Block Design Validation Paper

Team 6:

LOOM project

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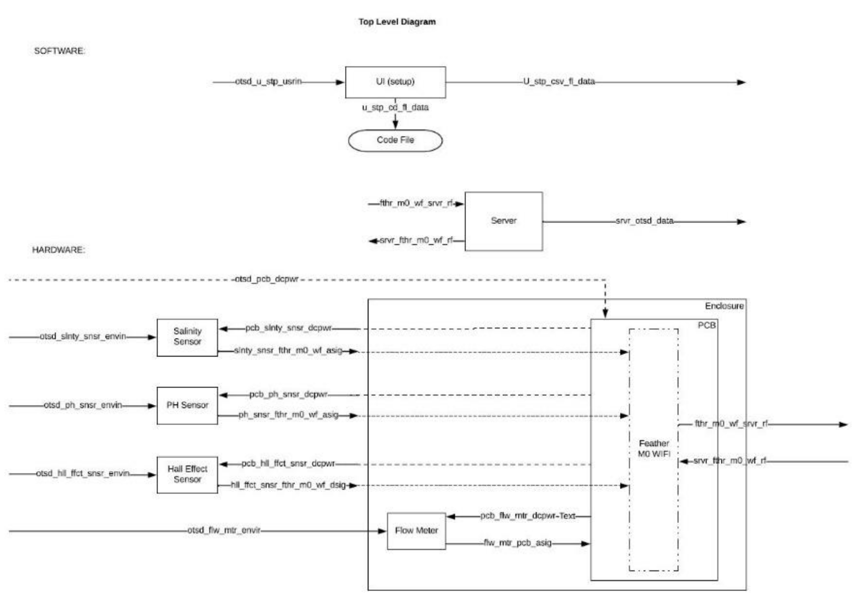
Abstract:

This article is talking about the LOOM project which is an application of the Internet of Things. The project consists of a server, actuators, microcontroller, and multiple sensors. The whole system could detect the environment signal and send the data to the server. The server has a visible user interface to show the collected data or saves the data to the cloud. There is a simple introduction to the Internet of Things. Meanwhile, this article discusses the implementation of the flowmeter in three parts, the sensor choice based on requirements of the flowmeter; Implementation of the flowmeter sensor module; The technique challenge of the flowmeter module. After that, there is a simple discussion about the PCB and enclosure design. Finally, the analysis of the whole design and method to improve the project in the future.

Section I.

Introduction

In the current electronic information area, the Internet of things (IoT) is becoming one of the most attractive topics. Some leading enterprise even considers IoT as a breakpoint for information technology. Many business giants rush to join the game of IoT. The market is growing so quick. According to Bain prediction, the combined markets of the Internet of Things will increase to $520B in 2021 which is more than double the $235B in 2017 [1]. It is obvious the Internet of Things is a big and promising market. Therefore, the internet of things is becoming a force to be reckoned.



LOOM project is one application of the internet of things. The LOOM project is creating a modular IoT learning and development platform for people whoever are interested in the internet of things. The platform contains three main parts that are the server, microcontroller, and sensors. The server provides a valuable user interface to help users control the actuator and check the data sent by microcontroller terminal. The other two parts, sensors, and microcontroller are creating an independent module that executes a particular function and collects data from an environment. In the module, multiple sensors provide with a different solution according to different scenarios. For example, the measurement of flow rate, pH value, and salinity.

Modules are the basis of the whole system. This essay is going to discuss how does the module be created and details about the flow meter sensor. In the microcontroller and sensors module, the feather m0 is used as the primary development board for its size and functions. Moreover, the assembled WiFi module provides a quick method to communicate with the server on the cloud. Besides, the feather development board is Arduino compatible. That means experienced users could easily edit the code according to their needs. After the development board is prepared, the next step is setting the sensor. According to specific using purpose, the choice of sensor much fit the project's requirements. For example, the target flow rate is quite low. The measuring range of flowmeter should cover the required range. Besides, the operating voltage, signal interface, and price should fit the whole system. Moreover, the accuracy, life range, response time, operating environment are other factors to be concerned to improve the module in the future. Next, the article shows more details and validation related in every block.

