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LED Pacing System for Runners

STEM Commercialization Plan

Part 1. Elevator Pitch:

An LED pacing system would revolutionize the way runners train. Training for optimal improvement requires the athlete to run at very specific paces, which can be extremely difficult even with a GPS watch. The LED pacing system will provide precise and continuous feedback to the runner, guiding them to their fitness goals.

Part 2. Executive Summary:

Exercise physiologists and coaches have proven that if a runner trains at paces specific to their fitness level and abilities they will quickly and safely improve their fitness. Furthermore, incorrect pacing yields suboptimal gains in fitness and can lead to injury. Most runners today use pacing methods like stopwatches and GPS watches, but they have proven inaccurate. An LED pacing system offer an exciting solution that could change the future of competitive running. A system of LED strips would provide a runner with continuous feedback via a moving trail of lights, allowing for accurate pacing around a track. Prototype testing has shown that runners using an LED pacing system can achieve their desired paces with significantly more accuracy than with traditional pacing methods. Research indicates that there is a large pool of potential consumers who are both financially capable and eager for a product like this. This product has the potential to take the running community by storm.

Part 3. Problem Summary and Proposed Solution:

Exercise physiologists and coaches have proven that if a runner trains at paces specific to their fitness level and abilities they will quickly and safely improve their fitness. This would seem like a simple task to do, just following a pace, but it is actually extremely difficult. Currently athletes and coaches use stopwatches, GPS watches, or perceived effort to pace while running on a track. Unfortunately all of these techniques have limitations in accuracy. Stop watches require the athlete to calculate and adjust their pace, but this can only reasonably be done every 200 meters on a track. GPS is not a distance measuring tool, so the watches calculate distance based on a series of GPS identified locations. Due to these limitations they have inherent errors while calculating distance on a running track which makes them insufficient for accurate pacing. A third way runners pace themselves is based off perceived effort. Unfortunately this method takes a lot of practice to master, making it not useful for the large majority of runners. This problem has been a struggle in the running community for far too long and it is time for a solution to be developed. In 2017, Nike organized the breaking 2 attempt in which exercise physiologist and coaches attempted to have an athlete run under 2 hours in the marathon. In the marathon record attempt, pacing was a crucial element and was heavily focused on. The athlete was paced using a car from which lasers were pointed on the ground to provide the athlete constant guidance. This system was an ideal solution to the pacing problem because it provided constant visual guidance to the runner. Unfortunately it requires a car with lasers. However, this concept could be applied to develop a solution for use on a track facility. The proposed solution uses a continuous strip of LEDs placed around the inside curb of the track. The system could light the LEDs at a selected pace and the runners could follow a trail of LEDs to train or race at their desired pace.

Part 4. STEM Concepts and Principles Underlying the Overall Plan:

The proposed solution incorporates concepts from both electrical engineering and computer science. On the electrical engineering side of this solution lies the principles of electrical circuits, microcontrollers, power, and LED's. In the prototyping of this system an Arduino Uno microcontroller was used. Microcontrollers are small single board computers which serve a dedicated function, such as operating the LED strip. LED strips are ideal for this application because they are low power and easily managed by a microcontroller. The microcontroller simply needs to be wired to the 5V input, ground input (GND), and Data Input (DIN). Then on the computer science side of this solution lies the programming principles required to operate the system. In the development of the prototype software, a programming language similar to C++ was used. A Graphical User Interface (GUI) was developed, displaying speed selection options. After selecting a GUI option, the microcontroller creates a trail effect for the selected speed, enabling the user to follow the LEDs and achieve their goal pace.

Part 5. Commercialization Assessment of the Overall Plan:

Problem, pain point or market opportunity:
Running is one of the most popular ways to stay fit with about 60 million runners in the US alone (Gough, 2018). The majority of these runners have encountered the problem of inaccurate pacing during training or racing. According to the National Center for Education Statistics there were 23,814 public high schools and 4360 degree granting institutions in the 2016-2017 academic year. Assuming that only 50% of these schools have 400m track facilities that would still be 14,087 potential consumers. Since most track facilities are owned by universities and high schools which sponsor competitive track and field teams, there would be many eager clients trying to get a competitive edge from the pacing system.

