SELP 695/696 integrative Project/Thesis

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CREATING AN AIR-CLEANING CAT LITTER BOX USING SYSTEM ENGINEERING APPROACH

Overview

- Project Plan
  - Objective
  - Merit & Description
  - Outline
  - Ethics
  - Information & tools
  - Assumption
- Requirement decomposition
  - Objective
  - Requirement: 1st iteration
  - Trade study: method of air purification
  - Risk Analysis: odor detection sensor
  - Requirement: 2nd iteration
  - Trade study: Method of occupancy detection
  - Risk Analysis: Occupancy detection sensor
  - Power budget
  - Requirement: 3rd iteration

Overview (Cont.)

- Architecture Definition
  - Objective
  - OV1: high level operational concept graphic
  - OV2: operational node connectivity description
  - OV3: operational information exchange Matrix
  - OV5: operational activity model
  - SV1: system interface description
  - SV8: system evolution description
- Product Integration and Test
  - Objective
  - Activity description
  - Integration and test flow
- Lessons learned
  - Objective
  - Final Schedule
  - Requirements vs. Enhancements
  - Simulation vs. Reality
  - Integration Difficulties
  - Conclusion

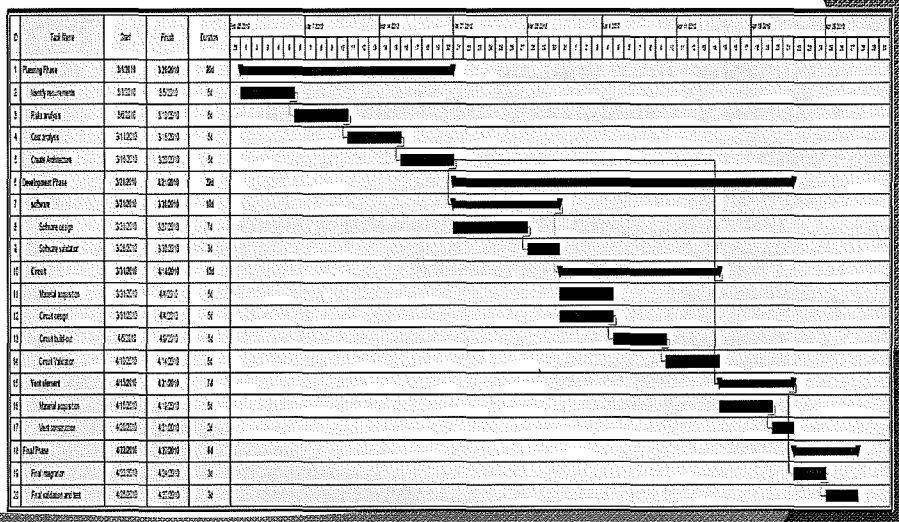
Project Plan:
Objective

- Dealing with Cat litter box
  - Strong unpleasant odor from excrement
  - Strong over-bearing odor from cat litter
  - Dust participles induced irritation
- Reduce or eliminate above undesirable traits

Project plan:
Merit & Description

- Merit
  - Electrical engineering skills
  - Computer engineering skills
  - System engineering skills
- System of Systems Description
  - Software codes in processor as a system
  - Processor, sensor, power units as a system
  - Vent and filtration as a system
  - Together form a system of systems

Project Plan:
Preliminary Outline



Project Plan:
Ethics

- No questionable behaviors arise from Project's standpoint
- Will consider a disposal method that has less impact on the environment

Project Plan:
Information & tools

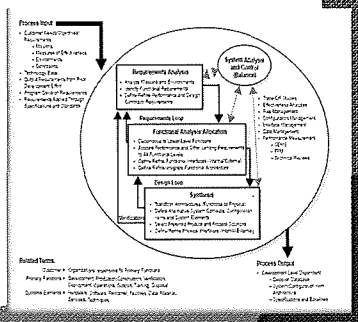
- Information
  - Gathered from internet
  - Conduct research and test if necessary
- Tools
  - Software
    - MS Office: Word, Excel, PowerPoint, Visio
    - PICAXE Programming Editor
  - Hardware
    - Breadboard
    - Digital multi-meter
    - Soldering Iron
    - Saw

