Florida Light and Power

Image Recognition for Pad Mounted Equipment

Concept Selection

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1. **Binary Pairwise Comparison**
    a. **Customer Requirements**
    The customer requirements were derived from the previous customer needs. The primary requirements for the hardware beacon were an inexpensive design, quick installation, binary signal input, non invasive and weather proof design, a long lifespan, and compatibility with transformers. The primary requirement for the computer vision system was its confidence in making quick and accurate detections.

Inexpensive	Quick Installation	Binary Signal	Non Invasive	Weatherproof	Confidence	Long Lifespan	Compatible With Transformer	Sum
-	1	0	0	0	1	0	0	2
0	-	0	0	0	1	0	0	1
1	1	-	0	1	1	1	0	5
1	1	1	-	1	1	1	0	6
1	1	0	0	-	1	1	0	4
0	0	0	0	0	-	1	0	1
1	1	0	0	0	0	-	0	2
1	1	1	1	1	1	1	-	7

2. **House of Quality**
    a. **Engineering Characteristics**
    From the customer requirements, nine engineering characteristics were determined. Characteristics of the beacon include its visibility, lifespan, that it's sufficiently powered by the transformer's voltage, that it has an on and off state, and finally its installation time. Characteristics of the computer vision system include the model confidence and runtime, notification success, and data storage capacity.

    b. **Importance Weight Factor**
    An importance weight factor was determined for each of the customer requirements in order to determine a hierarchy of importance. The

most important requirement of the design is to be *Compatible With the Transformer*. Since ultimately the goal of the beacon is to integrate with the transformer to indicate faults without damaging its structural integrity, without this compatibility the design would be useless. The second most important requirement is to be *Non Invasive*− as a beacon that interferes with the transformer's normal functions is an undesirable and potentially harmful addition. The next most important requirement is the successful use of a *Binary Signal.* The transformer will provide a binary signal by powering the device, which must be received to ensure proper functionality. Next, comes a *Weatherproof* design, so it can be detected, protect the transformer, and remain functional in all Florida weather conditions. Then, comes two requirements tied in importance: that the device is *Inexpensive* and the beacon has a *Confidence* of over 80%. These beacons are intended to be placed on thousands of pad mounted equipment and should be relatively inexpensive to produce. Furthermore, in addition to having an effective beacon the computer recognition system must also be able to detect the beacon with significant accuracy and confidence. Finally, the last two requirements are a *Quick Installation* and a *Long Lifespan*. Quick installation is important for simplifying the process of adding the beacon to equipment and a long lifespan will ensure the beacons continue to work effectively to reduce maintenance costs.

House of Quality										
	Units	ft	years	V	0/1	%	frames/s	%	Mb	hrs
Customer Requirements	Importance Weight Factor	Visibility of Beacon	Beacon lifespan	Voltage sufficiently powers beacon	Beacon is on or off	Model confidence	Model runtime	Notification success	Storage capacity	Installation time
Inexpensive	2		3			9	9		3	3
Quick Installation	1									9
Binary Signal	5	3		9	9					
Non Invasive	6									
Weatherproof	4	3	1							
Confidence	2	9	1	9	9	9	9			
Long Lifespan	1		9							
Compatible With Transformer	7	1		3	3					
Raw Score	334	52	21	84	84	36	36	0	6	15
Relative Weight %		15.57	6.29	25.15	25.15	10.78	10.78	0.00	1.80	4.49
Rank Order		2	4	1	1	3	3	7	6	5

c. **House of Quality Results**

The House of Quality Chart is intended to rank engineering characteristics based on the relative importance of the different customer requirements. The first step is to determine the Importance Weight Factor of each customer requirement, which was accomplished using the Binary Pairwise Comparison Chart. The rest of the cells contain a value to indicate how much the characteristic contributes to each customer requirement. These values are on a scale with values 1, 3, 5, 7, 9 to exaggerate the results. Values in each row are multiplied by the corresponding Importance Weight Factor and the weighted sum is totalled down each column. These raw scores were added together and the relative weight (%) of each was determined by dividing its raw score by the sum of the raw scores. This was used to determine a rank order of engineering characteristics from most to least important: (1) Voltage sufficiently powers beacon, (1) Beacon is on or off, (2) Visibility of Beacon, (3) Model Confidence, (3) Model Runtime, (4) Beacon Lifespan, (6) Storage capacity, and (7) Notification success.

