First Responder Heat Exposure Monitoring Device

ENGS 89/90

Project Group 9

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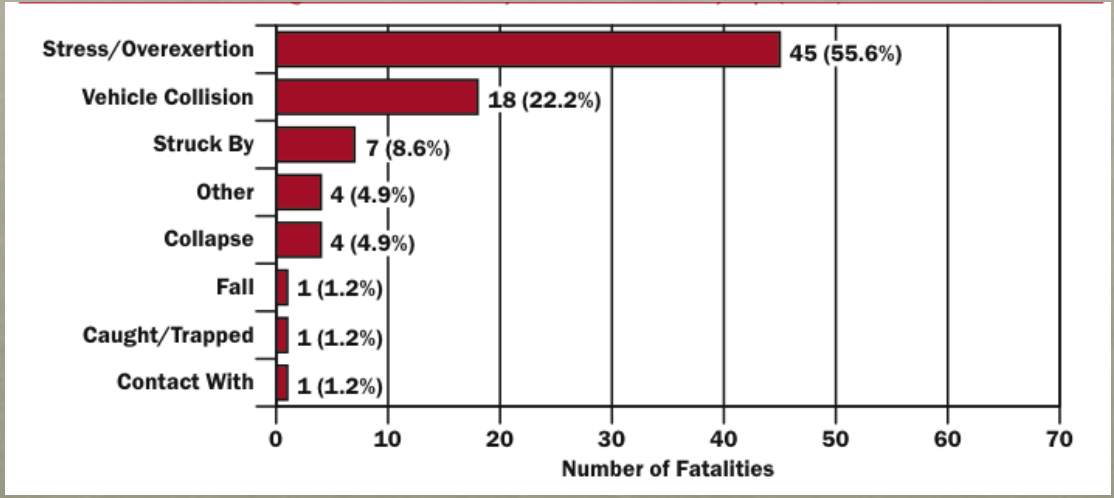
Sponsored by Boston Engineering

OVERVIEW


Firefighters Hurt in Claremont

Firefighter deaths by injury:



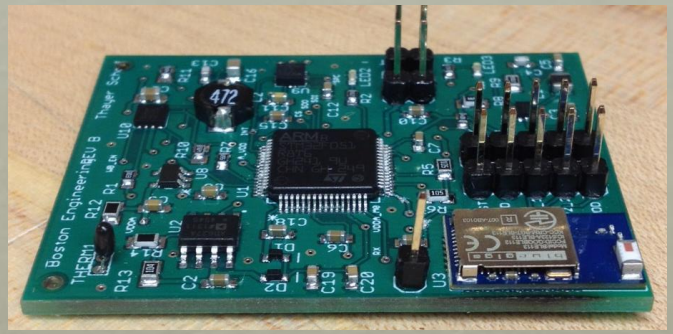
http://www.fs.fed.us/fire/safety/fitness/heat_stress/photos/hs4.jpg

PROBLEM/NEED STATEMENT

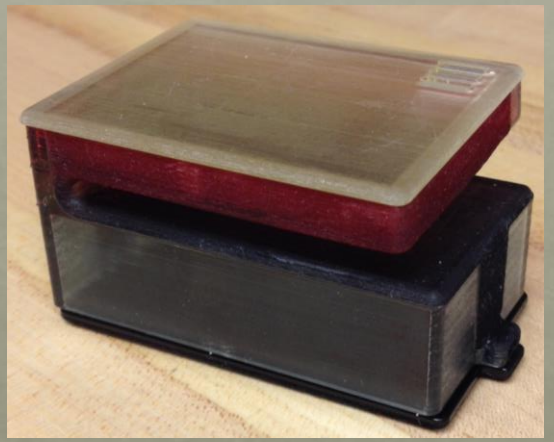
- The thermal envelope of modern turnout gear traps firefighter's body heat, which can lead to injury and death due to acute heat stress.
- Boston Engineering needs a device that allows them to log and wirelessly transmit temperature data inside firefighter's turnout gear.

DELIVERABLES

- Two Assembled Devices
  - + Schematic and Layouts
- Software
  - C and Matlab
- 3-D printed Case
  - + CAD files
- Documentation
  - BOM, testing procedure, manufacturing, etc.



Rev 2 pictured



Final colored case

DELIVERABLES WITHIN SCOPE

Engs 89/90

Grant (SBIR) Device

- Firefighter Ready
- Very similar to final device
- Intended to win SBIR funding

Discovery Device

- Additional measurements required
  - Humidity
  - Core Body Temp
- Determine Biometric model

Life-Saving Device

- Streamlined final version of device
- Final specs determined by the biometric model

DRIVING REQUIREMENTS

Ref.	Requirement	Justification	Spec - Min	Spec - Target	Spec - Max	Spec - prescriptive	Source of Spec
A.8	Cost	Device should be inexpensive relative to current gear	-	$50 / unit	$50 / unit	-	Discussions with Boston Engineering and Firefighters
B.1	Power Life	Device must be long lasting and minimize battery replacement or charge.	1 Month (5% duty cycle)	2 Month	-	-	Theoretical Power analysis of components, with a minimum equal to current gear battery life
B.3	Data Accuracy	Device will sample user temperature in a location as close to the body as feasible	+/- 1 F	+/- 0.7 F	+/- 0.1 F	-	Range determined by discussion with Dr. Paradis and Boston Engineering
C.1	Size	Device should be as small as possible while providing the desired capability	2" x 3" x 1"	-	3" x 5" x 2"	-	Reasonable size estimates for device built around AA batteries

