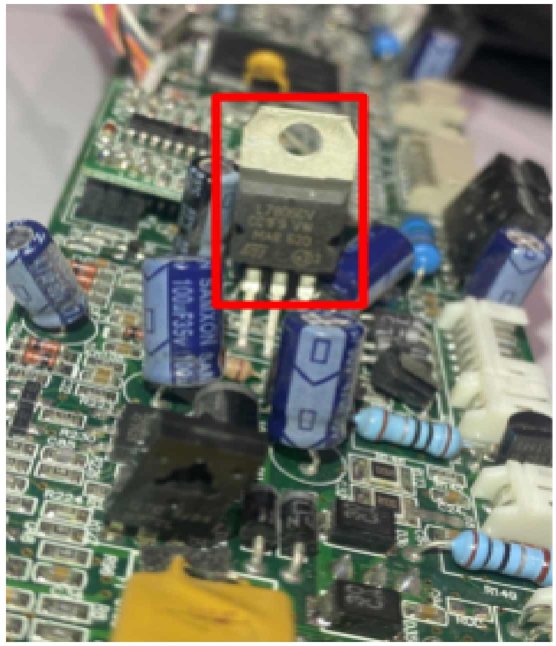
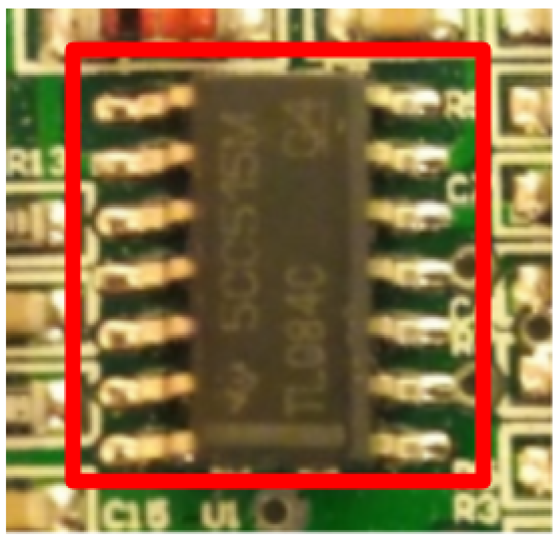
Step 4: Inspection of DC Motor circuit board.	**Step 5:** Inspection of DC Motor.	**Step 6:** Remove back wheel cover.
		
Step 7: Remove back plate.	**Step 8:** Remove screws holding the gears in place.	**Step 9:** Remove all inner components.
		

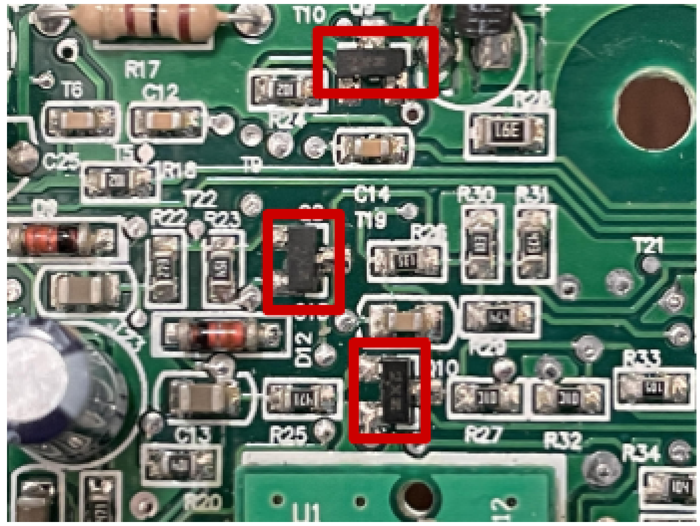
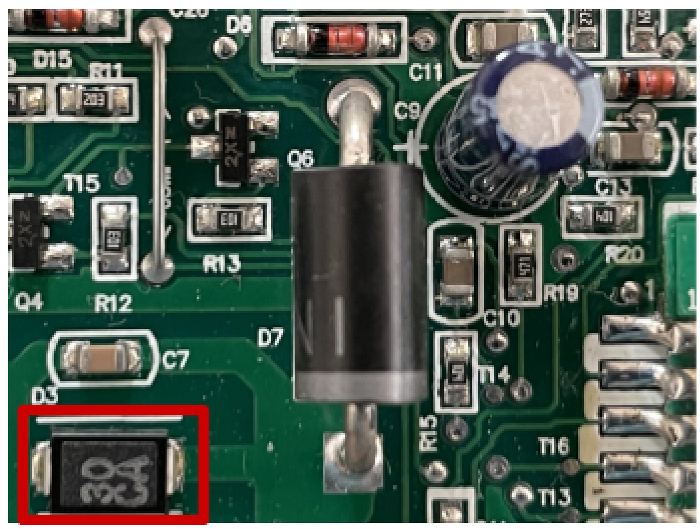
Vacuum Intake		
Isometric View	**Front View**	**Outer-Side View**
		
Step 1: Unscrew Dirt Sensor housing.	**Step 2:** Remove PCB cover.	**Step 3:** Lift PCB case off of vacuum intake.
		
Step 4: Take PCB out of case.	**Step 5:** Desolder PCB from wires.	**Step 6:** Flip over to have isolated dirt sensor.
		

