

CMPE242  
Spring 2023

1/

Jan 25th (Wed), 2023

Organizational Meeting.

1<sup>o</sup> Class Syllabus, "Greensheet". Make a good use of the O.H. But it will expire by the end of the Semester, By the end of

San José State University

the class. 3<sup>o</sup>.

Computer Engineering Department

CMPE 242 Embedded Hardware Systems, Section 1, S2023 Lab

#### Course and Contact Information

Instructor: Hua Harry Li, Ph.D.

Office Location: Engineering Building, Rm 267A

Telephone: (650) 400-1116 Text Message Only

Email: [hua.li@sjsu.edu](mailto:hua.li@sjsu.edu)

Office Hours: Mondays and Wednesdays 4:30 – 5:30 pm

Zoom link for the Office Hours

Join Zoom Meeting [https://us04web.zoom.us/j/9841607683?](https://us04web.zoom.us/j/9841607683?pwd=UIA3aEk1TnV4bjNLQk5CQkw0dDk4UT09)

pwd=UIA3aEk1TnV4bjNLQk5CQkw0dDk4UT09 Meeting ID: 984 160 7683

Passcode: 121092

Room/Facility: Rm 268.

Access Form.

Class Days/Time: Monday and Wednesday 3:00 – 4:15 pm

Classroom: Engineering Build Room 325

Prerequisites: CMPE 180A and 180D, classified standing, or instructor consent

NDA Jackson Ward

2gb

4gb

Note: 4<sup>o</sup>. Nature of the Class

Hardware : Target Platform Selection:

Broadcom

R. pic 32bit, Pic 4.

Software: 1<sup>o</sup> Kernel Source Dist. JetPack;

2<sup>o</sup> Device Development SPI,

I2C, PWM, 3<sup>o</sup> Python, C/C++

#### Course Format

#### Technology Intensive, Hybrid, and Online Courses (Required if applicable)

This course requires use of computer/laptop, special microprocessor/ARM hardware for system prototyping, Python and/or C/C++ compiler for software programming. Students must have to participate in classroom activities and after class homework and projects assignment.

#### Faculty Web Page and MYSJSU Messaging (Optional)

Copies of the course reference materials such as datasheets, project references etc. can be found on line at <https://github.com/hualili/CMPE242-Embedded-Systems-> and/or SJSU CANVAS. Office hours Zoom link (during the Pandemic): Join Zoom Meeting [https://us04web.zoom.us/j/9841607683?](https://us04web.zoom.us/j/9841607683?pwd=UIA3aEk1TnV4bjNLQk5CQkw0dDk4UT09)

pwd=UIA3aEk1TnV4bjNLQk5CQkw0dDk4UT09 Meeting ID: 984 160 7683 Passcode: 121092

#### Course Description (Required)

Advanced topics dealing with microprocessor and microcontroller hardware and firmware including processor architecture, advanced memory and I/O systems design, multilevel bus architecture, interrupt systems. Design project. Prerequisites: CMPE 180A and 180D, classified standing, or instructor consent.

5<sup>o</sup> GitHub

6<sup>o</sup>. Homework/projects submission on CANVAS.

#### Course Learning Outcomes (CLO) (Required)

[hualili / CMPE242-Embedded-Systems-](#)

#### Course Learning Objectives (CLO):

Publi

Course Description/Nature: Hands-on,  
Sound Theoretical Background, Coverage  
of Theory. Note: Sensors. LSM303

3D printer, CNC machines.



Motors

Stepper motors. NEMA 17

3phase BLDC motor.

Automobile Window Wipper Motor



Robotics.

#### Required Texts/Readings (Required)

Note: Datasheets.

##### Textbook

1. S3C6410 RISC Processor datasheets, Samsung Electronics  
[https://github.com/hualili/CMPE244/blob/main/2021F-105-%230-cpu-arm11-2018S-29-CPU\\_S3C6410X.pdf](https://github.com/hualili/CMPE244/blob/main/2021F-105-%230-cpu-arm11-2018S-29-CPU_S3C6410X.pdf) and Development Board schematics  
<https://github.com/hualili/CMPE244/blob/main/2021F-105b-%232018S-29-SCH-Tiny6410SDK-1111-PCB.pdf>
2. Nvidia Jetson NANO datasheets.
  - (a) Jetson Nano development kit document [https://github.com/hualili/CMPE244/blob/main/2021F-108-%231NVIDIA\\_Jetson\\_Nano\\_Developer\\_Kit\\_User\\_Guide.pdf](https://github.com/hualili/CMPE244/blob/main/2021F-108-%231NVIDIA_Jetson_Nano_Developer_Kit_User_Guide.pdf)
  - (b) Jetson NANO System-on-Module  
[https://github.com/hualili/CMPE244/blob/main/2021F-108b-%23JetsonNano\\_DataSheet.pdf](https://github.com/hualili/CMPE244/blob/main/2021F-108b-%23JetsonNano_DataSheet.pdf)
  - (c) Optional (not used) SoC Park CPU reference [https://github.com/hualili/CMPE244/blob/main/2021F-106-tx2-%23Parker\\_TRM\\_DP07821001p.pdf](https://github.com/hualili/CMPE244/blob/main/2021F-106-tx2-%23Parker_TRM_DP07821001p.pdf)
3. Broadcom Raspberry Pi CPU datasheets, BCM2835 CPU  
<https://github.com/hualili/CMPE244/blob/main/2021F-104-%230-cpu-pie-BCM2835-ARM-Peripherals.pdf> and [https://github.com/hualili/CMPE244/blob/main/2021F-104d-simplifiedCPU-datasheet-%23rpi\\_DATA\\_CM\\_1p0.pdf](https://github.com/hualili/CMPE244/blob/main/2021F-104d-simplifiedCPU-datasheet-%23rpi_DATA_CM_1p0.pdf)

##### Other Readings

1. Professor Li's PPT, handout materials, lecture notes on line <https://github.com/hualili/CMPE242-Embedded-Systems->

Ref: On github, Lecture Notes.



2022S-101-notes-cmpe242-3-14.pdf

CmpE242  
Spring 2023

### Grading Information (Required)

Midterm Examination	30%
Homework and Projects	30%
Final Examination	40%

The examination grades are given based on the written answer in exams; In-Person, In-Class. grades are given based on the work submitted, prototype system programming source code. The detailed rubrics for each homework assignment is given, check online both CANVAS and <https://git> project will be given to students for each submission with multip learning. Rubrics examples for project 1 submission, for example software implementation counts 40%, report counts 20%, so the

Exams: In-Person, In-Class.

Submission To CANVAS.

Need Laptop & Prototype System in the Exam.

Alternative 1: Broadcom Raspberry Pi 3, 3B+, 4.

### Determination of Grades

Jan 29 (Monday).

1. Homework, 0 pt. Honesty pledge.  
Due this Wednesday, ON CANVAS.

Ref from the github

2022S-101-notes-cmpe242-3-14.pdf

Example: Selection of Target platform.

Build Selection Matrix Below.

#### 1. Architectural Aspects.



#### 2. User Basis / Market Share.

#### 3. OS Kernel Aspect: Linux / Unix.

#### 4. Forward Looking: $\rightarrow$ GPU $\rightarrow$

GP GPU (general Purpose)  $\rightarrow$   
AI/ML.

for Example: Jetson Nano

↓ Quad CPU: ARM.

↓ GPU (128 GPUs)

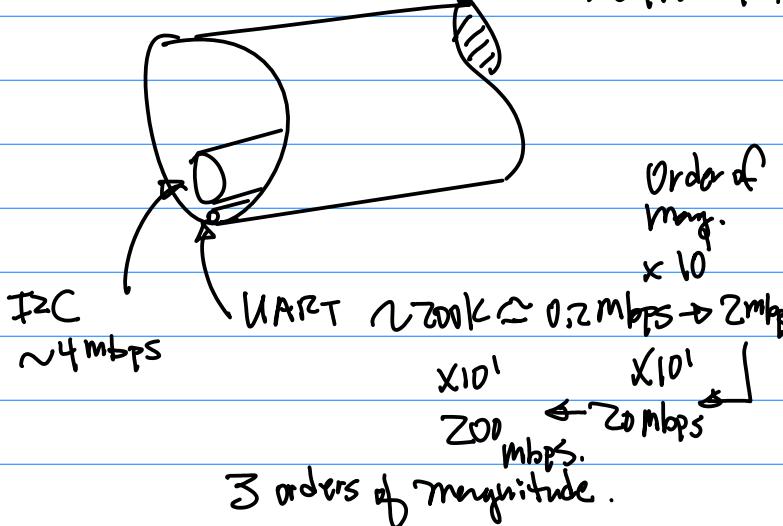
Quad ARM.

Discussion: I/O I/F for An Embedded System:

- 1° UART (Serial Communication) Tx/Rx/GND
- 2° SPI. ~10Mbps Mini Com / Putty
- 3° I2C { SDA SCK ~100Kbps Slow!
- 4° PWM
- 5° CAN
- 6° ADC

"3+1" MOSI  
MISO  
SCK  
EN

SPI Bit Rate  
 $\sim 10 \text{ Mbps}$ .



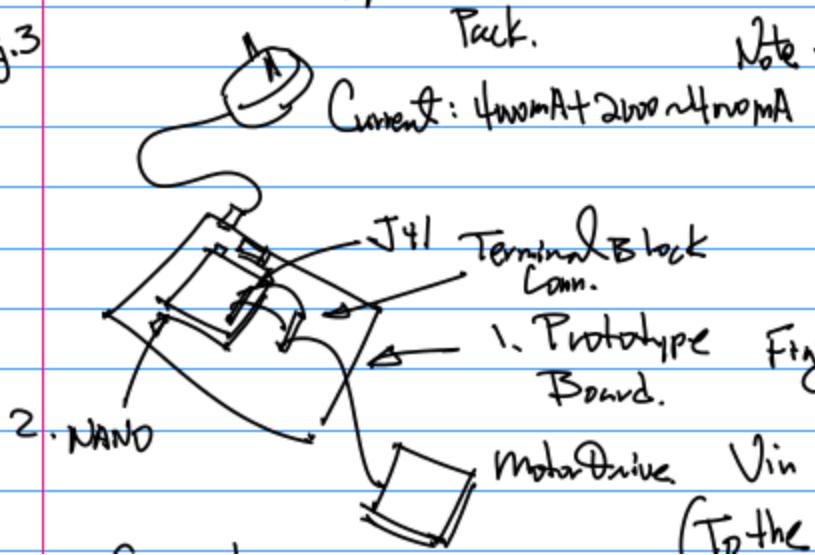
NAND, ~\$140  
4gb.

Check 2gb Towards the end  
of Life.

**Homework Preparation.**

1° Build A Prototype Board. Ref. pp.3. Fig.3

Fig.3



Note: 1° prototype Board. Dimension:

Feb 1. (Wednesday).

Note: 1. Target Board Selection

By today. Bring your

Target Together with the

Prototype Board to the Class

a week from today.

Example: To prepare the first Homework.

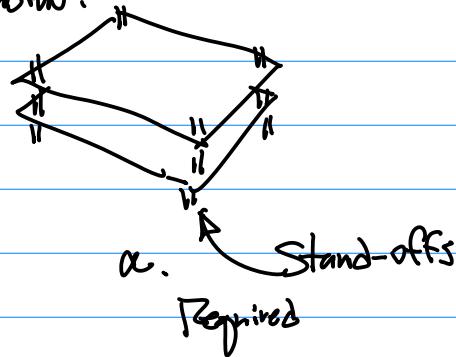
Note: 1° First Homework: "Hello, the  
World" prototype System.

Python (PyCharm IDE) program  
to flip LED. Turn ON/OFF LED.

2° Prototype Board.

Order online (Amazon) or  
Local store, Anchor Electronics  
(Santa Clara.)

Dimension:



b. Connectors Encouraged/  
Required:



10pcs Upgraded Tiny Whoop JST-PH 2.0  
Male and Female Connector Cable for  
Battery JJRC H36 H67 Blade Inductrix  
E010 E013

C. BreadBoard for Quick Prototyping.

d. Right gauge of the prototyping wires, #28 or  
higher (etc. 1 or 2 steps. Ref: 10mA)

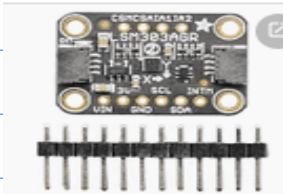
Up to 40mA

3. LED Assorted, Red, Yellow, etc.

Resistors.

Capacitors. 4.7nF (1nF to 10nF)

## 4<sup>o</sup> LSM303 (I2C, SPI)



[Adafruit Industries](#)  
[LLC 4413](#)

This board/chip uses I2C 7-bit addresses 0x19 & 0x1E

## 5<sup>o</sup> I2C Approximity Sensor.

Note: I2C Mux for Multi-I2C Devices.

## Pin Assignment Table

Pin	Description	Note
J41-1	3V3	
J41-2	5V	
J41-39	GND	
J41-12	GPIO	GPIO79 Output
J41-40	GPIO	GPIO78 Input

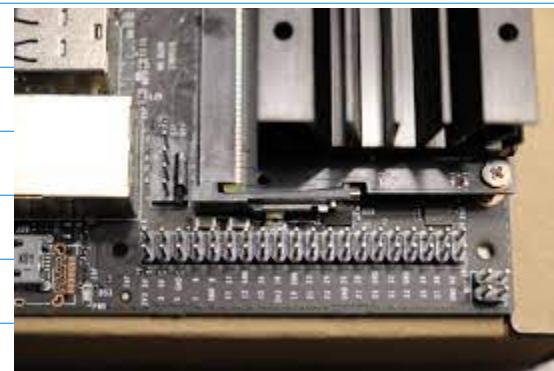
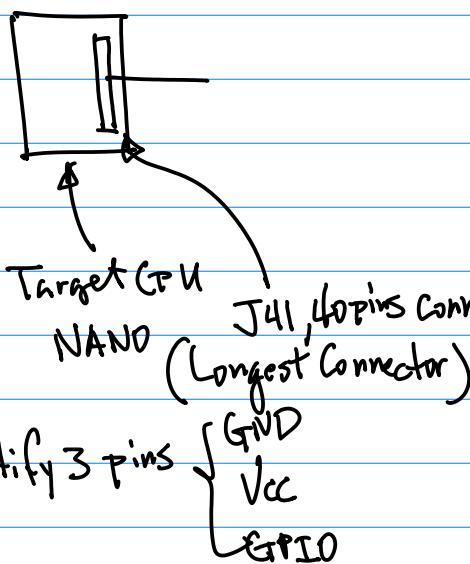


element14 Community



## Jetson Nano Dev-Board Expansion Header

Alt Function	Linux(BCM)	Board Label	Board Label	Linux(BCM)
DAP4_DOUT	78(21)	D21	40 39	GND
DAP4_DIN	77(20)	D20	38 37	D26
UART2_CTS	51(16)	D16	36 35	D19
		GND	34 33	D13
LCD_BL_PWM	168(12)	D12	32 31	D6
		GND	30 29	D5
		D1/D0_SC	28 27	DQ/D_S0
SP11_CS1	20(7)	D7	26 25	GND
SP11_CS0	19(8)	D8	24 23	D11
SP12_MISO	13(25)	D25	22 21	D9
		GND	20 19	D10
SP12_CS0	15(24)	D24	18 17	3.3V
SP12_CS1	232(23)	D23	16 15	D22
		GND	14 13	D27
DAP4_SCLK	79(18)	D18	12 11	D17
		RXD/D15	10 9	GND
		TXD/D14	8 7	D4
		GND	6 5	SCUD



<https://jetsonhacks.com/nvidia-jetson/>

NVIDIA Jetson Nano J41 F

Feb 6 (Monday).