Proposed solution:
The proposed solution uses a continuous strip of LEDs placed around the inside curb of the track. The system could light the LEDs at a selected pace and the runners could follow a trail effect of LEDs to train or race at their desired pace. The system could also provide multiple trail effects of different colors to allow for training groups of different levels to use the system at the same time. A model of the proposed solution is shown in Figure 1.

Figure 1: Scale Model of Product

Target customers and intended users:

The target customers are competitive running teams such as high schools and colleges. There would be more of a focus on marketing to schools that have track and field facilities since the product is intended for use on a track.

Competitors:

The most prevalent competitors of this product are the many GPS watch companies including Garmin, Polar, and Fitbit. These watches utilize GPS to track changes in the location of the user. From these location changes the watch calculates distance and pace, displaying these data fields on the watch face.

Customer value proposition & competitive advantage:

While the GPS watch is very popular for pacing, it is known throughout the entire running community to be unreliable for exact pacing measurements. These errors occur because GPS is intended for location and is not ideal for tracking distance or pace. These pacing errors are compounded on a track due to the many turns. As a result, GPS watches are usually disregarded for track workouts. Since GPS watches have inherent pacing errors, an LED system would definitely be the best pacing system on the market, allowing the athlete to follow the lights with total confidence that they are running the correct pace.

Principal revenue streams expected:

The components required to build the proposed system are a microcontroller, similar to the Arduino Uno, 400 meters of LED strips, 40 power supplies, and 400 meters of copper wire. According to paigewire.com, 12AWG copper wire would be required to power the entire strip around a 400 meter track. Research on Alibaba.com reveled that these components are available at relatively low cost. Boards similar to the Arduino Uno are sold for less than $3 dollars. Waterproof LED strips on average are sold for $2.50 per meter. 5V power supplies can be bought for $0.50. 12AWG copper wire is sold for $0.50 per meter. Based on these prices an LED strip with the copper wire and power supplies could be integrated for a price of $3.05 per meter. Adding a shipping price of around $300 it can be estimated that the cost of one 400 meter system would be $1,523. From this pricing data the cost can be determined for different lengths of the system. One of these 400m systems could easily be sold for $5,000 especially considering that the target customers are larger organizations with a greater financial backing. Additionally the cost of a typical all-weather 400m track can range from $200,000 to $400,000 (Running Track Cost Comparison: Installation: Wichita, KS 2020), so an increase of $5,000 to add the LED Pacing System is relatively small. A reasonable goal for the first two years would be to sell the system to 1 percent of the potential consumers. The expected revenue is summarized in Table 1.

Table 1: Expected Revenue

Length of Track (m)	Cost per Product	Retail price	Profit	Cost for 140 Units (1% goal)	Profit from 140 Units (1% goal)
400	$1,523	$5,000	$3,477	$213,220	$486,780

Principal startup and operating costs expected to be incurred:
Successful marketing would be critical to develop interest in this product early on. A website could be developed for $250 to provide the public with useful information about the pacing system. Another marketing opportunity would be setting the system up on the Ohio State University's track. This would help to market to both colleges and high schools since the Jesse Owen's classic, a large college track meet, and the Ohio High School state meet are held at the facility. In addition to marketing, there are other startup costs required for manufacturing. These include starting the outsourcing of the LED strips and control boards, which would cost approximately $10,000, and stocking of the components required to build 10 systems. While these principal startup costs seem large, they would be covered after the sale of only six 400m systems. A summary of the expected startup costs is shown in Table 2.