Section II.

Block 1: Flowmeter

This block is aiming to measure the low flow rate of liquid flow and send the collected data to the server in a particular format so that user could quickly check the result. After checking the data in the system's user interface, the user could have more information and react to the result. One imagined scenario is using in the biology laboratory to measure some liquid flow from equipment. First thing concerned about the flowmeter is accuracy. One of engineering requirement is the accuracy of the measured flow rate will be within 10% of the known flow rate. With the prerequisites of the project, the interface of the flowmeter should fit the development board and power condition as much as possible. By using the thermo-transfer (calorimetric) principle, the FS1012 has an advantage over resistor-based flow solutions that it is more sensitive. According to the datasheet of FS1012 [2], its measuring flow rate range is from 0.05 SLPM to 0.5 SLPM which is feasible for the necessary condition. The data type of flowmeter sensor is analog, and the voltage value is around 90 mV to 30 mV with 5 V header. The supply voltage is 3V to 5 V which gives more choice to use different solutions. Besides, the sensor provides a good response time what is 5ms.

The FS1012 has two inside thermopiles to detect the temperature change of the liquid flow. The thermopile gives the feedback in voltage change. However, the voltage of the flowmeter sensor could have offset as the sensor working. A differential amplifier circuit is useful to adjust the input offset so that the flow rate measured could be accurate.

Meanwhile, the using of a differential amplifier could increase the sensor's continuous using time. The differential amplifier circuit could design on a PCB board which belongs to the other block to make the module design simple. With 3.3V analog reference of feather development board M0, the gain of the differential amp could be around 30 which could give the output voltage value vary from 1.8V to 2.7V. In this way, the accuracy of reading data in the development board could be improved. To design a differential amp circuit. A Precision Unity Gain differential amplifier is necessary. With an appropriate value resistor, INA105 [3] from Texas Instruments could be adjusted to higher gain. One important thing is the amplifier need at least 5V supply power which could be provided by PCB. That means the PCB need to have 5V power point to drive the amplifier. Now that 5V power is accessible on PCB, the power could supply to more components. Therefore, the battery could have more choice as long as it combines with a voltage regulator which drop the voltage to 5.0V. The 5V power could also supply the microcontroller board.

In this processing, there are some significant challenges. The first, what is a good design for a differential amplifier circuit to make the accuracy as high as possible? Meanwhile, how to decrease the cost of components? The current solution is using resistors to adjust the amplifier's and make the signal easy for measuring by the microcontroller. Second, to make a reliable module, the connector of the sensor should be waterproof. The flowmeter needs to use wisely to simplify the design of an enclosure. Meanwhile, the enclosure should meet the requirements that sensors should be easy to change and the enclosure itself should be able to protect the inside components.

To improve the flowmeter block in the future. The differential amp circuit needs to be more effective. Even the method to deal with the voltage offset could be changed to single-end input offset adjustment circuit according to which type of circuit has a better performance. Moreover, the microcontroller code could also be improved. For example, by manually testing, find out the relationship between voltage and flow rate to simulate a new equation.

Name	Properties
otsd_flw_mtr_envin	**Other:** Liquid Flow **Water:** Min flow rate: 0.05 SLPM **Water:** Max flow rate: 0.5 SLPM
flw_mtr_pcb_asig	**Other:** Response time = 100 ms **Other:** Accuracy 10% **Vmax:** 90 mV **Vrange:** 15-65 mV
pcb_flw_mtr_dcpwr	**Inominal:** 17 mA +- 3mA **Ipeak:** 30 mA **Vmax:** 5.6 V **Vmin:** 3 V

The validation used for verifying the flowmeter is mainly testing. Before the test, related components need to ready to set up. Assembly all the components required for the flowmeter block which are flowmeter sensor, amplifier, and power supply. Besides, some other types of equipment are using to create the necessary working condition. A computer is using for showing the output data coming from the module. An oscilloscope is using for displaying the signal changes at a real time. For creating liquid flow, a pump is using with varying power. The factors need to show are the voltage read by the microcontroller, the response time, the changing signal by flows, the maximum and minimum voltage supplied for the sensor.

