USE OF ELECTROLUMINESCENT WIRE FOR MONITORING FATIGUE IN MANUAL MATERIALS HANDLING

by

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Executive Summary

In the field of manual materials handling, millions of dollars are lost each year in accidents caused by physical fatigue. The purpose of this project is to design a device for monitoring fatigue in manual material handling operations. Combining our knowledge of electronics, new product design, ergonomics, and human factors, we were able to design and test a product to meet these specifications in hopes of developing a prototype for marketability. While we have only developed a prototype, the economic justification is performed for mass production of the product. Using statistics gathered on the percentage of injuries caused each year due to fatigue and their cost to employers, we concluded a product costing less than $60.86 would be justifiable for manual materials handling companies. If more than 6,215 units are sold per year, this goal is achievable, with profit margins of 23.7% for 10,000 units per year, 61.99% for 50,000 units per year, and 68.50% for 200,000 units per year when sold at the previously mentioned cost.

Acknowledgments

We would like to thank Professor Larry Rinzel for his invaluable assistance in pointing us in the correct direction of how to modify a circuit schematic as well as where to look for such components in the local area to build our prototype. David Lane deserves praise for the time and expertise he lent in testing and debugging the physical circuit once the circuit design had been created. Finally, Professor Reza Pouraghabagher provided the connections, feedback, and support to execute a project of this nature (a very "out of the box" application of industrial engineering). Thank you all for your contributions, they are greatly appreciated.

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Introduction

The field of manual materials handling (MMH) is one of the most injury prone amongst industry; the U.S. Department of Labor estimates that 4 out of 5 compensable injuries are within MMH [21]. Furthermore, research shows that there is a direct correlation between heart rate and fatigue. The American Heart Association (AHA) and the U.S. Occupational Safety and Health Administration (OSHA) both have recommendations for proper heart rates for various forms of activity [17]. Despite encouragement from management to rest and take breaks, many MMH operators are driven by a financial bottom line to work harder, faster, and longer. Especially within the current economic climate, many assume that by working harder, they will be able justify their worth for promotion or worse, to retain their jobs in case of layoffs. Due to this factor, many operators do not self-monitor their heart rate even when suggested by management.

To combat the overexertion and resulting fatigue of operators, it would be effective to have an external monitoring system or device of an MMH operator's heart beat so that a superior can notice employees exerting themselves too much and have them take a brief rest. The major deliverables for this project will be a prototype heart rate monitor based on the suggested technology for this application, and the economic justification within this report to recommend it to companies within MMH.

The applicable courses for this project within our major are:

• IME 156: Basic Electronics Manufacturing

• IME 239: Industrial Costs and Controls

• IME 314: Engineering Economics

• IME 319: Human Factors Engineering

• IME 408: Systems Engineering

• IME 418: Product-Process Design

Furthermore, the concepts learned within EE 201: Basic Circuit Theory and EE 321: Electronics were used to great extent.

Background

Originally, David Gillette, the Director of Liberal Arts and Engineering Studies (LAES) at Cal Poly presented this idea. Professor Gillette had been in discussion with Professor Diana Stanton of the dance department about a multidisciplinary collaboration. The dance company "Orchesis" were interested in incorporating biofeedback into their performances. They wanted a suit that lit up with the dancers' heart beat and flashed different colors according to heart rate. The idea of incorporating human heart beat into music and dance has been around for some time, but not implemented in the fashion Professor Stanton desired. Furthermore, there are no mass production pieces of such equipment for them to purchase, only custom individual models, and so such a design would need to be built from the ground up.

Due to issues of contact and cooperation amongst our clients (Professors Gillette and Stanton), it was decided that the research done would be reapplied to the use of MMH and/or high exertion labor (e.g. firefighters, rescue personnel, construction workers).

The intended system would let the user and the supervisor know when their work is becoming dangerous to their own health. Such a system could also be applied to sports. Athletes work out in different zones depending on their heart rate. Awareness of what zone they are in and for how long is crucial to high performance athletes in order to get the most out of their workout. In sports like martial arts, where control of one's mind, body, and soul are more important, this system can be used to constantly monitor heart rate. A third application is within the original scope of the performing arts.

The concept of this system does not currently exist on the market, something that combines the aforementioned ideas into one product. The closest product to this design is an electrocardiograph or EKG. EKGs are used by health centers and hospitals across the globe. This product uses electro sensitive pads stuck on a patient's skin to read the electric signal given out by the heartbeat through the epidermis. The display of the heartbeat is

Figure 3: An EKG Machine in Use[3]

output as a digital reading of the heart rate and an electronic beeping noise. It is viewable by both the user and people around the user. However, unlike our design, it is not comfortable or practical for the user to wear this all the time while performing an activity. Also, it is not as user friendly as our design. Reading an EKG takes

training and operating one is more complicated than turning it on. The proposed system would allow an operator to put it on, flip a switch, and observe the three basic colors that are currently standardized as global norms for good (green), caution (yellow), and dangerous (red).

Literature Review

Manual Materials Handling

Manual materials handling is a broad field, encompassing approximately 3.6 million operators. The Department of Labor defines this profession as those who manually move materials and perform other unskilled, general labor [11]. They include those who move freight, stock, and other materials to and from storage and production areas, loading docks, delivery vehicles, ships, and containers. In factories, they may move raw materials or finished goods between loading docks, storage areas, and work areas, as well as sort materials and supplies and prepare them according to their work orders [11].

According to OSHA, the principle source of compensable injuries occur within the field of MMH [21]. With 227 cases per 10,000 full-time workers, this field has the highest incidence rate of injury amongst any [20]. Using a workplace injury cost calculator, the lowest cost of an individual injury applicable to fatigue was $46,365 [4]. Approximately 26,000 injuries related to overexertion occur each year within the field, resulting in a cost of $1.205 billion to employers [20]. The purpose for our product, however, is to prevent fatigue, and here the National Sleep Foundation

estimates workplace fatigue costs industry $77 billion per year, and was the cause for accidents such as the Exxon Valdez and Three Mile Island [18, 23]. Furthermore, the most recent survey by Circadian Technologies, Inc. (CTI), reports that operations managers believe 18% of all accidents and injuries are a direct result of fatigue [18].

Workers whose job is to manually handle material have the risk of becoming over-worked and raising their heart rate. According to the Occupational Health and Safety Association (OSHA), an operator with heart rate in the target range is more productive than one who is over-worked. Recommendations for men and women are 90-112 beats per minute when continuously performing materials handling. This applies to all MMH personnel regardless of age, gender, or experience. It is also quite necessary to know when one is becoming fatigued to avoid making careless mistakes that could be costly to the company or cause a work related accident.