PUGH SOLUTIONS MATRIX

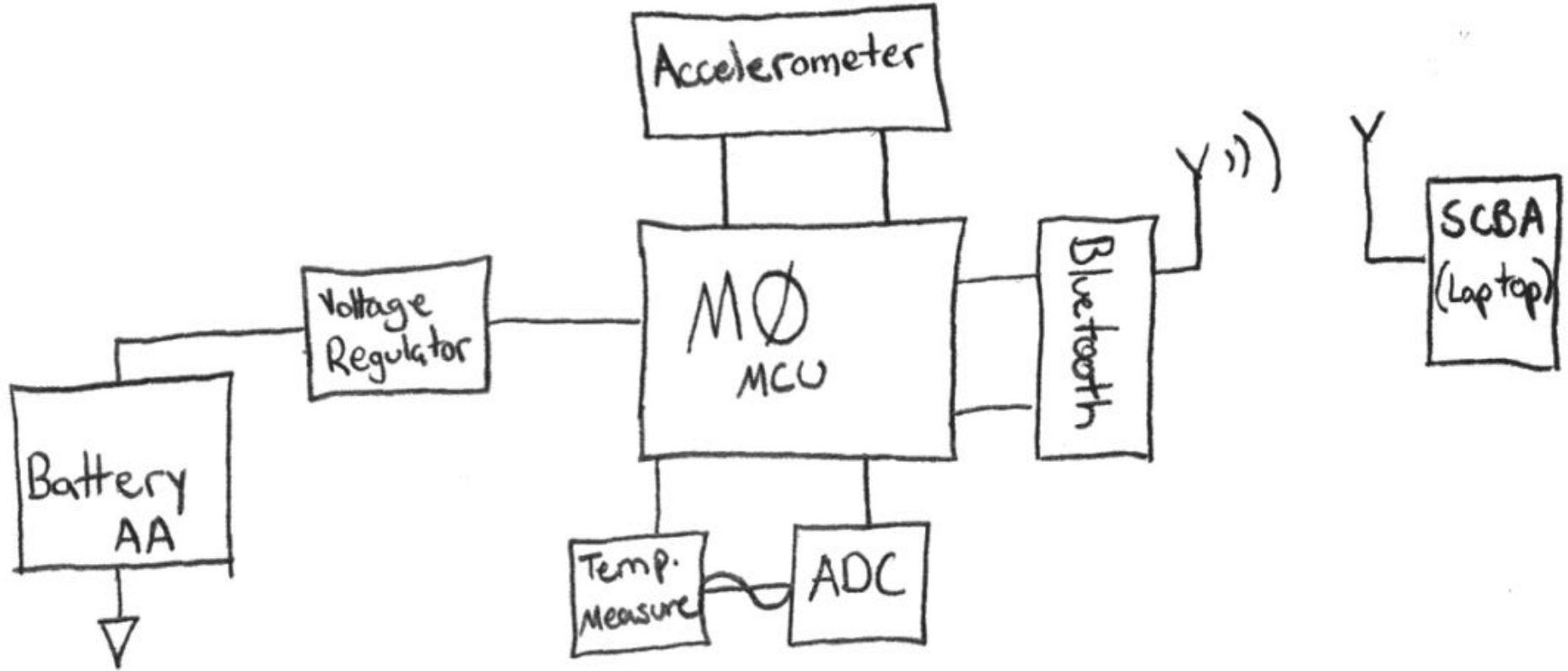
	Safety	Cost	Wearer Comfort	Communication	Data acquisition	User interface	Power Life	Mechanical Life	Sum
Groin	4	4	2	5	1	5	3	4	28
Rectum	0	4	1	5	4	5	3	3	25
Oral	1	4	1	1	4	5	3	3	22
Ear	3	4	2	5	4	5	3	4	30
Pill Thermometer	3	1	3	5	5	5	1	2	25
Skin	5	4	4	5	0	5	3	4	30
Biomodel + Device	**5**	**2**	**5**	**5**	**4**	**5**	**3**	**4**	**33**
Analog thermometer	3	5	4	0	3	4	5	3	27
Color Changing Material	5	4	5	0	3	3	5	5	30
Astronaut Style Cooling	5	1	5	n/a	n/a	5	4	3	23
NUST Lab Thermal HUD	5	4	3	4	2	1	3	4	26

ALTERNATE SOLUTIONS MATRIX

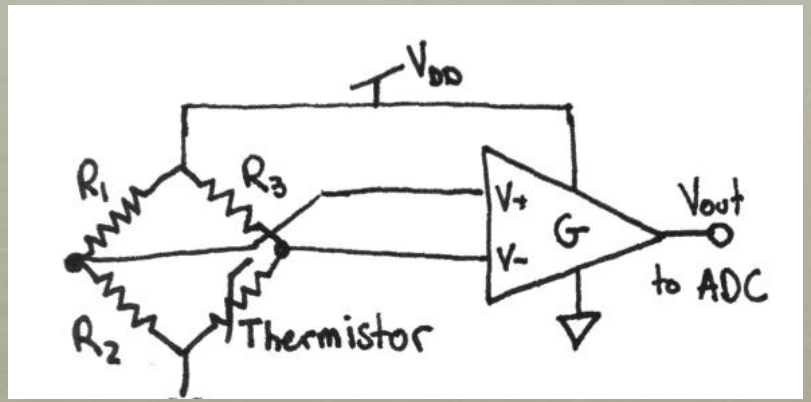
	Power Life	User Interface	Data Accuracy	Data Sampling Rate	Size	Power Source	Communications
TI Sensor Tag	0	0	0	1	1	0	1
ThermaData Series I	1	0	1	0	1	0	0
Sensonics Minnow	1	0	1	1	0	0	1
Holux M-241	0	0	0	1	1	1	1