Table 2: Expected Startup Cost

Marketing	**Cost**
Website	$250
Ohio State	$1,503
Miscellaneous Advertising	$1,000
Total:	$2,753
Product Stocking (10 units)	**Cost**
Outsourcing Startup	$10,000
Integrated LED Strip	$12,200
Development Board	$30
Shipping	$3,000
Total:	$25,230
Overall Startup Cost:	**$27,983**

Part 6 Science and Technology Proof of Concept:

Review and assessment of the scientific literature:
A review of scientific literature yielded several articles that describe the physiological basis and need for developing this product. Exercise physiologist, Jack Daniels, stresses the importance of controlled training when he states, "Remember that the purpose of the workout is to stress lactate-clearance capability, not to overstress that capability" (Daniels, 2019). Jack Daniels and others have developed methods to determine the specific pace that a distance runner should train to achieve the optimal physiological effect. The optimal pace is determined using a runner's anaerobic threshold, which is the exertion level at which lactic acid begins to accumulate in the muscles. There are two main ways our bodies produce energy during exercise: Aerobically, with oxygen, and anaerobically, without oxygen. At an easy pace, a runner can take in enough oxygen that most of the energy is produced aerobically. As the runner speeds up, they breathe harder to get more oxygen but eventually they can't get enough oxygen and so their energy production transitions to mostly anaerobically. Unfortunately, a waste product of the anaerobic process is lactic acid. The buildup of lactic acid causes fatigue, cramps, and soreness in the muscles, which results in decreased race performance. Training at a predetermined pace enables an athlete to increase their anaerobic threshold, making it easier to run faster in races.

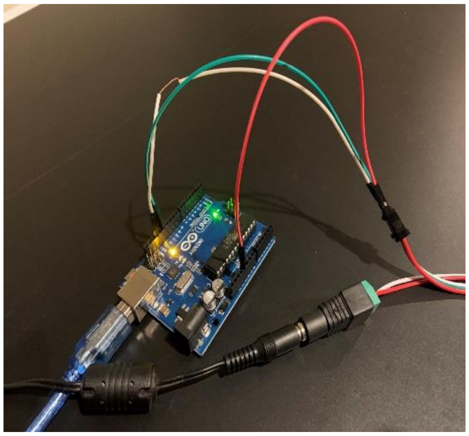
Upon establishing the need for the product, further research identified several articles that discussed relevant technology that could be used to develop this product. LED strips commanded by a microcontroller were found in several applications with precise timing requirements. The Arduino brand of microcontroller was identified as very compatible with LED's, offering many different lighting capabilities (What is an Arduino? 2013). The FastLED library of code offers a wide variety of options (e.g. color, pattern, timing, etc.) for lighting the LED strip with an Arduino (Luijten, 2019). To control an Arduino, a graphical user interface or GUI can be created. A GUI is a system that can display controls such as buttons which can be pressed to carry out a pre-coded function. A software application named Processing can be used to develop a GUI. Some of the benefits of Processing are that it is free to download, it is compatible with many operating systems, it is well documented, and there are many code libraries. Aside from using buttons, a GUI can contain sliders, textboxes and knobs for a variety of different control options (Rathod, 2017).

Prototype goal:
Produce a device that provides visual guidance to enable a runner to maintain a selected pace.

Prototype Development:
For the prototype, an Arduino Uno, laptop, power supply, and 20 meters of LED strips were used. The Arduino was plugged into the computer and the Arduino IDE software was downloaded. The Arduino was then connected to a laptop and power supply. Before

programming the system, the Arduino was wired to the LED Strip, connecting the 5V pin to the 5V input, the GND pin to the GND input, and the 4 pin to the Din input (Figure 2).

Figure 2: Prototype Circuitry



The blue cable in the bottom left connects the Arduino to the laptop/power supply.

The black cable connects the LED strip to a power supply.

The red wire connects the 5V pin and input.

The white wire connects the GND pin and input.

The green wire connects the 4 pin to the Din.

The Arduino was then programed to control the LED strip, first by controlling the color and brightness and then creating a trail effect of several consecutive lights (Figure 3). An algorithm was then developed to light the LEDs at the correct timing intervals in accordance with the selected paces. The final step for the software was the development and implementation of a GUI for pace selection (Figure 4).