Heart Rate and Fatigue

No muscle is more important to the human body than the heart. At the core of the human physique, the heart pumps blood throughout the entire body, giving it the power and strength it needs to live and perform normal daily tasks. The importance of this powerful organ has led to a countless variety of research projects and examinations of the human heart. Currently on the market are hundreds, even thousands of products relating to the heart and the monitoring of its performance. There are wristwatch heart rate monitors (see Figure 2), pacemakers, heart rate monitors that attach to the chest, wireless heart rate monitors, devices that can display

heart rate by reading a fingerprint, but nothing has been developed for more than the individual to be monitoring, as well as being appropriate for the workplace.

Figure 4: Example of a Heart Rate Wristwatch[13]

There are six primary factors that influence heart rate. They are age, gender, eating habits, exercise, body temperature, and drugs (such as caffeine)[22]. Those applicable to our project are age, gender, and exercise (i.e. activity).

Resting and daily average heart rate does not change significantly with age. However, maximum heart rate decreases due to physiological effects of aging, such as telomere shortening and associated deconditioning [22]. Gender can also play a role in heart rate, with women averaging higher than men. The general consensus is that women are typically smaller than men, and so require a faster heart beat to facilitate metabolism [22].

Most importantly for our project, however, is activity. Due to increased demand for incoming oxygen and outgoing carbon dioxide, the heart pumps faster. Heart rate can increase two to three times above resting heart rate depending on the intensity and duration of activity [22].

Since OSHA has established an absolute value for target heart rate for men and women of all ages, it would be easy to program a device that meets their standards. The programming would display a green light when the user's heart rate was between 90-112 beats per minute, a yellow light for 112-142 beats per minute, and a red light for heart rates greater than or equal to 143 beats per minute. These standards from OSHA make the manufacturability of this product easy but not quite practical. These specifications assume every human heart operates at the exact same pace, but that is an overgeneralization.

Taking these factors into account, the American Heart Association (AHA) suggests different standards for manual material handling acceptable heart rates. Health professionals know the importance of proper pacing during continuous manual material handling. According to the AHA, a person's maximum heart rate is about 220 minus their age. The figures in Table 1, below, are averages, and should be used as general guidelines [17]. AHA suggests that for continuous manual material handling, a person should be within 50-75% of their maximum heart rate. Between 75-85% is acceptable but should show a warning and over 85% of your maximum heart rate is too strenuous and a break should be taken until the user is back within an acceptable heart rate range.

The table below shows estimated target heart rates for different ages.

Age	**Target HR Zone 50–85 %**	**Average Maximum Heart Rate 100 %**
20 years	100–170 beats per minute	200 beats per minute
25 years	98–166 beats per minute	195 beats per minute
30 years	95–162 beats per minute	190 beats per minute
35 years	93–157 beats per minute	185 beats per minute
40 years	90–153 beats per minute	180 beats per minute

45 years	88–149 beats per minute	175 beats per minute
50 years	85–145 beats per minute	170 beats per minute
55 years	83–140 beats per minute	165 beats per minute
60 years	80–136 beats per minute	160 beats per minute
65 years	78–132 beats per minute	155 beats per minute
70 years	75–128 beats per minute	150 beats per minute

Table 2: Target Heart Rates

Heart Rate in Sports

Typically in exercise and sports there are four different zones to work out in. The zones are separated by percentages of maximum heart rate (MHR) shown in Table 2 below:

Percentage	Zone
60-70%	Recovery Zone
70-80%	Aerobic Zone
80-90%	Anaerobic Zone
90-100%	Red Line Zone

Table 3: Exercise Zones

While these concepts are applied to sports in general, the same concepts apply for any time of physical activity (i.e. manual materials handling). In line with the previous suggestions from AHA and OSHA, above 70% or so will not allow for adequate recovery over extended periods of time. Moving into the aerobic zone results in greater strain on the heart to move oxygen and carbon dioxide around within the body.

Shifting in to the anaerobic zone leads to the glycogen in muscles quickly being used up. One of the byproducts of burning glycogen is lactic acid. Also in this zone, the amount of lactic acid in muscles builds up to the point where it cannot be removed as quickly as it is produced [6]. Excessive lactic acid build ups result in tiredness and

muscle pains for the body. The calculation of a zone value, X%, is performed by subtracting the resting heart rate (RHR) from maximum heart rate (MHR), resulting in a working heart rate (WHR). Next calculate the required X% from the WHR, and add to the RHR [6].

Example: The athlete's MHR is 190 and their RHR is 70 - determine the 70% value

MHR - RHR = 190 - 70 = 120

70% of 120 = 84

84 + RHR = 84 + 70 = 154 bpm

Light Emitting Devices

While LEDs and Electroluminescent (EL) displays have been used in many commercial applications for decades, their application within clothing is relatively sparse. Work has been done into “e-broidery” [14], and one of the examples is a light emitting dress. However, this type of clothing has yet to become mainstream, or even more than custom, one-of-a-kind productions. While light sources are integrated into many pieces of equipment, and some of them wearable, they are almost always used as an indicator rather than attempting to be the main focus of the system. Some of the largest barriers have been the miniaturization of power sources and the flexibility of light emitters. However, possible solutions have been seen in recent mass media [9,10]. The implication is that within several years, such technology will make much headway into wearable goods.

EL wire and tape is a phosphor coated wire through which an AC current is passed through; the entire wire acts as a capacitor which then emits light as it discharges when the current alternates [5]. This wire is highly flexible, and so is a good option for our device (which must be flexible to fit its user's range of motion). While it has been used for clothing before, the number of published articles relating to such are incredibly rare [8,9,19]. This stems from such technology not being new, cutting-edge research, but rather an innovative combination of pre-existing developments. Some interesting applications of electroluminescent paint have been developed, but the process is noted as proprietary and so very little information exists on how it is created [19].

Figure 5: EL Wire Lined Clothing[7]

Design

What we hoped to develop was a heart rate monitor that constantly measured a person's heart rate and to display this as a beam of light or a flashing beam of light. This would allow a person's heart rate to be monitored at all times by themselves, as well as those around them. When the person's heart rate was in a normal, healthy functioning region, (known as a person's target heart rate, 50-85% of their maximum heart rate) the device would display a green light. When their heart rate becomes elevated above their target heart rate, the device would change colors from green to yellow, indicating that they are above their target heart rate and should slow down

their activity. When a person's heart rate became elevated to a dangerous level (approximately 30-35 beats per minute above their target heart rate) the device would light up red letting the user and everyone around them know that they need to take a break.

To develop this system, several separate systems were integrated into one device. First, a heart rate monitor itself was selected that would meet the requirements of our application. Second, the output of the monitor (light) was chosen and wired to the monitor. Third, a component housing was chosen so that operators could carry the system with them while they are working. While there are plenty of options for each, consideration for use as a portable, non-hindering, visible, affordable unit was necessary.

