Criteria for hardware selection of Wireless Vibration Sensor

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Abstract— **Vibration Sensor Hardware has three sub-fields as accelerometer, microcontroller and wireless device. This paper is dedicated to deliver more detail information on individual hardware and list of criteria for hardware selection in Wireless Vibration Sensors.**

Keywords-component; accelerometer; microcontroller; wireless device; individual hardware

I. INTRODUCTION

The hardware field for the sensor will obviously be similar to Figure 1. There are 3 major components. End Device (ED) is the actual sensor. The sensor also has multiple limitations bounded to its design. They are listed below.

- Sensor output must be digital
- Sensor must be modular with parts on-board
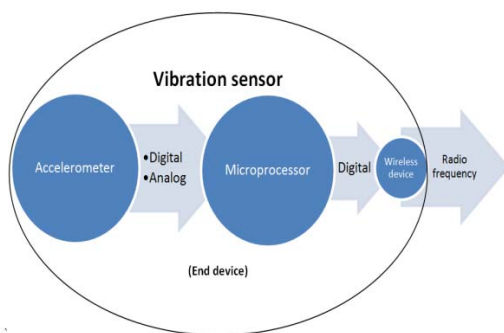- Sensor wireless communication in radio frequency

Figure1. Schematic diagram of end device

II. ACCELEROMETER

The SmartVib has few concerns in circuit complexity, hardware compatibility and signal transmission. Ordinary accelerometer requires external circuit to perform the data transmission and manipulation. Nowadays, advance technology has improved electronic component manufacturing. Particularly, MEMs technology is one of many techniques that integrate the capability of accelerometers and bring the hardware configuration into nano technology.

Fundamentally, there is one thing needs to be clarify is the measurement unit. It is extremely significant in conversion from one quantity to another, especially for measurement instrument. Accelerometer has two types of expression in its unit of measurement. There are milllivolt per g (mV/g) and picoCoulombs per g (ρ C/g) (33). It means every millivolt or picocoulombs change in the voltage reading there is a 1g (9.81m/s2) change in acceleration of the object being sensed [1].

According to ENDEVCO [1], it indicates a few types of accelerometer such as Piezoelectric (PE), Piezoresistive (PR), Variable Capacitance (VC), Force-Balance Servo (SERVO), Thermal Zero Shift (TZS) and Transducer Electronic Data Sheet (TEDS). Texas Instrument adds more types of accelerometer including Hall effect, magnetoresistive and heat transfer. The table of characteristic of each type accelerometer illustrates in the Appendices part A for design reference purpose.

According to above core selection criteria, the manufacture reduced down to three major brands. The table below indicates the detail further.

TABLE I. AVAILABLE ACCELEROMETER BASED ON REQUIREMENT

Model	Axis	Range	Output	Sensitivity (mg/LSB)	Bit revolution	Availability
Analog Device						
ADXL345	3	±16g	I²C, SPI	29~36	10	After April, 2010
ADXL346	3	±16g	I²C, SPI	29~35	10	After April, 2010
ADIS16240	3	±19g	SPI	X=17.125, Y=8.407	10	Active
STMicroelectronics						
Model	Axis	Range	Output	Sensitivity (mg/LSB)	Bit revolution	Availability
LIS331HH	3	±24g	I²C, SPI	12	12	Active
BOSCH						
Model	Axis	Range	Output	Sensitivity (mg/LSB)	Bit revolution	Availability
BMA220	3	±16g	I²C, SPI	500	6	Active
BMA120	3	±16g	I²C, SPI	500	6	Active

Clearly, Table I indicates there three major differences between each model. These are sensitivity, bit revolution and availability. In particular, model LIS331HH has the highest sensitivity in three axes with highest bit revolution. The availability status of this model is also active. Model LIS331HH seems a good options from this three factors. Following section gives a more detail comparison to ensure the accelerometer option.

A. Selection criteria

There are many selection criteria from different aspect of view; Table II shows the final version of selection criteria in descending order. Since there is no standard for accelerometer selection the table can be used as a guide to select a proper accelerometer for general application. For instance, the typical application is criticizing automobile, electric motor, vibration mechanism, hardware monitoring etc.

TABLEII.   CREATED ACCELEROMETER SELECTION CRITERIA.