- Binary rating
- Solution assigned 0 if failed to meet requirement

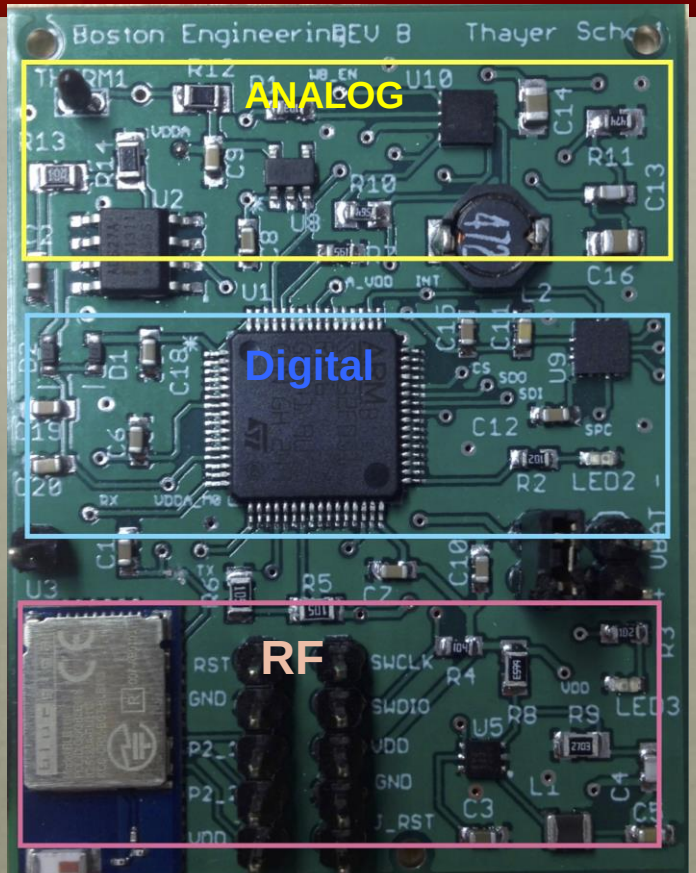
HIGH-LEVEL DESIGN



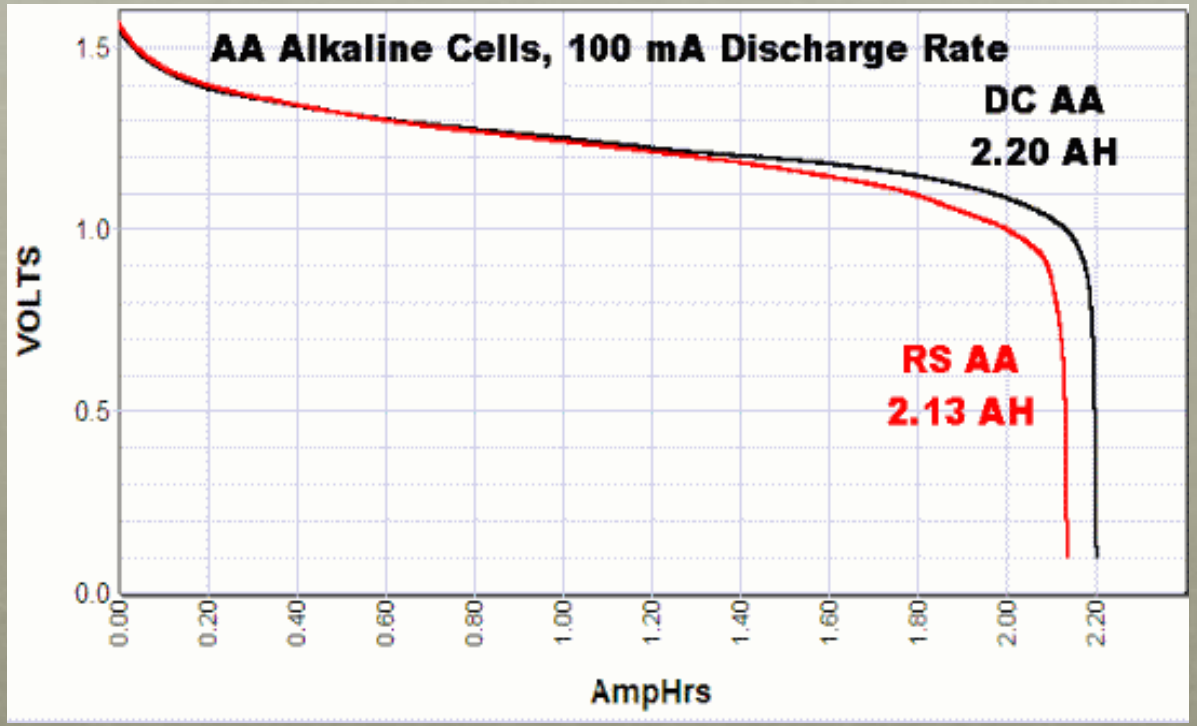
HARDWARE



- Low Noise Design
  - Wheatstone Bridge
  - Isolation of Analog from RF/Digital
- Two-layer, single sided, board for lower costs