Pulse Monitor

While there are currently many heart rate monitors on the market, almost all of them display the information digitally as a number. Finding a monitor that output a signal in time with the actual beating of the heart was very difficult to find; after much searching, one was discovered, manufactured by a company based in the United Kingdom [15]. The company, unfortunately, did not ship their products overseas. With this challenge, the schematic for the heart rate monitor was found and adapted to meet our requirements (see Appendix C).

There are currently two main ways to monitor heart rate: by infrared or electric impulse. Infrared heart rate monitors work by shining an infrared light through a thin

part of the human body (e.g. finger, ear lobe). When the heart beats, an increase in the amount of blood in the extremity absorbs more of the infrared light, and so an infrared transistor can detect the change in light on the other side. Electric impulse technology senses the change in electrical current near the heart. Very early on, we decided to use infrared, since electric impulse technology requires contact with bare skin, typically near the heart. This may be inconvenient for MMH operators, and would present sanitary issues if one system was not purchased for each individual. The advantage of electric impulse technology is its accuracy, but the reduction in accuracy with infrared was outweighed by the other considerations presented.

While our design uses a prototyping breadboard to connect all the components (see Figure 4), a printed circuit board would be used for the actual product.

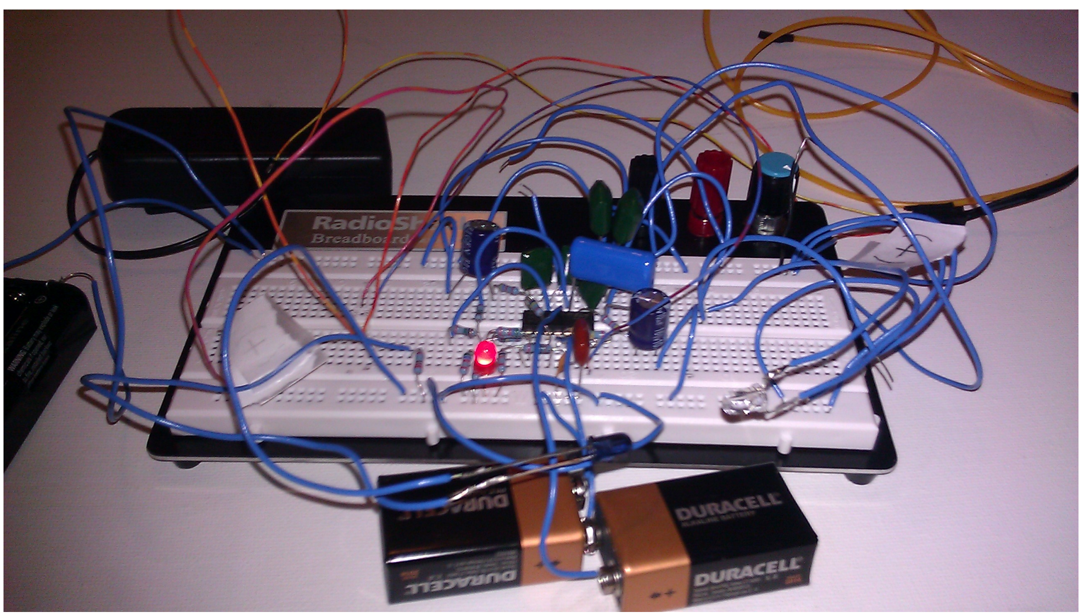

Figure 6: Prototype Heart Rate Monitor

This would greatly reduce the weight and size as opposed to our prototype. Furthermore, many of the functions of the circuit could be replaced by a programmed microcontroller. Both alternatives (physical circuit and microcontroller) are discussed in the economic justification.

Electroluminescent Wire

To display the operator's heart rate as a visual signal, there were several alternatives. The two most competitive are light emitting diodes (LED's) and electroluminescent wire or tape. Both were considered due to their low power requirement, long lifespan, and affordability. However, EL wire was decided upon because of its greater visibility for our application; instead of being a single point of light, the entire surface of the wire is lit, making it much more visible for supervisors to see. Furthermore, the additional labor that would be needed to place the string of LED's into the component housing would be much greater than running the EL wire in the same location. The large drawback of EL wire is its need for alternating current, and so an inverter must be added to the design.

To integrate the EL wire circuit with the heart rate monitor, we replaced the piezobuzzer (see Figure 10) with an optoisolator, a form of field effect transistor that uses light instead of electricity to trigger the switch. This was chosen due to the varying voltages used for the electroluminescent wire and the heart rate monitor itself, so that there was no chance of excessive current damaging components of the EL wire inverter. With the optoisolator in place, the circuit of the EL wire is

completed only when the heart beats, so that the light flashes in time to beating (see Figure 9).

Component Housing

To carry all the equipment necessary for such a device, some kind of housing needed to be chosen that would not interfere with an MMH operator's work, maintain visibility of the light for supervisors, and be cost effective. Three alternatives were looked at: a backpack, a lumbar support belt, and a watch. The backpack would be a very small design, similar to a Camelbak® backpack (see Figure 5). Here, the EL wire would be a part of the shoulder straps, and so would be highly visible from the front, back, and above. The lumbar support belt would be slightly less visible, since the light would be at waist height wrapping around the belt, but has the added advantage of not adding additional equipment to the load of an MMH operator; many are already required to wear support belts to prevent injury (see Figure 6). Finally, a watch would be geared more towards the consumer market, as another variation for personal heart rate monitoring. Here, the light would be part of the wristband, with the watch itself holding all of the electronics.

Figure 7: Camelbak® Backpack[2]

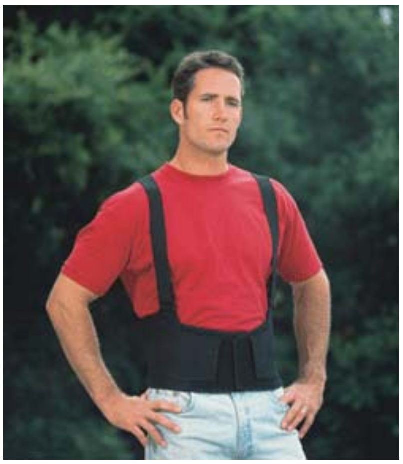

Figure 8: Man Wearing a Lumbar Support Belt[10]

The criteria to select the component housing (minimizing obstruction of work movements, affordability, and visibility of the EL wire) must all be considered; however, visibility has the strongest role as the basis of this device is for external parties (i.e. not the user themselves) to be able to tell when an individual should rest. All three alternatives meet the other requirements. There is no large difference in the cost of the housing, in relation to the cost of the heart rate monitor or the EL wire. All three do not interfere with range of motion and are easily wearable. However, the backpack has the greatest visibility, and so is the model we chose for the prototype. Further market research would need to be performed to see if the other alternatives would be more preferable.