Today's Topics: Design of

Prototype Board to Bring up the target platform (NANO).

Ref: 1<sup>o</sup> Github

[CMPE242-Embedded-Systems- / 2022S / 2022S-103-SDcard-source-distribution-tool-chain-menuconfigu-2021-10-8.pdf](#)

2<sup>o</sup> Github, Lecture Notes

[/stems- / 2022S / 2022S-101-notes-cmpe242-3-14.pdf](#)

Note: Bring your target platform to the class for inspection on Wednesday.

- a. Target platform.
- b. Work in progress.

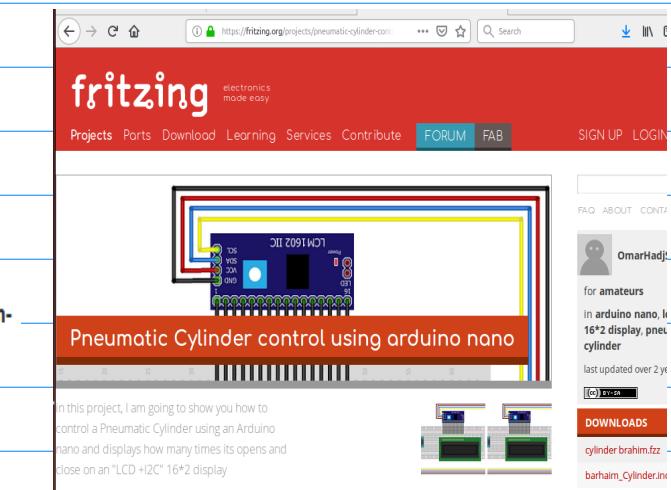
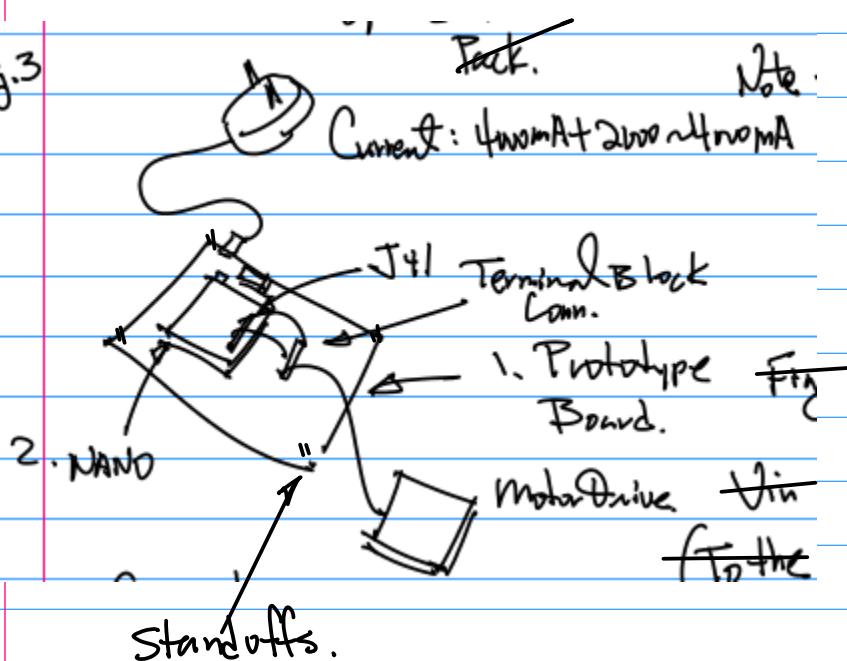


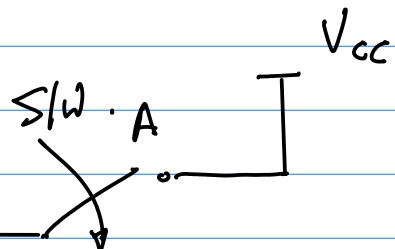
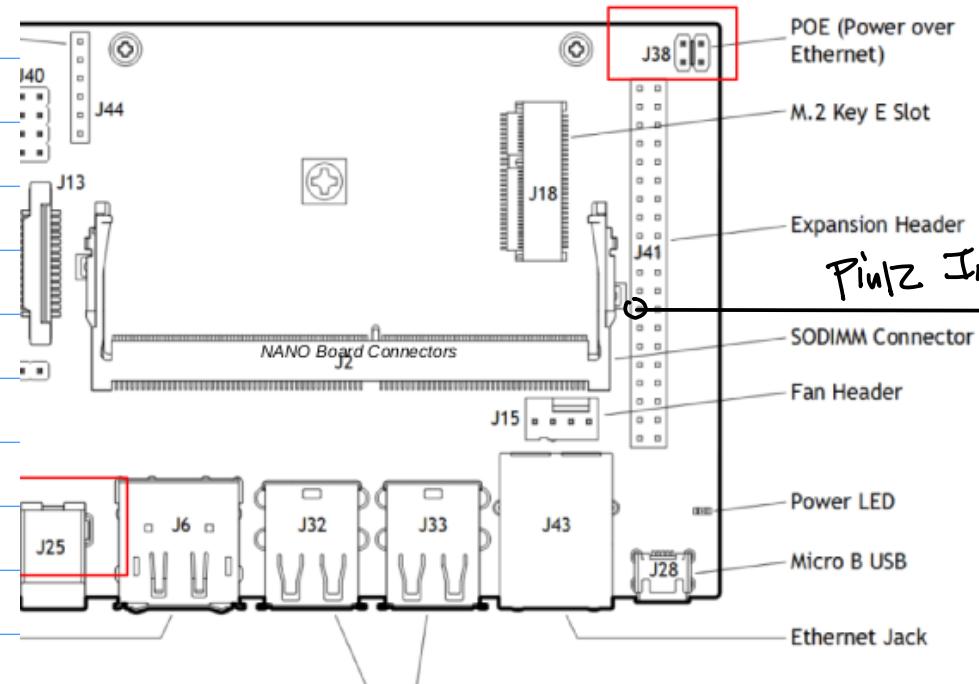
Fig.3



Example: Continuation ON GPIO I/F Design.

Design for the Input Testing.

Top View



↓ modify the Design  
to Add  $R_1$

Let  $I_1 = 10 \text{ mA}$ , find  $R_1$ .

$$V_{CC} - R_1 I_1 = V_{in}$$

where  $I_1 = 10 \text{ mA}$ ,  $V_{in} = 0 \text{ V}$ .

$$V_{CC} - R_1 \times 10 \times 10^{-3} = 0, R_1 = \frac{V_{CC}}{I_1} = \frac{3.3}{10^{-2}} = 330 \Omega$$

Next, update the Design  
to add  $R_2$  to regulate  $I_2$ .

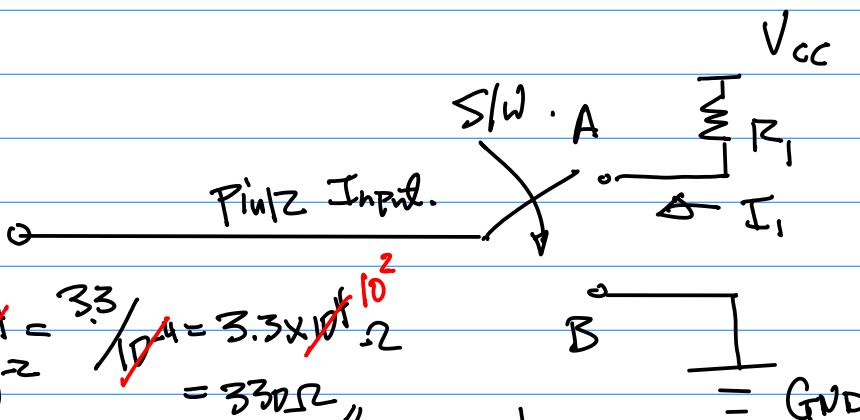
$$\text{make } I_2 = 10 \times 10^{-3} \text{ A}$$

Assume  $V_{in} = V_{CC} = 3.3 \text{ V}$ .

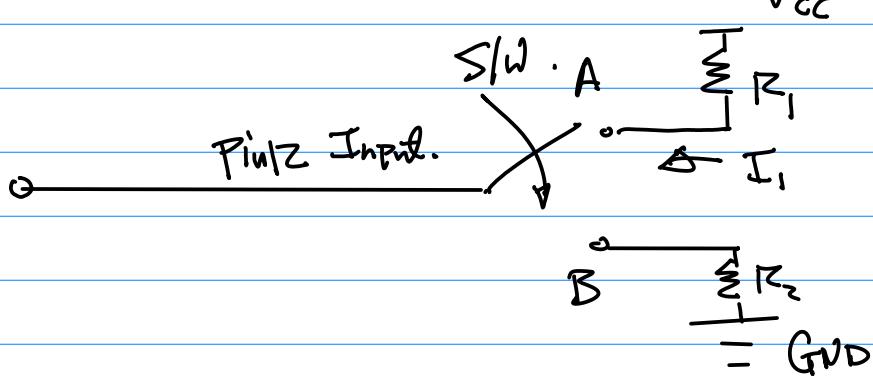
$$V_{in} - I_2 R_2 = 0, \text{ hence}$$

$$V_{CC} = I_2 R_2 \quad | \quad I_2 = 10 \times 10^{-3}$$

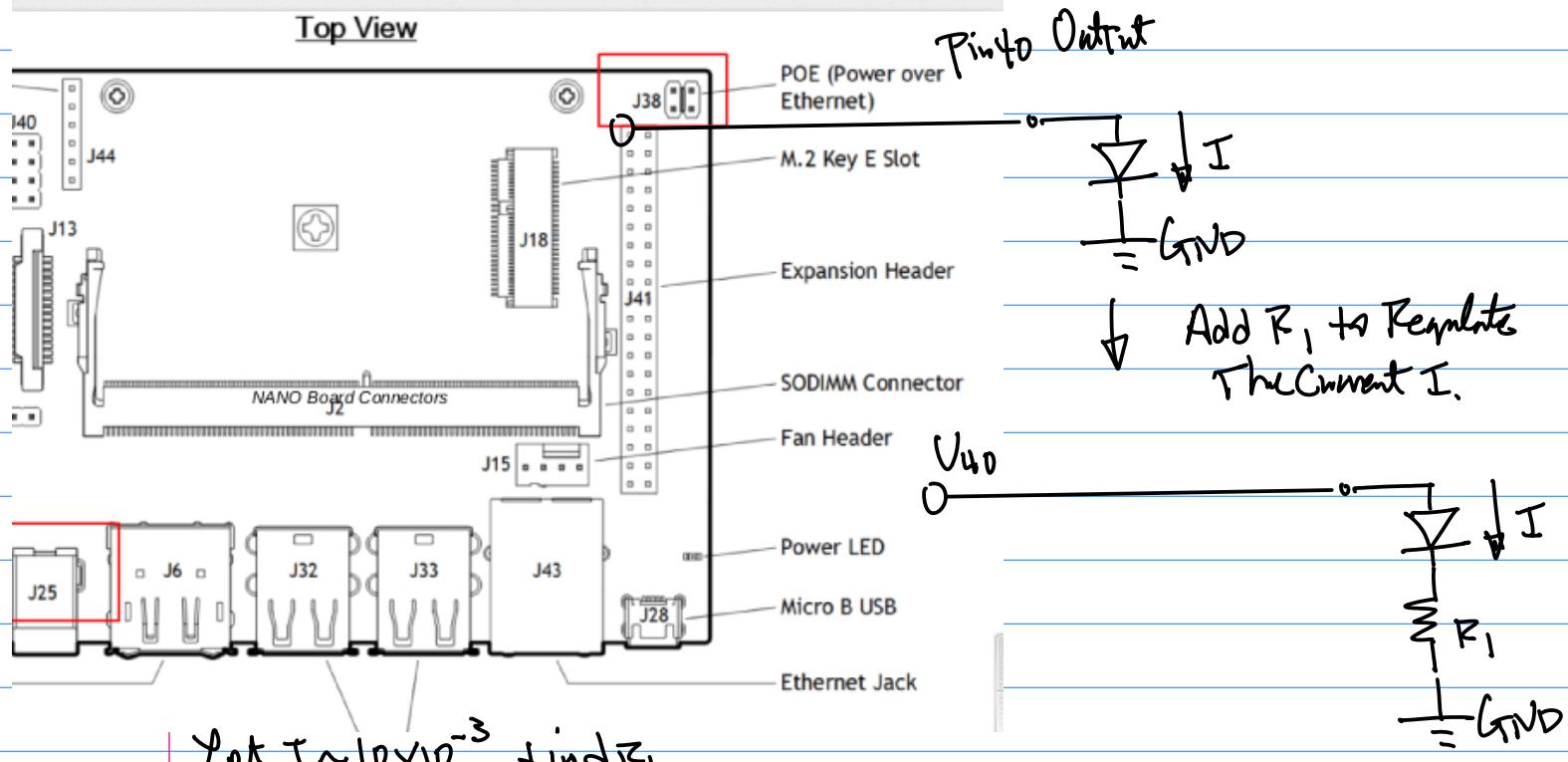
$$\therefore R_2 = \frac{V_{CC}}{I_2} = \frac{3.3}{10^{-2}} = 330 \Omega.$$



↓ modify the Design  
By adding  $R_2$



## Output Testing Circuit.



Let  $I \approx 10 \times 10^{-3}$ . find  $R_1$ .

$$V_{4D} - IR_1 = 0, \quad R_1 = V_{4D}/I \quad | \quad V_{4D} = V_{CC} = 3.3V. \quad I = 10 \times 10^{-3}$$

$$= 3.3 / 10^2 = 330\Omega.$$

[2022S-103-SDcard-source-distribution-tool-chain-menuconfigu-2021-10-8.pdf](https://www.balena.io/etcher/)

### Software Design:

#### Step 1. Prepare microSD Card, 16GB

or 32GB (for additional APP.).