Order	Criteria
1	Analog/Digital
2	Number of axis
3	Type of measurement
4	Type of technology
5	Measurement range and Sensitivity
6	Frequency range
7	Bandwidth
8	Impedance/Buffering
9	Voltage supply
10	Temperature range
11	Linearity
12	Communication port
13	Reliability
14	Cost
15	Size

1) Criterion1: Analog/Digital

Analog/Digital criterion is placed in first because it will determine some other criterion. For example, designer select digital option and the criterion 9 can be ignored as it applies to analog accelerometer. Another reason is the available option on the market is divided into half and this means designer is half way closer to the expecting accelerometer. According to research and organizing of varies selection method, the most common criterion come across (in first hand) is to choose either analog or digital accelerometer. This is actually dependent on design's preference. As previous section 1.2 mentions few drawbacks of analog device and it gives encouragement for designer to create a new digitized sensor. Besides, Eren states that digital signal has the following advance feature as immune to noise, reduced error correction and, encryption and security can be easily addressed. Thus, digital based accelerometer tends to be a better option for the purposed sensor [2].

2) Criterion 2: Number of axis

The second criterion has divided the total half into three portions. Thus designer is closer to the proper selection of accelerometer. The number of axis detection is dependent on the measurement application. It is not necessary to purchase a tri-axis accelerometer. Single axis accelerometer can be combined to form the same application as tri-axis.

The WiVi sensor is tends to have three axes vibration detection.

3) Criterion 3: Type of measurement

Criterion three guides designer to define the type of measurement for application. Bruce (S.W.P 33) states that type of measurement has divided into four major categories. There are vibration, shock motion and seismic. Obviously, the WiVi new sensor fits into vibration category [3].

4) Criterion 4: Type of technology

It indicates there are PE, IEPE, PR, VC.SERVO, TZS, TEDS etc, it gives advantage and disadvantage of each type of accelerometer and includes the desire applications.

5) Criterion 5: Measurement range and Sensitivity

According to WEG paper, the general electric motor has vibration amplitude from 1.8 to 4.5 mm/s. However, the WiVi sensor is tended to have a slightly wider measurement range.

Another consistency criterion is the sensitivity. Sensitivity shows the accuracy of device. For example, 1000mV/g gives the every 1000mV change in the voltage reading there is a 1g change in the acceleration of object being sensed (arabrise.org). The higher sensitivity the better is in accuracy.

In compare the measurement range from table 3, STMicroelectronics seems to have the highest measurement range ±24g with high sensitivity 12 (mg/LSB) in measurement.

6) Criterion 6: Frequency range

Toliyat indicates the frequency range is between 10Hz and 1000Hz [4]. Frequency range illustrates the capability of amplitude that accelerometer can still function probably during measurement period.   If the frequency range of mechanism hardware is an unknown value, following table gives a recommended frequency spans for reference in some general cases [5].

Designer tends to select wide frequency range as much as possible from three particular manufactures. Refers to the data sheet that provides in appendices part F, the following table can be built.

TABLE III.   TABLE OF FREQUENCY RANGE COMPARISON

Manufactures	Model	Frequency range
Analog Device	ADXL345/346	6.25Hz ~ 3200Hz
	ADIS16204	360Hz ~ 440Hz
STMicroelectronics	LIS331HH	0.5Hz ~ 1000Hz
BOSCH	BMA120	50Hz ~ 1000Hz
	BMA220	32Hz ~ 1000Hz

Based on the result of comparison from table III, the ADXL345/346 has the most wide frequency range than others. Unfortunately, table 3 indicates the availability status is after April 2010, thus the best option is the LIS331HH

accelerometer from STMicroelectronics. The frequency range is from 0.5Hz to 1000Hz and it has sufficient margin for hardware health monitoring system.

7) Criterion 7: Bandwidth

Bandwidth is the frequency difference between high-pass filter (HPF) cutoff frequency and low-pass filter (LPF) cutoff frequency. It gives the amount of time per second that device can take a reliable acceleration reading. Ignored ADXL345/346 due to availability status, the following table gives the comparison result of bandwidth from each accelerometer.

TABLE IV.   TABLE OF BANDWIDTH COMPARISON

Manufactures	Model	Bandwidth		
Analog Device	ADIS16204	360Hz ~ 440Hz		
STMicroelectronics	LIS331HH	ODR	HPF cutoff Frequency (Hz)	LPF cutoff Frequency (Hz)
		50	1, 0.5, 0.25, 0.125	37
		100	2, 1, 0.5, 0.25	74
		400	8, 4, 2, 1	292
		1000	20, 10, 5, 2.5	780
BOSCH	BMA120	50Hz, 75Hz, 150Hz, 250Hz, 600Hz, 1kHz		
	BMA220	32Hz ~ 1000Hz		

Table IV indicates the LIS331HH has adjustable bandwidth according to ODR and HPF cutoff frequency. Compare to others, LIS331HH accelerometer has higher flexibility in bandwidth scale. The scale has lower level bandwidth range from 0.125Hz to 37Hz and upper level bandwidth range from 20Hz to 780Hz.