Methodology

To determine if our product would work, a prototype was developed and tested. The true measure of success, however, would come from an economic justification, proving that the additional expense of the product would be worth the initial investment on the behalf of companies.

Prototype

By creating a circuit schematic to monitor heart rate based off of one found online, we were able to create a pulse rate monitor that could be easily connected to an EL wire output (see Appendix C). While we developed a prototype, and so this is not identical to the Bill of Materials for our actual recommendation, the entire device fits within the backpack housing we chose. Challenges in wiring the circuit were

encountered, but with the assistance of an electrical engineering major, David Lane, we were able to test and verify the circuit using the electrical engineering undergraduate lab (see Figures 7 & 8). The final prototype was completed and tested (see Figure 9).

Feasibility Threshold

In order to determine if purchasing such a product would be economically justified for a company to employ, several calculations were derived. First, the Bill of Materials was derived for the two alternatives analyzed (microcontroller vs. physical circuit) (see Appendix E). From here, costs for batch sizes of 100 units, 1000 units, and 5000 units were calculated. The overhead costs were calculated, and then a five year payback was used for initial investment. Once the per unit cost was calculated for each batch size and alternative, the cost to equip all MMH operators with such devices was calculated. This cost was compared to the total cost of overexertion injuries within the field of MMH [4, 23]. The ratio given was described as the percentage of injuries within MMH necessary to justify the cost of equipping MMH operators with the preventative equipment (see Table 4). If this percentage is lower than the 18% estimated by the National Sleep Foundation, then companies would be economically justified to equip their operators with the gear.

Results

Economic Justification

In order for this product to be used by companies, it must make economic sense. By performing an analysis of the cost to produce the product, we can compare this initial investment to the theoretical future saved costs of health expenses due to injury.

Above, in the section “Methods”, the steps to derive the data are described. From the calculations performed, Tables 3-5 and 7-10 were generated (see Appendix F). Below is a summary:

Alt.	Number Sold per yr	Components	Labor/yr.	Overhead/yr.	Initial (5yr. Payback)	Total/yr.	Cost/Unit
1	10,000	21.63669	234087.6	26400	10000	477854.5	47.78545
1	50,000	21.63669	234087.6	26400	10000	1343322.1	**26.866442**
1	200,000	21.63669	234087.6	26400	10000	4588825.6	22.944128
2	10,000	17.85034	234087.6	26400	33931.07875	442384.1079	44.23841079
2	50,000	17.85034	234087.6	26400	33931.07875	1156397.708	**23.12795416**
2	200,000	17.85034	234087.6	26400	33931.07875	3833948.708	19.16974354

Table 4: Cost per Unit for Varying Units Sold per Year

Clearly, Table 3 shows us that microcontrollers (Alt. 2), while having a higher initial cost due to the necessity to hire a staffed computer programmer to write the initial code, end up being between \$3.54 to \$3.74 cheaper than building a physical circuit (depending on batch size used). Looking at Table 4 to see the percentage necessary to justify cost, batch sizes of 1000 were used (the economies of scale at batch sizes of 10,000 were not a significant increase in comparison to the change of batches of 100 to 1000; see Tables 7 & 8). For estimated sales of 10,000 (0.280% of the market), 50,000 (1.402%), or 200,000 (5.609%), the number of injuries due to fatigue (as a

byproduct of overexertion) must be 13.08%, 6.84%, or 5.67%, respectively (when choosing alternative 2, microcontrollers, see Table 4 below).

Alternative	# sold/yr.	Cost/Unit	Cost to equip all MMH	breakeven % due to fatigue
1	10,000	47.785	$170,386,974.50	14.13425035
1	50,000	26.866	$95,796,096.20	7.946652083
1	200,000	22.944	$81,811,420.80	6.786569843
2	10,000	44.238	$157,739,436.60	13.08508877
2	50,000	23.128	$82,467,509.60	6.840994915
2	200,000	19.169	$68,350,903.30	5.669968502

Table 5: Percentage of Injuries due to Fatigue Required for Breakeven at Varying Units Sold per Year

All three of these values are lower than the 18% of injuries estimated to be caused by overexertion, and so, despite the wide margin of difference between the three different estimated sales per year, all three, with their various prices per unit, are economically justified for a company to purchase [18, 23].

In fact, a per unit price of $60.86 is necessary for the product to become unjustified (see Table 5). At breakeven cost, this requires less than 6,215 units to be sold per year. This, as well, seems very unlikely, as 6200 operators is only 0.174% of the field. If $60.86 is charged for any batch size, the following profit margins exist for various units sold per year:

Units Sold/Yr	Cost/Unit	Cost to equip all MMH	% injuries due to fatigue needed to justify	Profit Margin
200,000	19.169	$68,350,903.30	5.669968502	68.50053406
50,000	23.128	$82,467,509.60	6.840994915	61.99490592
10,000	44.238	$157,739,436.60	13.08508877	27.30589105
6,215	60.855	$216,990,673.50	18.00020519	0

Table 6: Profit Margins for Varying Units Sold per Year

While the batch sizes were chosen based upon the typical batch size spread provided by Digikey, an online parts supplier for electronics, the estimated sales per year were arbitrarily chosen. However, since the greatest volume is still only 5.6% of the MMH market, none of these values appear to be unfeasible.

Other Applications

Since the device is simple and practical, it lends itself to many applications. The basic idea of monitoring a person's heart rate and displaying it so they can be aware of it as well as people around them in a small, comfortable, portable device is something that currently does not exist in the consumer market. In addition to manual material handling, this device would lend itself to any situation in which the user is actively doing something that could possibly raise or lower their heart rate.

Athletics

In athletes, variability between heart rates will be too much to control to make a standardized device that would work for everyone like for manual material handling [12]. Although a device like this would be highly applicable and useful to the field it is much more complicated to construct. It would have to be programmable to each individual user to have the same benefits as a device standardized for manual material handling. Athletes typically have lower resting heart rates than people who don't exercise regularly [6]. However, they have about the same maximum heart rate which gives them a larger working heart rate range (WHR). Since resting heart rate is so different from person to person there is no general calculation to determine it. To get a precise value for resting heart rate, one must physically measure it. The heart is a muscle, so with regular exercise it will become larger and become more efficient as

a pump. As a result you will find your resting heart rate lowers so you will need to check your RHR on a regular basis (e.g. Monthly)[6].