Figure 3: Trail Effect

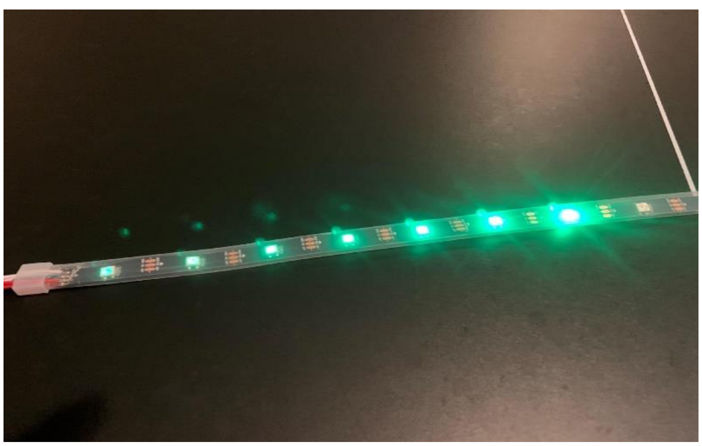


Figure 4: GUI

Product Testing:
The final prototype was then tested using 18 participants to compare its effectiveness to GPS watches and perceived effort. The 20 meter LED system was set up on the track and the start and end of the system were marked. Participants were instructed on the goal pace and how to follow the LED system and use the GPS watch. The participants were filmed while attempting to run 7:33 pace for 20 meters on the track. Each participant ran the test three times, once for

each of the pacing methods being tested (LED assisted, GPS assisted, and perceived effort). The order in which the participants did each pacing method was randomized to reduce bias in the data. After the testing was complete the videos were analyzed using Kinovea™, which is a free video system used for sports analysis (Figure 5). The video Analysis from Kinovea™ was used to determine each participants exact times for the tests (Table 3). The difference between each participant's time and the goal time of 5.66 seconds was calculated (Table 4).