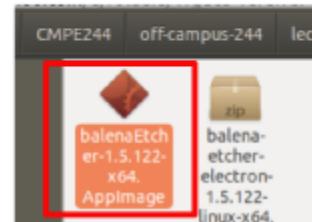
Download pre-compiled Built Kernel Image from the Nvidia Site

<https://developer.nvidia.com/embedded/learn/get-started-jetson-nano-devkit#write>

Step 2. Download the software "Etcher" to your host machine in order to write the kernel image to your Micro SD Card.

(2.1) for Linux host, Download, install, and launch Etcher.

<https://www.balena.io/etcher/>



Step 3. Take the MicroSD, insert it to your target platform.



the power up the NAND Board,  
Config the Board By Following the  
prompt.

Note: It is recommended to  
use 4 Amps Power Adaptor.

Step 4. Init & Config. for GPIO  
Driver.

Ref.

2022S-104-gpio-systemLevel-and-c-#2021F-114-gpio-nano-v3-hl-2021-10-20.pdf

TP.2. Note: a. Website, Ref. Sources.

Pi and NANO are pin to pin compatible

Jetson Nano GPIO - JetsonHacks <https://www.jetsonhacks.com...>GPIO/I2C>  
Jun 7, 2019 — As you may have heard, the GPIO pin layout on the Jetson Nano is compatible with the 40 pin layout of a Raspberry Pi (RPi).

b. Up pin Connector is Compatible  
With Raspberry Pie.

c. By Default, the Kernel Image (OS.)

Has already Configured GPIO  
Driver, So, use Command Line

to Turn On/Off LED As follows.

\$echo 79 > /sys/class/gpio/export

Connect to the GPIO  
Driver.

\$ echo out > /sys/class/gpio/gpio79/direction

Config the  
GPIO As An  
Output

\$echo 1 > /sys/class/gpio/gpio79/value

Set Output = 1

\$echo 0 > /sys/class/gpio/gpio79/value

Set Output = 0

\$echo 79 /sys/class/gpio/unexport

Release GPIO

Homework : GPIO Testing. Due A  
Week from Today.

Bring the Board to Class for Demo.

Feb 8 (Wed).

Wednesday

Homework. Due Feb 15th. (GPIO Homework)

1° Written Requirements for the Homework  
Will be posted on CANVAS.

2° Submission ON CANVAS. No E-mail  
Submission.

3° Target platform with Prototype  
Board

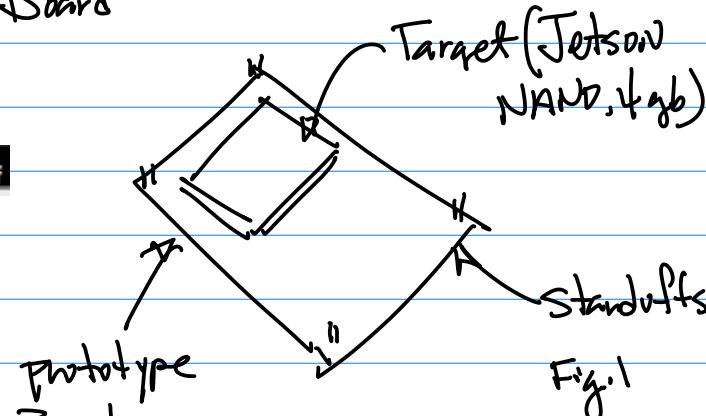
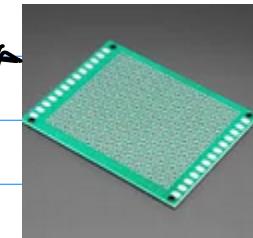


Fig.1



1°

Note: Bread Board for this Homework  
is OK, But for the Rest of the  
homework, We must use  
Prototype Board.

2° Standoffs.

3° Wire for prototyping should  
be in the Range of 28AWG ~ 32  
AWG



"Wire Wrap" Thin Prototyping &  
Wire - 200m 30AWG Blue  
PRODUCT ID: 1446

Add to Cart

\$7.50  
In stock

Fig.2

CMP-E242

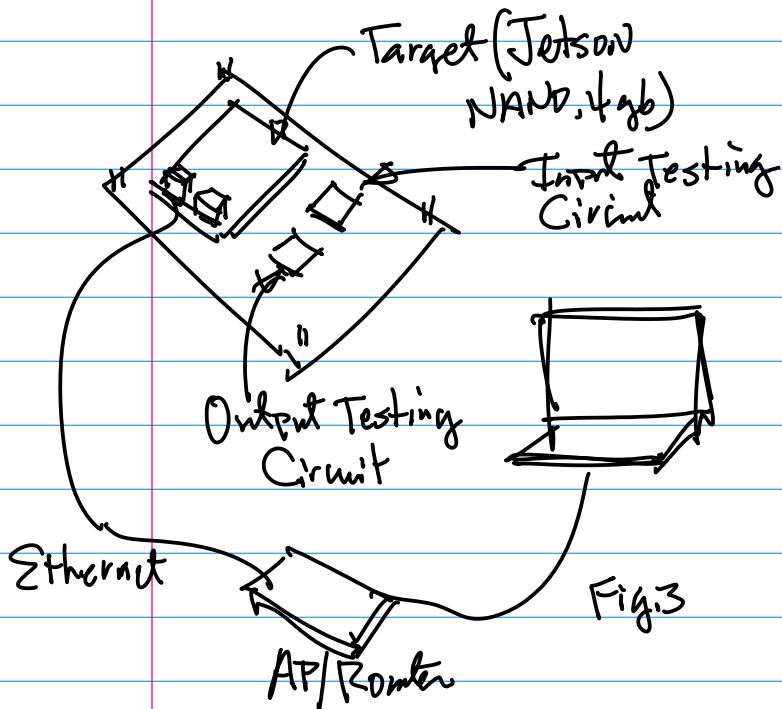
Spring 2023

(1).

4° Input/Output Testing Circuit

Has to be included,  
please take photos of

(a) Entire System.



(b) I/P, O/P circuit of  
the Board. "Closed-In"  
View.

5° Readme. file ~1 page.

6° Screen Capture of the  
Program Execution & Result.

Make sure the screen Captures  
have your personal identifier.

7° Some code Listing.

a. "Template" Name of the program:

Coded by:

Date: Release  
Version: Debug

Purpose:

Copyright:

Note:

8° Short Video Clips, Not exceeding 15~  
30 Sec.

Options. (github for the class.  
for your work.  
Video Clip(s). YouTube.

Bill of material. Needed for the  
Coming homework and lectures.

1. LSM303 Sensor

\$12.95 from  
digikay.

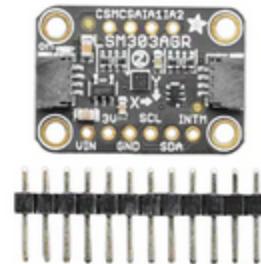
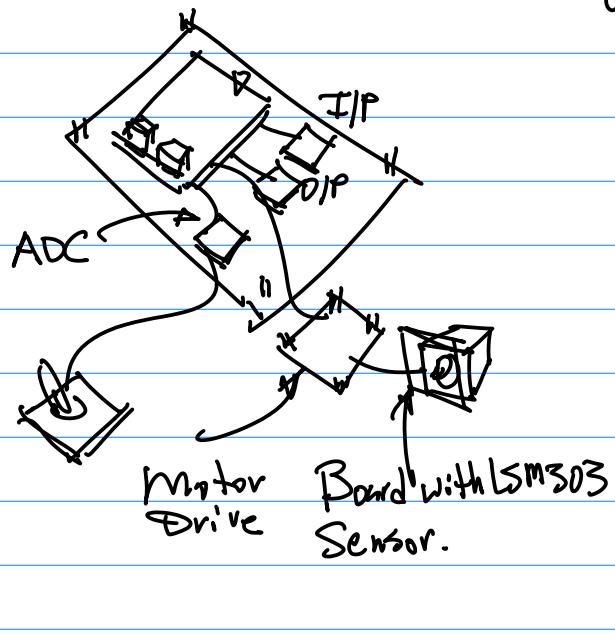


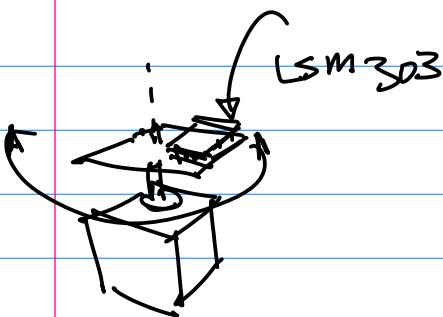
Fig.4

Fig.5



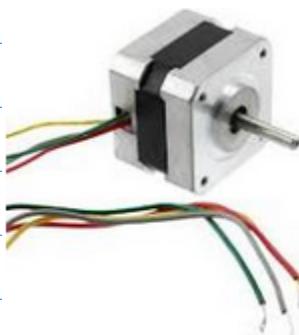
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11/



2. Motor.

Option 1. Steppermotor  
NEMA 17



[Adafruit Industries LLC](#)  
324 Bipolar Stepper  
Motor Hybrid Frame Size  
17 200 Step 350mA

\$14.00  
[Digi-Key](#)



4 Axis Nema23 Stepper  
Motor 270oz-in 76mm  
3A Dual Shaft+TB6560  
MD430 Driver CNC

\$178.00  
[Amazon.com](#)  
Free shipping

Option 2. Motor for E.V.

BLDC (Brushless D.C. motor)  
for Scooters, eBike, or \$50 ~\$200



Option 3. Motors from Automobile Industry,  
from Amazon. \$35 ~\$200



## Human Control Interface

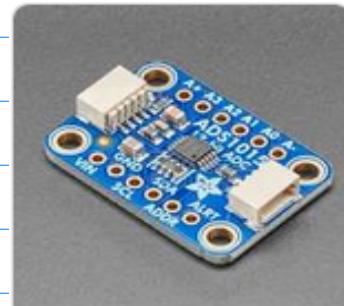
Devices: HandBar Controller for Scooters.



\$12.

[Ads · Shop ada i2c pie](#)

Datasheet



adafruit-ADS1015

12-Bit ADC - 4

\$9.95

Adafruit Industries

Python Reference  
Code is Available as well.

## Wireless Game Console Controller.



~\$199.

DualSense Edge wireless controller -

OR: Potential meter.



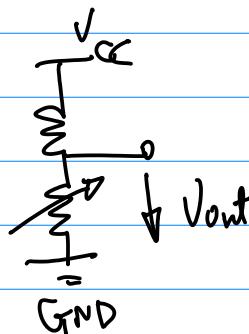
Bourns Inc.  
PDB181-

\$1.47  
Digi-Key

Feb 13 (Monday).

Note: Homework Due Feb 15 (11:59pm).  
PPA Submission on CANVAS.  
Inspection.

Example: I2C Based Sensor Interface  
LM303





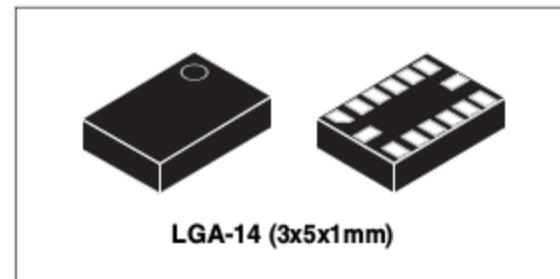
## LSM303DLHC

Ultra compact high performance e-compass  
3D accelerometer and 3D magnetometer module

Preliminary data

### Features

- 3 magnetic field channels and 3 acceleration channels
- From  $\pm 1.3$  to  $\pm 8.1$  gauss magnetic field full-scale
- $\pm 2g/\pm 4g/\pm 8g/\pm 16g$  selectable full-scale
- 16 bit data output
- I<sup>2</sup>C serial interface
- Analog supply voltage 2.16 V to 3.6 V
- Power-down mode/ low-power mode
- 2 independent programmable interrupt generators for free-fall and motion detection
- Embedded temperature sensor
- Embedded FIFO
- 6D/4D orientation detection
- ECOPACK® RoHS and "Green" compliant



### Description

The LSM303DLHC is a system-in-package featuring a 3D digital linear acceleration sensor and a 3D digital magnetic sensor.

LSM303DLHC has linear acceleration full-scales of  $\pm 2g/\pm 4g/\pm 8g/\pm 16g$  and a magnetic field full-scale of  $\pm 1.3/\pm 1.9/\pm 2.5/\pm 4.0/\pm 4.7/\pm 5.6/\pm 8.1$  gauss. All full-scales available are fully selectable by the user.

Interface Design:

Hardware Design.

Software Design.

I<sup>2</sup>C Protocol

Coding.

Command Line Based Code

Python Code.

Target Platform.

Target platform:

Jetson Nano. J41 Connector

has I<sup>2</sup>C pins.

2022S-108-LSM303DLHC.PDF

Ad

2022S-108b-AngularSensing-i2c-LSM303-f...

Ad

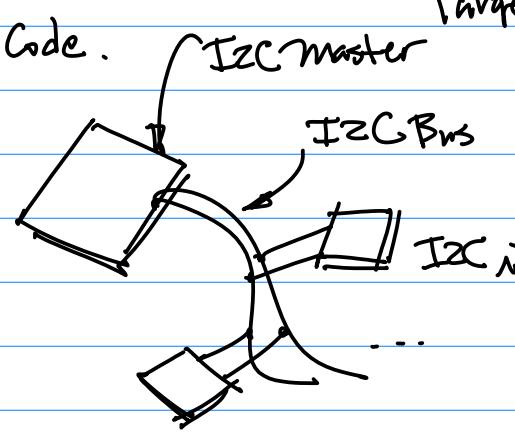


Fig. 1

Consider I<sup>2</sup>C Hardware Interface Design.