The design of the device would be different for sports applications. There would need to be at least four levels to monitor the different zones. It would also have to be adjustable to the athlete's MHR and RHR. It would involve more programming and a digital user interface so the user could input things like gender, age, MHR, and RHR. A different alternative could be only age input and RHR. From that information a microprocessor can calculate the MHR of the user. Adding a user interface and software to run the programming would be more costly and drive the price of the product up, but for sports applications, these adjustments are more than necessary. I would also suggest including five different colors to constantly monitor heart rate:

Color	Zone	Percentage
Blue	Resting Heart Rate	< 60%
Green	Recovery Zone	60-70%
Yellow	Aerobic Zone	70-80%
Orange	Anaerobic Zone	80-90%
Red	Red Line Zone	90-100%

Table 7: Colors for Sports Application

If this product were affordable to produce, it would apply to virtually any sport. It could be used in football, basketball, baseball, and soccer for tryout purposes. When scouts and coaches get together and run clinics or drills, they can observe not only who is working hard and performing well, but whose heart rate is in the target range,

and who is over exerting themselves earlier than others. It's almost a way of cheating for coaches to know who is getting tired and who can push through being tired and keep performing.

This also has applications in a class setting. Gyms offer different types of fitness classes from cycling, to step aerobics, to martial arts. A device like this would allow an instructor to observe the level of fitness of everyone in the class. If everyone was red lining, it would be an indication to make the class less strenuous. If only 1 person was redlining, it would alert the instructor that that person may be over exerting themselves and might be on the verge of passing out. Instructors would be more in control of the class as a whole, as well as able to focus on struggling individuals for health reasons.

Many non-athletes are concerned with their physical fitness and have gym memberships or workout regularly on their own. Many may have little idea how to correctly work out, or at least how to hard to exert themselves to reach and maintain a desired heart rate. The device could be used as an instructional tool for beginners. By always reflecting back information about their current heart rate, it would let them know at what pace they should work out at.

Dance and the Arts

Originally, this project was intended for use by the Cal Poly dance performance team, Orchesis. Professor David Gillette came to the Industrial Engineering department on behalf of Diana Stanton, Assistant Professor of Dance at Cal Poly, and the

Founder/Co-Artistic Director of *Variable Velocity Performance Group* in San Luis Obispo, CA. Orchesis is one of the performing groups that Diana actively directs, and produces choreography for. She was interested in using biofeedback from a dancer's heartbeat in her Spring show entitled *Shift*. She was specifically interested in designing a suit that lit up to a dancer's heartbeat. The idea was to have multiple dancers on the stage at one time with different color lights and different light up sequences depending on their heart-rates and how fast they were dancing.

Since this was the proposed concept for the original project, we looked into what has been done before in this field. There has been very little exploration into applying this concept to performance arts worldwide. Dance is a very physical and kinesthetic process. Typically it is taught from one person to another by observing movements and either copying them or moving as their counterpart. Due to this aspect of dance, choreographers have been reluctant to use any type of technology at all in their performances. Only in recent years has there been use of biofeedback in live performances; more rarely is biofeedback from the heart. Still, all products are designed specifically for one show.

The earliest example of this was in 1968 featured in Teitlbaum's *Organ Music* [16]. The piece implemented heart beat and breathing sounds through contact microphones and EEG signals to make electronic music. The solo artist on stage would control the music with his own heart rate and breathing pace. A company by the name of Palindrome later came out with a piece entitled *Heartbeat Duet*[1]. In this piece the

dancers wore chest electrodes and transmitters while they danced. Each dancer's heart beat was broadcast as a different musical note. The resultant rhythm, a counterpoint between two heartbeats, was integrated into the composed musical score. Other than these couple explorations, little else has been done to design cardiac biofeedback technology for performance art.

Our product would lend itself to many different types of shows and instead of being a single-purpose/custom product, this new concept mixed with a little creativity could revolutionize the realm of performing arts. The concept of being able to reflect one's heartbeat through electroluminescent wire alone could be transformed into light up suits that change color and flashing pace. It could easily be integrated into lighting for the stage as well, and with more time and research it could control the beat of the music as well.

Conclusion

Once our system was designed, analyzed for best alternatives, priced out, and compared with national statistics on incidences of injury due to fatigue, injuries and accidents occurring specifically within manual materials handling, it becomes evident that this would be a wise product to develop for companies to employ. Looking at the midline option in terms of units sold per year, a 27% profit margin is possible if charging up to the cost of economic feasibility. By lowering the cost from this line of $60.86, companies have more incentive to purchase the product due to the savings in health care.

It was interesting learning how the physiology of a person affects work performance, and how design can be made to appropriately fit humans in with the work they perform. Something as simple as preventing the building up of fatigue can lead to savings of millions of dollars for an industry, and should be strongly considered. Furthermore, this leads to higher safety, and the prevention of injuries increases the quality of life of employees for a particular company. By using our knowledge of engineering design, human factors, economics, and researching that which we did not, we were able to create the idea for a product that is simple, visible, easy to use, and low cost, and would not only benefit the bottom line of companies, but the lives of their employees.