HARDWARE - BATTERY STUDIES



- Dual voltage level power scheme
- Low power components selected

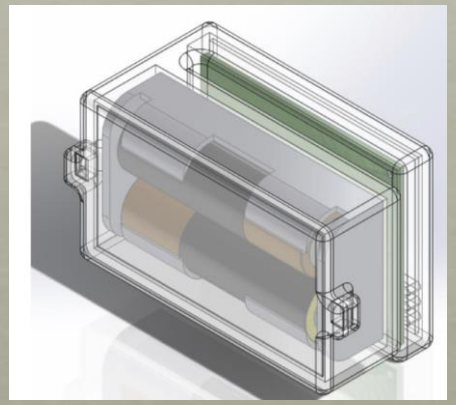
SOFTWARE STACK

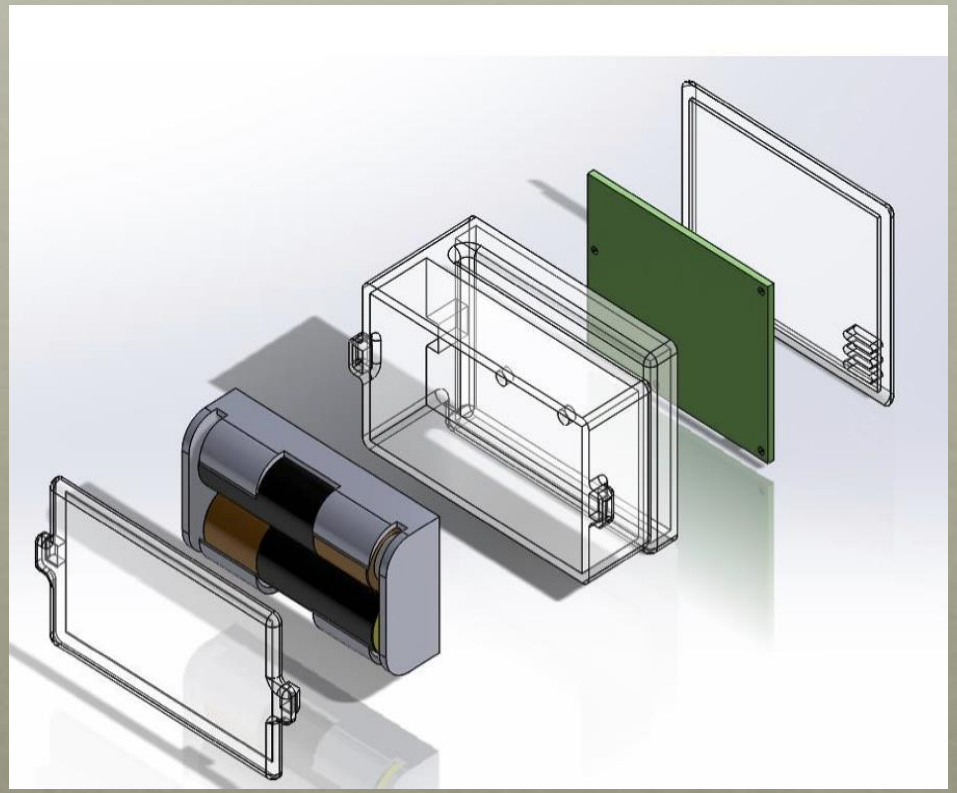
C
- Embedded System

MATLAB
- Serial port listener

Sinatra
- Web application

MECHANICAL



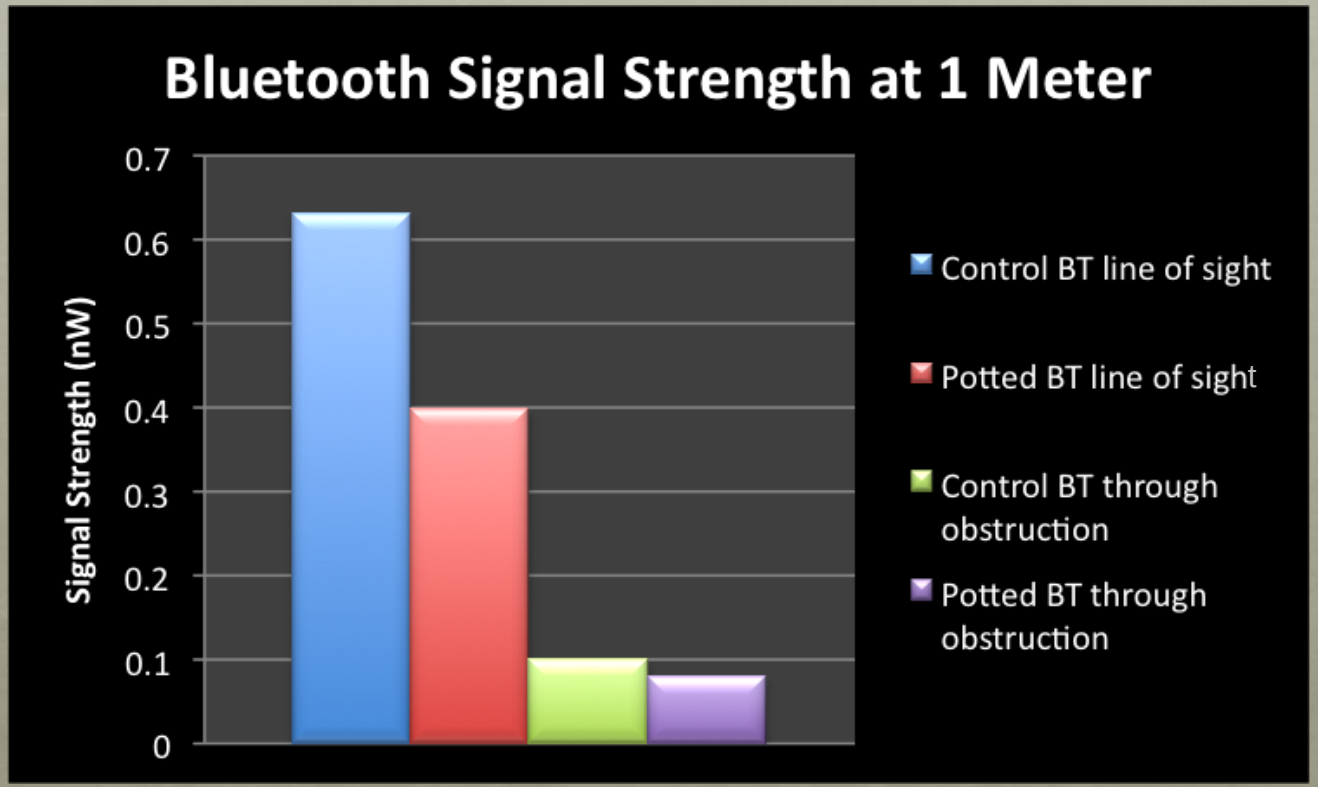


SAFETY

TASK	FAILURE MODE	ASSUMPTIONS	HAZARD	RISK SCORING				RISK REDUCTION PLAN
				FREQ	LIKLHD	SEV	TOTAL	
Data Transmission	short circuit	Dust or water shorts circuit	injury (shock)	3	2	1	6	No action required
Data Transmission	short circuit	Dust or water shorts circuit	Explosion	3	2	5	30	Pot the electronics
Data Transmission	Improper heat dissipation from circuitry	Device becomes hot	injury (burn)	3	1	2	6	Ventilation in case
Data Transmission	Radiation	Bluetooth communication close to body	injury (radiation)	3	1	1	3	No action required
Data Transmission	Case Breaks	Puncture risk	injury (puncture)	3	2	2	12	Reinforce case
Data Transmission	Improper heat absorption by case	Device becomes hot	injury (burn)	3	2	2	12	Low heat conductivity material for case

High Risk (action required)	Medium Risk (action required)	Low Risk (no action required)	Low Risk (no action needed)