Project Plan:
Assumption

- Project is not for mass production
  - will not address manufacturing aspect
  - Limited funding
  - No Stereo Lithography Apparatus (SLA)
  - No injection molding
  - Prototype grade
  - Demonstration purpose
- Not all aspect of system engineering can be applied
  - No operational & maintenance phase from "V" model
  - No operational handbook
  - No technical support

Requirement Decomposition:
Objective

- Show how top level requirements get broken down into functional and technical requirements
- Multiple iteration approach will be used
  - Mimic system engineering process loop
  - Trade off studies or risk analysis in between each iteration



Requirement Decomposition: 1st iteration

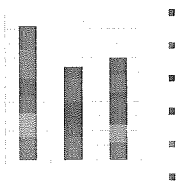
1	The cat litter box shall reduce the smell of excrement.
1.1	The cat litter box shall incorporate an air-cleaning system.
2	The cat litter box shall not frighten the cat.
2.1	The air-cleaning system shall not be enabled when the cat litter box is in use.
2.1.1	There shall be a sensor so that the air-cleaning system can identify cat's presence.
2.1.2	The program shall not activate the air-cleaning system if cat's presence is identified.
3	The cat litter box shall be capable of being placed anywhere in the house
3.1	The air-cleaning system shall be self-contained.

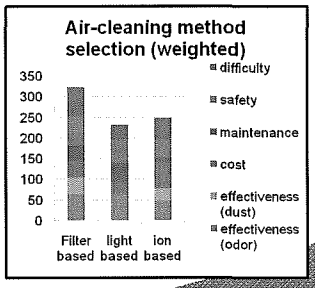
Requirement Decomposition:
Trade Study on Method of Air Purification

- Candidates
  - High Efficiency Particulate Absorbing (HEPA)/active carbon filter
  - Ultraviolet Germicidal Irradiation (UVGI)/ Photo-Catalytic Oxidation (PCO)
  - Ionizer purifier
- Methodology
  - Effectiveness against odor
  - Effectiveness against dust
  - Cost
  - Maintenance
  - Safety
  - Implementation difficulty

Requirement Decomposition:
Trade Study on Method of Air Purification (Cont.)

criterion	weight	Filter based	(weighted)	light based	(weighted)	ion based	(weighted)
effectiveness (odor)	8	8	64	8	64	6	48
effectiveness (dust)	5	8	40	0	0	6	30
cost	7	6	42	4	28	9	63
maintenance	6	6	36	8	48	2	12
safety	7	10	70	8	56	6	42
difficulty	9	8	72	4	36	6	54
total		46	374	32	232	35	249





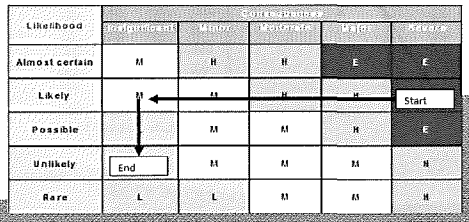
Requirement Decomposition:
Risk Analysis on Odor Detection Sensor

- Dilemma
  - No general smell/odor sensor in marketplace
  - Fecal odors are a complex mixture of compounds
- Assessment
  - Consequences: Severe. That's the main objective of this project
  - Likelihood: likely. Searching the internet found no fecal odor sensor.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	Start
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

Requirement Decomposition:
Risk Analysis on Odor Detection Sensor (Cont.)

- Mitigation Plan
  - Consequence mitigation
    - Detect cat's exit should be sufficiently effective
    - Risk is reduced from severe to insignificant
  - Likelihood mitigation
    - Human nose to perform smell test to adjust system on time duration, fan speed, filter, etc.
    - Risk is reduced from likely to unlikely



Requirement Decomposition: 2nd iteration

1	The cat litter box shall reduce the smell of excrement.
1.1	The cat litter box shall incorporate an air-cleaning system.
1.1.1	The air-cleaning system shall re-circulate air inside the litter box.
1.1.1.1	There shall be two vents on top of the box: One (1) to intake air from the box and one (1) to exhaust air back into the box. A shaft shall connect the two vents.
1.1.1.2	There shall be a door at the entrance for cat access; the door keeps air within the box.
1.1.1.3	There shall be a replaceable filter with a powered fan contained within the vents shaft
1.1.1.4	There shall be a microcontroller to govern the power of the fan.
2	The cat litter box shall not frighten the cat.
2.1	The air-cleaning system shall not be enabled when the cat litter box is in use.
2.1.1	There shall be a sensor so that the air-cleaning system can identify cat's presence.
2.1.2	The program shall not activate the air-cleaning system if cat's presenceis identified.
3	The cat litter box shall be capable of being placed anywhere in the house
3.1	The air-cleaning system shall be self-contained.
3.1.1	The air-cleaning system shall re-circulate air inside the litter box.
3.1.2	The air-cleaning system shall provide its own power source.