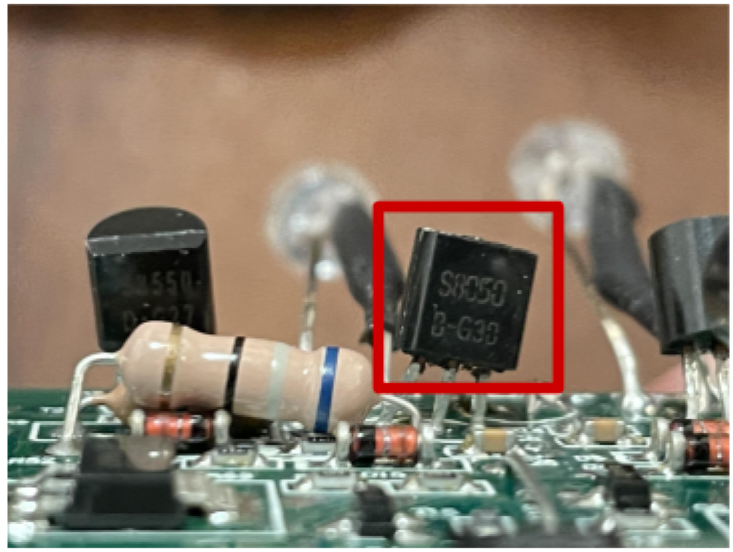
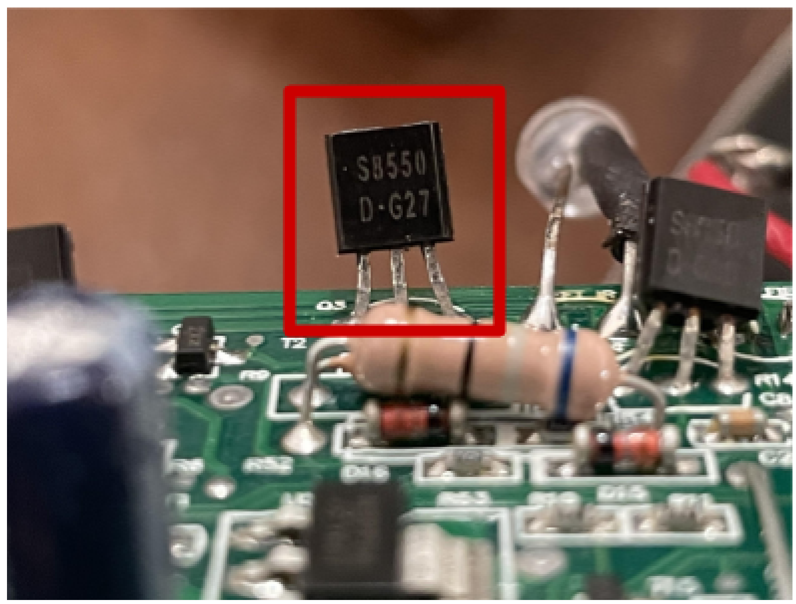
Appendix C: Parts Lists

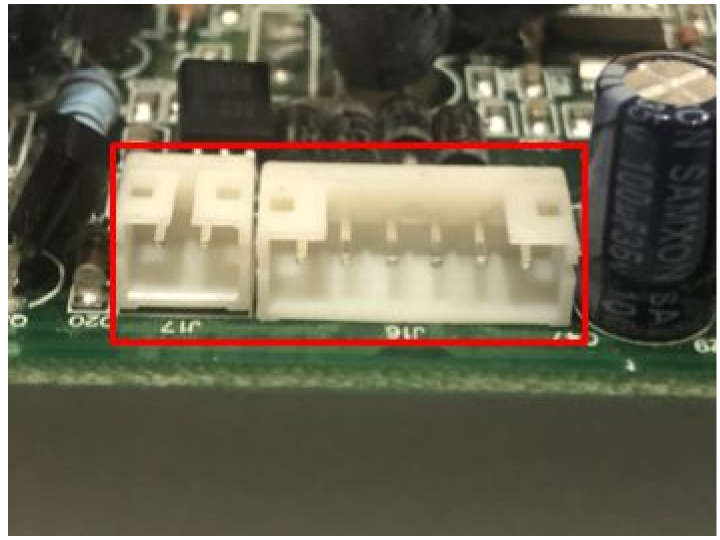
List of Components - Sensors	
Description / Location	**Picture**
IR Signal Emitter - Front Bumper **(Figure C1)** An LED that emits infrared signals which bounce off of objects, used for distance tracking.	
IR Photo Diode Sensor - Front Bumper **(Figure C2)** An LED that only receives infrared signals that have bounced off of objects determining the distance based on angles.	
Dirt Sensor - Attached to the inward side of the vacuum intake **(Figure C3)** A piezoelectric sensor that detects large patches of dirt and triggers vacuum to start.	
Optical Wheel Encoder System **(Figure C4)** Keeps track of the revolutions turned by counting the times a gear has blocked light coming from an LED to a photosensor	

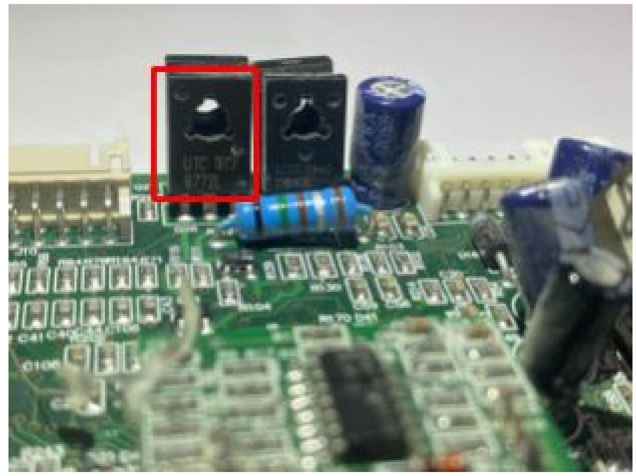
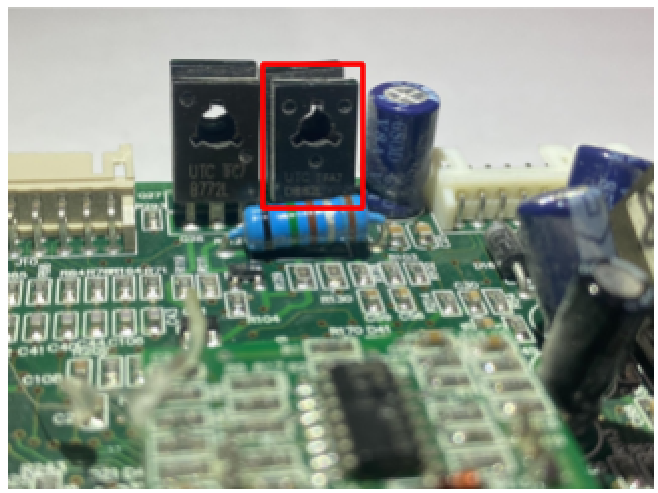
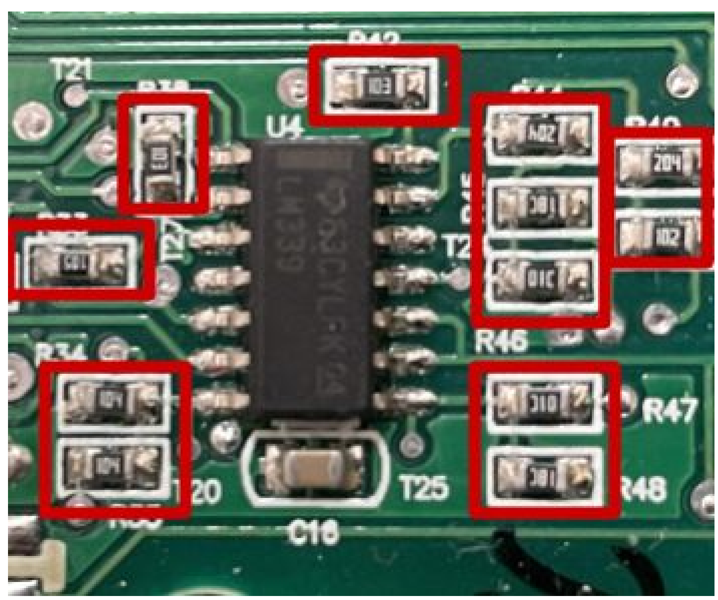
List of Components - Integrated Circuits		
Chip / Description / Manufacturer	**Picture**	**Datasheet URL**
63CYLFK-LM339 - Quad Comparator **Texas Instruments** **(Figure C4)** 4 independent voltage comparators, compares signals and can shift voltage.		https://www.ti.com/lit/ds/symlink/lm2901.pdf?ts=1604675293288&ref_url=https%253A%252F%252Fwww.google.com%252F
MC9S12E128 - Microcontroller **NXP Semiconductor** **(Figure C5)** Microcontrollers are typically compact integrated circuits (IC's) designed to perform specific functions or tasks within larger embedded systems.		http://www.farnell.com/datasheets/2295660.pdf?_ga=2.117078662.1677503991.1603779458-622760620.1603779458