BLUETOOTH SIGNAL STRENGTH

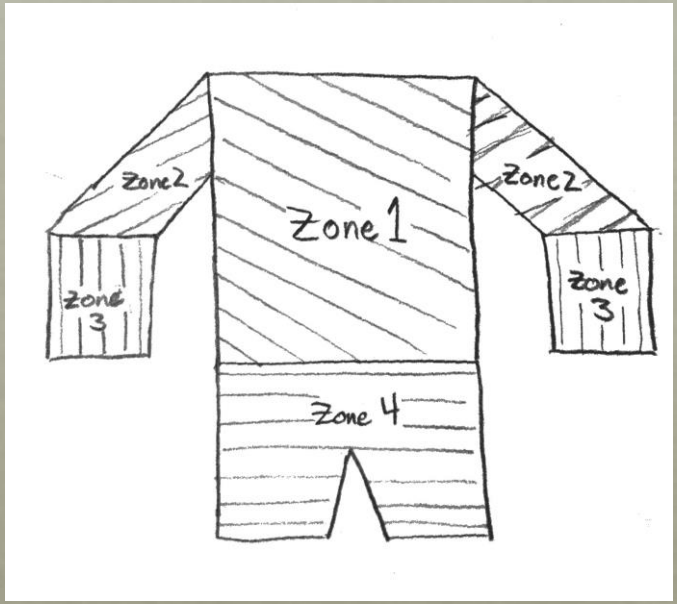


Control Potted

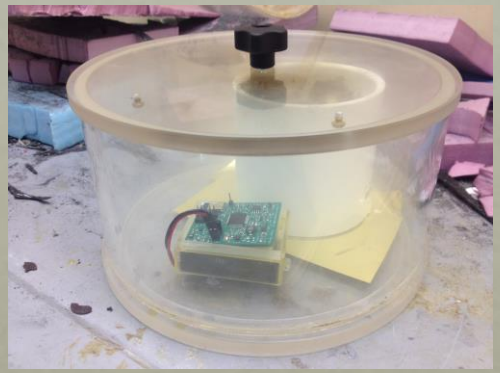
TESTING OF SPECIFICATIONS

Ref.	Requirement	Justification	Spec - Min	Spec - Target	Spec - Max	Spec - prescriptive	Source of Spec	Test	Test Results
A.8	Cost	Device should be inexpensive relative to current gear	-	$50 / unit	$50 / unit	-	Discussions with Boston Engineering and Firefighters	Analysis of price from company and supplier quotes	Device costs under $50 / unit
B.1	Power Life	Device must be long lasting and minimize battery replacement or charge.	1 Month (5% duty cycle)	2 Month	-	-	Theoretical Power analysis of components, with a minimum equal to current gear battery life	Measure current levels in all relevant power states. Estimate power life from typical firefighter work cycles	Power life estimated to be 5 months
B.3	Data Accuracy	Device will sample user temperature in a location as close to the body as feasible	+/- 1 F	+/- 0.7 F	+/- 0.1 F	-	Range determined by discussion with Dr. Paradis and Boston Engineering	Testing of temperature output of device against bare thermistor measured with an Ohm meter	Device exhibited +/- .36 F accuracy
C.1	Size	Device should be as small as possible while providing the desired capability	2" x 3" x 1"	-	3" x 5" x 2"	-	Reasonable size estimates for device built around AA batteries	Measurement of final design area and confirmation of comfort with Hanover FD	Final Device measured 2.8" x 1.75" x 1.35".

TESTING

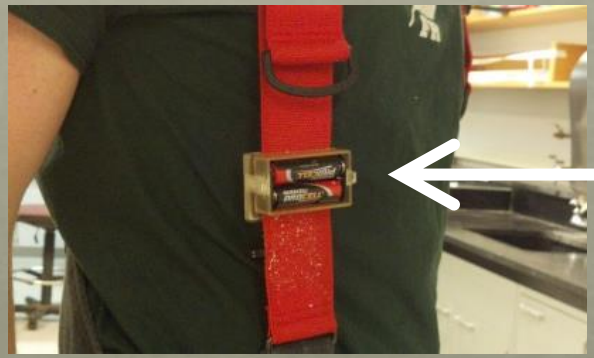


Suit Characterization Testing
- **Humidity varies widely (15%)**
- **Temperature varies moderately (3%)**



Environment Scenario Testing

(Smoke test pictured)



Clamping Force

3.8 lbs required to dislodge device

DEVICE COSTS

		10+ Units	1000+ Units	10000+	NRE Costs
	Components	37.24	24.56	24.56	418.3
Electronics	Board Manufacturing	49.77	1.77	1	
	Board Assembly	90	7.22	4.93	
Case	Rapid Prototype	**11.96**	**11.96**	11.96	0
	Injection Mold	2212	22.13	**2.20**	22,122
	Per Unit Cost:	230.8	45.9283	32.75	
	Total Run Cost:	2308	45928	327516	

- Costs per unit, broken down by volume
- Manufactures

MARKET SIZE

- 30,000 Fire Departments in the United States
- **1.1 Million Firefighters**
- 10 – 30% Market Penetration

MARKETING PLAN

- Grant Funding

http://www.launchtn.org/wp-content/uploads/2012/08/sbir-sttr.png

- Industry Partnership

http://www.fireproductsearch.com/assets/Uploads/Scottsafetylogo.jpg

- Market Plan

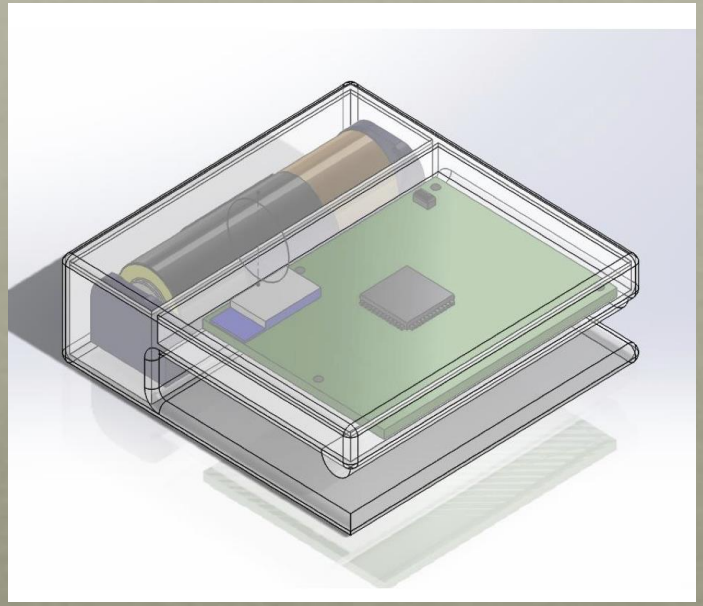
Stage	Grant Device (10 Units)	Discovery Device (1000 Units)	Production Device (10,000 Units)
High	$1,268.80	$41,539	$357,490
Low	$676.20	$31,119	$265,390