8) Criterion 8: Impedance/Buffering

A typical example, analog accelerometer performance with PIC & AVR microcontroller requires to have output impedance under 10KOhm in order to properly perform A/D. Particularly, Analog Device accelerometer has output impedance of 32KOhm. Hence, it needs a low input offset rail to rail OP amp as a buffer to lower the output impedance. Since requirement analysis has limited accelerometer must be digital, therefore, criterion 8 does not in concern.

9) Criterion 9: Voltage supply

Voltage supply is another important issue in measurement life span. Luckily, this is not the concern of the analog sensor due to the cabling connection. The cable is capable to provide the power source. Unlike the digital sensor, the common way to deliver the power is to add the battery pack. By selecting lowest power consumption of accelerometer to prevent frequently renews battery pack. Again, refers to provide data sheet, the comparison of supply voltage and current consumption for each type of accelerometer can be constructed.

TABLE V.   POWER CONSUMPTION OF EACH ACCELEROMETER.

Manufactures	Model	Supply voltage (V)	Current consumption		
Analog Device	ADIS16204	3.0 ~ 3.6	Normal mode	Fast mode	Sleep mode
			12 ~ 15mA	37 ~ 43mA	150mA
STMicroelectronics	LIS331HH	2.16 ~ 3.6	Normal mode	Low-power mode	Power-down mode
			250µA	10µA	1µA
BOSCH	BMA120	1.8 (±10%)	Full performance	Low-power mode	Suspend
			430µA	2µA	1µA
	BMA220	1.8	Full performance	Low-power mode	Suspend
			430µA	2µA	1µA

10) Criterion 10: Temprature Range

Temperature has directly effect on particular type of accelerometer technology. For instance, PR is sense to temperature and it needs to compensation for output. On the other hand, VC is insensitive to temperature as table 19, appendices A.3, expresses the characteristic of VC accelerometer.

Manufactures	Model	Temperature
Analog Device	ADIS16204	-40°C to +125°C
STMicroelectronics	LIS331HH	-40 °C to +85°C
BOSCH	BMA120	-20°C to +70°C
	BMA220	-20°C to +70°C

TABLE VI.   TABLE OF TEMPERATURE COMPARISON FOR EACH ACCELEROMETER.

Although table VI indicates ADIS16204 has wide temperature range that other, the PE type accelerometer has temperature drift about 2Hz. Hence, LIS331HH is the better option for WiVi sensor.

11) Criterion 11: Linearity

The difference between the actual transfer function and best straight line within particular operating range called linearity. According to datasheet, ADIS16204 has nonlinearity about 0.2% of the full-scale output, whereas, BMA series has ±2% of the full-scale output. However,

LIS331HH has zero percent nonlinearity in full-scale output.

12) Criterion 12: communication port

The most popular communication conduit of accelerometer is SPI, I2C or both coexisting. Moreover, clock frequency of data transmission is different between both communication interfaces. Table VII, below, gives the different clock speed between both communication interfaces for each accelerometer.

Manufactures	Model	Communication port			
Analog Device	ADIS16204	Clock frequency	SPI		
			Standard mode	0.01~1MHz	
			Fast mode	0.01~2.5MHz	
STMicroelectronics	LIS331HH	Clock Frequency	SPI	I²C	
			10MHz	Standard mode	0~100KHz
				Fast mode	0~400KHz
BOSCH	BMA120	Clock Frequency	SPI	I²C	
			Not available		
	BMA220	Clock Frequency	SPI	I²C	
			Not available		

TABLE VII.   CLOCK SPEED OF TWO COMMUNICATION INTERFACE FOR EACH ACCELEROMETER.

LIS331HH has both communication interfaces with 10MHz clock frequency in SPI and 400KHz in fast mode of I2C , whereas , ADIS16204 is not preferred due to unique communication interface, SPI, with 2.5MHz at fast mode. Obviously, LIS331HH has flexibility of communication interface than others.