I<sup>2</sup>C { SDA : Serial Data, Bi-directional  
2n8 Mbps

SCK : Serial Clock. Output from the Master

Note: A Typical I<sub>2</sub>C "Slave Address"

takes 7 bits,  $\rightarrow 2^7 = 128$

Device Address.  $\rightarrow$  Very Often,

I<sub>2</sub>C Master Can Only Drive to  
a few Devices, Such as 4 Devices.

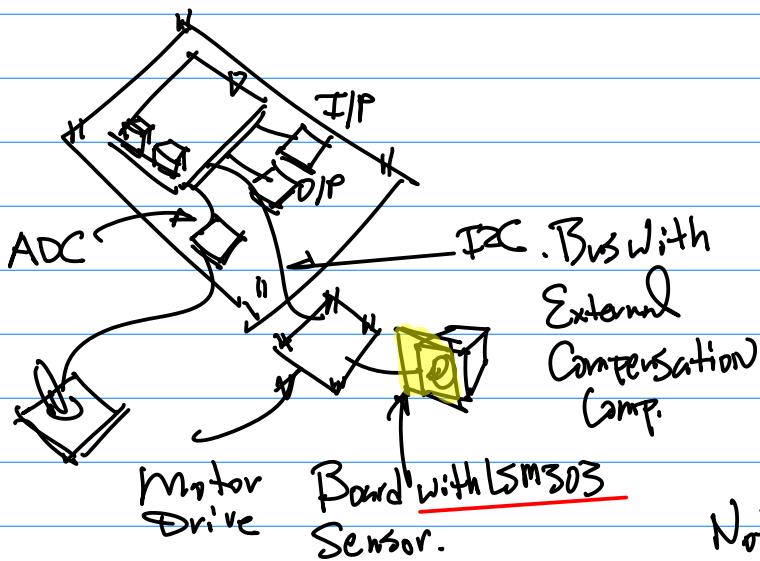
Ref:



2022S-108c-I2C-jetson-nano-2022-04-06 1... Add

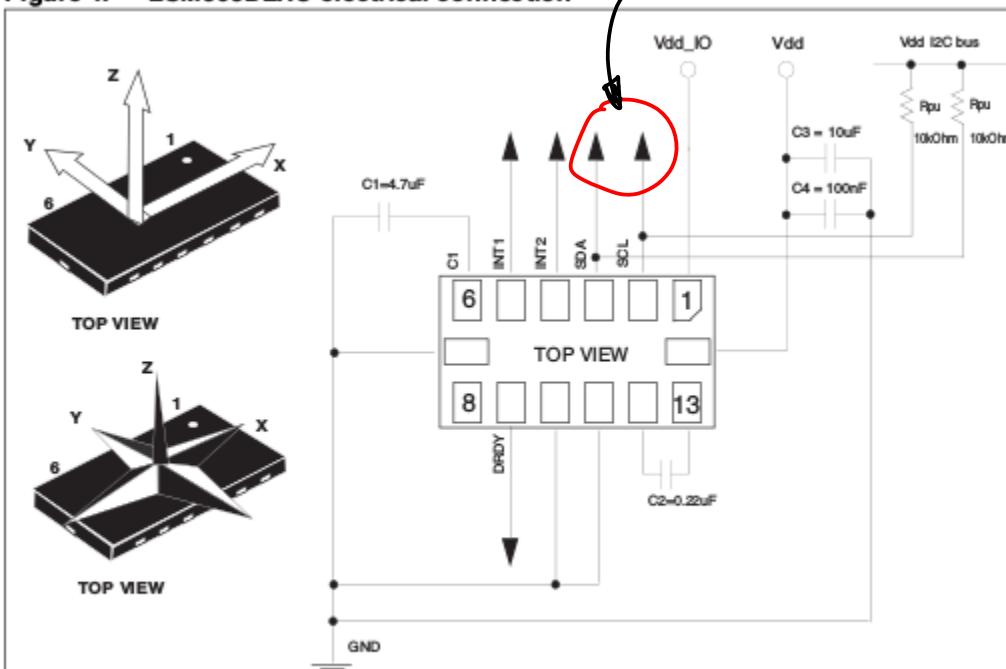
Describes the I<sub>2</sub>C Command Line  
Testing.

From Fig. 1, Build LSM303 I/F. as  
follows.



Note: 1° SDA, SCL, I<sub>2</sub>C Bus. with  
10kΩ Pull up Resistors.

Figure 4. LSM303DLHC electrical connection



2° External Caps.  
100nF (C4),  
10μF (C3)  
to form Low Pass  
filter to Remove  
"high freq." Noise.  
And C1 (4.7μF),  
C2 (0.22μF).

Note: 1° Python Code. Works for NVDA Jetson NANO.

2° Command Line Testing.

Step 1. Config. I2C

Step 2. Install I2C Tools

Step 3. Install SMBus for Python Code

From Nvidia developer forum, the reference is provided here

<https://www.instructables.com/Raspberry-Pi-I2C-Python/>

Enable i2c:

Step 1. configure i2c

`sudo usermod -a -G i2c $USER`

```
harry@harry-desktop:~$ sudo usermod -a -G i2c $USER
[sudo] password for harry:
harry@harry-desktop:~$
```

Step 2. Check if i2c tool is installed, also use this to install it if not:

`sudo apt-get install i2c-tools`

```
harry@harry-desktop:~$ sudo apt-get install i2c-tools
Reading package lists... Done
Building dependency tree
Reading state information... Done
i2c-tools is already the newest version (4.0-2).
```

Step 4. Reboot to make installed tools working, then check if any i2c is detected `i2cdetect -y 0`

```
harry@harry-desktop:~$ sudo usermod -a -G i2c $USER
[sudo] password for harry:
harry@harry-desktop:~$ i2cdetect -y 0
Warning: Can't use SMBus Quick Write command, will skip some addresses
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133440: 
133441: 
133442: 
133443: 
133444: 
133445: 
133446: 
133447: 
133448: 
133449: 
133450: 
133451: 
133452
```

Note: 1. Magnetometer.

With Reference to the North Pole. & Accelerometer X, Y, Z-Axis.

## 3D Accelerometer and 3D Magnetometer LMS303

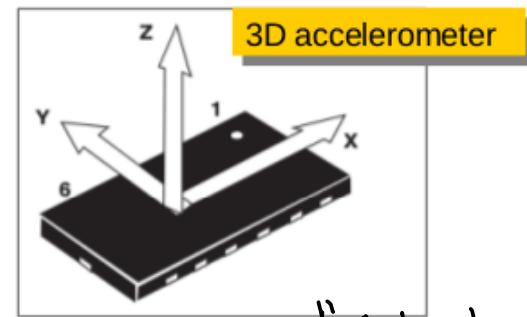
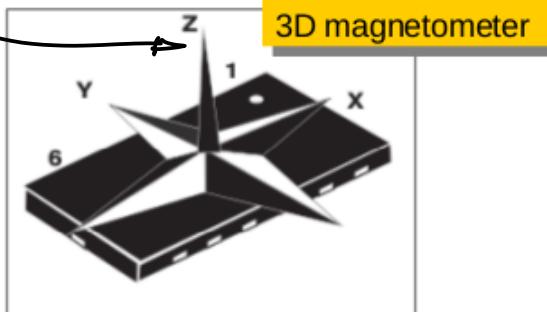


Table 9

Pin name	Pin description
SCL	I <sup>2</sup> C serial clock (SCL)
SDA	I <sup>2</sup> C serial data (SDA)

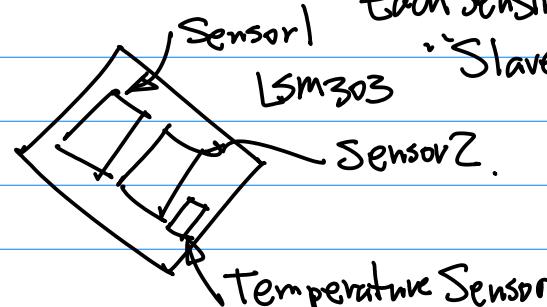
Reference: Table 9, pp 19, from  
LMS303 datasheet

### I<sup>2</sup>C Interface

- (1) The transaction started through a START (ST) signal, defined as a high-to-low on the data line while the SCL line is held high.
- (2) After ST, the next byte contains the slave address (the first 7 bit), bit 8 for if the master is receiving or transmitting data.
- (3) When an address sent, each device compares the first seven bits after ST. If they match, the device is addressed.

"Active Low"

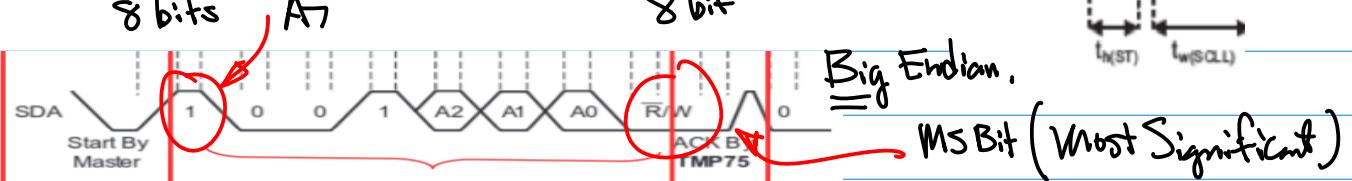
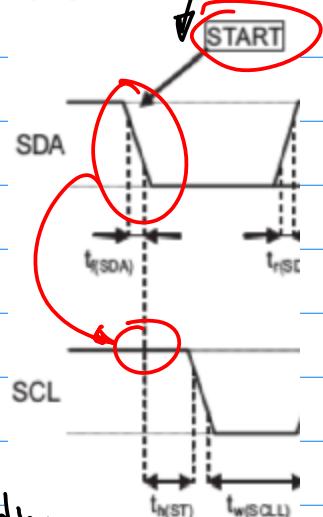
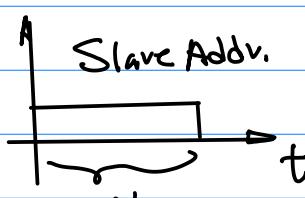
Harry Li, Ph.D. April 2015



Each Sensing Unit has its own I<sup>2</sup>C Address.

"Slave" Address.

Note: 2.



Big Endian.

MS Bit (Most Significant)

Feb 15 (Wed)

Homework:

1° Build I<sup>2</sup>C Sensor Interface to the prototype System.

Sensor LSM303 with I<sup>2</sup>C Interface.

2° Using Your target platform to Show I<sup>2</sup>C Interface is Supported, with Command line function.  
\$ icdetct.

To Demonstrate the NAND is properly configured with i2ctools installed, And sm-bus package for python programming is imported.

3° Hardware Implementation to Connect LSM303 Sensor to the NAND.

Using connectors is recommended;

4° Write A python Code to read Sensor Output:

(a. Magnetometer,  
b. acceleration.)

Print the Sensor input on the Console.

then, make your program work with gpio Code.

when gpio input = "1", Read/Print

Magnetometer Information;

When gpio = "0", Your Program will read/Print Acceleration information.

5° Submit Source code

6° Create readme(1 page) file.

7° photos.

a. Entire System Setup.

b. Closed-In View of the NAND & Sensor interface (pins/connectors visible for inspection).

c. Screen Capture(s) with personal identifier To show the program execution & Data.

8° All the files into one zip document.

(Readme, photos, Schematics make one pdf file. C/python code stand-alone is ok.)

Video Clips optional

9° Submission on CANVAS.

Example: Continuation of I<sup>2</sup>C Sensor Interface.

Background: Step1.

Hardware Design → Identify the I<sup>2</sup>C pins on NAND.  
Since I<sup>2</sup>C Sensor module is ready

I<sup>2</sup>C parts  
Ref: ZY4 github.

## I2C on Jetson Nano J41 Header

<https://www.jetsonhacks.com/nvidia-jetson-nano-j41-header-pinout/>

connected to assigned. By power) are assigned for functions are in a different device

I2C, Pin 3 and 5 can be utilized for I2C interface design.



Sysfs GPIO	Name	Pin	Pin	Name	Sysfs GPIO
	3.3 VDC Power	1	2	5.0 VDC Power	
	I2C_2_SDA I2C Bus 1	3	4	5.0 VDC Power	
	I2C_2_SCL I2C Bus 1	5		GND	
gpio216	AUDIO_MCLK	7	8	UART_2_TX /dev/ttyHS1	
	GND	9	10	UART_2_RX /dev/ttyHS2	
gpio50	UART_2_RTS	11	12	I2S_4_SCLK	gpio79

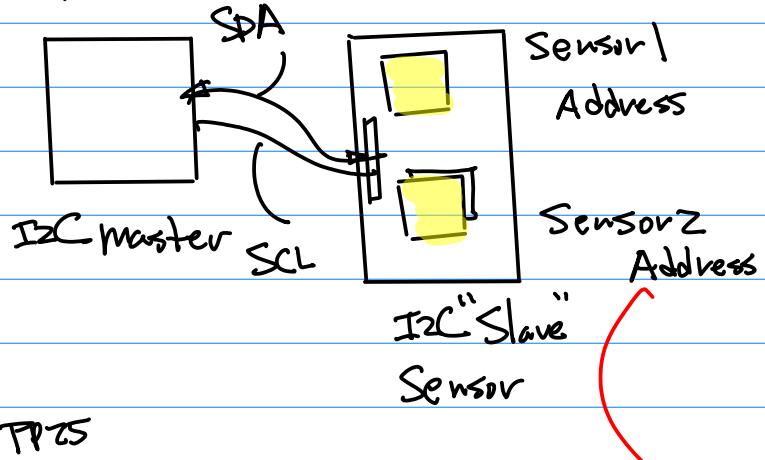
Connectivity table

J41-27	SDA
J41-28	SCL
J41-3	SDA
J41-5	SCL.

Step 2. Set up & Verify the I2C Drivers By Using Command Line, pp15.

Step 3. Design methodology.