Requirement Decomposition:

Trade Study on Method of Occupancy Detection

- Candidates
  - Contact switch
  - Piezo vibration sensor
  - Reflectance sensor
  - Infrared proximity sensor
  - Ultrasound range finder

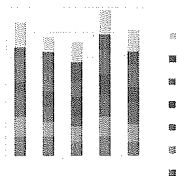
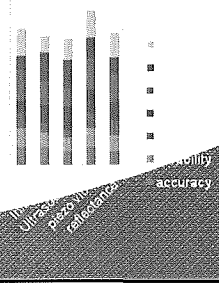



- Methodology
  - Accuracy of detection
  - Durability of sensor over product's life
  - Sensor cost
  - Robustness against fault until intervention (i.e. cleaning)
  - Safety of pet
  - Implementation difficulty
  - Power consumption

Requirement Decomposition:

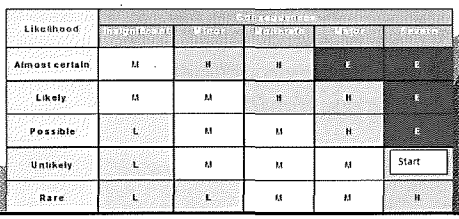
Trade Study on Method of Occupancy detection (Cont.)

criterion	weight	Contact	(weighted)	Infrared	(weighted	Ultrasound	(weighted	piezo vibe	(weighted	reflectance	(weighted
accuracy	6	8	48	8	48	6	36	8	48	6	36
durability	6	8	48	6	36	6	36	8	48	7	42
cost	4	10	40	6	24	4	16	9	36	9	36
robustness	8	4	32	6	48	8	64	8	64	6	48
safety	8	10	80	8	64	6	48	10	80	9	72
difficulty	9	4	36	8	72	8	72	6	54	5	45
consumption	7	10	70	6	42	8	56	10	70	9	63
Total			354		334				400		

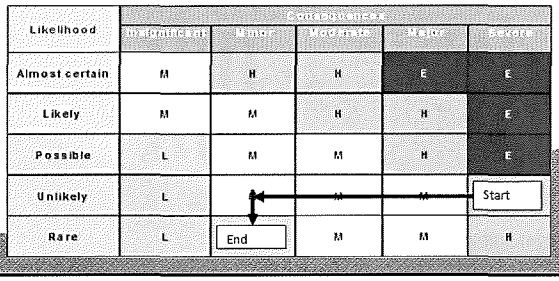
Requirement Decomposition:
Risk Analysis on Occupancy Detection Sensor

- Dilemma
  - Possible incompatibility with microcontroller setup
  - Lack of experience and technical know-how
- Assessment
  - Consequences: Severe. This hinders mitigation plan for the lack of odor detector sensor. Also, the requirement to avoid scaring of the cat is not met.
  - Likelihood: unlikely. Datasheet and users of this sensor shows fairly simple installation.



Requirement Decomposition:
Risk Analysis on Occupancy Detection Sensor (Cont.)

- Mitigation Plan
  - Consequence mitigation
    - Use next best sensor: contact switch
    - Risk is reduced to minor
  - Likelihood mitigation
    - Consult domain expert
    - Risk is reduced to rare



Requirement Decomposition:
Power Budget

- 3 sections:
  - Power consumed (-)
  - Power Source (+)
  - Power requirement (=)

Power consumed (max speed):	nomeceture	Voltage	Amp	Watt
Fan	Antec 3 Speed 120mm fan	12	0.5	6
microcontroller	PIC18F1XK22	5	0.095	0.475
occupancy sensor	MEAS SEN-09196	0	0	0
DC-DC converter	LM7805	12	0.005	0.06
Mosfet	IRF510	0.27	0.5	0.135
Total				6.67
error margin	20%			8.004
Power source:	amount	Voltage	Amp*Hour	Watt*Hour
"D" battery in series	8	12	12	144
Power requirement:				
number of times used a day	2			
duration (in minute) per used	30			
number of days before replcing battery	17.9910045			