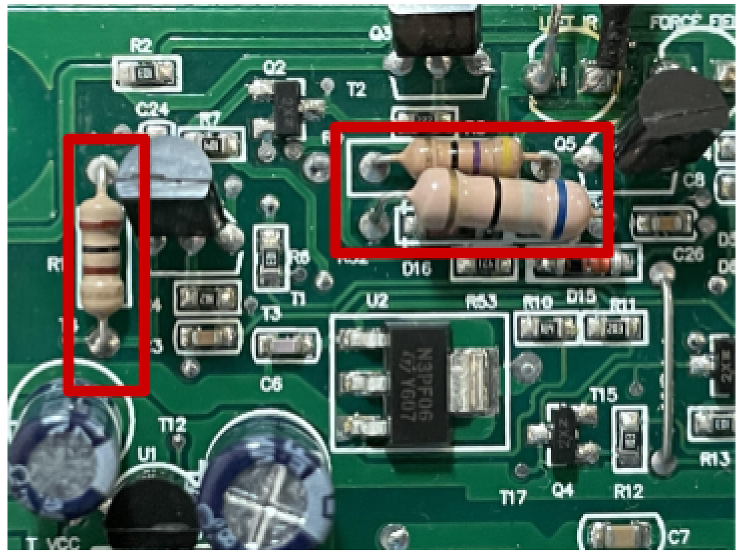
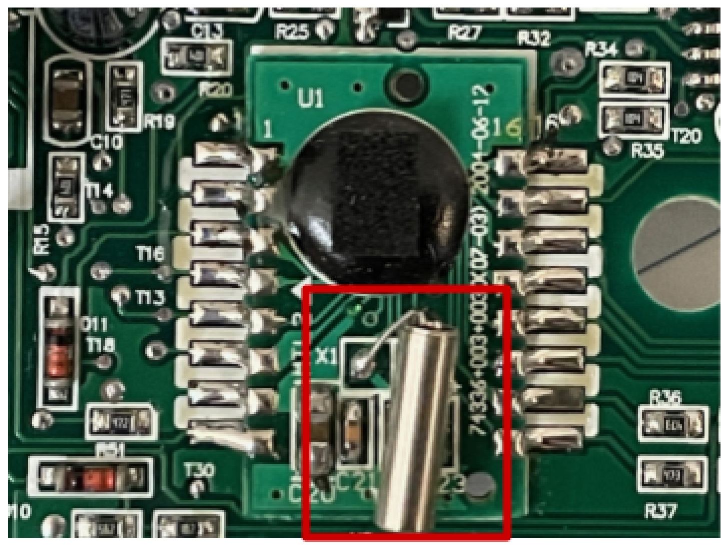
L7805CVCC1F9 - Voltage Regulator - STMicroelectronics **(Figure C6)** A three-terminal positive voltage regulator with an output current up to 1.5A and output voltages up to 24V.		[L7805CV.pdf]()
TL084C - Quad Operational Amplifier - Texas Instruments **(Figure C7)** A high-speed JFET input, quad operational amplifier incorporating well matched, high voltage JFET and bipolar transistors in a monolithic integrated circuit.		https://www.ti.com/lit/ds/symlink/tl084.pdf?HQS=TI-null-null-mousermode-df-pf-null-wwe&ts=1605162982224&ref_url=https%253A%252F%252Fwww.mouser.com%252F
78L05 - Positive Voltage Regulator - STMicroelectronics **(Figure C8)** A 3 terminal positive regulator whose purpose is to regulate the voltage within a given application.		https://pdf1.alldatasheet.com/datasheet-pdf/view/22687/STMICROELECTRONICS/78L05.html