The first interface, otsd_flw_mtr_envin, is ruling the outside environment properties. The properties are limiting the type of flow that could measure and the range. With changing the flow rate, the signal showed on the oscilloscope and data read by the microcontroller is changing. With the flow rate changing from the minimum to the maximum rate, the flowmeter should work as expected and give a reasonable measure result.

Interface flw_mtr_pcb_asig is standing for the analog signal comes from the flowmeter sensor. An oscilloscope could measure the response time. The oscilloscope should catch that change within a certain time that represents the response time of the flowmeter. The accuracy of the measurement result could be tested by comparing the measured flow rate with the known flow rate. The voltage of the flowmeter should always in the range given in the chart when the flowmeter is working. The Vmax is saying that the voltage will never go above that value in the whole process. The testing of Vrange and Vmax should easily show during the testing.

Interface pcb_flw_mtr_dcpwr is the power supply of the sensor. The property Inominal is showing on the power supply directly. The value of that will always be around 17 mA. The Ipeak value gives the maximum current value when the sensor is working with the extreme condition which is 5.6V. The Vmax and Vmin give the max and min voltage that flowmeter could function normally. These properties could be tested by verifying the value on equipment of a lab.

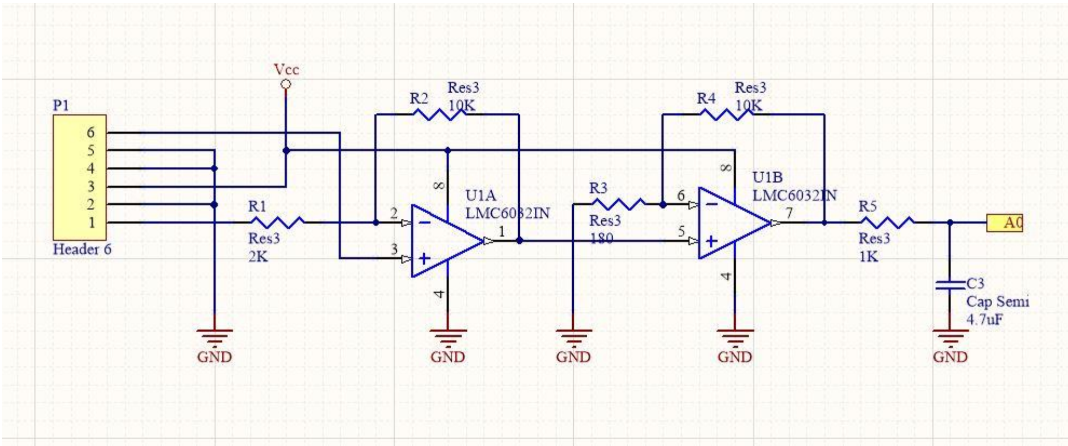
Block 2: PCB

PCB block provides the necessary circuit for the system. According to situations, circuits can be used to achieve different functionalities. There are two small modules in PCB circuit. One is an amplifier, and the other is a voltage regulator.