3. Pugh Charts

Two datums were selected for the first Pugh Chart: a lighthouse to compare hardware beacon options, and the Faster R-CNN algorithm to compare software options. After the first Pugh Chart, the software algorithm became an irrelevant comparison factor. All of the eight designs used YOLOv5 to perform object detection, as it is the current algorithm used by FPL in other object detection cases. Its accuracy and speed are also ideally suited for this project. After the first chart, the two least viable options (to cool the transformer lid with an internal device for infrared detection and to use strips of cooled stainless steel wrapped around the transformer edges) were removed. The option of a stainless steel flap that opens with transformer power was decided as datum for the next chart. After the second Pugh Chart, the option to use a plastic LED beacon was discarded. An external thermal device was decided as the datum for the final Pugh Chart. From this third Pugh Chart, the design with the highest final score was originally the fifth design option. It consists of mounting an LED on top of a stainless steel lever that lifts to indicate a fault.

Selection Criteria	Lighthouse	Faster R-CNN	Concepts 1	2	3	4	5	6	7	8
Voltage sufficiently powers beacon	Datum	Datum	+	+	+	-	+	-	+	-
Beacon is on or off			s	-	s	-	s	-	+	-
Visibility of Beacon			-	-	-	-	+	s	-	s
Model confidence			s	s	s	s	s	s	s	s
Model runtime			+	+	+	+	+	+	+	+
Beacon lifespan			+	+	-	-	-	-	-	-
Installation time			+	+	+	s	+	+	s	-
# of pluses			4	4	3	1	4	1	3	1
# of minuses			1	2	2	4	1	3	2	4
# of same			2	1	2	2	2	2	2	2

Legend	
1	Transformer-powered plastic LED attached using a polyurethane sealant. Corresponding image recognition system that takes in RGB video uses trained YOLOv5 to make detections
2	Stainless steel external device that cools with transformer power and is attached with rivets. Computer vision system analyzes infrared videos using YOLOv5
3	Stainless steel mechanical flap that opens up with transformer power and is attached with rivets. Computer vision system analyzes RGB videos using YOLOv5
4	Cool the transformer lid with an internal device and detect the cooled lid with infrared video input using YOLOv5
5	Mount an external LED on the top of a stainless steel lever attached using rivets and powered by the transformer and infrared video input with YOLOv5 algorithm
6	External cooled rod made of stainless steel (or same metal as transformer) and infrared video input with YOLOv5 algorithm
7	Side rod of stainless steel powered by transformer. When fault is detected it is raised and RGB video is captured to be processed with the YOLOv5 algorithm
8	Strips of stainless steel wrap around edges and are cooled by the transformer. Infrared video is captured and beacon is detected with YOLOv5

		Concepts				
Selection Criteria	Concept 3	1	2	5	6	7
Voltage sufficiently powers beacon	Datum	+	-	s	-	s
Beacon is on or off		s	s	+	-	s
Visibility of Beacon		s	-	+	-	-
Model confidence		s	s	+	s	s
Model runtime		s	s	s	s	s
Beacon lifespan		+	+	s	+	+
Installation time		s	-	s	-	s
	# of pluses	2	1	3	1	1
	# of minuses	0	3	0	4	1
	# of same	5	3	4	2	5

Legend	
1	Transformer-powered plastic LED attached using a polyurethane sealant. Corresponding image recognition system that takes in RGB video uses trained YOLOv5 to make detections
2	Stainless steel external device that cools with transformer power and is attached with rivets. Computer vision system analyzes infrared videos using YOLOv5
3	Stainless steel mechanical flap that opens up with transformer power and is attached with rivets. Computer vision system analyzes RGB videos using YOLOv5
5	Mount an external LED on the top of a stainless steel lever attached using rivets and powered by the transformer and infrared video input with YOLOv5 algorithm
6	External cooled rod made of stainless steel (or same metal as transformer) and infrared video input with YOLOv5 algorithm
7	Side rod of stainless steel powered by transformer. When fault is detected it is raised and RGB video is captured to be processed with the YOLOv5 algorithm

		Concepts		
Selection Criteria	**Concept 2**	**1**	**5**	**6**
Voltage sufficiently powers beacon	Datum	+	+	s
Beacon is on or off		+	+	s
Visibility of Beacon		-	+	+
Model confidence		s	s	s
Model runtime		s	s	s
Beacon lifespan		-	-	s
Installation time		s	+	-
# of pluses		2	4	1
# of minuses		2	1	1
# of same		3	2	5

Legend	
1	Transformer-powered plastic LED attached using a polyurethane sealant. Corresponding image recognition system that takes in RGB video uses trained YOLOv5 to make detections
2	Stainless steel external device that cools with transformer power and is attached with rivets. Computer vision system analyzes infrared videos using YOLOv5
5	Mount an external LED on the top of a stainless steel lever attached using rivets and powered by the transformer and infrared video input with YOLOv5 algorithm
6	External cooled rod made of stainless steel (or same metal as transformer) and infrared video input with YOLOv5 algorithm

4. AHP

a. Pairwise Matrix

A Pairwise Matrix was created to compare the engineering characteristics against each other, using a scale of 1, 3, 5, 7, 9.

