A Rugged Low-Cost Fractal Optical User Interface, Version 1.2

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One of the benefits of being retired is that I can spend as much time as I like on whatever I want. For the last few months, I periodically thought about a “better” interface for my eGas Gauge for my eBike[2]. My requirements were:

- Able to convey any integer from 0 to at least 9
- Rugged enough to survive being attached to a bicycle
- Cost under $1
- Visible in direct sunlight with sunglasses on
- Readable in under one second
- Compatible with an ATtiny85 system-on-a-chip (5V logic)
- Use only two wires
- Draws less than two milliamps on average

My first optical interface involved flashing a single red LED. I counted the flashes to determine the data. Trying to count up to 10 flashes was too distracting while riding my bike, but up to four flashes were acceptable. Taking a fractal approach, I flashed up to four times and then output a second set of up to four flashes. This worked but, after living it for a while, I found it too distracting.

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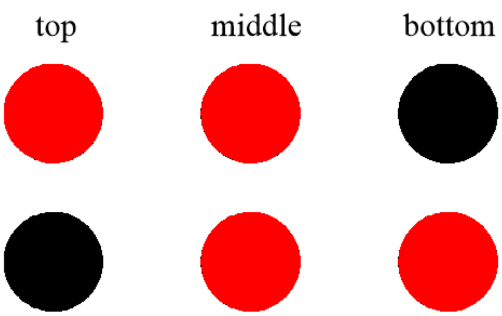
[2] See https://rick.sparber.org/eBikeGauge.pdf for the full story.

I then went to driving two LEDs. This scheme had two parameters: time and position.

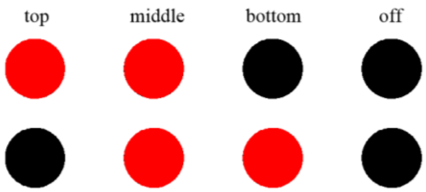
Time: I would flash up to four times to indicate the quarter.



Position: Which LEDs I flashed told me top, middle, or bottom within this quarter. For example, if the bottom LED flashed three times, it meant we were at the bottom of ¾. This format gave me the ability to convey any of 12 integers. I lived with this scheme for a few months but decided that even counting up to four flashes was a bit distracting.

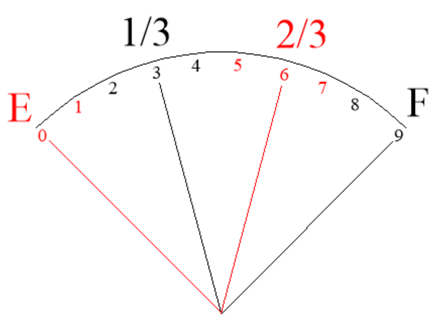
At first, I used a single red/green LED but discovered that my sunglasses blocked the green light.

My new scheme still uses two red LEDs, but there is no counting.



The two LEDs can convey four states. The meaning of these states depends on how long they are displayed. I display the "major" group four times longer than the "minor" group plus have both LEDs off for at least twice the sum of these times.

Specifically, the major group is displayed for 80 milliseconds, while the "minor" group gets 20 milliseconds. There are 200 milliseconds of darkness between them. After waiting 700 ms, the cycle repeats. These values were arrived at empirically.

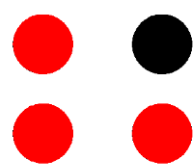


The major group can have the values of 3/3 (Full), 2/3, 1/3, or 0/3 (Empty)[3].

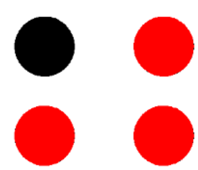
The minor group can have the values of above, at, or below nominal. Together, they convey the scale of my eGas gauge. Although I show integers in this figure, while on my eBike, I'm thinking more about where I am within the current third.

A few examples:

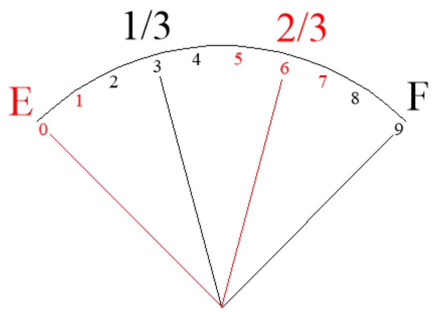
- I see both LEDs on for 80 ms, which means 2/3. The bottom LED is then on for 20 ms, which means below the nominal. In other words, I'm at the digit 5, as seen in the above figure.



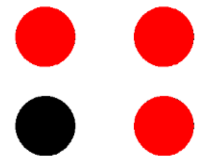
- I see the bottom LED on for 80 ms, which means 1/3. Then both LEDs are on for 20 ms, which means we are at the nominal. In other words, digit 3.



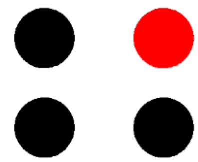
[3] At first I thought about this as top, middle, and bottom thirds but that is confusing. "Middle," for example, would be 2/3 but it is not in the middle.