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Appendices

Appendix A: Photos of Electrical Engineering Design Lab

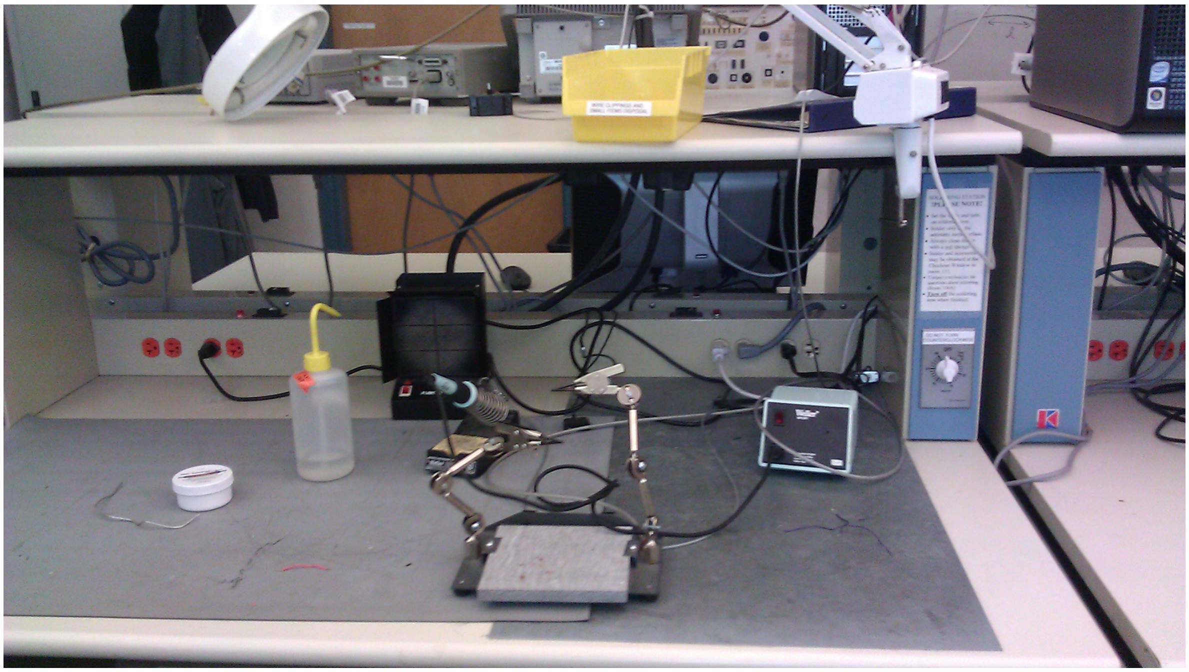


Figure 9: Soldering Lab

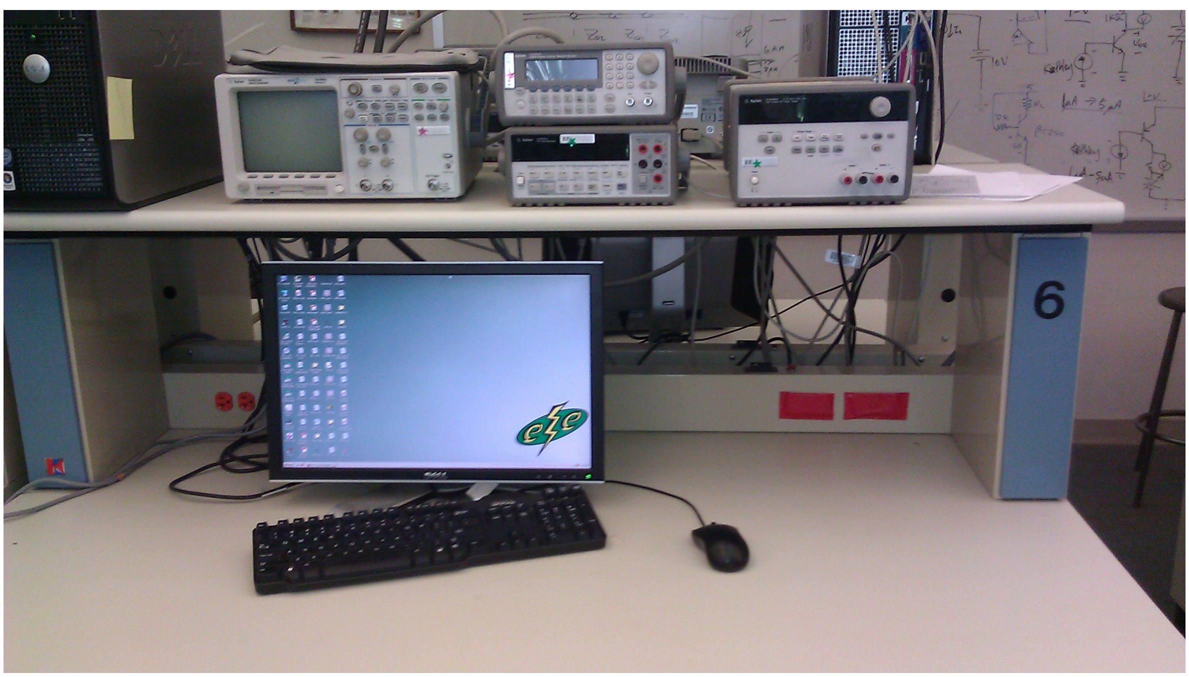


Figure 10: Circuit Testing and Analysis Lab

Appendix B: Photos of Prototype Circuit

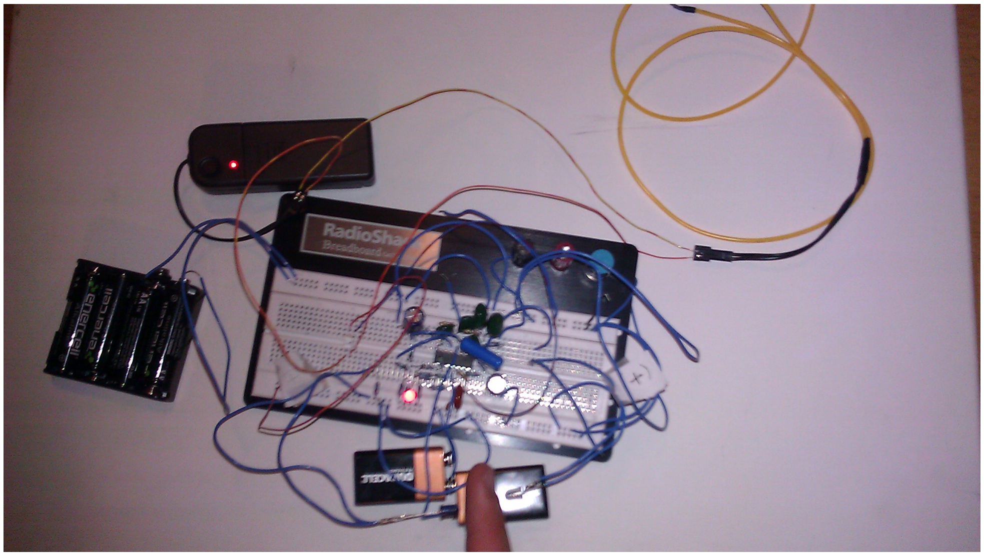


Figure 11: Heart Rate Circuit in Use

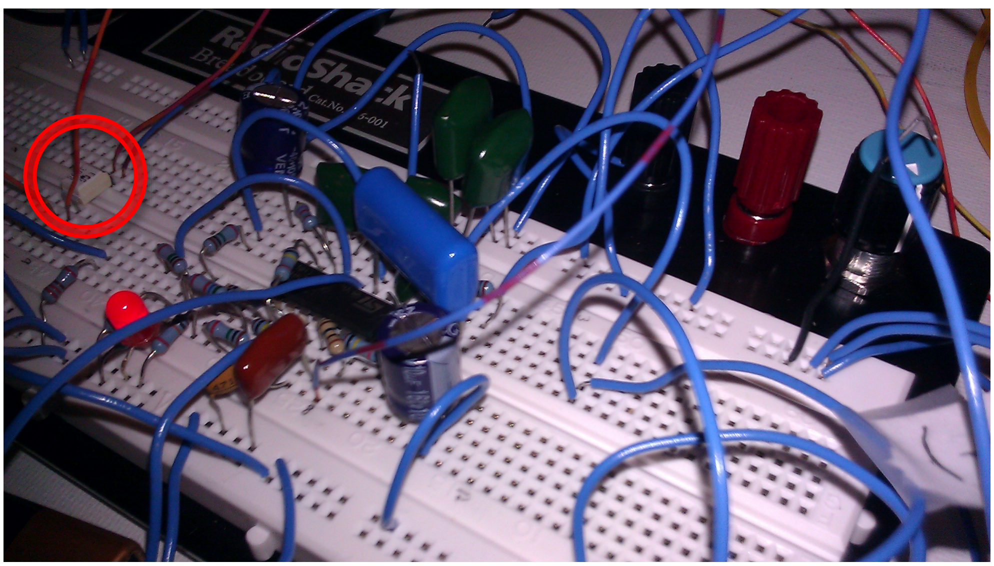


Figure 12: Close Up of Main Components
NOTE: Circle is highlighting the optoisolator