Pairwise Matrix	Visibility of Beacon	Beacon lifespan	Voltage sufficiently powers beacon	Beacon is on or off	Model confidence	Model runtime	Notification success	Storage capacity	Installation time
Visibility of Beacon	1	5	0.11	1	7	7	5	7	9
Beacon lifespan	0.2	1	0.2	0.2	3	3	0.2	7	7
Voltage sufficiently powers beacon	9	5	1	1	3	3	5	7	5
Beacon is on or off	1	5	1	1	7	7	1	9	7
Model confidence	0.14	0.33	0.33	0.14	1	7	1	5	7
Model runtime	0.14	0.33	0.33	0.14	0.14	1	0.14	0.2	0.33
Notification success	0.2	5	0.2	1	1	7	1	7	7
Storage compicity	0.14	0.14	0.14	0.11	0.2	5	0.14	1	5
Installation time	0.11	0.14	0.2	0.14	0.14	3	0.14	0.2	1
Sum	11.93	21.94	3.51	4.73	22.48	43	13.62	43.4	48.33

Normalized										
Pairwise Matrix (Normalized)	Visibility of Beacon	Beacon lifespan	Voltage sufficiently powers beacon	Beacon is on or off	Model confidence	Model runtime	Notification success	Storage capacity	Installation time	Criteria Weight { W }
Visibility of Beacon	0.08	0.23	0.03	0.21	0.31	0.16	0.37	0.16	0.19	0.19
Beacon lifespan	0.02	0.05	0.06	0.04	0.13	0.07	0.01	0.16	0.14	0.08
Voltage sufficiently powers beacon	0.75	0.23	0.28	0.21	0.13	0.07	0.37	0.16	0.10	0.26
Beacon is on or off	0.08	0.23	0.28	0.21	0.31	0.16	0.07	0.21	0.14	0.19
Model confidence	0.01	0.02	0.09	0.03	0.04	0.16	0.07	0.12	0.14	0.08
Model runtime	0.01	0.02	0.09	0.03	0.01	0.02	0.01	0.00	0.01	0.02
Notification success	0.02	0.23	0.06	0.21	0.04	0.16	0.07	0.16	0.14	0.12
Storage compicity	0.01	0.01	0.04	0.02	0.01	0.12	0.01	0.02	0.10	0.04
Installation time	0.01	0.01	0.06	0.03	0.01	0.07	0.01	0.00	0.02	0.02
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1

b. Design Alternatives

The next step included comparing the final three concepts against each other for each of the engineering characteristics. This matrix was then used to determine the gamma value, weighted sum vector, and consistency vectors for each characteristic.

See Appendix below.

c. Consistency Ratio

Calculating a consistency ratio ensures that a consistent ranking process was used for each concept. If all CR values were below 0.1 then the ranking process is consistent.

d. Winning Concept

As a final step, the Design Alternatives matrix was multiplied by the Design Alternatives Priorities P_i, which is the average of the normalized rankings. Based on these results, the lever mounted LED (Concept 5) was the winning idea.

Final Rating Matrix				
Selection Criteria	1	2	5	6
Visibility of Beacon	0.31	0.08	0.52	0.08
Beacon lifespan	0.1	0.37	0.17	0.37
Voltage sufficiently powers beacon	0.42	0.08	0.42	0.08
Beacon is on or off	0.22	0.09	0.59	0.09
Notification success	0.22	0.09	0.59	0.09
Installation time	0.12	0.41	0.41	0.07

Final Rating	
1	0.2467
2	0.1017
5	**0.4127**
6	0.0949

Legend	
1	Transformer-powered plastic LED attached using a polyurethane sealant. Corresponding image recognition system that takes in RGB video uses trained YOLOv5 to make detections
2	Stainless steel external device that cools with transformer power and is attached with rivets. Computer vision system analyzes infrared videos using YOLOv5
5	Mount an external LED on the top of a stainless steel lever attached using rivets and powered by the transformer and infrared video input with YOLOv5 algorithm
6	External cooled rod made of stainless steel (or same metal as transformer) and infrared video input with YOLOv5 algorithm

5. Final Selection

After completing the concept selection charts, Concept 5 was revealed as a clear leader. The design concept involving a lever that raises when powered by the transformer and has an LED mounted on the end provides more options for visibility. It changes the overall shape of the transformer when raised, and can be visualized using both RGB and Infrared cameras during both day and night time. Furthermore, it is minimally invasive to the inner workings of the transformer, and can be easily reset.