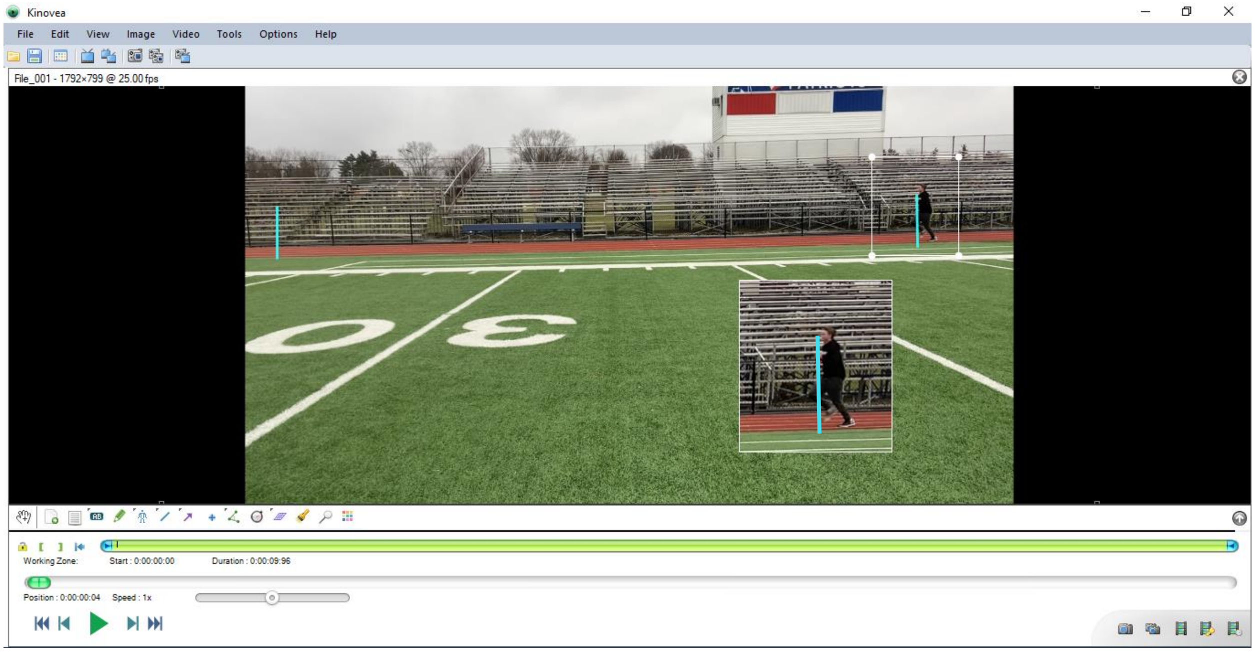
Table 3: Participant Times

Participant	LED	GPS	Feel
1	5.78	5.81	4.40
2	5.96	5.23	4.80
3	5.43	5.78	4.98
4	5.66	4.87	4.59
5	5.75	6.37	5.27
6	5.59	5.08	4.88
7	5.73	4.91	4.85
8	5.78	3.96	4.44
9	5.59	4.77	4.61
10	5.82	4.86	3.47
11	5.66	4.57	4.50
12	5.80	5.31	4.21
13	5.43	4.70	4.17
14	5.27	4.93	4.47
15	5.36	4.9	5.10
16	5.59	4.67	5.67
17	5.66	5.23	4.67
18	5.66	5.14	4.70
Average	**5.64**	**5.06**	**4.65**

Table 4: Time Differences

Participant	LED	GPS	Feel
1	0.11	0.15	-1.3
2	0.30	-0.43	-0.86
3	-0.23	0.12	-0.68
4	0.00	-0.79	-1.1
5	0.09	0.71	-0.39
6	-0.07	-0.58	-0.78
7	0.07	-0.75	-0.81
8	0.11	-1.7	-1.2
9	-0.07	-0.89	-1.1
10	0.16	-0.80	-2.2
11	0.00	-1.1	-1.2
12	0.14	-0.35	-1.5
13	-0.23	-0.96	-1.5
14	-0.39	-0.73	-1.2
15	-0.30	-0.76	-0.56
16	-0.07	-0.99	0.01
17	0.00	-0.43	-0.99
18	0.00	-0.52	-0.96
Average	**-0.020**	**-0.60**	**-1.0**

Figure 5: Analysis in Kinovea



The results were then statistically analyzed using a 2 sample t test to draw conclusions about the difference between the means of the data sets. The deviations from the goal time for the LED data and GPS data and then for LED data and perceived effort (Feel) data were compared. For each test the null hypothesis or the hypothesis being tested was that the deviations were the same for the data sets, which would indicate that they were equally effective. The alternative hypothesis or the new hypothesis was that the LED system was more effective. The results of the 2 tests are shown in table 5.

Table 5- Two-Sample paired T-test Results

	LED-GPS	LED-Feel
P-value	5.9×10^{-6}	2.7×10^{-7}

The p-values indicate the probabilities that the two systems are equally effective. With such low p-values the null hypothesis can be rejected supporting the alternative hypothesis that the LED system is significantly better than the other methods.

The individual accuracy of the three pacing methods was then analyzed using T-intervals of 99% confidence. T-intervals offer a range of times in which there is a 99% confidence that the population mean is contained in the interval. The intervals are shown below in table 6.

Table 6- T-Intervals and Deviations

	GPS	**Feel**	**LED**
Standard Deviation (seconds)	0.54	0.48	0.18
99% confidence interval (seconds)	(4.69, 5.44)	(4.33, 4.98)	(5.52, 5.76)
Average Deviation from Goal Pace (seconds/mile)	48.0	80.0	1.6

The intervals show that the LED system was the most accurate pacing because the goal time of 5.66 seconds was only contained in the LED interval. The LED system was also the most consistent because its standard deviation was the smallest.

Part 7 Acknowledgments:

I am thankful for the following people who greatly contributed to the success of this project.

- The participants who allowed me to test them for this project.
- My brother, Jack Agnew, who helped me set up my prototype for testing.
- My parents, John and Christine Agnew, who helped me with my research and assisted during testing. Both also helped me to edit this STEM commercialization plan.

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