NAND



PP25

Table 14. SAD+Read/Write patterns

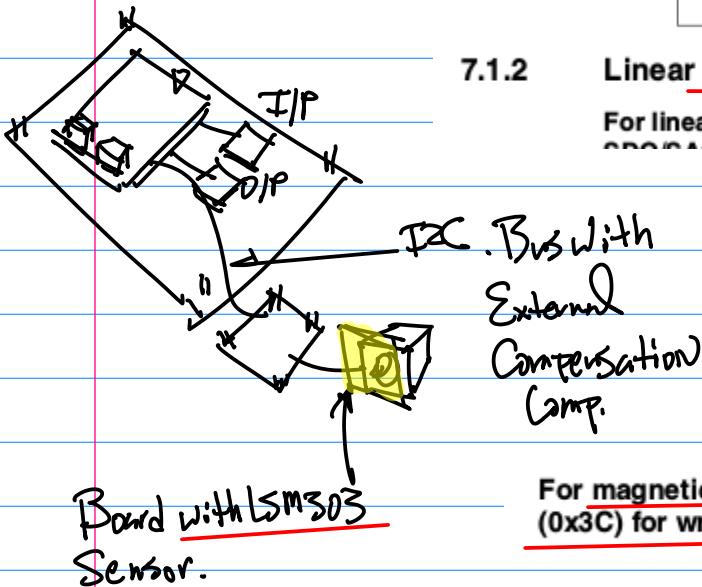
Command	SAD[6:1]	SAD[0] = SA0	R/W	SAD+R/W
Read	001100	0	1	00110001 (31h)
Write	001100	0	0	00110000 (30h)
Read	001100	1	1	00110011 (33h)
Write	001100	1	0	00110010 (32h)

### Linear acceleration digital interface

For linear acceleration, the default (factory) 7-bit slave address is 001100xb. T

For Acceleration Sensor. (sensor2)

0011 ; 00xx { 0D11 ; 0000 0x30 Write  
0011 ; 0001 0x31 Read



For magnetic sensor, the default (factory) 7-bit slave address is 0011110b (0x3C) for write operations, or 00111101b (0x3D) for read operations.

"Slave" Addr.

Sensor1	Meg.	0x3C	Write
		0x3D	Read
Sensor2	Accel	0x30	Write
		0x31	Read

for the 1st of the Dual Acceleration Sensors.

Next, for Writing the init & Configuration pattern to the Sensor unit

Note: Start

7 bits Slave Address

W: Write = "1"

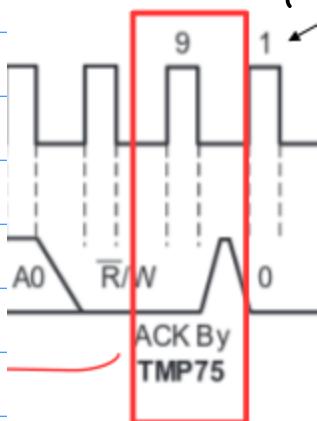
Additional Addr. for Special purpose Registers(s). Such as CONTROL Configuration Registers. Stop.

Table 11. Transfer when master is writing one byte to slave, pp 20, datasheet

Master	ST	SAD + W	SUB	DATA	SP
Slave			SAK	SAK	SAK

R: Read = "0"

Slave Acknowledgement  
hardware level, Response



The SAK slave acknowledges

## 8 Register mapping

The tables given below provide a listing of the 8-bit registers embedded in the related addresses:

Table 17. Register address map

Name	Slave address	Type	Register address		Default
			Hex	Binary	
Reserved (do not modify)			00 - 1F		
CTRL_REG1_A	TAB.13	rw	20	010 0000	00000111
CTRL_REG2_A	TAB.13	rw	21	010 0001	00000000
CTRL_REG3_A	TAB.13	rw	22	010 0010	00000000
CTRL_REG4_A	TAB.13	rw	23	010 0011	00000000

Cmpe422

Spring 2023

20

Feb 20 (Monday) :

Prepare for the Homework on

LSM303 Interface. March 1st Due.

1° Hardware Design. To build

Jetson Nano (J40, pin27, pin28)

For I2C Interface to LSM303.

2° Use Command Line Commands to

Verify the I2C Driver is

Mapped/Deployed to your Kernel  
(OS.) Image. See P.P.T. for

Additional reference.

3° Use Command Line Instructions

to perform Configuration of the

Sensor, And Read the

Sensor Output. See Class P.P.T.

for Additional Reference.

4° Use the Sample code (Python Code)

from adafruit. com. Modify the

Code to Perform Sensor init &

Config, and Read Sensor Data.

5° Readme file. (1 ~ 3 pages)

b° Source Code.

7° Photos of the System Setup.

↳ Execution of the Code.

8° Shot video clip (~15 sec.)

↳ Demo the Success of the  
implementation.

9° Integrate all files (Readme, photos)  
into one pdf Document, Zip it  
together with the Source Code,  
and Video Clip.

Submission on CANVAS.

Naming:

Cmpe422\_LSM303\_HW-

First\_LastName\_SID(4Digit).  
Zip.

Example: Continuation of I2C Sensor  
Interface.

Step 1. Identification  
of Jetson  
NANO pins.

J40-27,

J40-28

for I2C

Connect the Hardware  
Sensor.

↓  
Step 2. Verify Config Devile Driver (I2C)  
in the OS Kernel Space.

Command Line Instructions.

If Not Pre-Config'd, then we  
will Run the python code from  
Nvidia for Devile Driver  
Configuration.

Step 3. Command Line Instruction to Config the I<sub>2</sub>C Sensor, And to Read the Sensor Data.

In order to perform that task at Step 3. We Need to

Understand I<sub>2</sub>C protocol ;

I<sub>2</sub>C Sensor I/F with its Datasheet.

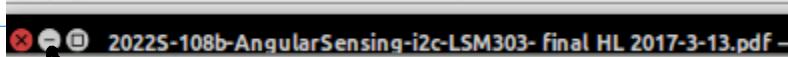
Perform Init & Config to Read Data from LSM303.

Slave Address.

(Sensor)  
(Magnet) 0x3C Write

↓  
SUB Control Register

↓  
Step 4. Put All Command Line Instructions from Step 2+3 into One Python Program.

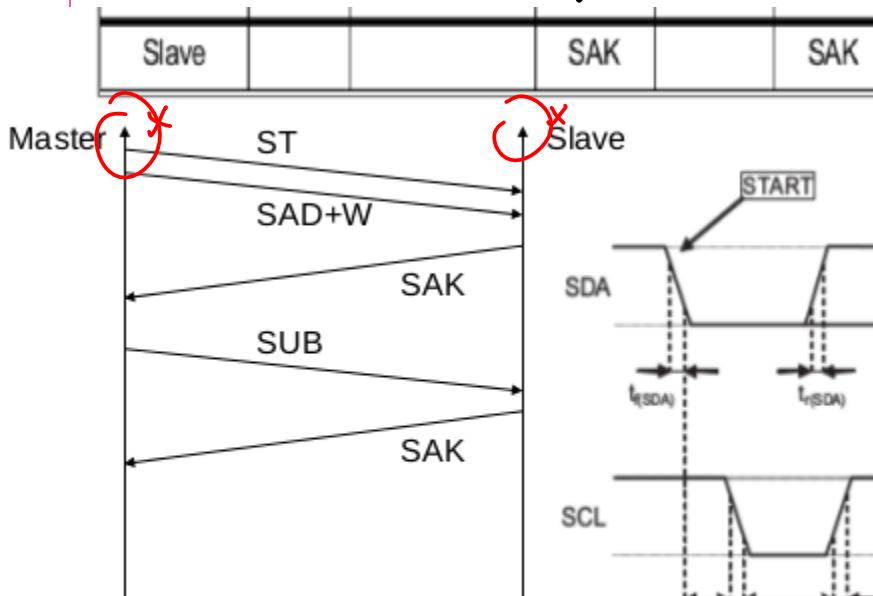


PPT. from the github

LSM303 Datasheet

2022S-108-LSM303DLHC.PDF -

Now, the Discussion on Table 11.  
Space-Time Diagram. Required.



Task: To Read Angular Info from the Mag. Sensor  
No Slower than 10 times a Second.

P.P. 3b.

## 7.2 Magnetic field sensing register description

### 7.2.1 CRA\_REG\_M (00h)

Table 70. CRA\_REG\_M register

TEMP_EN	0 <sup>(1)</sup>	0 <sup>(1)</sup>	DO2	DO1	DO0	0 <sup>(1)</sup>	0 <sup>(1)</sup>
---------	------------------	------------------	-----	-----	-----	------------------	------------------

1. This bit must be set to '0' for correct working of the device

Note: CRA\_REG\_M  
1:0 =

Control Register A for Magnetic Field

2<sup>3</sup> 8 Bit Reg.

$$\text{CRA\_REG\_M}[1:0] = 0\phi; \\ = \phi \quad \checkmark$$

Table 72. Data rate configurations

DO2	DO1	DO0	Minimum data output rate (Hz)
0	0	0	0.75
0	0	1	1.5
0	1	0	3.0
0	1	1	7.5
1	0	0	15
1	0	1	30

$$\text{CRA\_REG\_M}[4:2] = 0x4$$

then, enable the Temperature Sensing by setting

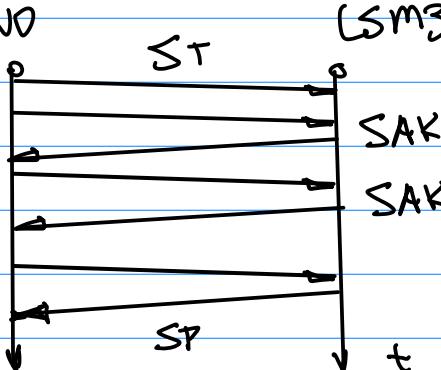
it to 1. Hence.  $\text{CRA\_REG\_M}[7:6] = 1001,0000 = 0x90$ ;

NAND (Sm303(Mag)).

SAD+W: 0x3C

SUB: 0x00

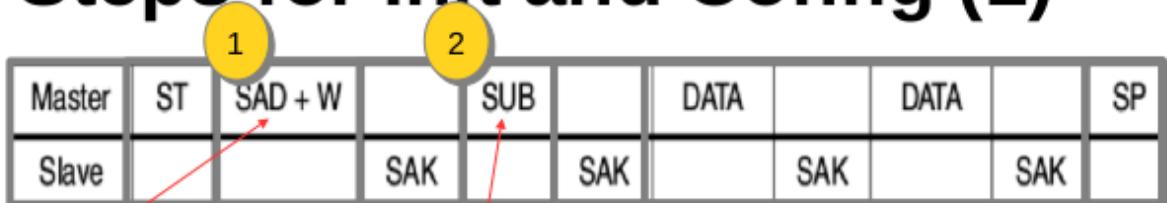
0x90



Ref. Confirms our discussion.

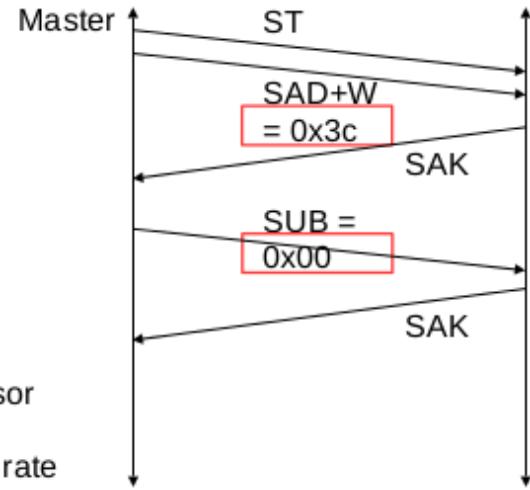
PP.7.

## Steps for Init and Config (1)

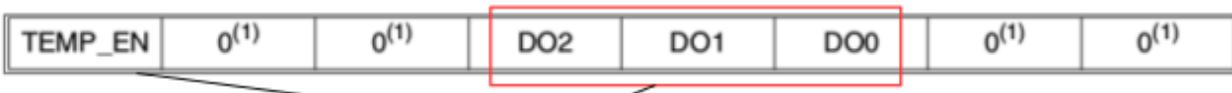


1. Perform init and config by identify the i2c device (device address, from datasheet 0x3c, pp. 21)

For magnetic sensors the default (factory) 7-bit slave address is 0011110xb. The x bit is 0 for read and 1 for write



2. identify control register(s) for the right sensor block with the sub-address to set data rate  
(1) CRA\_REG\_M register ( 0x00) to set data rate

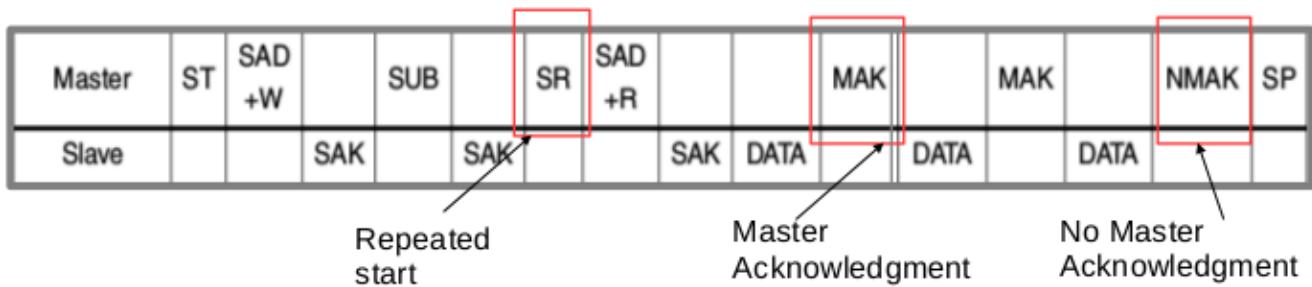


Example; 3.0 Hz data rate, so  $1\ 0\ 0\ 0\ 1\ 0\ 0\ 0$   $\rightarrow$  0x88, so write 0x88 to 0x00 location (CRA\_REG\_M)

Harry Li, Ph.D. Mar 2017

Now, Read Data. PP.10 P.P.T.

## Read the Sensor Data



Feb 22 (Wed)

Ref: from the class github/CMPE242 .

2023S-102-i2c-command-line-2023S-104-i2c-v2-jetson-nano-2023-02-8.pdf -

Example: Continuation of I2C Interface Design.

Given Tech. Spec. →  
Binary Pattern  
for Init & Config.

Coding for I2C Device Interface .