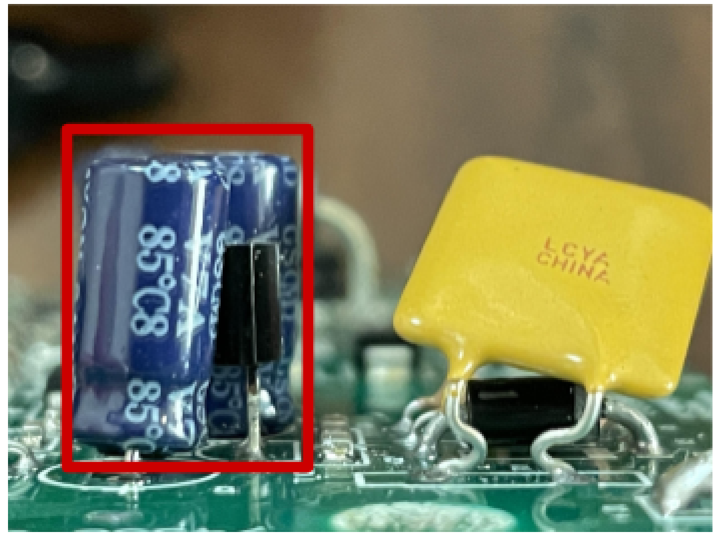
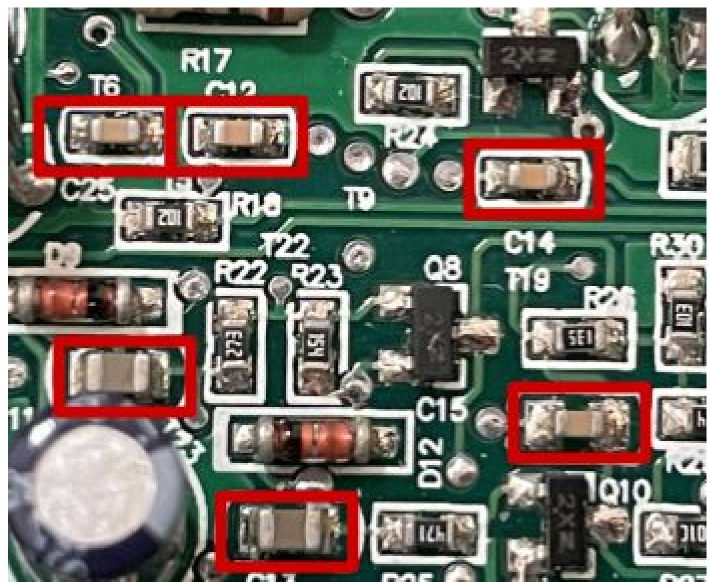
List of Components - Other Components	
Description	**Picture**
MMBT4401L (2X) - Transistor **(Figure C9)** An NPN-type switching transistor designed for automotive and other general purpose applications. Data Sheet: https://www.mouser.com/datasheet/2/308/MMBT4401LT1-D-108598.pdf	
30CA - Diode **(Figure C10)** A transient voltage suppression diode that is designed to protect circuits from high voltage transients. Data Sheet: [SMBJ 30 CA, 600W, SMD SMC (transient voltage suppressor diodes)]()	

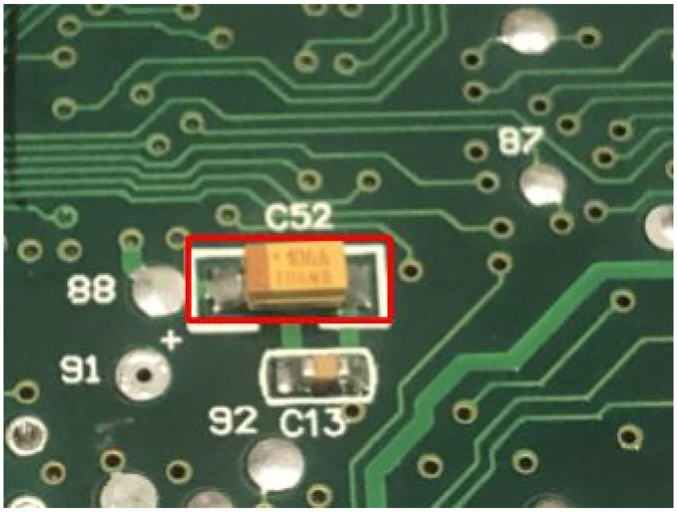
S8050 - NPN Silicon Transistor - Unisonic Technologies CO. LTD **(Figure C11)** A low voltage high current small signal NPN type transistor that is designed for audioamplication and for general purpose application. Data Sheet: https://components101.com/sites/default/files/component_datasheet/S8050%20Transistor%20Datasheet.pdf TD S8050	
S8550 -PNP Epitaxial Silicon Transistor - Unisonic Technologies CO. LTD **(Figure C12)** A low voltage high current small signal NPN type transistor that is designed for Class B push-pull audio amplifiers and general purpose applications. Manufacturer: Unisonic Technologies CO. LTD Data Sheet: https://datasheetspdf.com/pdf/576673/UTC/S8550/1	

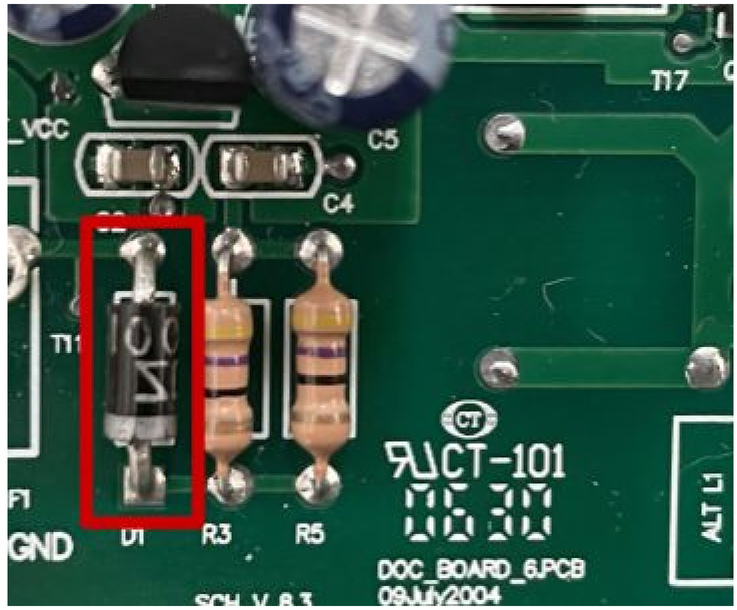
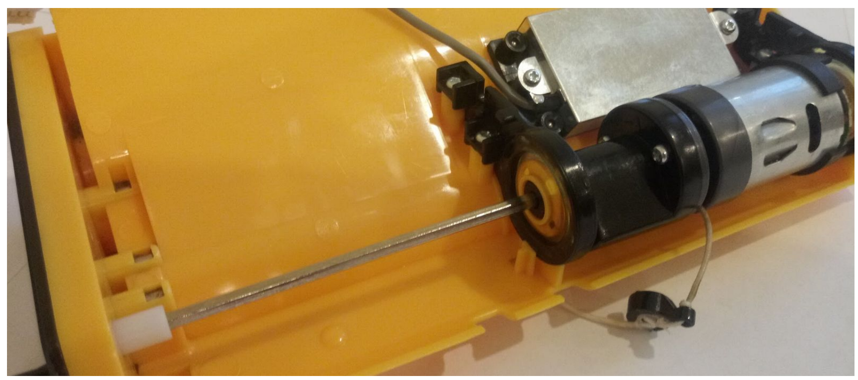
JST-XH Connector **(Figure C13)** A variety of general purpose JST connectors to combine electrical conductors and create electrical circuits. Data Sheet: http://www.jst-mfg.com/product/pdf/eng/eXH.pdf?5fa50d346228b	
N3PF06Y628 - Power MOSFET - STMicroelectronics - Motherboard **(Figure C14)** Power MOSFET with a maximum Drain-Source Voltage (Vdss) of 60V, a maximum drain current of 2.5 A, and max on-resistance of 0.22 Ohms. Data Sheet: https://www.mouser.com/datasheet/2/389/stn3pf06-956389.pdf	