Appendix C: Electronic Circuit Diagram

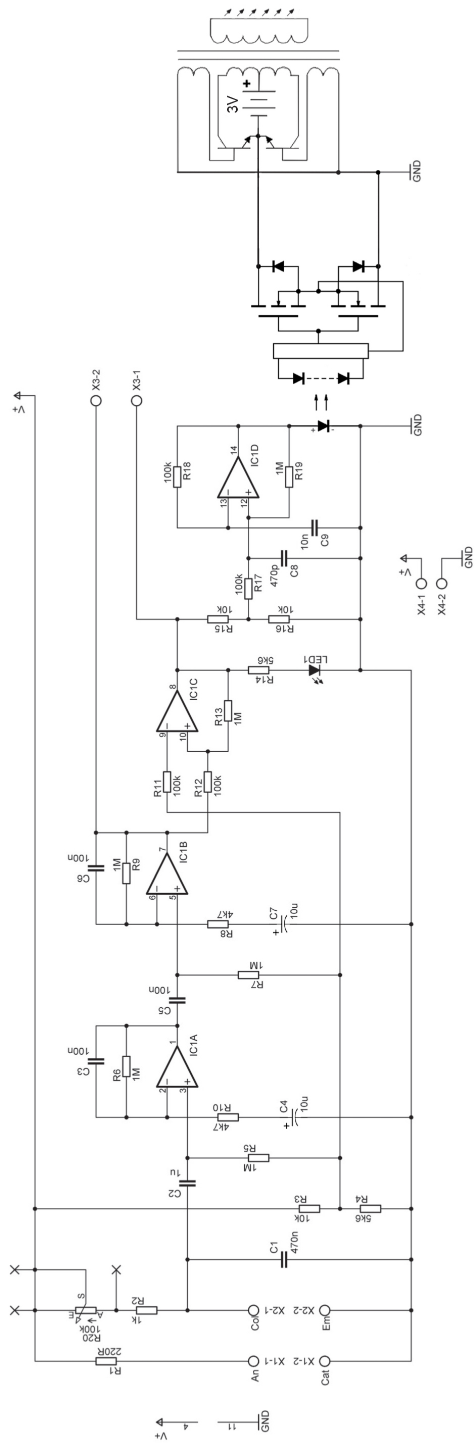


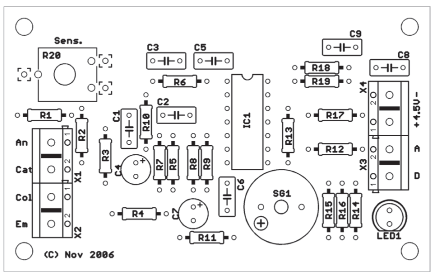
Figure 13: Electronic Circuit Diagram

Appendix D: Pulse Rate Schematic

-Courtesy of Middlesex University

Pulse Rate Monitor

MAP 446 (Page 1 of 2) - N56FL

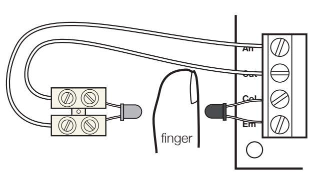


Part	Value	Device
PCB		JB07-45-1-0
C1	470n	Polyester capacitor
C2	1u	Polyester capacitor
C3	100n	Ceramic capacitor (5mm pitch)
C4	10u	Electrolytic capacitor, radial
C5	100n	Ceramic capacitor (5mm pitch)
C6	100n	Ceramic capacitor (5mm pitch)
C7	10u	Electrolytic capacitor, radial
C8	470p	Ceramic capacitor (5mm pitch)
C9	10n	Ceramic capacitor (5mm pitch)
IC1		14 pin DIL socket
IC1		LM324
LED1		Standard red 5mm LED
R1	220R	Resistor, 0.25W, Carbon film
R2	1k	Resistor, 0.25W, Carbon film
R3	10k	Resistor, 0.25W, Carbon film
R4	5k6	Resistor, 0.25W, Carbon film
R5-R7	1M	Resistor, 0.25W, Carbon film
R8	4k7	Resistor, 0.25W, Carbon film
R9	1M	Resistor, 0.25W, Carbon film
R10	4k7	Resistor, 0.25W, Carbon film
R11	100k	Resistor, 0.25W, Carbon film
R12	100k	Resistor, 0.25W, Carbon film
R13	1M	Resistor, 0.25W, Carbon film
R14	5k6	Resistor, 0.25W, Carbon film
R15	10k	Resistor, 0.25W, Carbon film
R16	10k	Resistor, 0.25W, Carbon film
R17	100k	Resistor, 0.25W, Carbon film
R18	100k	Resistor, 0.25W, Carbon film
R19	1M	Resistor, 0.25W, Carbon film
		Hex spindle
R20	100k	Potentiometer (hex slot)
SG1		Piezo transducer
X1-X4		2-way PCB terminal block
		4xAA battery box (with studs)
		PP3 battery clip
		IR 3mm LED
		IR 3mm phototransistor
		1 x length of wire
		1 x 2-way terminal block

- This kit uses infra-red radiation to detect your pulse. The output can be seen in the form of a LED flashing with your pulse, or heard via an on-board sounder.
- Requires 4xAA batteries

Operation

Insert 4xAA batteries. Place your finger between the IR LED and the phototransistor and adjust R20 until your pulse is coming through clearly. Be aware that changing light levels can affect the sensors.