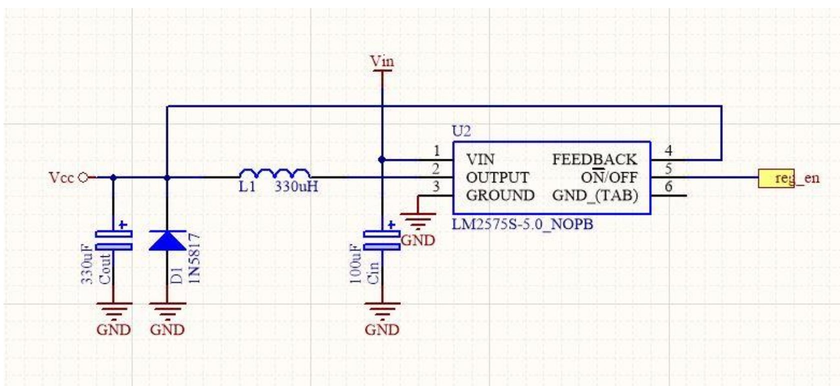
The reason that an amplifier is applied is to make the weak signal from sensor be significant. In the flowmeter block, the flowmeter sensor communicates with the microcontroller in the analog signal which's value is weak. The minimum amount could be small to 15mV. It is hard for the microcontroller to read such a weak signal precisely. The microcontroller used in the LOOM project is Feather M0 from Adafruit. To read an analog signal, the feather maps the input voltages between 0 and the operating voltage which is 3.3V into an integer between 0 and 1023 by using a 10-bit analog to digital converter. This feature of Feather yields a resolution between readings of 3.3 volts / 1024 units or, 0.0032 volts (3.2 mV) per unit. Assume that the sensor signal is read directly by the microcontroller, the minimum value 15mV is converted to the integer 5 (15 / 3.2). The maximum integer is 16 (50 / 3.2). It is tough for the system to get an accurate measurement with such a small range what 5 out of 1024 or 16 out of 1024. To enhance the difference and get precise measurements, the amplifier is necessary to be applied. According to the datasheet of the flowmeter sensor, the appropriate gain is from 20 to 100.

The voltage regulator is using to buck the battery voltage from 12V to 5V. The reason that using 12 V DC source is that the stakeholder's lab commonly uses a 12 V DC power source. Using the same type of power source could fit the general design. Meanwhile, the sensor has the best performance with the 5 V header. Considering the sum of the current, the regulator provides 5V 1A DC power for the whole module. For saving energy purpose, the regulator could be turned off by the uC. During the period when the regulator off, the backup battery becomes the power source for the uC. After the regulator back to work, the backup cutoff automatically and start to charge.

With decision the use of the amplifier and the regulator, the next step is finding appropriate chips for the design. The chip option is INA125 from TI for the amplifier. And LM2575 [4] from TI is using for the regulator. INA125 is an instrument amplifier which provides a pseudo-ground connection. The gain of this amplifier is from 4 to 10000. However, the test shows this chip misbehave for the system. The other chip option is lm6032 what is a dual operational amplifier. With lmc6032, a two stages amplifier circuit could be built and meet the requirement of gain. Meanwhile, the sensor gives the maximum voltage value what is up to 90 mV. The amplifying signal needs to smaller than the operating voltage of uC or be cut off to protect the uC. With the chips picked, the schematic shows as below.