Requirement Decomposition:
3rd iteration

1	The cat litter box shall reduce the smell of excrement.
1.1	The cat litter box shall incorporate an air-cleaning system.
1.1.1	The air-cleaning system shall re-circulate air inside the litter box.
1.1.1.1	There shall be two vents on top of the box: One (1) to intake air from the box and one (1) to exhaust air back into the box. A shaft shall connect the two vents.
1.1.1.2	There shall be a door at the entrance for cat access; the door keeps air within the box.
1.1.1.3	There shall be a replaceable filter with a powered fan contained within the vents shaft
1.1.1.4	There shall be a microcontroller to govern the power of the fan.

Requirement Decomposition: 3rd iteration (Cont.)

2	The cat litter box shall not frighten the cat.
2.1	The air-cleaning system shall not be enabled when the cat litter box is in use.
2.1.1	There shall be a sensor so that the air-cleaning system can identify cat's presence.
2.1.1.1	There shall be a piezo vibe sensor on the door connected to the microcontroller as an input.
2.1.2	The program shall not activate the air-cleaning system if cat's presence is identified.
2.1.2.1	The program shall keep track of door contact sensor increments counts.
2.1.2.2	The program shall not activate the air-cleaning system during odd counts.
2.1.2.3	The program shall activate the air-cleaning system during even counts for a set duration.

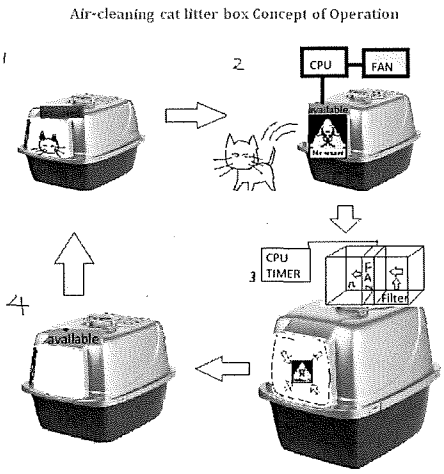
Requirement Decomposition: 3rd iteration (Cont.)

3	The cat litter box shall be capable of being placed anywhere in the house
3.1	The air-cleaning system shall be self-contained.
3.1.1	The air-cleaning system shall re-circulate air inside the litter box.
3.1.2	The air-cleaning system shall provide its own power source.
3.1.2.1	8 "D" alkaline batteries shall sustain the air-cleaning system.
3.1.2.2	The power source shall sustain the system for 14 days.

Architecture Definition:
Objective

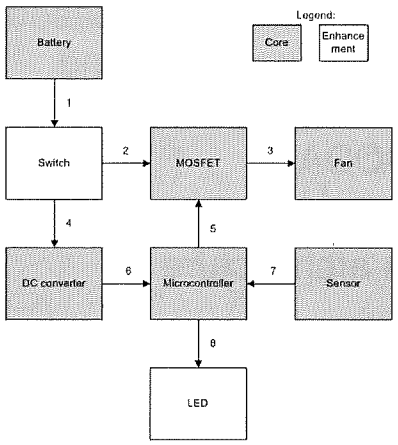
- Create a system architecture based on requirements decomposed using Department of Defense Architecture Framework (DODAF)
- Outline interfaces among all the systems involved in the architecture

Architecture Definition:
High-Level Operational Concept Graphic (OV-1)



Architecture Definition:

Operational Node Connectivity Description (OV-2)



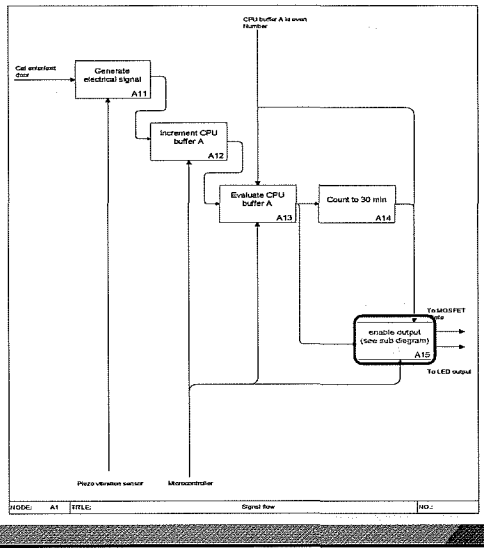
Architecture Definition:

