

Deadlift Assistant Plus

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1 Introduction

1.1 Objective

The deadlift is one of the top three popular weight training exercises along with the squat and the bench press. Yet, it is considered the most difficult amongst the three of them due to the weight involved in it. Many people tend to do the deadlift in a poor form to successfully complete the attempt, but end up hurting their backs or spines. They do not realize that they are doing the deadlift in the wrong way because they tend to avoid having an expensive lesson from a personal trainer.

Our solution will focus on preventing injuries while doing the deadlift by alerting the users whenever they are doing the deadlift in a poor form. We aim to make this cheaper than having the lesson from the personal trainer. A video camera with computer-vision will record the deadlift performance from the user and provide instant feedback on their forms by making a sound alert if the deadlift form is poor. The user will wear a color wristband which can be recognized by the computer-vision that the deadlift has been started. The wristband will also measure the heart rate of the user, and warns the user if the heart rate goes too high with a sound alert. In addition to the alert, the user will also be able to get the overall feedback on how their form got better or worse over time, as well as their heartbeat data. This will help users track their deadlift training and motivate them to improve their form.

1.2 Background

Deadlift is infamous for its risk when it is done in a poor form [1]. The reason for this happening is because of the weight that is involved in it. Normally people will start with 1.5 times of bodyweight for the deadlift barbell, which is approximately 315 pounds [2]. Considering that you are carrying a person similar to your weight with the power of your back only, the deadlift is definitely a challenging exercise.

The study shows that the professional weight trainers get back injuries from the deadlift 31% of the time [3]. Compared to the other popular weight exercise, the percentage is twice as high. This is what happens for the professional weight trainers, and it is obvious that those who are not professional in weight training will get more injuries due to the poor form.

1.3 Visual Aid

Figure 1 below shows the good and poor deadlift forms. The back needs to be straightened or curved outward. If the back is curved inward, that will injure the back. First two forms shown in Figure 1 are the poor forms because the head is not straight, and the back is curved inwards. The proper form is shown on the most right, where the head and back are both straight.



Figure 1. Visual Aid of Good vs Bad Deadlifting Form

1.4 High-Level Requirements

- The system must recognize form that poses potential harm to the user and emit an alert sound in less than 0.5 second.
- The camera subsystem must be able to make the alert sound when the heart rate of the user reaches 180 beat per minute.
- Both wristband and camera must be able to run for at least 1 hour continuously to satisfy the regular workout time.

2 Design

Our entire design is simply comprised of two subsystems: wristband subsystem and camera subsystem. The wristband subsystem will be worn by the user and it will measure the heart rate of the user while doing the deadlift. The heart rate data will be sent to the camera subsystem through Bluetooth. Figure 1 below shows the block diagram of both wristband subsystem and camera subsystem.

The camera subsystem is a camera with the tripod. This will be set next to where the user will be doing the deadlift and capture the motion of deadlift attempt. The camera lens will capture the motion in video, and the single-board computer inside the camera will process through computer-vision. If the deadlift form is good, then there will be no feedback, but if the deadlift form is bad, then there will be instant feedback from the camera with the unique alert sound through the speaker. The unique color of the wristband will act as the indicator for the computer-vision to understand that the deadlift attempt has started.

The heart rate data sent from the wristband is processed by the single-board computer and if the heart rate is too high, it will alert the user. For our product, we are going to set it at 180 beats per minute, which is the average maximum heart rate at 100 percent exertion [4]. Once the heart rate is above 180 bpm, the unique alert sound will be made through the speaker. This is different from the sound for the deadlift form feedback.

The overall summary of successful deadlift attempts will be shown through the LCD display at the end of entire deadlift exercise.

2.1 Wristband Subsystem

This is just a wristband that the user can wear it. It contains the heart rate sensor, the microcontroller, Bluetooth module, the LDO regulator, and 3.7V Li-on battery. The heart rate sensor will measure the heart rate of the user, and the microcontroller is used to process that and send the heart rate data to the camera subsystem via Bluetooth. All of these components will be powered by low-dropout voltage regulator that converts 3.7V to 3.3V. Figure 3 above shows the entire schematic of the wristband subsystem.

2.1.1 Heart rate Sensor

The heart rate sensor monitors the heart rate of the user and warn the user if the heart rate is too high. The heart rate data will be sent through the microcontroller via Bluetooth to the camera subsystem. This will be powered by 3.3V. We will use the hardware module “Pulse Sensor Amped”, which is made to communicate easily with existing Atmel libraries [5].