Amplifier Schematic



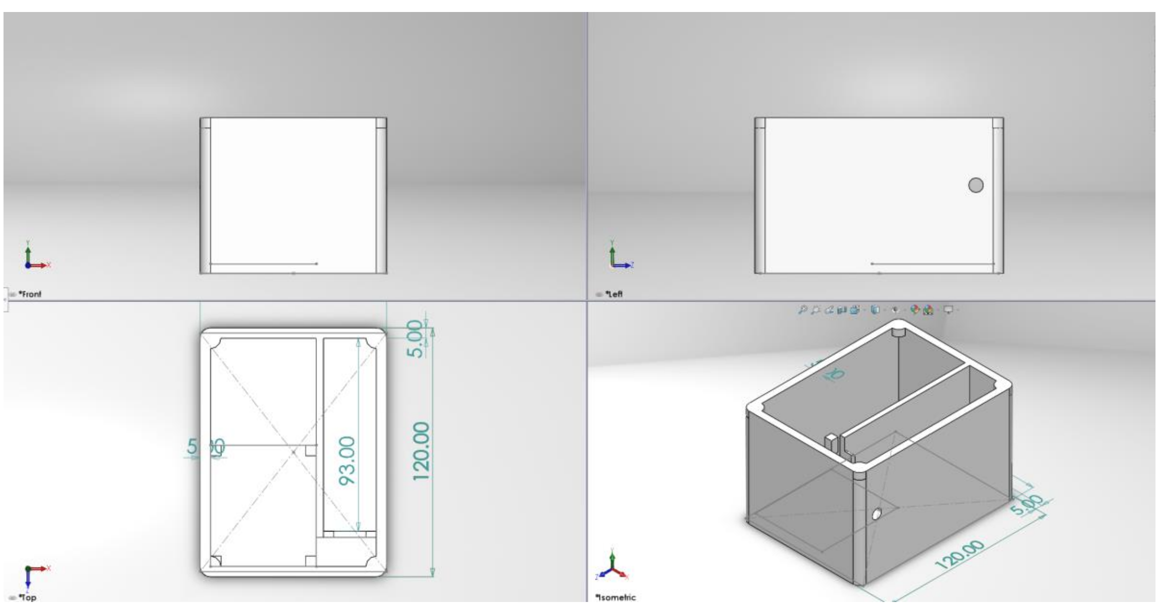
Regulator Schematic

According to the schematic, the PCB design could be completed. The first thing when trying to finish the design is to set the header for nC so that the uC could be stackable on the PCB. Another header is needed for the sensor. All the components are placed according to their function. In this PCB design, the uC is on the right of the PCB. The top left area is the regulator. The bottom left is the amplifier. Below the amplifier is the sensor header. The PCB design is a double layers board. Therefore, the bottom layer is full of copper and connected to the GND net. The first benefit is reducing the noise from outside. The second is easy to connect to the ground when placing the wire. The dimension of the whole design comes out is 58.24 * 50.8 mm. The small size PCB makes it possible to design a small size enclosure. In the end, the module could be portable.

Name	Properties
otsd_pcb_dcpwr	**Inominal:** 200 mA **Ipeak:** 1 A **Vmax:** 15 V **Vmin:** 9V **Vnominal:** 12 V
pcb_fthr_m0_wf_asig	**Other:** response time: 100 ms **Vmax:** 3.3V **Vrange:** 1.3 - 2.6V
pcb_flw_mtr_dcpwr	**Inominal:** 17 mA +- 3mA **Ipeak:** 30 mA **Vmax:** 5.6 V **Vmin:** 3 V

The validation of the PCB block is doing by inspection. The functions of the PCB are stackable with the microcontroller, fit the enclosure. Besides, the PCB has the requirement circuits on that which are amplifier circuit and voltage regulator circuit. The stackable is showing by applicating a feather board to the connector on the PCB. The PCB and the feather board could stack together with the female and male header. The size requirement is showing by putting the PCB in the enclosure. Both of these two functions mentioned above are testing directly. The performance of the circuits needs to be tested with some equipment in a lab. By giving the 12V DC power, the regulator should give 5 V output. With the value between 15 mV to 65 mV, the amplifier should make the signal significant and readable by the microcontroller.

Block 3: Enclosure



The enclosure is an essential part of a complete engineer product. With knowing all the components used in the module, the enclosure design should be able to contain and protect the parts inside. Depends on modules, enclosures could have special features. In the flowmeter module, the enclosure should be waterproof for the flowmeter have to expose to liquid flows. The design goal is clear for enclosure design. First, the components need to put inside the enclosure are the main battery holder, a backup battery, PCB board, flowmeter sensor, wires, and tubes. The general design could start with knowing the general dimension. Considering the portable ability of the module, the size of the enclosure should be as small as possible. The enclosure needs to be highly hermetic to meet the waterproof requirement. Therefore, the enclosure needs a cover to create a closed environment for inside components.