Operational Information Exchange Matrix (OV-3)

Need Line ID	From node	To node	Category	Type	Frequency	Voltage
1	Battery	MOSFET	Power	DC	constant	12V
2	Battery	MOSFET	Power	DC	constant	12V
3	MOSFET	Fan	Power	DC	switched	12V
4	Battery	DC converter	Power	DC	constant	12V
5	Microcontroller	MOSFET	Signal	DC	switched	5V
6	DC converter	Microcontroller	Power	DC	constant	5V
7	Sensor	Microcontroller	Signal	AC	pulse	<5V
8	Microcontroller	LED	Power	DC	switched	5V

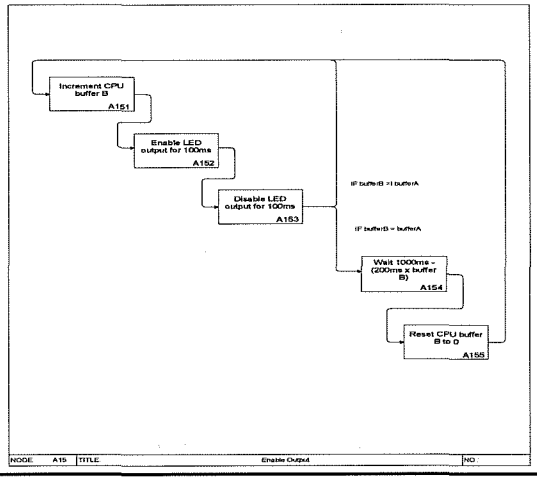
Architecture Definition:
Operational Activity Model (OV-5)

- Signal flow



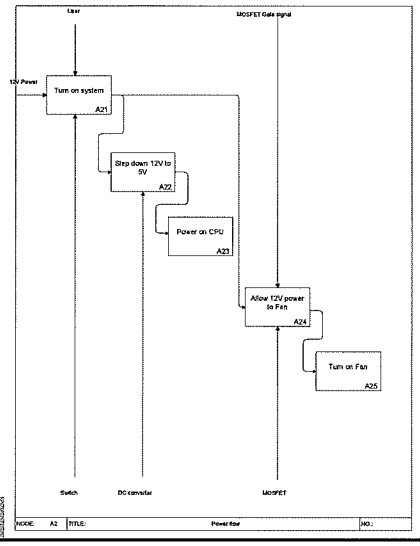
Architecture Definition:
Operational Activity Model (OV-5)

- Enable Output sub-diagram

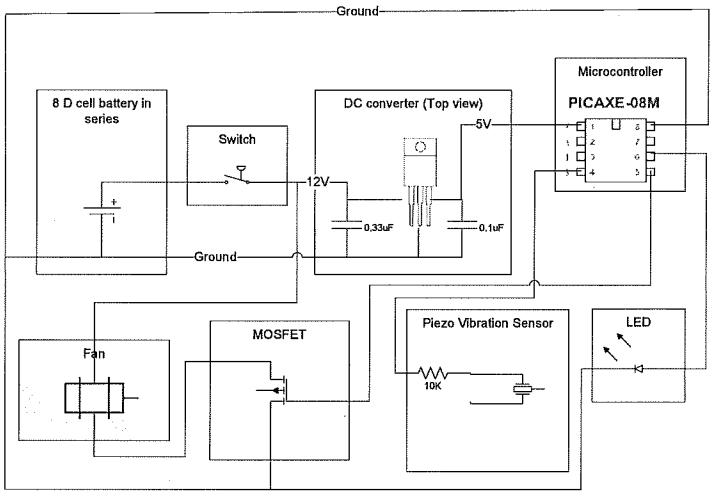


Architecture Definition:
Operational Activity Model (OV-5)