TRANSITION TO SPONSOR

- Handing over device that is “demonstration” ready
  - One revision away from being “firefighter” ready
- Eagle schematics and board layouts
- Testing procedures and Bill of Materials
- CAD files
- Software files

FUTURE RECOMMENDATIONS

- **Newest PCB and software revisions**
  - **Bluetooth redundancy**
- **Humidity Circuit**
- **Alternate device mounting**
- **SCBA Interfacing**
- Single AA-battery redesign (pictured)
- Kinetic Generator Harvesting



THANK YOU

Hanover Fire

Captain Mendenhall

Dr. Norman Paradis

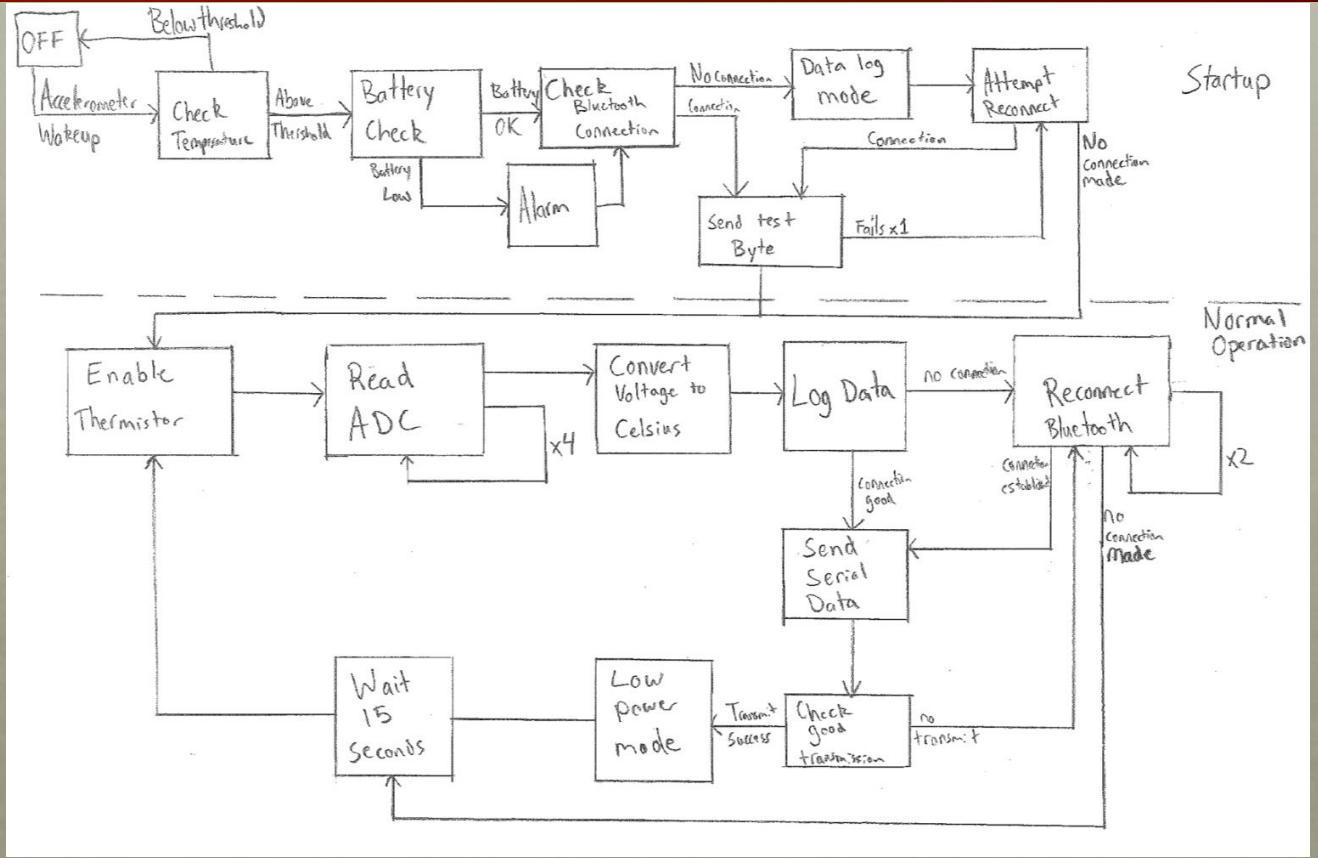
Mark Smithers and Guy Fichera

Professor Stephen Taylor

Directors Bill Lotko and Ryan Halter

The Review Board

FINITE STATE MACHINE



SENSOR TRADE STUDIES

Sensor	Cost	Power	Accuracy	Linearity	Sensitivity	Size	Response Time	Total	Average
Weights	**1**	**1**	**1.25**	**1**	**0.75**	**0.75**	**1**		
Thermocouple	4	5	3.75	4	2.25	2.25	4	25.25	3.60
RTD	3	3	6.25	5	3	3.75	3	27	3.85
Thermistor	**5**	**4**	**5**	**3**	**3.75**	**3.75**	**4**	**28.5**	**4.07**
IR sensor	2	2	5	5	3	2.25	5	24.25	3.46
Semiconduc-tor	3	2	3.75	4	3	3.75	1	20.5	2.92