The outside shape of the actual enclosure design is a cuboid which consists of a container and a cover. The container has two cells in it. One cell is using for putting the battery holder. Though a small room, the first cell connects with the other cell what is using for placing the PCB board and sensor. At the two sides of the sensor, there are two holes on the two sides walls so that the liquid tubes could go through the enclosure. The PCB platform is higher than the bottom of the enclosure. There is a room under the PCB so that the power cable could go under the PCB. In this way, the components arrangement is clean and tidy with the wires hidden. Due to the small size of the PCB, there is still a big room aside from the PCB where could be used for adjustment in the future. The cover and container assembly together by using screws. Heat sets are using to make the screws connection strong. The applicating of the hot glue is considering enhancing the water tightness in the future.

Name	**Properties**
otsd_enclsr_other	**Other:** Waterproof **Other:** All components could be put inside **Other:** Can be opened to access interior components. **Other:** L*W*H: 120*100*78 (+-2mm)

The validation of the enclosure block is direct. The property otsd_enclsr_other is ruling the environment condition for the sensor modules. First, the enclosure is going to contains all the components inside and make them safety placed. Waterproof of the enclosure is testing by pouring a certain amount of water on the enclosure. The enclosure should protect the components inside so that the module could work as usual after water flowing. Also, the enclosure could be opened by unscrewing the cover of the enclosure. With satisfying the properties above, the enclosure should also meet the size requirement. All these properties should be verified by inspection.

Section III.

Implementation and Discussion:

The LOOM project is a typical application of the Internet of Things. It combines cloud, actuator, and sensors. In this system, the sensors used contains a salinity sensor, a pH sensor, a Hall Effect sensor, and a flowmeter sensor. These sensors communicate with a microcontroller. The sensors and microcontroller create a client and send the collected data to the server. The server shows the data to the user through the visible software or saves the data on the cloud. The wireless communication method used in this project is mainly WiFi which is a convenient and reliable way. However, the WiFi module consumes much energy. One solution to make the system save energy and increase the battery life is make some unused module sleep and wake them up when necessary. Therefore, the interrupt could be used in the design. A straightforward way is using a physical button to send an interrupt wake up the module. Another method is using other transport protocol which consumes less energy. In a small range, Bluetooth and Zigbee could be another choice.

On the other hand, the using of the cloud is an essential element. It is not enough that the device communicates with the server in a room or building. The LOOM project is aiming to let users operate the actuators and check data remotely. Next step, the LOOM project need to be able to complete tasks set by users. Meanwhile, the server should report the processing of task and generate reports when tasks completed. The LOOM project needs a cloud server which like AWS to implement those features mentioned above.

Reference

[1]. L. Columbus, “IoT Market Predicted To Double By 2021, Reaching $520B,” Forbes, 16-Aug-2018. [Online]. Available: https://www.forbes.com/sites/louiscolumbus/2018/08/16/iot-market-predicted-to-double-by-2021-reaching-520b/#19e029121f94. [Accessed: 20-Jan-2019].

[2]. IDT, “Gas and Liquid Flow Sensor Module”, FS1012 Datasheet, November 19, 2018. [Online]. Available: https://www.idt.com/document/dst/fs1012-datasheet

[3]. Texas Instruments, Precision Unity Gain DIFFERENTIAL AMPLIFIER, INA105 Datasheet, August 1993.

[4]. Texas Instruments, LM1575/LM2575/LM2575HV SIMPLE SWITCHER® 1A Step-Down Voltage Regulator Datasheet, APRIL 2013. [Online]. Available: http://www.ti.com/lit/ds/symlink/lm2575-n.pdf

Revision Table

Modified date	Modified content
Jan 19th, 2019	First version
Feb 14th, 2019	Update PCB block related
Feb 16th. 2019	Update Enclosure block related
Mar 2nd, 2019	Add more validation for blocks. Check the whole paper.