B772 - PNP Epitaxial Silicon Transistor - Unisonic Technologies CO. LTD **(Figure C15)** A low voltage medium power transistor, which is designed for DC-DC Conversion, Voltage regulation, and Audio Amplification. Compliment to 2SD882. https://pdf1.alldatasheet.com/datasheet-pdf/view/33370/UTC/B772.html	
D882 - NPN Silicon Transistor - Unisonic Technologies CO. LTD **(Figure C16)** This transistor can handle output current up to 2A, features a low saturation voltage, and it is a complement to the existing 2SB772 Transistor. Data Sheet: https://datasheet4u.com/datasheet-pdf/UTC/D882/pdf.php?id=1046408	
Surface Mount Resistor **(Figure C17)** A rectangular ceramic body which has conductive leads on each end. Similar to a traditional resistor with it's ohmic value printed on the front.	

Through Hole Resistor **(Figure C18)** An electronic component, designed to limit the flow of electrons, that has a constant electrical resistance value.	
Quartz Crystal Oscillator **(Figure C19)** A high Q resonant component that generates sinusoidal signals as a response to an initial voltage change.	

Through Hole Electrolytic Capacitor **(Figure C20)** Capacitor which uses a high-ion concentrated liquid, known as an electrolytic, as its dielectric to store energy within an electric field.	
Surface Mount Capacitor **(Figure C21)** Ceramic capacitor typically used in high frequency applications. Dielectric materials used have very high dielectric constants such as Titanium Dioxide and Barium Titanate.	

Surface Mount Tantalum Capacitor **(Figure C22)** Tantalum capacitors achieve high capacitance values through the use of a tantalum pentoxide dielectric, a large plate area, and a thin dielectric thickness.	
Zener Diode **(Figure C23)** Zener diodes constrain current to only flow from anode to cathode. Except for when a voltage threshold is met, Zener voltage.	

Schottky Diode **(Figure C24)** A semiconductor diode which features low turn-on voltage, fast recovery time, and a low junction capacitance. Ideal for high frequency circuits.	
Brush Roller Motor **(Figure C25)** This internal motor controls the vacuum brush roller that picks dirt up off of the ground. Activated by the dirt sensor.	
Battery Pack **(Figure C26)** Nickel Metal Hydride battery pack responsible for powering the entire Roomba by supplying 14.4 volts.	

Appendix D: Tables

Graph 1.1: Total IC Chip Count

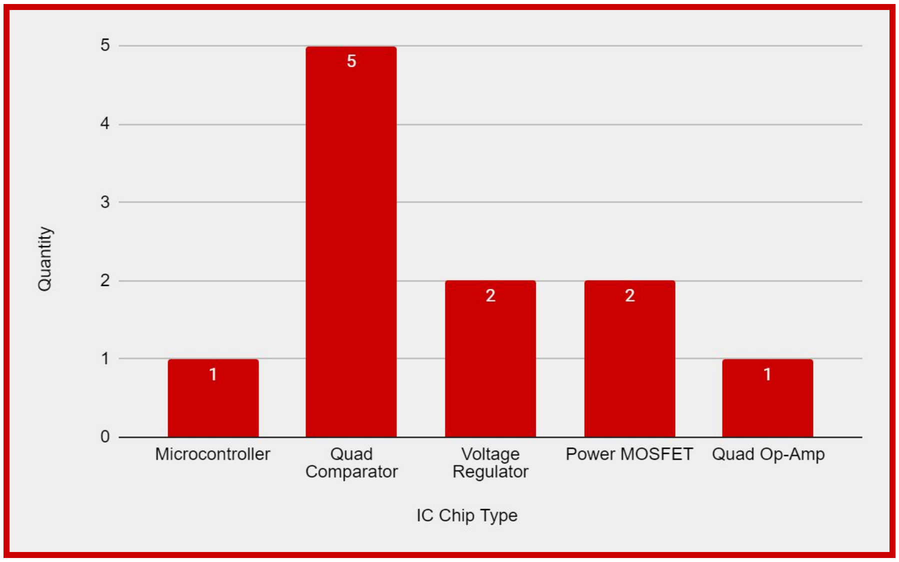


Fig. D1: Bar chart displaying integrated chip counts organized by chip types.

Graph 1.2: Total IC count by Manufacturer

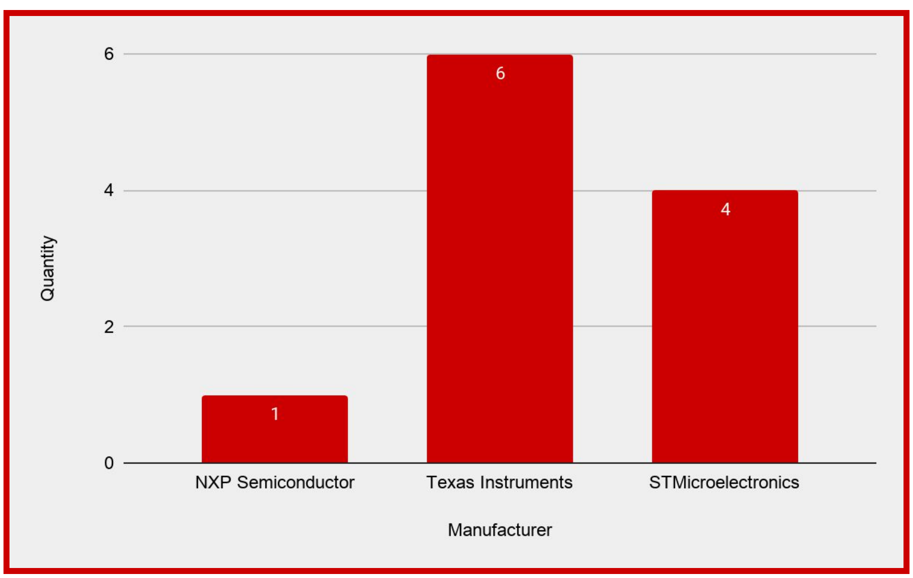


Fig. D2: Bar chart displaying integrated chip counts organized by manufacturer.