- Power flow

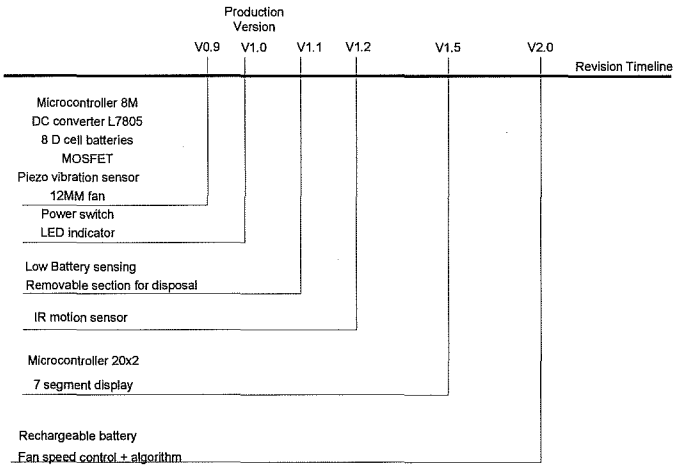


Architecture Definition:
System Interface Description (SV-1)



Architecture Definition:

System Evolution Description (SV-8)



Product Integration and Test:

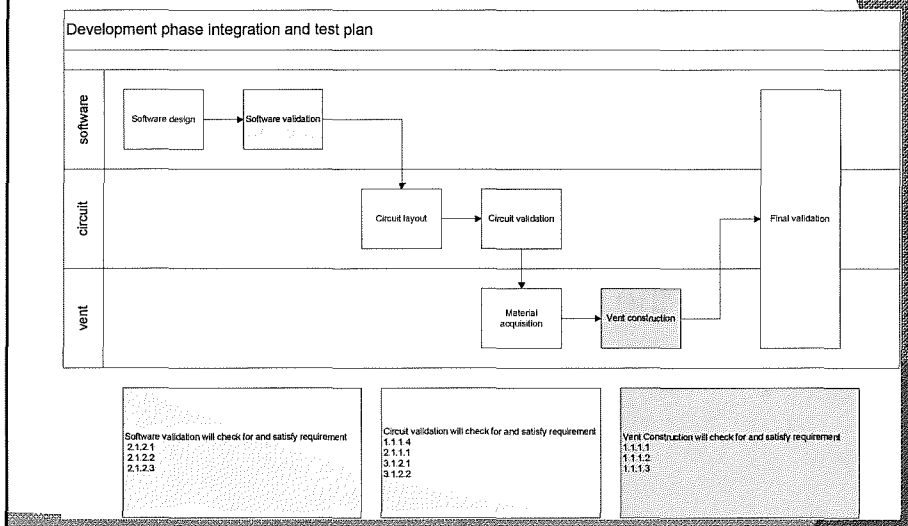
Objective

- Identify what activities need to happen in order to create the product
- Identify the order of executions of those activities
- Identify all requirements are being satisfy with the tests/activities

Product Integration and Test:
Activity Description

- Software Design
  - develop codes based on the signal flow established in OV-5
  - Explore coding language and determine best approach to achieve the desired result
- Software Validation
  - Ensure programming code performs to meet requirements
  - Ensure code will not produce undesired effect under normal operation
  - Ensure code will not crash due to out-of-ordinary scenarios
- Circuit layout
  - Develop physical location of all electrical components
- Circuit validation
  - Ensure all electrical paths are wired correctly
  - Ensure all inputs and outputs are performed as expected
  - Characterize power consumption during idle phase and fan-on phase to ensure power requirements are met
- Material acquisition
  - Acquire materials needed for vent construction
- Vent construction
  - Build vent and vent box
  - Ensure vent is suitable for air circulation
  - Ensure Filter element are replaceable
  - Ensure door is operational
- Final Validation
  - Ensure the system as a whole functions properly and satisfies all the main requirements
  - Perform calibration and adjustment to software and hardware if necessary

Product Integration and Test:
Integration and Test Flow



Lessons Learned:
Objective

- Compare initial (predicted) and final (actual) schedule
- Identify issues that caused the delays
- Offer an suggestions that could reduce or eliminate the issues encountered

Lessons Learned:
Final Schedule vs. Preliminary Schedule

	planned				actual			
	task	start	end	duration	start	end	duration	Δ
Planning phase								
	project plan	1-Mar	5-Mar	5	1-Mar	3-Mar	3	0.6
	requirement	6-Mar	15-Mar	10	4-Mar	24-Mar	21	2.1
	architecture	16-Mar	20-Mar	5	25-Mar	22-Apr	29	5.8
development phase								
	software design	21-Mar	27-Mar	7	23-Apr	25-Apr	3	0.4
	software validation	28-Mar	30-Mar	3	26-Apr	30-Apr	5	1.7
	circuit layout	31-Mar	9-Apr	10	1-Aug	30-Aug	30	3.0
	circuit validation	10-Apr	14-Apr	5	1-Sep	27-Sep	27	5.4
	vent material	15-Apr	19-Apr	5	28-Sep	4-Oct	7	1.4
	vent construction	20-Apr	21-Apr	2	5-Oct	20-Oct	16	8.0
final phase		22-Apr	27-Apr	6	21-Oct	6-Nov	17	2.8
	Total			58			158	