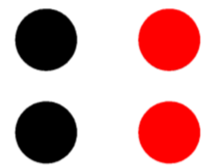
- When the top LED is on for 80 ms, and then both LEDs are on for 20 ms, it means we are at Full.



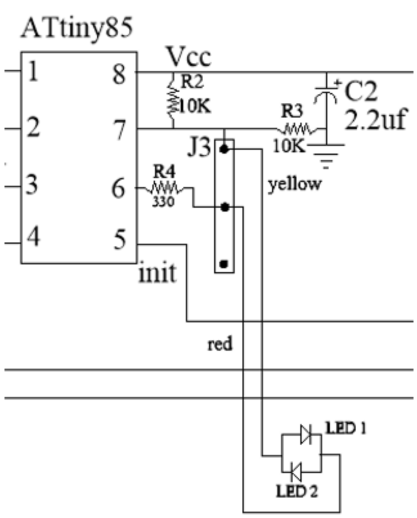
- When we only see the top LED on for 20 ms, it means we are just above Empty: 1.



- When we see both LEDs on for 20 ms, we are at Empty.



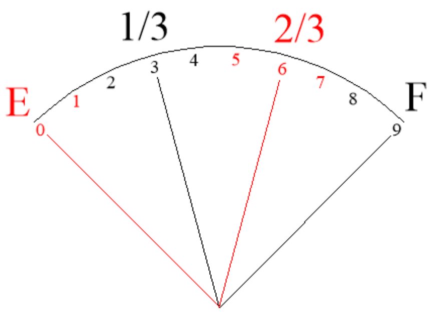
This sequence of flashes happens fast. Once I got used to the patterns, a glance caused the reading to pop into my head. It is the same as when you look at a familiar word and instantly know its meaning. You do not need to sift through the individual letters.



This portion of the schematic shows R4, LED1, and LED2. They are driven by an ATtiny85 system-on-a-chip. When pin 7 is at 5 volts, and pin 6 is at zero, LED1 lights and LED2 is dark. Make pin 7 zero and pin 6 at 5 volts and LED2 lights while LED1 is dark. When pins 6 and 7 are at the same voltage, both LEDs are off.

Being in one of these states for 20 milliseconds is sufficient for good visibility. I can also alternate states with each LED on for 5 milliseconds for a total of 20 milliseconds. The result is that both LEDs look like they are on at the same time.

When an LED is on, about 10 milliamps flows. The total on time is 100 milliseconds, and the cycle time is 1000 milliseconds. This means that the duty cycle is 10%. Our average current drain is therefore 10% of 10 milliamps or 1 milliamp. Power comes from 2200 mAh AA batteries, so they will last a long time.



The mapping from any number between 0 and 1 to the LEDs may not be obvious upon close inspection. Exactly where do you draw the line between 9ths? If the number is exactly 2/3, then clearly, we should show 6/9ths. But how much above 2/3rds should we go before saying it is 7/9ths?

Also, note that while 1/3 and 2/3 have three fractions in their range, Full and Empty have only two.

I arrived at this arrangement by first focusing on 1/3 and 2/3 and then seeing what was left over.

The result is that Full can either be 9/9ths or 8/9ths. In other words, Full can be middle or bottom but not top. Empty can be top or middle but not bottom. Any other configuration would cause the middle of 1/3 and 2/3 to not be at these values.

decimal value	9ths
1	9
0.944444444	
0.888888889	8
0.833333333	
0.777777778	7
0.722222222	
0.666666667	6
0.611111111	
0.555555556	5
0.5	
0.444444444	4
0.388888889	
0.333333333	3
0.277777778	
0.222222222	2
0.166666667	
0.111111111	1
0.055555556	
0	0

Here are the switch points. If the number is exactly 1, the output must be 9/9ths—nothing earthshaking there. As this number decreases, we approach $0.9\overline{4}$. When the number equals this value, we jump to 8/9 ths. This lower number is not included in the range for 9/9 ths. When the number equals $0.9\overline{4}$, the output jumps to 8/9 ths. We stay at this fraction until we reach $0.8\overline{3}$ at which point we jump to 7/9 ths.

Let's revisit my requirements and see how I did:

1) Able to convey any integer from 0 to at least 9 - yes
2) Rugged enough to survive being attached to a bicycle - yes
3) Cost under $1 – two red LEDs and a resistor can cost under 10¢
4) Visible in direct sunlight with sunglasses on – red LEDs work
5) Readable in under one second – it takes 300 milliseconds to read with a cycle time of one second
6) Compatible with an ATTiny85 system on a chip (5V logic) - yes
7) Use only two wires - yes
8) Draws less than 2 milliamps on average – yes

I lived with this output format for a while and then realized something was wrong. In normal speech, I do not say "2/3rds, middle." It would come out "middle of 2/3rds."

A small software change made it right. I now output the minor group first, wait 200 ms, and then output the major group.

Without trying this interface, it would be natural to think it is too complex. Given how easy it is to mock it up with an Arduino, I encourage you to give it a try. If necessary, tinker with the timing until it feels right.

I welcome your comments and questions.

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