Supplied by: Middlesex University Teaching Resources, Unit 10, The IO Centre, Lea Road, Waltham Cross, Herts, EN9 1AS. Web: www.mutr.co.uk

Figure 14: Pulse Rate Notes and Component List

Appendix E: Bill of Materials

Type	Part	qty per circuit
capacitor	470n	1
capacitor	1u	1
capacitor	100n	3
capacitor	10u	2
capacitor	470p	1
capacitor	10n	1
IC	lm324	1
LED	5mm std.	1
LED	3mm IR	1
TRANS	3mm phototransistor	1
resistor	100k potentiometer	1
knob	hex spindle	1
PCB	custom printed circuit board	1
wire	24 ga., 15 ft.	15
resistor	220R	1
resistor	1k	1
resistor	10k	3
resistor	5k6	2
resistor	1M	6
resistor	4k7	2
resistor	100k	4
EL Wire	4 ft.	4
inverter		1
wire	24 ga., 5 ft.	5

Figure 15: Component List and Count

Appendix F: Unit Costs for Various Batch Sizes

Alternative 1 - Physical Circuit

Type	Part	qty per circuit	Cost per 100	cost per circuit	Cost per 1000	cost per circuit	Cost per 5000	cost per circuit
capacitor	470n	1	0.138	0.138	0.0874	0.0874	0.0782	0.0782
capacitor	1u	1	0.162	0.162	0.1026	0.1026	0.0918	0.0918
capacitor	100n	3	0.102	0.306	0.063	0.189	0.0555	0.1665
capacitor	10u	2	0.195	0.39	0.1235	0.247	0.1105	0.221
capacitor	470p	1	0.102	0.102	0.063	0.063	0.0555	0.0555
capacitor	10n	1	0.144	0.144	0.0912	0.0912	0.0816	0.0816
IC	lm324	1	0.3057	0.3057	0.1732	0.1732	0.14775	0.14775
LED	5mm std.	1	0.2177	0.2177	0.11198	0.11198	0.09643	0.09643
LED	3mm IR	1	0.336	0.336	0.1904	0.1904	0.1624	0.1624
TRANS	3mm photo-transistor	1	0.4158	0.4158	0.2464	0.2464	0.2079	0.2079
resistor	100k potentiometer	1	7.3776	7.3776	5.76375	5.76375	5.76375	5.76375
knob	hex spindle	1	0	0	0	0	0	0
PCB	custom PCB	1	3.11	3.11	2.11	2.11	2.11	2.11
wire	24 ga., 15 ft.	15	27	4.05	67.55	1.01325	337.75	1.01325
resistor	220R	1	0.02465	0.02465	0.01104	0.01104	0.01049	0.01049
resistor	1k	1	0.02465	0.02465	0.01104	0.01104	0.01049	0.01049
resistor	10k	3	0.02465	0.07395	0.01104	0.03312	0.01049	0.03147
resistor	5k6	2	0.02465	0.0493	0.01104	0.02208	0.01049	0.02098
resistor	1M	6	0.02465	0.1479	0.01104	0.06624	0.01049	0.06294
resistor	4k7	2	0.02465	0.0493	0.01104	0.02208	0.01049	0.02098
resistor	100k	4	0.02465	0.0986	0.01104	0.04416	0.01049	0.04196
EL Wire	4 ft.	4	1.55	6.2	1.55	6.2	1.55	6.2
inverter		1	4.5	4.5	4.5	4.5	4.5	4.5
wire	24 ga., 5 ft.	5	27	1.35	67.55	0.33775	337.75	0.33775
		parts cost		**29.5731**		**21.6366**		**21.4331**

Table 8: Parts Cost for Alternative 1 in Batches of 100, 1000, and 5000

Alternative 2 - Microcontroller

Type	Part	qty per circuit	Cost per 100	cost per circuit	Cost per 1000	cost per circuit	Cost per 5000	cost per circuit
microcontroller	PIC24HJ12GP202-I/SP-ND	1	2.75	2.75	2.75	2.75	2.75	2.75
IC	lm324	1	0.3057	0.3057	0.1732	0.1732	0.14775	0.14775
resistor	100k	4	0.02465	0.0986	0.01104	0.04416	0.01049	0.04196
IC	lm324	1	0.3057	0.3057	0.1732	0.1732	0.14775	0.14775
LED	5mm std.	1	0.2177	0.2177	0.11198	0.11198	0.09643	0.09643
LED	3mm IR	1	0.336	0.336	0.1904	0.1904	0.1624	0.1624
TRANS	3mm photo-transistor	1	0.4158	0.4158	0.2464	0.2464	0.2079	0.2079
PCB	custom PCB	1	3.11	3.11	2.11	2.11	2.11	2.11
wire	24 ga., 15 ft.	15	27	4.05	67.55	1.01325	337.75	1.01325
EL Wire	4 ft.	4	1.55	6.2	1.55	6.2	1.55	6.2
inverter		1	4.5	4.5	4.5	4.5	4.5	4.5
wire	24 ga., 5 ft.	5	27	1.35	67.55	0.33775	337.75	0.33775
	parts cost			**23.6395**		**17.8503**		**17.7151**

Table 9: Parts Cost for Alternative 2 in Batches of 100, 1000, and 5000

Labor

Type	Quantity	Cost per Hour	Hours per year	Salary	Cost Multiplier	Cost to Company
manager	1			73520	1.1205	82379.16
sales	1			70200	1.1205	78659.1
packager	1	9.16	2000		1.1805	21626.76
warehouse	2	10.89	2000		1.1805	51422.58

Overhead Cost - Ongoing Overhead

Type	Quantity	Cost per mo	Cost per year	Cost to Company
Warehouse	2500	0.4	4.8	12000
Other	1200	1	12	14400

Overhead Cost - Initial Investment

Type	Quantity		Cost per year	Cost Multiplier	Cost to Company
Initial Office Investment	1		10000		10000
Computer Programmer	3	mo.	85430	1.1205	23931.07875

Table 10: Labor, Continuous Overhead, and Initial Investment Costs

*Cost Multiplier takes into consideration FICA, Medicare, FUTA, UI, ETT, and Workers Compensation.
**Computer Programmer is only hired for Alternative 2

Total Cost per Unit - 5 year payback

Alt.	Number Sold per yr	Components	Labor/yr.	Overhead/yr.	Initial (5yr. Payback)	Total/yr.	Cost/Unit
1	10,000	21.63669	234087.6	26400	10000	478854.5	47.88545
1	25,000	21.63669	234087.6	26400	10000	803404.85	32.136194
1	50,000	21.63669	234087.6	26400	10000	1344322.1	**26.886442**
1	100,000	21.63669	234087.6	26400	10000	2426156.6	24.261566
1	200,000	21.63669	234087.6	26400	10000	4589825.6	22.949128
2	10,000	17.85034	234087.6	26400	33931.07875	445777.2158	44.57772158
2	25,000	17.85034	234087.6	26400	33931.07875	713532.3158	28.54129263
2	50,000	17.85034	234087.6	26400	33931.07875	1159790.816	**23.19581632**
2	100,000	17.85034	234087.6	26400	33931.07875	2052307.816	20.52307816
2	200,000	17.85034	234087.6	26400	33931.07875	3837341.816	19.18670908

Table 11: Breakdown of Parts, Labor, and Overhead for Varying Quantities Sold per Year