1° O.S. Kernel Related Tool  
(Driver) .

2° Python Code .

→ find if the O.S. Kernel Image  
is equipped with Device Driver ;  
if Not, then what to do to  
bring the proper driver to install ;



Use Command line instruction(s)  
to interface the i2c Device(s).



Note: Good Ref.

Python Code implementation Sources .

From Nvidia developer forum, the referen

<https://www.instructables.com/Raspberry-Pi-I2C-Python/>

Enable i2c:

Step 1. configure i2c

sudo usermod -a -G i2c \$USER

Step 2. check is i2c tool is installed, also use this to  
install it if not:

\$sudo apt-get install i2c-tools

```
harry@harry-desktop:~$ sudo apt-get install i2c-tools
Reading package lists... Done
Building dependency tree
Reading state information... Done
```

For Python Coding Purpose, install

python-smbus

Step 3. Install python smbus:

\$sudo apt-get install python-smbus

```
harry@harry-desktop:~$ sudo apt-get install python-smbus
Reading package lists... Done
Building dependency tree
Reading state information... Done
```

To Detect i2c Devices

PWM φ

Step 4. Reboot to make installed tools working, then check if any i2c is detected \$i2cdetect -y 0

```
harry@harry-desktop:~$ sudo usermod -aG i2c $USER
[sudo] password for harry:
harry@harry-desktop:~$ i2cdetect -y 0
Warning: Can't use SMBus Quick Write command, will skip some addresses
  0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          ...
10:          ...
20:          ...
30:          ...
40:          ...
50:          ...
60:          ...
70:          ...
harry@harry-desktop:~$
```

"U" Not Ready to Be used.

"U" Examined, But No I2C Device found.

Step 5. Once you are done with step 4, then you are ready to write your i2c code to interface to LSM303

```
import io
io.open ("/dev/i2c-0")
```

Pin 27 (SDA), 28 (SCL) from Billy L:



Baseline Reference

<https://learn.adafruit.com/lsm303-accelerometer-slash-compass-breakout/python-circuitpython>

**Python & CircuitPython** for LSM303 sensor with CircuitPython and the Adafruit CircuitPython LSM303 Accelerometer

[https://github.com/adafruit/Adafruit\\_CircuitPython\\_LSM303\\_Accel](https://github.com/adafruit/Adafruit_CircuitPython_LSM303_Accel)  
[Adafruit CircuitPython LIS2MDL or](https://github.com/adafruit/Adafruit_CircuitPython_LIS2MDL)

Adafruit CircuitPython LSM303DLH Magnetometer libraries

[https://github.com/adafruit/Adafruit\\_CircuitPython\\_LSM303DLH\\_Mag](https://github.com/adafruit/Adafruit_CircuitPython_LSM303DLH_Mag)  
These libraries allow you to easily write Python code that reads the accelerometer and magnetometer values from the sensor.

```

import time
import board
import adafruit_lsm303dlh_mag
i2c = board.I2C() # uses board.SCL and board.SDA
sensor = adafruit_lsm303dlh_mag.LSM303DLH_Mag(i2c)
while True:
    mag_x, mag_y, mag_z = sensor.magnetic
    print('Magnetometer (gauss): ({0:10.3f}, {1:10.3f}, {2:10.3f})'.format(mag_x, mag_y, mag_z))
    print('')
    time.sleep(1.0)

```

Using command Line instruction  
for debugging.

## 2. \$i2cget #for reading/writing testing

```

harry@harry-desktop:~$ i2cget
Usage: i2cget [-f] [-y] I2CBUS CHIP-ADDRESS [DATA-ADDRESS [MODE]]
I2CBUS is an integer or an I2C bus name
ADDRESS is an integer (0x03 - 0x77)
MODE is one of:
  b (read byte data, default)
  w (read word data)
  c (write byte/read byte)
  Append p for SMBus PEC
harry@harry-desktop:~$ 

```

```

nvidia@nvidia-desktop:/sys/class/i2c-dev$ i2cset 0 0x19 0x20
WARNING! This program can confuse your I2C bus, cause data lo
I will write to device file /dev/i2c-0, chip address 0x19, d
0x20, data 0x7f, mode byte.
Continue? [Y/n] y
nvidia@nvidia-desktop:/sys/class/i2c-dev$ i2cget -y 0 0x19 0x
0xd7
nvidia@nvidia-desktop:/sys/class/i2c-dev$ i2cget -v 0 0x19 0x

```

Note: I2c Operation, pp.19

Table 13. Transfer when master is receiving (reading) one byte of data from slave:

Master	ST	SAD + W		SUB		SR	SAD + R		NACK	SP
Slave			SAK		SAK			SAK	DATA	

① Data are transmitted in byte format (DATA). Each data transfer contains 8 bits. The number of bytes transferred per transfer is unlimited. Data is transferred with the most significant bit (MSB) first. If a receiver can't receive another complete byte of data until it has performed some other function, it can hold the clock line SCL LOW to force the transmitter into a wait state. Data transfer only continues when the receiver is ready for another byte and releases the data line. If a slave receiver doesn't acknowledge the slave address (i.e. it is not able to receive because it is performing some real-time function) the data line must be left HIGH by the slave. The master can then abort the transfer. A LOW to HIGH transition on the SDA line while the SCL line is HIGH is defined as a STOP condition. Each data transfer must be terminated by the generation of a STOP (SP) condition.

Feb 27 (Monday)

Note: 1° Homework on I2C LSM303 Sensor Interface.

Consider Motor Activation Design & Implementation

Stepper motor

BLDC (Phase A, B, and C)

Ref: Definitions/Introduction of Stepper Motor and Stepper Motor Drive

2022S-105b-StepperMotor-Control-part1-2018-2-13.pdf

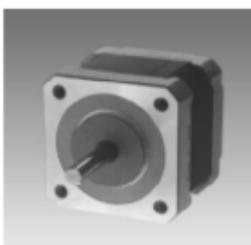
2° Motor Drive (Professional Grade) Example.

2022S-105b-StepperMotor-Control-part1-2018-2-13.pdf

3° Human Hand Control with P.D.T. for Debugging

2022S-105c-motor-drive-manual-updated-hl-2022-2-23.pdf

Example: Characterization of A Stepper Motor. T.P.Z.



Stepper Motors

Note 2: The 4-wires of the motor are not directly connected to the CPU of the target platform.

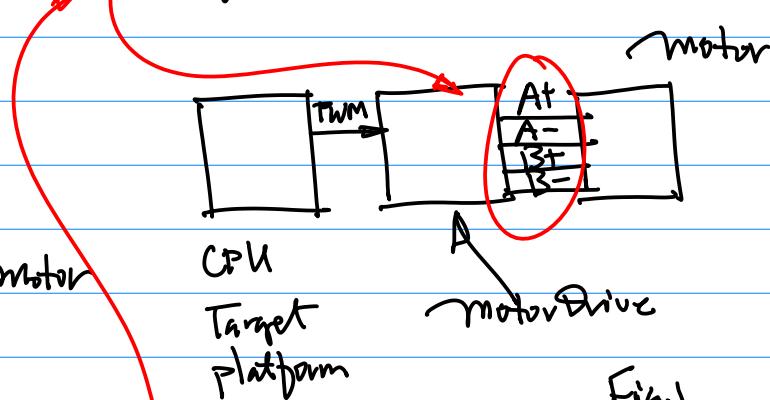


Fig.1.

3° Behavior of A Stepper Motor

a. Full Step Activation of A motor.

200 Steps for 360° Revolution.  
1 Full Step (FS)  $\rightarrow$  1.8 Degree Angular Displacement.

Note: PWM of A Target platform.

Note 1°: 4-wires { A+, A-  
B+, B- }

## Standard Stepper Motor



Note:

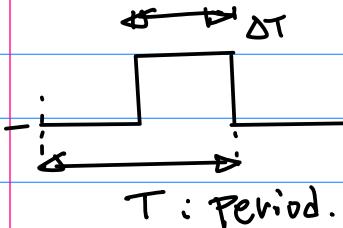
- One revolution (360 degree) = 200 steps;
- 1.8 degree per step;
- Four wire stepper motor can provide

A full step:	1.8 degree;
A half step:	1.8/2 degree;
A quarter step:	1.8/4 degree;
One eighth step:	1.8/8 degree.

- Stepper drive circuit provide 4 wires output to connect to the 4-wire (A1, A2, B1, B2) stepper motor, by modulation of the base band signal of each wire, the above step size can be achieved.

Witbot NEMA17  
Stepper Motor ...  
\$9.59  
Amazon.com

PWM: Pulse width Modulation.



$$\eta = \text{Duty Cycle} = \frac{\Delta T}{T} \dots (1)$$

The control of  $f_{\text{PWM}}$ , and Duty cycle  $\eta$  are done by Coding of the Special purpose Registers.

$f_{\text{PWM}}$ : Common Range 500 Hz ~ 1 kHz.

b. Half Step (HS)

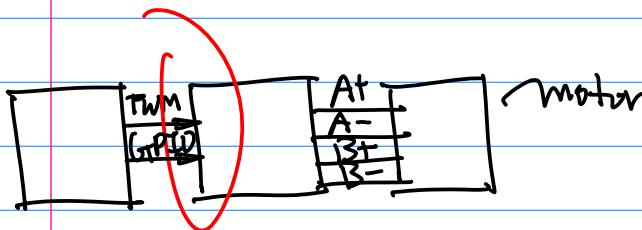
Angular Displacement

0.9 Degree/Step

c. Quarter Step (QS): 0.45 Degree/step

d. 1/8 Step: 0.225 Degree/step.

Consider the inputs to A Stepper motor Drive.



CPU  
Target  
platform

A  
motordrive

Fig. 2.

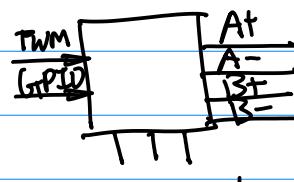
CPU	DriveBoard	Note
PWM (Output)	Input	Controls the speed.
GPID (Output)	Input	Direction (C.W. or C.C.W.)

Note: pins / Connectors Information  
To Be Added to Complete this table.

Suppose we would like to have 5 Different Step Options for the DriveBoard, Since

$2^3 = 8$ ,  $2^2 = 4$ . Hence, we will

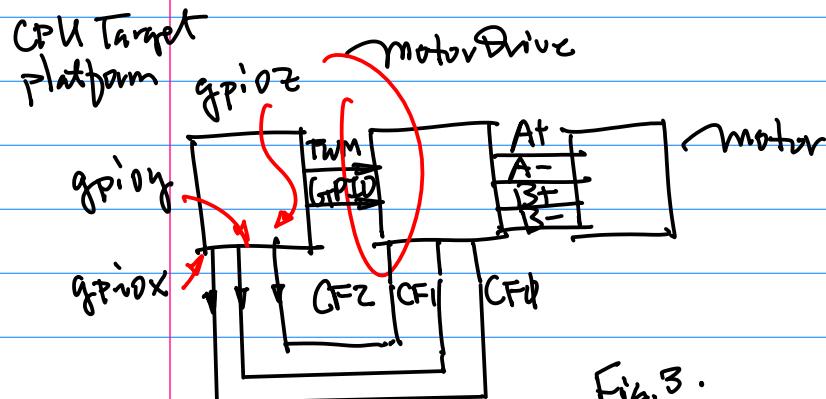
Need 3 pins added to the Driver Board.



Configuration Pins

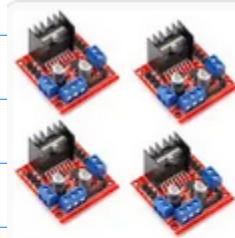
CF2	CF1	CF0	
0	0	0	F.S.
0	0	1	H.S.
0	1	0	1/4 Step
0	1	1	1/8 Step
⋮	⋮	⋮	⋮

Use 3 Additional GPIO pins for the upgrade of Step Configuration.



Note: It is OK to use L298N

As Entry  
Level Drive  
Board



4 PACK  
L298N Motor  
\$11.59  
Amazon.com

March 1st (Wed)

Note! Homework is coming for  
Design & Implement Stepper  
motor Control with PWM.

Next Level Higher, Recommended

2<sup>o</sup> Bring your LSM303  
Homework to the class for  
Inspection & Demo.

Motor Drive Board.

1<sup>o</sup> Speed of the Activation,  
f<sub>PWM</sub> from the target Board.



Microstepping  
Stepper Drive:

2.2A per phase,  
2-phase output,  
12-24 VDC, 400 to  
12800 steps ...

\$27.50  
AutomationDirect...  
Get it by 3/6



10Pcs A4988  
StepStick ...  
\$14.29  
Amazon.com



HiLetgo 2pcs  
A3967  
\$13.49  
Amazon.com

Current ~1000mA to 1500mA.  
Speed  $\leq f_{PWM} \approx 1\text{ kHz}$ .

Not Recommended.

Now, Discussion On P.I.D. Controller  
Design.

Proportional Integral Derivative

Ref.

2022S-107a-PID-v5-2019-4-25.pdf

Example: Robotics (Cart) Application.

Task: To Drive the Robot

from Point A to Point B.

 $\vec{P}_A(x_A, y_A), \vec{P}_B(x_B, y_B)$ .

y

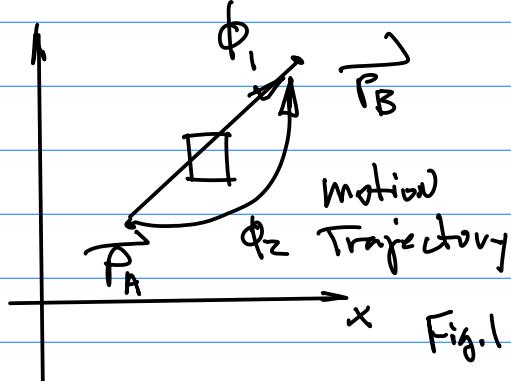


Fig.1

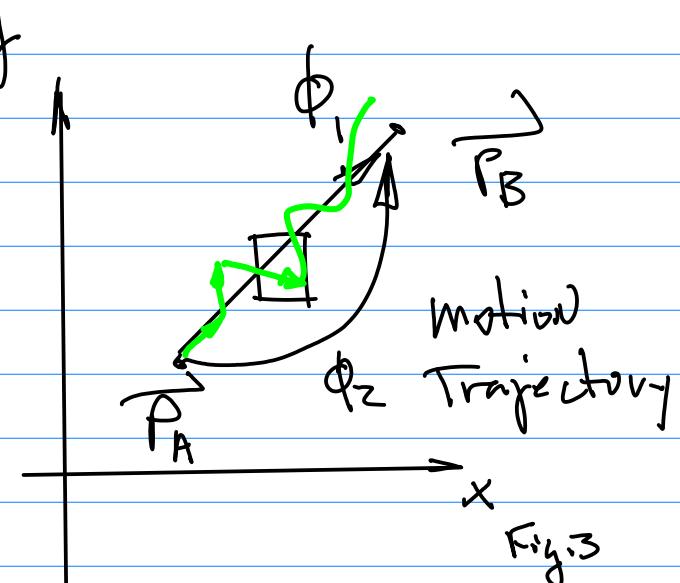


Fig.3

motorized

 $\phi_1, \phi_2$  are the trajectories from Existing Technology, Such as D.L.