13) Criterion 13: Reliability

Reliability of accelerometer is highly dependent on the absolute maximum ratings for some parameters such as operating temperature range, supply voltage, pins supply voltage, shock resistance etc. For example, LIS331HH has shock survivability about 10000g for 0.1 milliseconds and 3000g for 0.5 milliseconds either unpowered or powered. ADIS16204 has shock survivability about 4000g for 0.5 milliseconds for any axis either unpowered or powered.
Therefore, LIS331HH has higher survivability than ADIS16204.

14) Criterion 14: Cost

The cost of accelerometer does not a major concern in the overall project since the revolution of technology. The price of accelerometer from varies of manufacture has not big difference. Therefore, it can be considered as a second last two of criterion.

15) Criterion 15: Size

Since size is dependent on the application and it can be microminiaturization in later design production stage. Most

digital sensor manufactures have applied the MEMs technology as mention previously, the size of digital accelerometer is much smaller.

B. Selected accelerometer

Based on selection criteria in above section, LIS331HH has more criterions with better ranking in compare to other manufactures. Thus, LIS331HH has selected. The picture blow illustrates the dimension of LIS331HH accelerometer. It is a 3mmX3mmX1mm with 16 pins accelerometer.
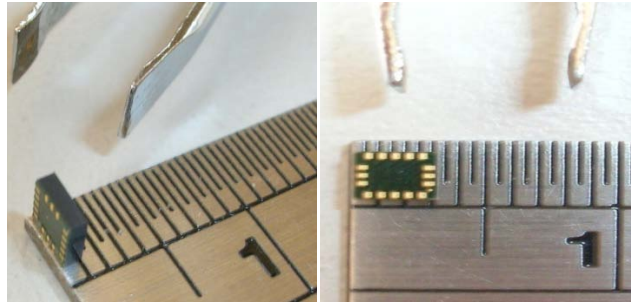
(a)   LIS331HH angle view and bottom view
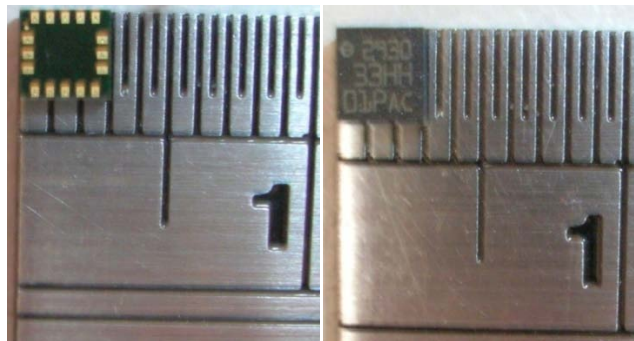
(b)   LIS331HH close bottom view and top view.
Figure 2. LIS331HH hardware component.

Wireless communication

Wireless communication is known as a coreless data transmission from one point to another. The application of wireless communication is now associated with our daily lives, a simple example is the mobile phone. Moreover, middle part of electromagnetic spectrum is largely used by modern wireless communication systems [2]. The middle part of electromagnetic spectrum is divided into several frequency ranges as shown in the following table.

TABLE VIII.   : FREQUENCY BAND OF DIFFERENT WIRELESS COMMUNICATION SYSTEM.

Type of wireless communication system	Frequency band
Radio frequencies	10kHz to 1GHz
Microwave frequencies	1 GHz to 500 GHz
Visible and infrared frequencies	500 GHz to 1THz

Halit states that wireless techniques application requires greater bandwidth [2]. Nevertheless, Stig Petersen, Simon Carlsen and Amund Skavhaug states that contribution of wireless communication can enormously reduced installation and operation cost [6]. Meanwhile, it allows remote and hostile installations. This practically an approach is called cost-efficiency in device communication aspects. Recently, the application of wireless technology in oil, gas and resources industries has significant improve the operation to some extent. Akhondi states that wireless communication is capable in contributing low operation cost and eliminating the need for core installation [7].

Amount those advantages above, wireless communication is likely to adopt into WiVi sensor. According to spread spectrum IEEE 802 standard, it regulated wireless network usage for popularity application as Internet, portable devices and laptop computers. Table 11 indicates IEEE 802 wireless network standards for different function.

TABLE IX.   TABLE OF IEEE 802 WIRELESS NETWORK STANDARDS [2].