- Takes 3 times as long to complete the project
  - In delta column red shows exceed preliminary estimate, green show on time
  - Problems encountered throughout the project

Lessons Learned:

Requirements vs. Enhancements

- Enhancements are double-edge sword
  - Power switch
    - Not a requirement
    - Convenient and provide quick way to shutdown
  - LED
    - Provides feedback to user
    - If excluded it could eliminate the microcontroller's interrupt dropout issue
- Must choose wisely to prevent over-engineering

Lessons Learned:

Simulation vs. Reality

- Simulation is a great tool in SE
  - Predict system outcome in different scenarios
  - Test new ideas before execution
- Simulation has limitation
  - Simulated LED flashing sequence work flawlessly
  - Circuit validation show LED flashing out of spec.
  - Additional code needed in reality for hardware to perform as expected
- Implement "Test as you fly" to minimize unexpected simulation limitation

Lessons Learned:

Integration difficulties

- Piezo vibration sensor not sensing correctly
  - Test well in circuit validation, but not with door
  - Developed new code to troubleshoot
  - Added additional circuit and changed detection method from digital to analog
  - Re-route to a different pin of microcontroller and re-write code for analog input
    - Created a resource problem for the interrupt and LED flashing sequence
  - Second microcontroller are installed to read the sensor exclusively, interface with the original microcontroller

Lessons Learned:

Integration difficulties (Continued)

- Bonding material failure
  - "Crazy Glue" used for vent box construction
  - Different type of plastics on litter box
  - Had to remove residual of old glue and apply silicon sealant
- Perform "Pathfinder" activities to reduce the impact of revising architecture or even requirements

Conclusion

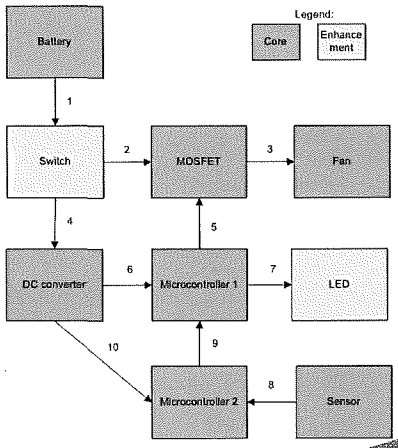
- System Engineering was developed to manage complex projects
  - Space shuttle program
  - Microprocessor
- SE can be apply to any project
  - This project is lot less complex
  - Benefitted from SE equally
- SE process loop
  - Apply lessons learned into next cycle

Demonstration

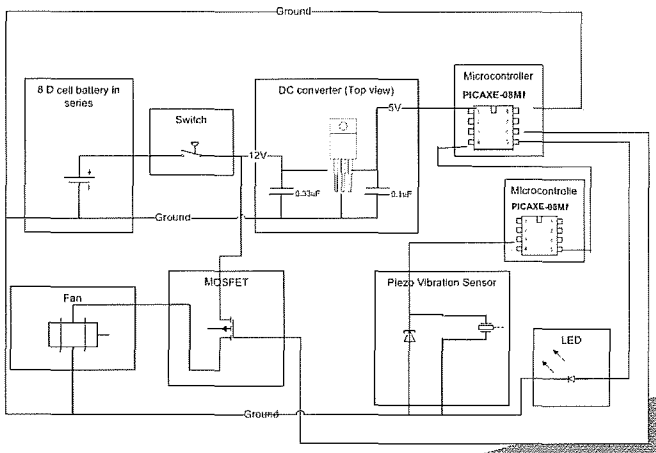
- Questions?

Back up slides

Latest OV2



Latest SV1


Ground
8 D cell battery in series
Switch
DC converter (Top view)
12V
5V
0.33uF
0.1uF
Microcontroller
PICAXE-08M
Microcontrolle
PICAXE-08M
Ground
Fan
MOSFET
Piezo Vibration Sensor
LED
Ground