Graph 1.3: Total IC Count by Location

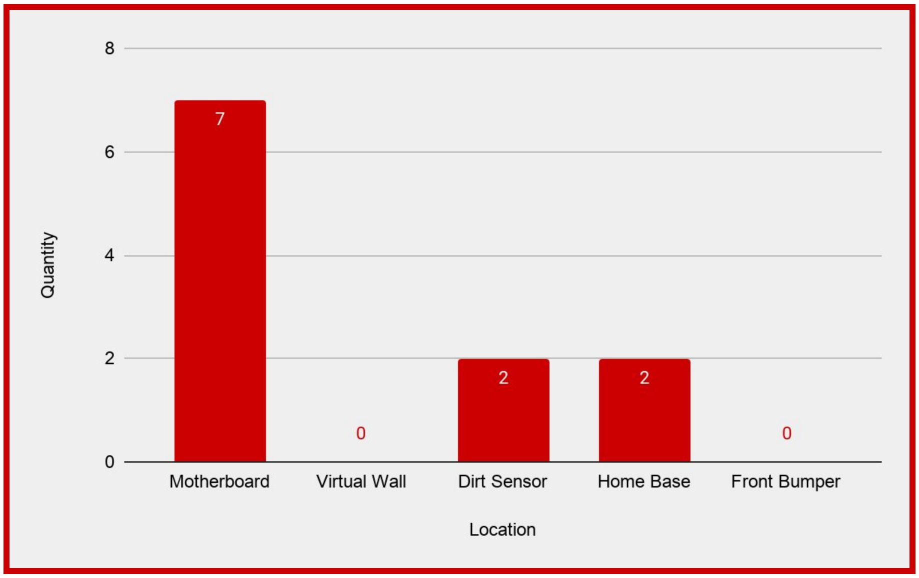


Fig. D4: Bar chart displaying total integrated circuit counts organized by their location in the Roomba.

Graph 1.4: Total Component Count

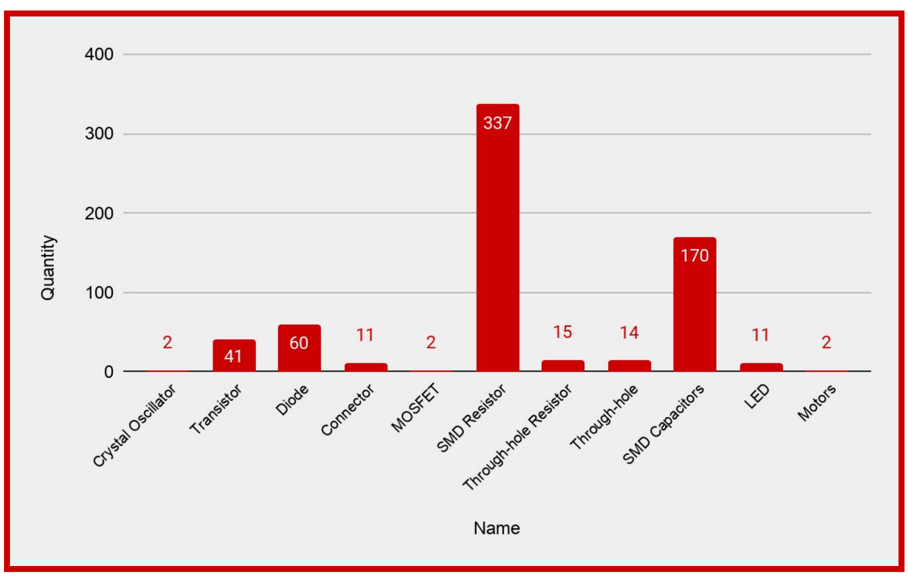
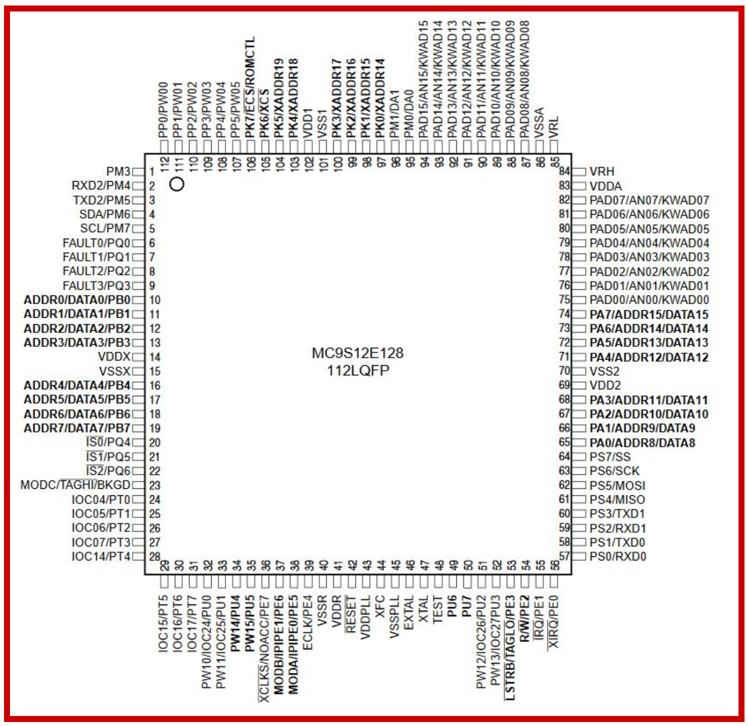


Fig. D5: Bar chart displaying total electronic component counts organized by component names.