Appendix (Design Alternatives)

Legend	
1	Transformer-powered plastic LED attached using a polyurethane sealant. Corresponding image recognition system that takes in RGB video uses trained YOLOv5 to make detections
2	Stainless steel external device that cools with transformer power and is attached with rivets. Computer vision system analyzes infrared videos using YOLOv5
5	Mount an external LED on the top of a stainless steel lever attached using rivets and powered by the transformer and infrared video input with YOLOv5 algorithm
6	External cooled rod made of stainless steel (or same metal as transformer) and infrared video input with YOLOv5 algorithm

Comparison (Visibility of Beacon)				
	1	2	5	6
1	1	5	0.33	5
2	0.2	1	0.2	1
5	3	5	1	5
6	0.2	1	0.2	1
Sum	4.4	12	1.73	12

Comparison (Visibility of Beacon) Normalized					
	1	2	5	6	Weight { W }
1	0.23	0.42	0.19	0.42	0.31
2	0.05	0.08	0.12	0.08	0.08
5	0.68	0.42	0.58	0.42	0.52
6	0.05	0.08	0.12	0.08	0.08
Sum	1.00	1.00	1.00	1.00	1.00

Comparison (Beacon lifespan)				
	1	2	5	6
1	1	0.33	0.33	0.33
2	3	1	3	1
5	3	0.33	1	0.33
6	3	1	3	1
Sum	10	2.66	7.33	2.66

Comparison (Beacon lifespan) Normalized					
	1	2	5	6	Weight { W }
1	0.10	0.12	0.05	0.12	0.10
2	0.30	0.38	0.41	0.38	0.37
5	0.30	0.12	0.14	0.12	0.17
6	0.30	0.38	0.41	0.38	0.37
Sum	1.00	1.00	1.00	1.00	1.00

Comparison (Sufficient Voltage)				
	1	2	5	6
1	1	5	1	5
2	0.2	1	0.2	1
5	1	5	1	5
6	0.2	1	0.2	1
Sum	2.4	12	2.4	12

Comparison (Sufficient Voltage)					
	1	2	5	6	Weight { W }
1	0.42	0.42	0.42	0.42	0.42
2	0.08	0.08	0.08	0.08	0.08
5	0.42	0.42	0.42	0.42	0.42
6	0.08	0.08	0.08	0.08	0.08
Sum	1.00	1.00	1.00	1.00	1.00

Comparison (Beacon is on or off)				
	1	2	5	6
1	1	3	0.2	3
2	0.33	1	0.2	1
5	5	5	1	5
6	0.33	1	0.2	1
Sum	6.66	10	1.6	10

Comparison (Beacon is on or off)					
	1	2	5	6	Weight { W }
1	0.15	0.30	0.13	0.30	0.22
2	0.05	0.10	0.13	0.10	0.09
5	0.75	0.50	0.63	0.50	0.59
6	0.05	0.10	0.13	0.10	0.09
Sum	1.00	1.00	1.00	1.00	1.00

Comparison (Notification Success)				
	1	2	5	6
1	1	3	0.2	3
2	0.33	1	0.2	1
5	5	5	1	5
6	0.33	1	0.2	1
Sum	6.66	10	1.6	10

Comparison (Notification Success)					
	1	2	5	6	Weight { W }
1	0.15	0.30	0.13	0.30	0.22
2	0.05	0.10	0.13	0.10	0.09
5	0.75	0.50	0.63	0.50	0.59
6	0.05	0.10	0.13	0.10	0.09
Sum	1.00	1.00	1.00	1.00	1.00

Comparison (Installation Time)				
	1	2	5	6
1	1	0.2	0.2	3
2	5	1	1	5
5	5	1	1	5
6	0.33	0.2	0.2	1
Sum	11.33	2.4	2.4	14

Comparison (Installation Time)					
	1	2	5	6	Weight { W }
1	0.09	0.08	0.08	0.21	0.12
2	0.44	0.42	0.42	0.36	0.41
5	0.44	0.42	0.42	0.36	0.41
6	0.03	0.08	0.08	0.07	0.07
Sum	1.00	1.00	1.00	1.00	1.00