(Deep Learning), D.R.L (Deep Reinforcement Learning)

Input: ① PWM + ② GPIO

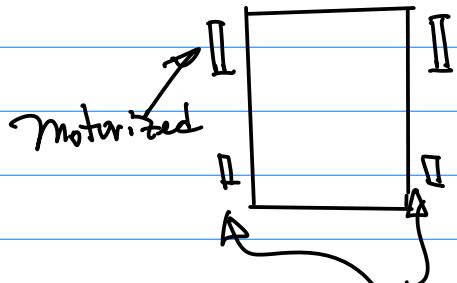
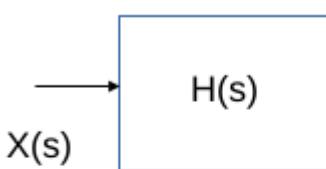


Fig.4

Angular Displacement

A diagram showing the relationship between angular displacement and actual displacement. A green arrow labeled "Actual Displacement" points along a circular arc, while a blue arrow labeled "Angular Displacement" points along the radius.

Fig.5



$Y(s) \rightarrow$  Output Displacement; Angular Displacement

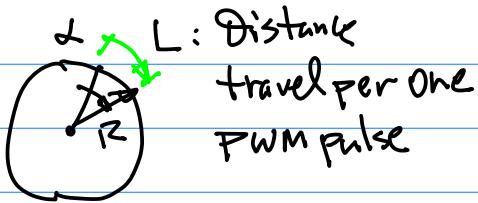
$f_{PWM} \rightarrow$  Displacement

Start with open loop, where plant  $H(s)$  can be a stepper motor for example, so we have

$$Y(s) = H(s) X(s) \dots \quad (1)$$

Fig.2

$f_{PWM} \rightarrow$  Configuration of the motor  $\rightarrow$  Physical Dimension Drive, F.S. H.S.  $\frac{1}{4}S$  etc.



$\alpha$  if Full Step:

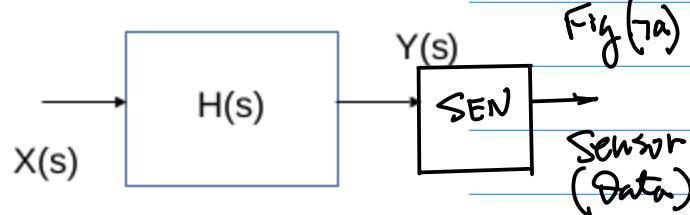
$$\frac{360^\circ}{2\pi} \text{ for one pulse}$$

from a PWM.

Based on this, we can find travel distance of the wheel, physical displacement

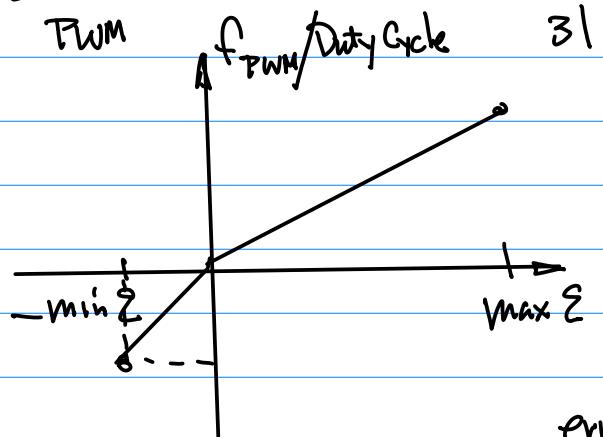
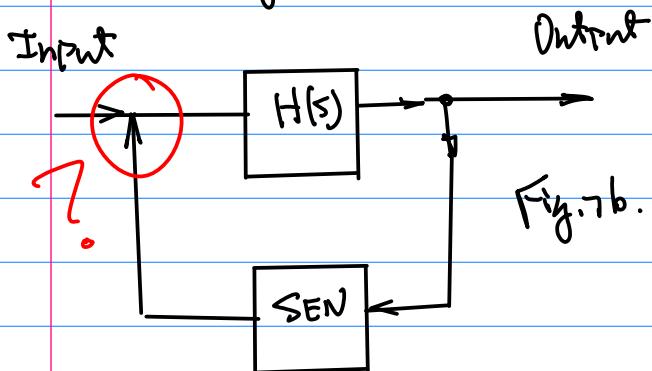
Add Sensors to measure the System Performance.

### Open Loop System



With Sensor Data, we can measure the performance of the "Open Loop" System.

Use the sensor data to Control/Adjust the input with the objective of minimizing the error.



Assume Duty Cycle 0% ~ 95%

$$f_{PWM} = 500 \text{ Hz.}$$

GPIO controls Direction.

Fig. 8

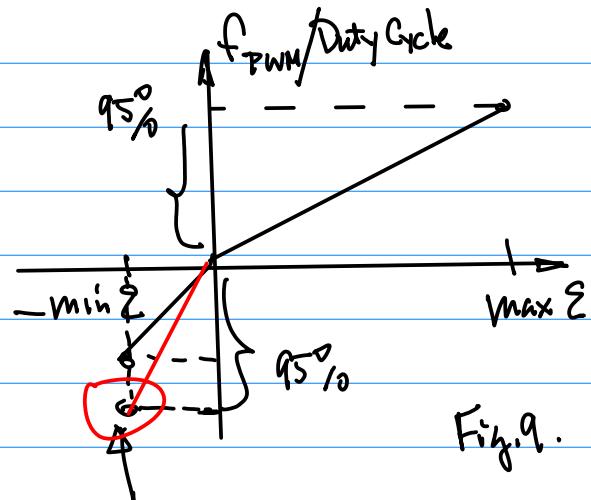


Fig. 9.

March 6 (Monday).

Note: 1° Homework, Due A week from the Wednesday (15th).

Brief Description of the Homework; use PWM to control the motor of your choice, Motor Can be a stepper motor, or other type of motor.

Example: Design methodology for P.I.D. Close Loop Control

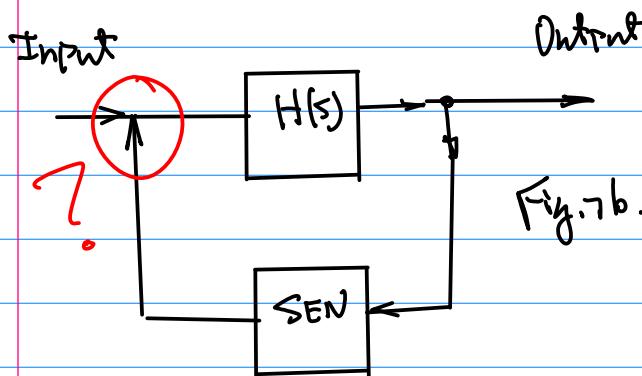


Fig. 7b. PP31.

2<sup>o</sup> Based on the feedback loop, we would like to correct the error(s) by control action(s).

Find  $f_p(e)$  and  $f_n(e)$  by using the following technique.

$$\frac{y_2 - y_1}{x_2 - x_1} = \frac{y - y_1}{x - x_1} \dots (1)$$

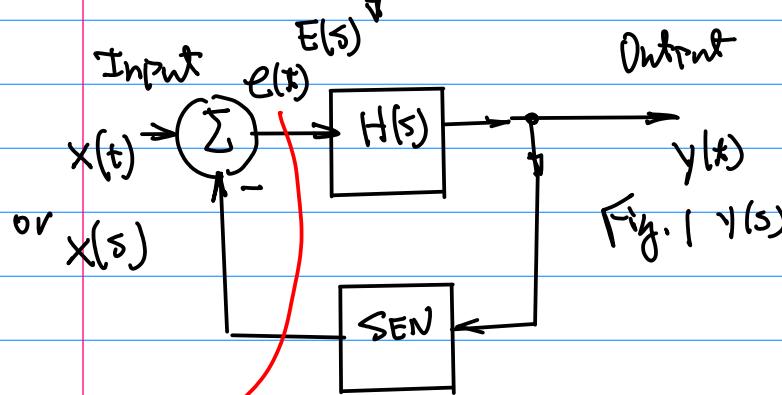


Fig. 1 y(s)

$(x_1, y_1), (x_2, y_2)$  are the pairs of the line.

Note: Take this formulation.

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1} (x - x_1) \dots (2)$$

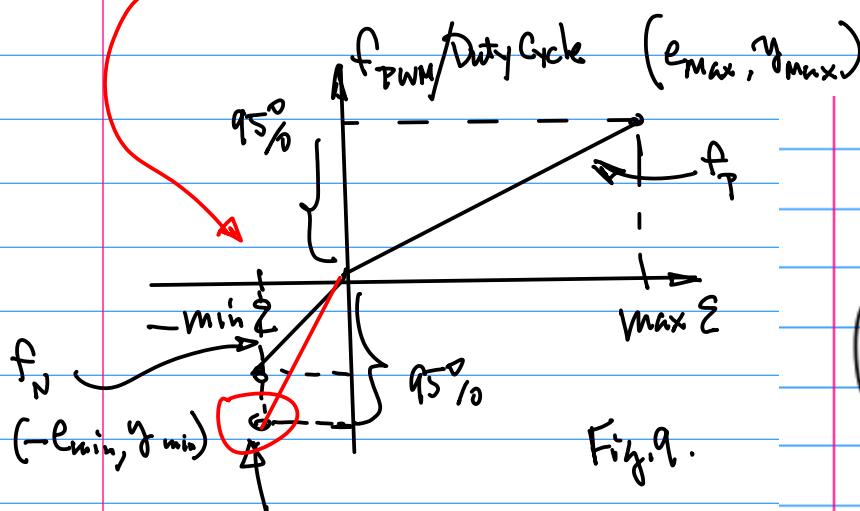


Fig. 9.

Design Objective : To find a control action to reduce the error, and eventually to minimize the error overtime.

Given : 1<sup>o</sup> Characteristic Curve of the Error Distribution.  
 $f_p$ , and  $f_n$ .

2022S-101-note-part2-cmpe242-2022-05-9.pdf

PP17.

$$\frac{x - x_2}{y - y_2} = \frac{x_1 - x_2}{y_1 - y_2} = \frac{x_2 - x_1}{y_2 - y_1} \dots (3)$$

$$y = ax + b.$$

$$x - x_2 = \frac{x_1 - x_2}{y_1 - y_2} (y - y_2)$$

$$\frac{y_1 - y_2}{x_1 - x_2} (x - x_2) = y - y_2$$

from the Ref. (Lecture Notes,  
2022S, pp.17)

$$y = \frac{y_1 - y_2}{x_1 - x_2} x - \underbrace{\frac{y_1 - y_2}{x_1 - x_2} x_2 + y_2}_{c}$$

$b$                              $c$

hence

$$\underline{y = bx + c} \quad \dots (4)$$

where

$$\underline{b = \frac{y_2 - y_1}{x_2 - x_1}} \quad \dots (4-b)$$

$$\underline{c = -\frac{y_2 - y_1}{x_2 - x_1} x_2 + y_2} \quad \dots (4-c)$$

$$ay + bx + c = 0$$

Given the motor Configuration  
With or without GearBox.



Gear Box

- Nema 8 Stepper Motor Bipolar w/ 64:1 Planetary Gearbox
- Nominal Voltage: 6 V
- Stall Current: 0.6 A
- Stall Torque: 127.5 oz.in
- Shaft Diameter: 6 mm

The Nema 8 Stepper Motor Bipolar w/ 64:1 Planetary Gearbox is an 8 stepper motor with 38 mm body and 0.6 A rated current, integrated a planetary gearbox of 64:1 gear ratio. It's a good solution to applications with limited space but need low speed and/or high torque.



Example for A quick Calculation:

Suppose  $e = 109.75$ , find the

Characteristic Equation (4) And  
Corresponding PWM Control Signal.

Assuming.  $f_{PWM} = 500$  Hz

Duty Cycle Range is illustrated in

Fig.9. pp31.

$\ell_{max} = 1000$ ;  $\ell_{min} = -800$  from

Experiments.

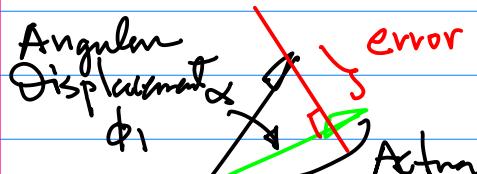


Fig.5  
from pp.30.

Given  $f_{PWM}$ , Duty Cycle  $\rightarrow$  Given Stepper (F.S., H.S., etc.)  
motor config.

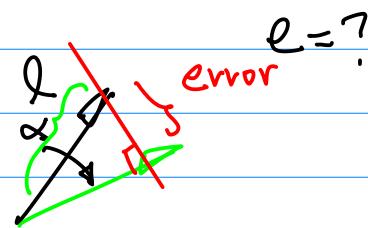
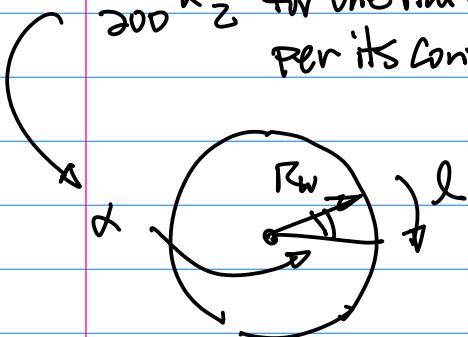
Given the wheel Dimension  
 $R$ , (10", 12", etc).

Find the error / Displacement  
distance. for  $\times$  No. of  
Pulses.