<i>Requirement</i>	<i>Verification</i>
1. The heart rate sensor must be able to constantly measure the heart rate.	1. A) Attach the sensor to the finger of a person. B) Connect the sensor to the oscilloscope. C) Observe the heart rate being measured.

2.1.2 Microcontroller

The microcontroller processes the heart rate data sent from the heart rate sensor and sends it to the camera subsystem via Bluetooth. The heart rate sensor itself cannot really measure the heart rate data, so the microcontroller needs to assist in order to convert it into digital data. This heart rate data will be sent to the camera subsystem through Bluetooth. ATmega328 will be used.

<i>Requirement</i>	<i>Verification</i>
1. The microcontroller must be able to digitize the heart rate signal from the sensor to the digital data.	1. A) Power the microcontroller with 3.3V. B) Attach wave generator to analog input pins on the microcontroller. C) Produce sine wave through wave generator. D) Connect the microcontroller to PC. E) Monitor the sine wave being interpreted by the microcontroller with serial monitor.

2.1.3 Bluetooth

The Bluetooth module communicates between the wristband and the camera subsystem to send the heart rate data. This will act as the wireless communication between the wristband and the camera subsystem. HC06 will be used for the Bluetooth module.

<i>Requirement</i>	<i>Verification</i>
1. Bluetooth module must be able to communicate with the microcontroller through UART (Universal Asynchronous Receiver/Transmitter).	1. A) Power the microcontroller with 3.3V. B) Attach wave generator to analog input pins on the microcontroller. C) Produce sine wave through wave generator. D) Connect Bluetooth module on the microcontroller and connect to PC through Bluetooth. E) Monitor the sine wave being interpreted by the microcontroller with serial monitor.

2.1.4 LDO Voltage Regulator

An LDO voltage regulator converts 3.7V to 3.3V. An LDO voltage regulator is used because the dropout voltage needs to be small and the device on the wristband need to be small. The circuit size will be small as the number of components attached to LDO voltage regulator is smaller than that of switching regulator. LP2985 LDO voltage regulator will be used.

<i>Requirement</i>	<i>Verification</i>
1. The voltage regulator must provide $3.3V \pm 5\%$ at 150mA.	1. A) Attach 5Ω resistor as a load. B) Supply the regulator with DC 3.7V. C) Measure and ensure the output voltage remains between 3.15V and 3.45V using the oscilloscope.

2.1.5 DC 3.7V Battery

3.7V Li-on battery will be used to power the wristband subsystem. DC 3.7V will be converted to DC 3.3V so the entire wristband subsystem can be powered. The battery will be small so that the user cannot feel much weight from it while doing the deadlift. We will use 40mAh Li-on battery and the size is 22mm long and 11.5mm wide.

<i>Requirement</i>	<i>Verification</i>
1. The battery must be able to store enough charge to provide at least 150mA at 3.7V to 4.2V for 1 hour once fully charged. 2. The battery must be unable to discharge if left plugged.	1. A) Attach 8.4Ω resistor as a load. B) Measure the current through oscilloscope and ensure the output current is approximately 150mA. C) Discharge battery for 1 hours and measure to see whether the voltage output is still above 3.7V. 2. A) Fully charge battery and plug the battery on the wristband. B) Allow to sit for 5 days. C) Measure the cell voltage and ensure it is above 3.7V.

2.2 Camera Subsystem

The camera subsystem contains a camera lens, the single-board computer, Bluetooth module, the speaker, the LCD display, the switching voltage regulator, and 7.4V Li-on battery. The video recorded through the camera lens will be analyzed by the single-board computer through the computer-vision. The computer-vision algorithm will use OpenCV to detect the motion of the body movement [6]. The alert sound will be made if the deadlift form is poor after the analysis. The analysis will be done in real-time.

The Bluetooth module will be used to communicate between the wristband and the camera so the heart rate data can be received to the single-board computer. If the heart rate is above 180bpm, the alert sound will be made. This alert sound will be different from that of the deadlift form analysis alert sound.

The final summary result of proper deadlift attempt is shown through the LCD display. Each attempt will be stacked accordingly in the single-board computer memory. The result is calculated in percentage and displayed on the LCD display.

All the components in the camera subsystem are powered by the switching regulator with a 5V conversion from the 7.4V battery.

2.2.1 Camera

The camera lens captures the video of the deadlift attempt of the user. The video will be recorded and analyzed on the single-board computer. We will use the supported Raspberry Pi Camera V2 for easy compatibility with our single-board computer.