Standard	Name	Function
802.1	Internetworking	Routing, bridging, and Internet work communication
802.2	Logical link control	Error control and flow control over data frames
802.3	Ethernet LAN	Forms of Ethernet media and interfaces
802.4	Token bus LAN	Forms of Token bus media and interfaces
802.5	Token ring LAN	Forms of Token ring media and interfaces
802.6	Metropolitan area networks	MAN technologies, addressing and services
802.7	Broadband Advisory Group	Broadband networking media, interfaces, equipment
802.8	Fiber-optic Advisory group	Fiber-optic media, network types, technologies
802.9	Integrated networks	Integration of voice and data traffic in a network medium
802.10	Network security	Network access control, encryption, certification, other security
802.11	Wireless networks	Wireless networks, frequency usage
802.12	High-speed networking	Variety of 100 Mbps-plus technologies
802.13	Unused	
802.14	Defunct working group	Data transfer over cable TV
802.15	Wireless personal area networks	Emerging standards for wireless PANs
802.16	Wireless metropolitan area networks	Wireless MANs
802.17	Resilient packet ring	Very high speed ring-based LANs and MANs
802.18	Wireless Advisory Group	Radio-based wireless standards

Table IX indicates 802.11 is particularly classified for wireless networks and it is commonly known as Wi-Fi. Since there are variety of wireless communication system, table X gives the comparison of advantages and disadvantages of systems. According to the Bose's lecture two [3], there are four major types of wireless communication. There are indicates at table below.

TABLE X.   TABLE OF COMPARISON FOR VARIES TYPE OF WIRELESS COMMUNICATION   .[3]

Type of wireless communication	Advantages	Disadvantages	Description
Radio communication	-easy to generate -long distance travelling -penetrate building	-frequency depend -low bandwidth -license required by government	The earliest and most popular wireless communication and still exist today.
Microwave	-long distance communication -high signal ratio -inexpensive	-low penetration ability -weather and frequency dependent	Point to point transmission through tall tower and anntna.
Infrared and millimeter waves	-short range communication	-Unable to pass through solid objects -Indoor wireless LANs only	10m transmission range
Lightwave Transmission	-easily install -No need for license	-Unable to penetrate rain or thick fog. -Turbulent air can diverted lightwave	

Clearly, radio frequency is the earliest and most popular type of wireless communication. Importantly, radio communication enables to penetrate through building, whereas, others depend on the transmission tower or only used indoor WLAN application. Table 14 indicates the transmission distance for varies radio transmissions. Obviously, WLANs is the better option for WiVi sensor. The transmission range for different radio transmission is given in the following table 14. It indicates the WLANs has transmission distance less than 1Km. For the purpose of monitoring system is sufficient.

TABLE XI.   TYPE OF RADIO FREQUENCY AND TRANSMISSION DISTANCE [3]

Type of radio transmission	Transmission distance
Infrared	< 10m
Bluetooth	<100m
WLANs	<1km
Mobile Technology WLL	<50km
FM radio frequency	<100km
MW radio frequency	<300km
SW radio frequency	<500km
Satellite Links	<1000km

Table XI gives the specification of IEEE 802.11 standard. The wireless LANs is what designer looking for in order to

ease utilization measurement instrument communication. Wireless modules research whitepaper (Wireless module research n.d.) states that 892.11(b,g,n) are common widely used from household.

III. FUTURE WORK

A. Future Wireless Option

The future of wireless 802.11n has been released in full specification into the market. The connection between the wireless dongle and the microcontroller is using a USARTs connection which is very generic.

Therefore, this design allows future wireless module replacement in ease. This design is not limited to wireless 802.11 frequency communications. There are other wireless option that uses the same USARTs connection such as, Bluetooth, 4G, 3G, ZigBee, etc.

B. Custom designed microcontroller

If the prototype proves successful, it is possible to request custom microcontroller that is specifically designed to the needs of this device. This will greatly reduce the power consumption and allow the device to focus on what it is designed to do.

C. Power Source

The current power source is based on battery packs supplies. The future preference would be to acquire the power from the vibration itself. This is made possible by turning the kinetic energy generated by the vibration into electrical energy. However, the vibration can only generate limited amount of energy. Thus, the device must run on circumscribed power source.

D. Coalition Device Network

If more than one same device in the network is place separately on a single machine. The data of these devices can be combined to simulate the machine. There are infinite potential in understanding the vibration profile of this machine [8][9][10][11].

IV. CONCLUSION

In this paper has been tired to research and consider all criteria for hardware selection to find the best hardware which suitable and applicable for our project.

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