THERMISTOR STUDY

Thermistors	Cost (single unit)	Resistance (Ohm)	Accuracy	Size (mm)	Response Time (s)	Temperature Range	Beta Value (K)	Self Heating (mW/C)
Murata WF104	$0.43	100k	+/- 1%	4 x 2	4	-40C to 125C	4250K	1.5
Murata XH103	$0.43	10k	+/- 1%	4 x 2	4	-40C to 125C	3380K	1.5
US Sensor PS104J2	$3.19	100k	+/- 0.1C	2.5 x 3	10	-80C to 150C	3892K	1
LMT87 IC	$0.73	N/A	+/- 0.6C	2 x 1	<4	-50C to 150C	N/A	N/A

Selection: Murata WF104

http://media.digikey.com/Photos/Murata%20Photos/NXRT15%20Series.JPG

INSTRUMENTATION AMPLIFIER STUDY

Inst. Amp	Power Consumption	Temperature Range	Voltage Input Offset	Input current bias	Slew Rate	Bandwidth	Cost
AD627-A	60uA	-40C to 85C	50uV	2nA	0.06V	80 kHz	$6.32
AD627-B	60uA	-40C to 85C	25uV	2nA	0.06V/us	80 kHz	$8.84
IN122	60uA	-40C to 85C	150uV	10nA	0.16V/us	120kHz	$6.35

Selection: Analog Devices AD627-A

http://thumbs4.ebaystatic.com/d/l225/m/mQ3dmflSAghiIysEopTnb-Q.jpg

PROCESSOR STUDY

Embedded	Data Storage	Power draw	UART	Interrupts	Clock Management	Power States	Development Environment	Debug	NRE
STM32F0 (M0)	8kb	4mA	2	32	Yes	Sleep + awake	Eclipse + GCC	Eclipse	low
STM32L (M3)	16 kb	2 mA	3	32	Yes	Low power sleep + awake	Eclipse + GCC	Eclipse	low
Arduino	86 kb	13mA	4	Yes	Yes	Sleep + awake	Arduino	Arduino	very low

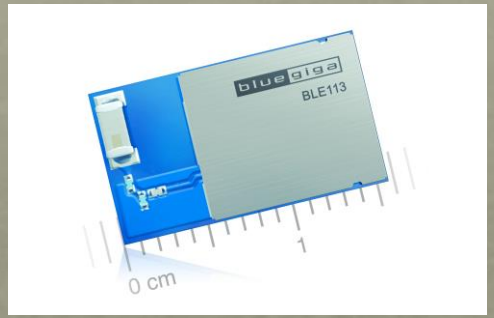
Selection: STM32L

http://elektronikab2b.pl/images/stories/Jnc9NDg0Jmg9MzI5/71450:STML_top.jpg

BLUETOOTH STUDY

Bluetooth	Power Draw (@ 0dB TX)	TX distance	BlueTooth Version	Baud Rate	Size (mm)	Security	Cost
RN42-XV	25mA	1 meter	2.1	9600+	20 x 10	128 bit	$20
BlueRadios (LE4.0-SA2)	27 mA	1 meter	4	9600+	18 x 12	128 bit	$13.95
LSR (TiWi-uB1)	20 mA	1 meter	4	9600+	11.6 x 17.9	AES 128	$13
Bluegiga (BLE113)	14mA	1 meter	4	9600+	14.5 x 9	128 bit	$16.56

Selection: BlueGiga BLE113



http://www.alcom.nl/01/images/logos/logos_h50/Bluegiga-BLE113_CMYK.jpg

PAIRWISE - ELECTRONICS

ELECTRONICS	Power Life	Power Source	Communication	Data Acquisition	Data Alert	Data Storage	Data Reset	Sampling Rate	Programming Langauge	Durability - Elec.	PCB Life	Multi Observational	Backup Radio	TOTAL	Percent
Power Life		1	1	0	1	1	1	1	1	1	1	1	1	11	0.846154
Power Source	0		0	0	1	0	1	1	1	0	1	1	1	7	0.538462
Communication	0	1		0	1	1	1	1	1	1	1	1	1	10	0.769231
Data Acquisition	1	1	1		1	1	1	1	1	1	1	1	1	12	0.923077
Data Alert	0	0	0	0		0	0	0	0	0	0	0	1	1	0.076923
Data Storage	0	1	0	0	1		1	1	1	0	1	1	1	8	0.615385
Data Reset	0	0	0	0	1	0		0	1	0	0	0	1	3	0.230769
Sampling Rate	0	0	0	0	1	0	1		1	0	0	1	1	5	0.384615
Programming Language	0	0	0	0	1	0	0	0		0	0	0	1	2	0.153846
Durability - Elec.	0	1	0	0	1	1	1	1	1		1	1	1	9	0.692308
PCB Life	0	0	0	0	1	0	1	1	1	0		1	1	6	0.461538
Multi Observational	0	0	0	0	1	0	1	0	1	0	0		1	4	0.307692
Backup radio	0	0	0	0	0	0	0	0	0	0	0	0		0	0

PAIRWISE - USER

USER CONCERNS	Location on Body	User Interface	Wearer Comfort	Self Contained	Aesthetics	Safety	Cost	Ethics	Legality	TOTAL	Percent
Location on Body		0	0	0	1	0	1	0	0	2	0.2222222
User Interface	1		0	1	1	0	1	1	0	5	0.5555556
Wearer Comfort	1	1		1	1	0	1	1	0	6	0.6666667
Self Contained	1	0	0		1	0	1	0	0	3	0.3333333
Aesthetics	0	0	0	0		0	0	0	0	0	0
Safety	1	1	1	1	1		1	1	1	8	0.8888889
Cost	0	0	0	0	1	0		0	0	1	0.1111111
Ethics	1	0	0	1	1	0	1		0	4	0.4444444
Legality	1	1	1	1	1	0	1	1		7	0.7777778

PAIRWISE – MECHANICAL

MECHANICAL ENCLOSURE	Size	Weight	Durability	Mechanical Life	TOTAL	Percent
Size		1	0	0	1	0.25
Weight	0		0	0	0	0
Durability - Mech.	1	1		0	2	0.5
Mechanical Life	1	1	1		3	0.75

REQUIREMENTS

- See Spreadsheet

BILL OF MATERIALS (BOM)