Appendix E: MC9S12E128CPV Microcontroller Supporting Circuits

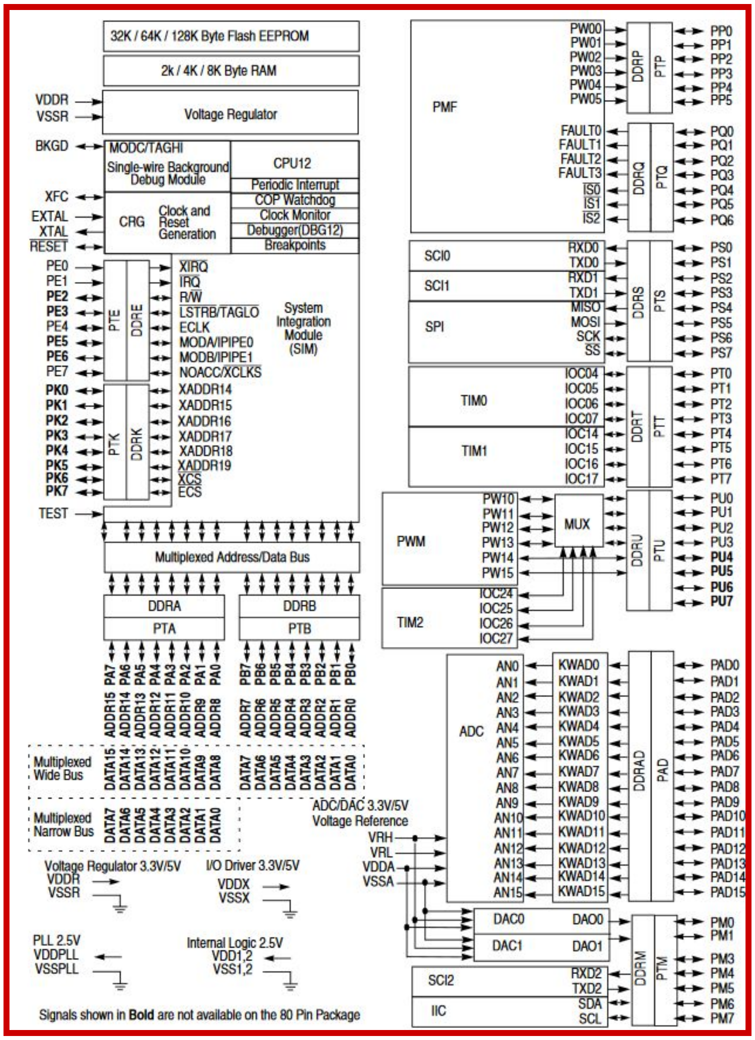
Package



Source: [MC9S12E128CPV Datasheet]

Fig. E1: The pinout for the 112 connections available for this variant of the MC9S12.

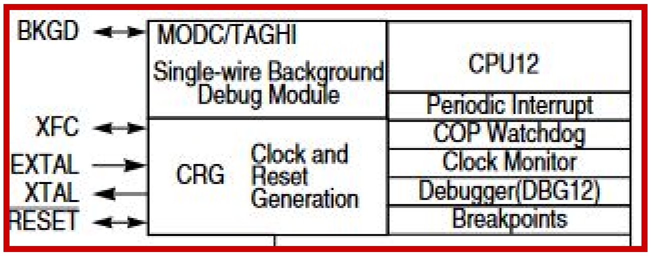
Circuit Block Diagram



Source: [MC9S12E128CPV Datasheet]()

Fig. E2: This shows the numerous integrated circuits that enable the MC9S12E128CPV to execute tasks and take in data from sensors.

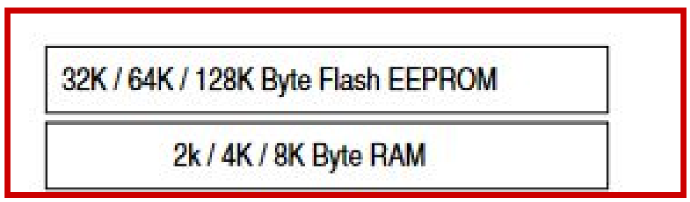
Central Processing Unit (CPU)



Source: MC9S12E128CPV Datasheet

Fig E3: The HC12, a derivative of the 68HC11 by Motorola, is used for processing instructions through simple arithmetics, I/O, and logic operations.

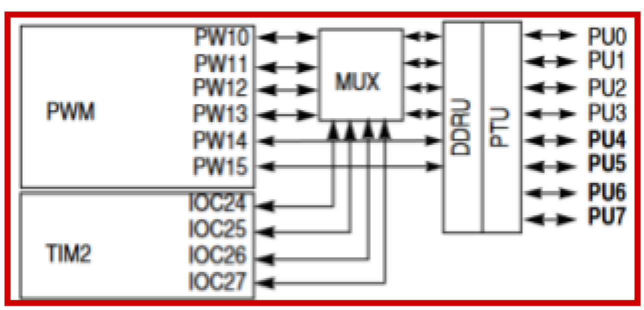
Memory



Source: MC9S12E128CPV Datasheet

Fig. E4: The MC9S12E128CPV contains 128K Bytes Flash EEPROM to store program data and it has 8K Bytes RAM for temporary data storage.

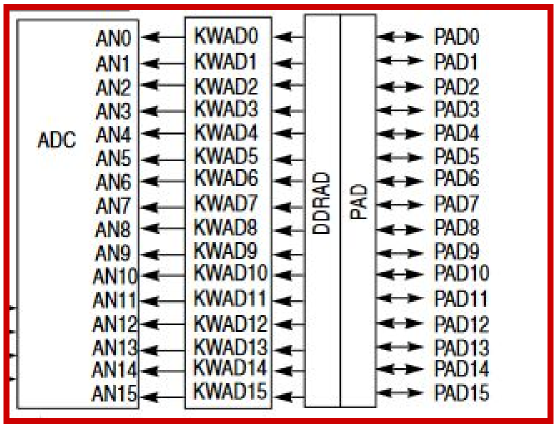
I/O Peripherals



Source: MC9S12E128CPV Datasheet

Fig. E5: The MCU contains 6 independently programmable Pulse Width Modulation channels for generating digital signals with custom period and duty cycles.

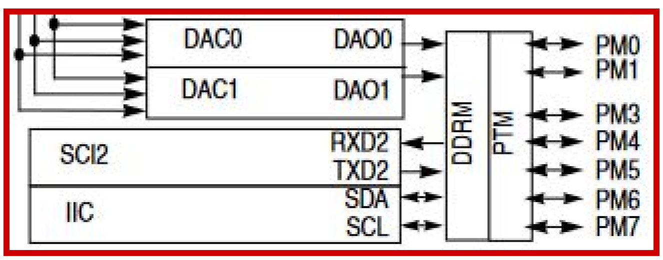
Analog to Digital Converter (ADC)



Source: [MC9S12E128CPV Datasheet]

Fig. E6: The ADC within the MCU allows for communication between external analog devices by converting analog waveforms into digital signals.

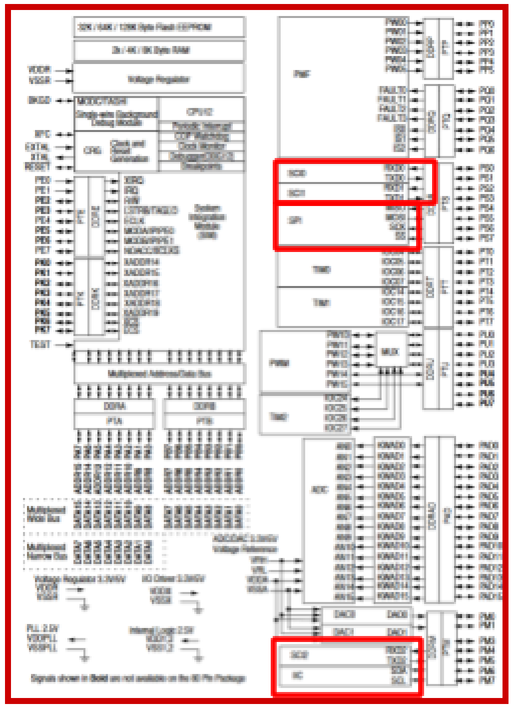
Digital to Analog Converter (DAC)



Source: [MC9S12E128CPV Datasheet]

Fig. E7: The inverse of the ADC, which allows the MCU to create custom analog signals for frequency or voltage generations.