Suppose,  $f_{PWM} = 500$  Hz, Duty =  
50%, H.S.

Angle.

$\frac{360}{200} \times \frac{1}{2}$  for one Half Step  
per its Configuration.



Now, with 1:1 GearBox Reduction.

$$\alpha' = \frac{1}{64} \alpha, \text{ Reduction Ratio} = R_p$$

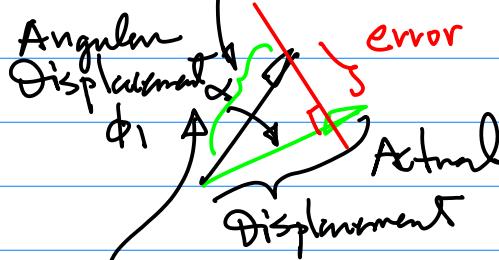
$$\alpha' = \frac{1}{R} \alpha \quad \dots (5)$$

To find physical displacement

$$l = \alpha \cdot R \quad \dots (b)$$

$$\text{OR, Displacement} = \alpha' \cdot R_w \quad \dots (7)$$

$$\text{dist} = \alpha' \cdot R_w \quad \text{from Eqn(7)}$$



Angle is from LSM303  
(Deviation from the Desired Trajectory)  
Therefore, the error.

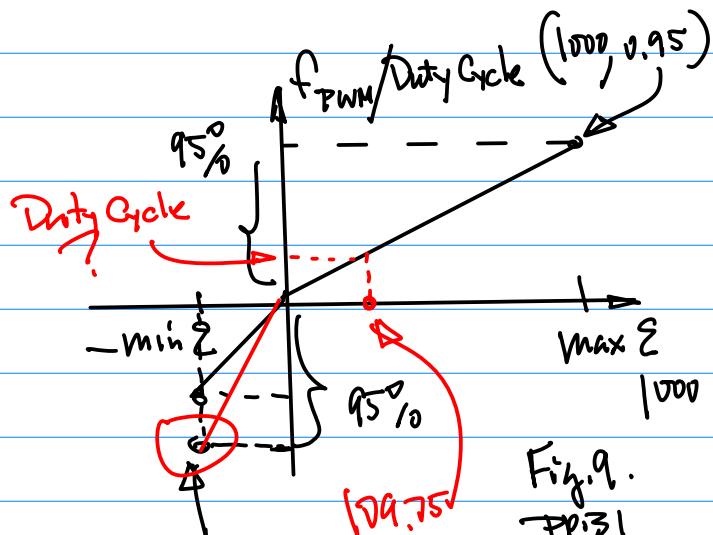


Fig. 9.  
pp.31.

from Eqn(4)

$$y_f = bx + c$$

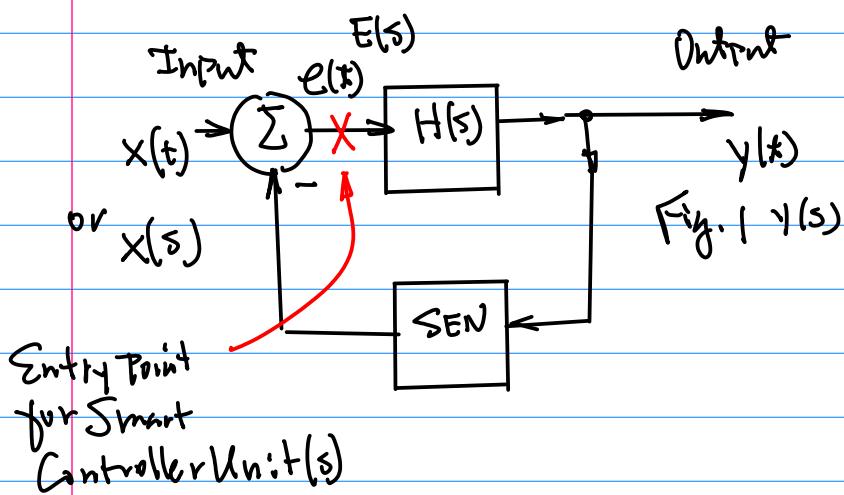
Slope from  
the Characteristic  
Equation.

$$\text{Where } x = 109.75$$

Duty Cycle for Correction.

March 8th (Wed),

Midterm Exam scheduled on the 22nd  
(Wed). Please Bring the Prototype  
Board to the Exam.



Observe the Responses of the System, Note to Reduce | Eliminate the error(s) in the past (e.g. Accumulative Error), we Can Build integral Controller, Such as the one below.

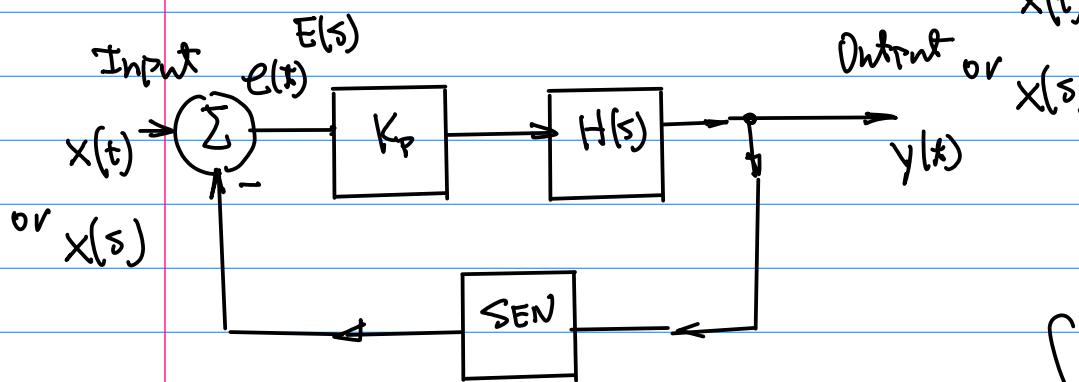


Fig.2

$K_p$ : Gain for Proportional control.

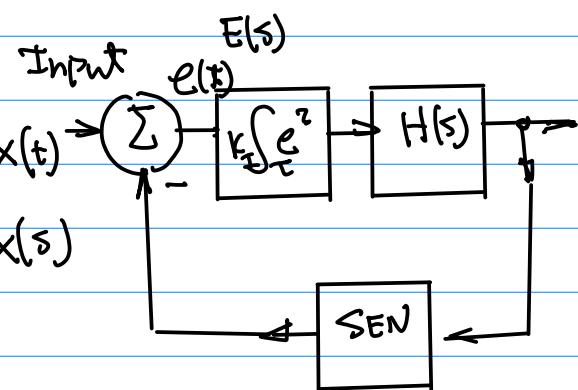


Fig.1

$$\int_{\frac{T}{2}}^T e(t) dt = \dots (1)$$

T: Time Interval

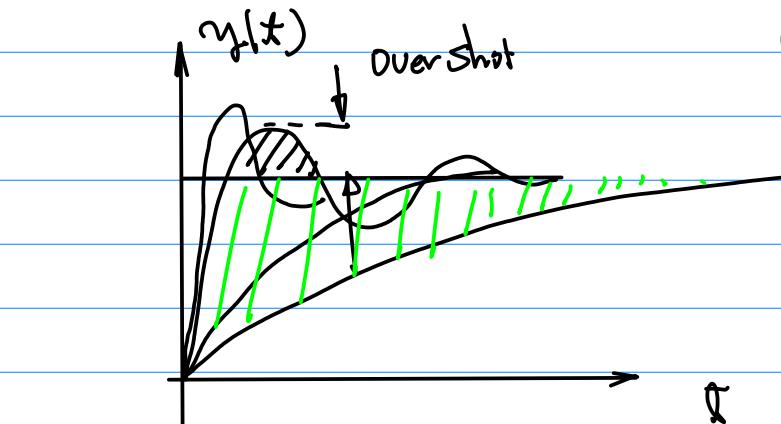


Fig.3

Question:  
the Positive Error Area of the Response Curve From Fig. 1,?

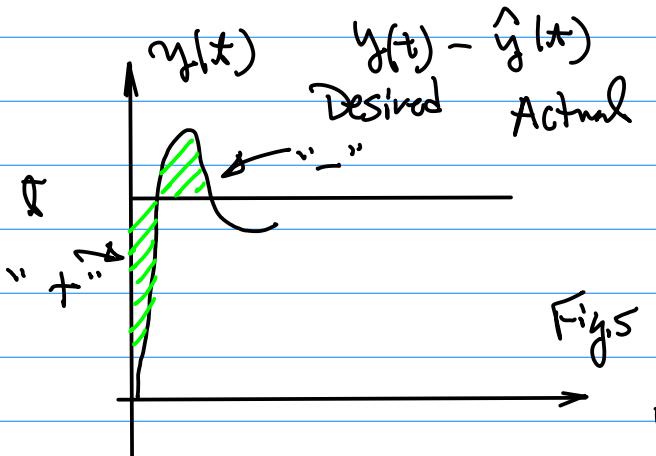


Fig.5

Integration of the error may have the cancellation due to the positive areas v.s. negative areas.  $\rightarrow$  try Absolute Error.

$$\text{Error: } f(e) = |e|$$

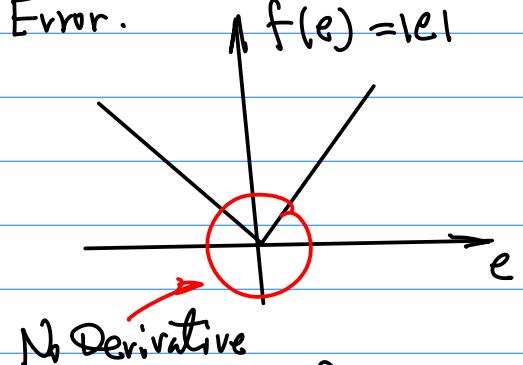


Fig.6

No Derivative

Therefore, signed error is adopted, hence, Eqn(1) becomes.

$$K_I \int_{t_0}^t e^2(\tau) d\tau \quad \dots (2)$$

For the discrete time :

$$K_I \sum_{i=-T}^0 e^2(i) \quad \dots (2-b)$$

Design a controller that can predict the error in the future.  
Derivative Control.

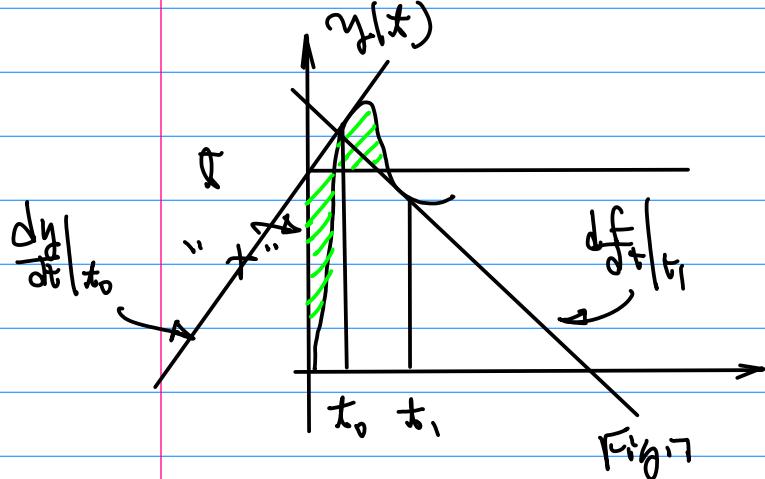


Fig.7

at  $t=t_0$   $\frac{df}{dt}|_{t_0} > 0$ , "Slop is up"

Error is increasing a short step ahead of  $t_0$

if  $\frac{df}{dt}|_{t_0} < 0$ , "Slop is down", negative, then the error is decreasing. a short step ahead of  $t_0$ .

Hence, the derivative controller is defined as follows,

$$K_d \frac{de(t)}{dt} \quad \dots (3)$$

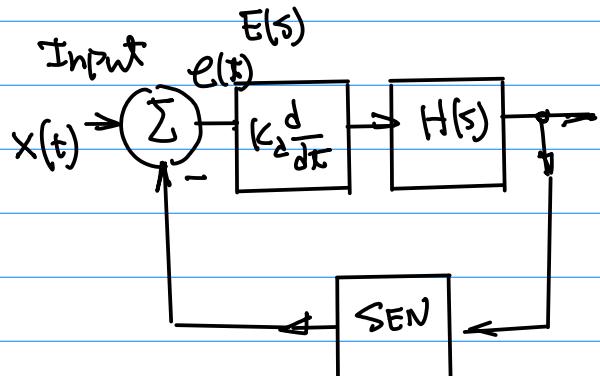


Fig.8

Numerical Computation of  $\frac{df(t)}{dt}$

for

$$\frac{df(t)}{dt} = \lim_{\Delta t \rightarrow 0} \frac{f(t+\Delta t) - f(t)}{\Delta t} \quad \dots (4)$$

$$\approx \frac{f(t+1 \cdot \Delta t) - f(t)}{1 \cdot \Delta t} \quad \dots (4-b)$$

then, knowing  $\Delta t$ , then simplify the notation, we have

$$\approx f(t+1) - f(t) \dots (4-c)$$

for the error function, we have

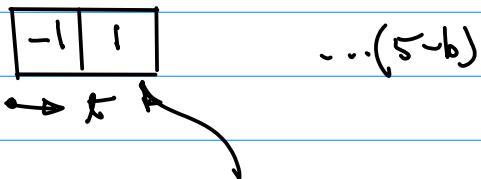
$$f(t) = e(t),$$

so

$$e(t+1) - e(t) \dots (5)$$

$$= 1 \cdot e(t+1) + (-1) \cdot e(t)$$

Design a kernel



Example: Suppose we have the error given in the following Table, find  $\frac{de}{dt}$  the derivative of the error.

$t$	0	1	2	3	4
$e(t)$	0.75	0.93	1.1	0.9	0.7

Step 1

$$\begin{array}{|c|c|} \hline -1 & 1 \\ \hline \end{array}$$

$$-1 \times 0.75 + 1 \times 0.93$$

$$= 0.18$$

Step 2

$$\begin{array}{|c|c|} \hline -1 & 1 \\ \hline \end{array}$$

$$-1 \times 0.93 + 1 \times 1.1$$

$$= 0.08$$

Step 3

$$\begin{array}{|c|c|} \hline -1 & 1 \\ \hline \end{array}$$

$$-1 \times 1.1 + 1 \times 0.9 = -0.2$$