<i>Requirement</i>	<i>Verification</i>
1. The camera must be able to record in 480p resolution at 15fps.	1. Check for packet loss in the transmission and ensure that it is receiving all data sent

2.2.2 Single-board Computer

The single-board computer processes the computer-vision so the deadlift form can be analyzed after receiving the video through the camera lens. The user's heart rate will be also monitored. The overall summary report of successful deadlift attempt will be calculated. For this project, Raspberry Pi 4 will be used.

<i>Requirement</i>	<i>Verification</i>
1. The SBC must able to communicate over MJPEG to receive the deadlift video.	1. Check through our program that the data is indeed in MJPEG format in 15 fps at 480p resolution.
2. The SBC must be able to calculate the summary report.	2. A) Connect Raspberry Pi to PC. B) Use Serial monitor to calculate mathematical equations. C) Display the output of result on the serial monitor and verify the answer.

2.2.3 Bluetooth

Bluetooth module communicates between the wristband and the camera subsystem to send the heart rate data. This will act as the wireless communication between the wristband and the camera subsystem. We will use inbuilt Bluetooth inside the Raspberry Pi 4.

<i>Requirement</i>	<i>Verification</i>
1. Bluetooth module must be able to communicate with the Raspberry Pi through UART (Universal Asynchronous Receiver/Transmitter).	1. A) Power the Raspberry Pi with 5V. B) Attach wave generator to analog input pins on the Raspberry Pi C) Produce sine wave through wave generator. D) Connect Raspberry with PC through Bluetooth. D) Monitor the sine wave being interpreted by the Raspberry Pi and the transmission through Bluetooth with serial monitor.

2.2.4 Speaker

The speaker outputs the alert sound when the bad deadlift form is detected or when the heart rate is too high. These two unique alert sounds are different so the user can distinguish them. Adafruit stereo speakers will be connected to the Raspberry Pi audio jack.

<i>Requirement</i>	<i>Verification</i>
1. The speaker must be able to make the two different alert sounds.	1. A) Connect the speaker to the PC. B) Play a sine wave at 1000Hz. C) Check the sound coming out from the speaker. D) Play a sine wave at 10000Hz. E) Check the sound is different from the previous sound.

2.2.5 LCD Display

The LCD display displays the entire workout summary report. The result shows the total number of deadlifts attempts since the device started and the total number of successful deadlift attempts. The percentage of successful attempts over the total attempts is also shown. Adafruit LCD display will be used to display the result.

<i>Requirement</i>	<i>Verification</i>
1. The LCD display must be able to display the numerical result.	1. A) Connect the LCD display to the SBC and connect SBC to PC. B) Input numerical values through serial monitor. C) Verify the LCD display properly shows the inputted numerical values.

2.2.6 Switching Voltage Regulator

A switching voltage regulator will convert DC 7.4V to DC 5V. Instead of using LDO voltage regulator, the switching voltage regulator is used to save the battery life. The single-board computer and the camera will consume lots of battery power and the switching voltage regulator will definitely help. The audio output might get a slight bit of noise due to the switching property of the regulator, but the quality of the audio is not a big deal for this product. TPS82150 from Texas Instruments will be used for the conversion of DC 7.4V to DC 5V.

<i>Requirement</i>	<i>Verification</i>
1. The voltage regulator must provide 5V±5% at 1A.	1. A) Attach 5Ω resistor as a load. B) Supply the regulator with 7.4V DC. C) Measure and ensure the output voltage remains between 4.75V and 5.25V using the oscilloscope.

2.2.7 DC 7.4V Battery

Two 3.7V Li-on batteries are used to power the camera subsystem. DC 7.4V will be converted to DC 5V so the entire camera subsystem can be powered. Two 1Ah Li-on batteries will be used.

<i>Requirement</i>	<i>Verification</i>
1. The batteries must be able to store enough charge to provide at least 1A at 7.4V to 8.4V for 1 hour once fully charged. 2. The battery must be unable to discharge if left plugged.	1. A) Attach 8.4Ω resistor as a load. B) Measure the current through oscilloscope and ensure the output current is approximately 1A. C) Discharge battery for 1 hours and measure to see whether the voltage output is still above 7.4V total. 2. A) Fully charge battery and plug the battery on the camera. B) Allow to sit for 5 days. C) Measure the cell voltage and ensure it is above 7.4V.

2.3 Software

There will be two different sides to the software implementation of our system – the software involved on our single-board computer (Raspberry Pi), and the software implemented on our microcontroller (Atmel). For the former, we will need to use OpenCV and python to create a basic skeletal identifier for our user. This will need to run relatively fast, which is difficult as the Raspberry Pi has relatively low processing power for machine learning applications. This is important as OpenCV builds upon TensorFlow, a machine learning/neural network library, when doing image recognition and classification. Additionally, we will use blob detection to find the wristband and track the trajectory of the barbell.