Ref.	Part name	Pcs/unit	Description	Manufacturer	Part number	Supplier	Cost / 1 qt.	cost / 1000	Ext / 1000
U1	STM32F051RCT6	1	ARM Core Low Power	STMicroelectronics	511-STM32F051R6T6	Digikey	$4.50	$1.00	$1.00
U2	AD627ARZ-R7	1	Instrumentation Amplifier	Analog Devices	AD627ARZ-R7CT-ND	Digikey	$6.22	$3.22	$3.22
U5	TPS62240DRVTG4	1	Regulator Switching (Digital)	Texas Instruments	595-TPS62240DRVTG4	Mouser	$1.52	$0.70	$0.70
U10	AS1337B-BTDT	1	Regulator Switching (Analog)	AMS	AS1337B-BTDTCT-ND	Digikey	$1.54	$0.72	$0.72
U8	ADP160AUJZ-2.5-R7	1	Linear (LDO)	Analog Devices	ADP160AUJZ-2.3-R7CT-ND	Digikey	$1.10	$0.47	$0.47
U9	LIS3DHTR	1	Accelerometer	ST	497-10613-1-ND	Mouser	$2.34	$0.99	$0.99
THERM1	PJ104J2	1	Thermistor	US Sensor	615-1006-ND	Digikey	$3.19	$1.45	$1.45
U3	BLE113-A-V1	1	BlueRadios Bluetooth Module	BlueGiga	1446-1028-ND	Digikey	$16.30	$13.65	$13.65
LED2	LOL29K-H2L1-24-Z	1	LED Orange	Vishay	78-TLMO1000	Mouser	$0.25	$0.15	$0.15
LED3	LSL29K-G1J2-1-Z	1	LED Red	Vishay	78-TLMS1000	Mouser	$0.25	$0.15	$0.15
R2,R3	RC0603JR-071KL	2	Resistor 1k 5%	Yageo	311-1.0KGRCT-ND	Digikey	$0.10	$0.02	$0.03
R7	RC0603JR-07560RL	1	Resistor 560 Ohm 5%	Yageo	311-560GRCT-ND	Digikey	$0.10	$0.02	$0.02
R4	RC0603JR-07100KL	1	Resistor 100k 5%	Yageo	RC0603JR-07100KL	Digikey	$0.10	$0.02	$0.02
R1	RC0603JR-0710KL	1	Resistor 10k 5%	Yageo	311-10KGRCT-ND	Digikey	$0.10	$0.02	$0.02
R5, R6	ERA-6AEB105V	2	Resistor 0.1% Divider Vbat	Panasonic	P1MDACT-ND	Digikey	$0.43	$0.06	$0.12
C13	GRM1885C2A221JA01D	1	Capacitor 220pF	Murata	81-GRM185C2A221JA01D	Mouser	$0.11	$0.02	$0.02
R10	RC0603JR-07560KL	1	Resistor 5% 560k Divider Reg Analog	Yageo	311-560KGRCT-ND	Digikey	$0.10	$0.02	$0.02
R11	RC0603JR-07470KL	1	Resistor 5% 470k Divider Reg Analog	Yageo	311-470KGRCT-ND	Digikey	$0.10	$0.02	$0.02
R9	ERJ-6ENF2703V	1	Resistor 1% 270k Divider Reg Digital	Panasonic	P270KCCT-ND	Digikey	$0.23	$0.03	$0.03
R8	ERJ-P06F6653V	1	Resistor 1% 665k Divider Reg Digital	Panasonic	P16077CT-ND	Digikey	$0.10	$0.01	$0.01
R12	ERA-6AEB8063V	1	Resistor 806k 0.1%	Panasonic	P806KDACT-ND	Digikey	$0.43	$0.06	$0.06
R14	ERA-6AEB2672V	1	Resistor 26.7k 0.1%	Panasonic	P26.7KDACT-ND	Digikey	$0.43	$0.06	$0.06
R13	ERA-6AEB104V	1	Resistor 100k 0.1%	Panasonic	P100KDACT-ND	Digikey	$0.43	$0.06	$0.06
C1, C6, C10, C7, C15, C12, C2	GRM188R71E104JA01D	7	Capacitor 100nF 0603	Murata	81-GRM188R71E104JA01D	Mouser	$2.24	$0.04	$0.26
C18, C3	GRM188R60J475KE19D	2	Capacitor 4.7uF 0603	Murata	81-GRM18R60J475KE19D	Mouser	$0.32	$0.04	$0.07
C19	GRM188R71H103JA01J	1	Capacitor 10nF 0603	Murata	81-GRM18R71H103JA01J	Mouser	$0.32	$0.04	$0.04
C20, C8, C9	GRM188R61C105KA93D	3	Capacitor 1uF 0603	Murata	81-GRM39R105K16	Mouser	$0.96	$0.04	$0.11
C4	GRM1885C2A330JA01D	1	Capacitor 33pF 0603	Murata	81-GRM1885C2A330JA01	Mouser	$0.32	$0.03	$0.03
C11, C5	GRM188R60J106ME47D	**2**	Capacitor 10uF 0603	Murata	81-GRM188R60J106ME47	Mouser	$0.64	$0.08	$0.15
C14	GRM219R60J106KE19D	**1**	Capacitor 10uF 0805	Murata	81-GRM219R60J106KE9D	Mouser	$0.32	$0.07	$0.07
C16	GRM21BR60J226ME39L	**1**	Capacitor 22uF 0805	Murata	81-GRM21R60J226ME39L	Mouser	$0.32	$0.08	$0.08
D1, D2	DB2S30800L	**2**	Schottky Diode	Panasonic	DB2S30800LCT-ND	Digikey	$0.48	$0.04	$0.09
L1	LQM2HPN2R2MJ0L	**1**	Inductor 2.2uH 1008	Murata	81-LQM2HPN2R2MJ0L	Mouser	$0.40	$0.18	$0.18
L2	MOS6020-472MLB	1	Inductor 4.7uH	Coilcraft	MOS6020-472MLB	Coilcraft	$0.98	$0.43	$0.43
							Prototype		Bulk
							$42.77		$24.50