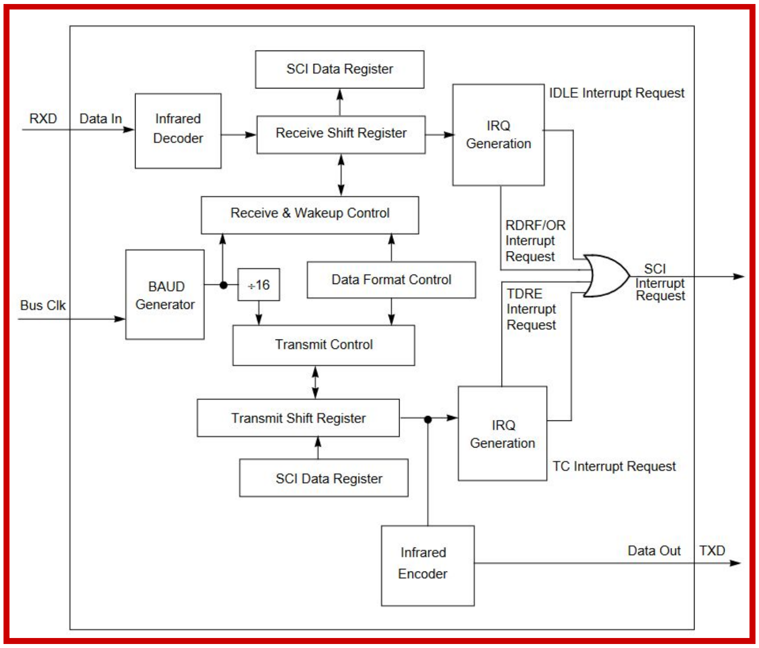
Serial Interfaces



Source: [MC9S12E128CPV Datasheet]

Fig E8: Shows the location of the Serial Communication Interfaces (SCI), Serial Peripheral Interface (SPI), and the Inter-Integrated Circuit (IIC).

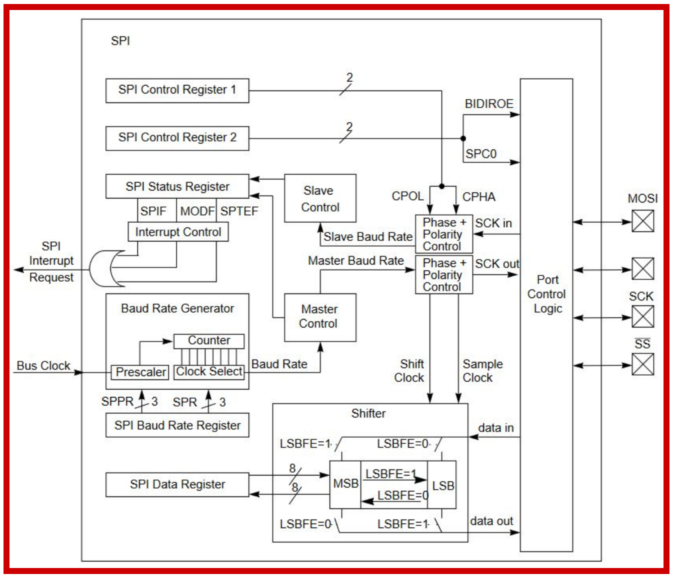
Serial Communication Interface (SCI)



Source: [MC9S12E128CPV Datasheet]

Fig. E9: The SCI above allows full-duplex, asynchronous, serial communication between the CPU and the external devices.

Inter-Integrated Circuit (IIC)

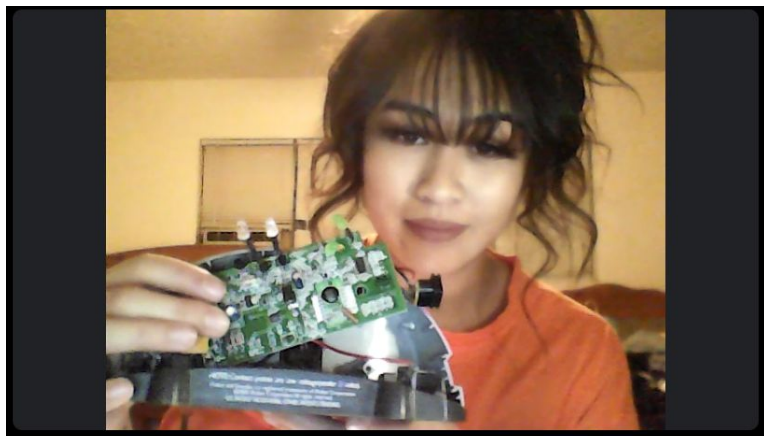


Source: [MC9S12E128CPV Datasheet]

Fig. E10: IIC allows for efficient exchange of data between devices. Suitable for short distance communications. Operates up to 100 Kbps in the MC9S12E128CPV .

Appendix F: Authors

Mt. San Antonio College Students	
Name / Contribution	**Picture**
Jovany - Electrical Engineering Major **(Figure F1)** Jovany worked on the motherboard and the microcontroller. Further, he worked on assembling the parts lists, and he led the team.	
Michael - Computer Science Major **(Figure F2)** Michael focussed on the motor module and the motor encoders. Additionally, he researched the JFET Operational Amplifier.	
Thomas - Computer Science Major **(Figure F3)** Thomas contributed to researching the dirt sensor and the vacuum intake. Further, he assisted in proof-reading and in formatting the report.	

Taha - Computer Science Major **(Figure F4)** Taha contributed by studying the virtual wall along with all the components inside of it. Additionally, he helped with creating the disassembly procedures.	
Kimberly - Mechanical Engineering Major **(Figure F4)** Kimberly helped by taking apart the home base along with researching the LM339 Differential Comparator. She Created the Tables seen in Appendix D.	
Brandon - Electrical Engineering Major **(Figure F4)** Brandon worked on the front bumper along with formatting the report. He also helped with putting together the parts list.