The only benchmark we have been able to find is a similar project that uses a Raspberry Pi to classify objects in an image – and while this is not an exact replica of our project, it is a useful

insight into the capability of our program. This program runs at approximately 0.9 FPS [7]. However, this program is able to recognize multiple different objects over a pretrained set of data.

Our skeleton program will essentially need to do a fraction of this. Furthermore, the resolution size of the image can be lowered to make for faster analysis. For the exact benchmark of what should be acceptable, 3-4 FPS is achievable and plenty good. If FPS becomes too much of a problem, we can also implement an algorithm that only calculates skeleton when it has detected the user began a lift. Using a simple motion algorithm while tracking the wristband, we can wait until the user begins a lift, record 3-4 FPS of video in the duration of the lift, and then process any frames we could not after the lift is over. This might make a small delay in our system, similar to the delay in the original project, yet would easily achieve a high enough FPS. OpenCV written by Gupta is an informative article about where we would base our skeletal detection algorithm [6]. We could create a separate neural network and use this processed skeletal data to detect good or bad form based on a set of data we create.

The second aspect of our program will be the software on our microcontroller. This will, in order to interface easily with our heartrate monitor, use the Arduino software packages to interface with the microcontroller. Furthermore, there is plenty of support for this as well as the Bluetooth module – this should be a straightforward bit of code. This will also need to communicate with the Raspberry Pi, so some small bit of code will need to be implemented on the single-board computer in order to properly send and receive signals.

2.4 Tolerance Analysis

The hardest part of this project is without doubt the computer vision algorithm that detects the wristband and determines the position. The software will also detect how bent the person's back gets while lifting. A noisy detection that results in false positives or false negatives can be very dangerous so we will need to figure out everything needed to get accurate detection. Different lighting conditions and different positions of the person related to the camera will make it difficult to make confident decisions.

We are checking both the pose of the skeleton to make sure the back of the lifter is straight, and the velocity & trajectory of wristband to make sure the barbell moves in a straight trajectory perpendicular to the ground. For this to work properly both wristbands as well as the core parts of the lifter's body must be visible to the camera. The barbells particularly can obstruct the vision of the camera. To prevent this the camera should be high enough that the wristbands are visible during the entire lifting process.

The position of the camera is very important because even though finding how straight the back of the lifter is with joint detection is relatively independent of the position of the camera, to find the position and velocity of the wristbands we must now the exact position of the camera in relation to the wristband.

If the camera is placed at the side of the lifter then a straight path up would still look like a straight line when viewed from a camera that is placed slightly higher than the position of the

wristband. This means that the height of the camera doesn't interfere with our detection of how straight the path of the barbell is as the lifter lifts it. Determining the velocity though will require us to know the position of the wristband

Because the size of the wristband will be known, if detected properly one can use perspective to figure out how far away the wristband is from the camera. We would first need to find the focal length of the camera which can either be already known or we can find it by using triangle similarity with the equation shown below [8].

$$Focal\ Length = \frac{Pixels \times Distance}{Width_{Known}}$$

Once we know the focal length, we can use the same formula to find the distance of the wristband from the camera if we know the size of the wristband.

After finding this distance, we can find the starting position of the wristband. One can imagine a right triangle between the camera, the ground right under the camera, and the starting position of the wristband. From simple trigonometry we know that at the beginning of the lift we have the equation below.

$$Distance_{Camera} = \sqrt{(Height_{Camera} - Height_{Barbell})^2 + (Distance_{Ground})^2}$$

From this equation we could find $Distance_{Ground}$, which is the distance parallel to the ground. $Distance_{Camera}$ is the distance from the wristband to the camera tripod, which is the hypotenuse distance between the height difference and the distance parallel to the ground. $Height_{Camera}$ is the height of camera tripod and $Height_{Barbell}$ is the distance from the wristband and the ground.

Assuming the lift is perpendicular to the ground, doing this right before the lift would give us three corners of a trapezoid whose corners are the camera, the feet of the camera, the starting position of the wristband, and the current position of the wristband. With this information we would know at any point how high up the wristband is from the ground at any timestamp which would let us find the velocity.

Additionally, it might be difficult to design a wristband that is big and unique enough for the algorithm to detect, while also making sure it is comfortable. An ergonomic design is important because if it is uncomfortable people would not use it. It could also distract people while lifting and worsen their form which instead of improving it.

3 Project Differences

3.1 Overview

Main point of both the original project and our project is to improve the deadlift form through the assistant device. It is designed that the user can use this product alone without the help from the other people. Eventually, this product should save money for the user by not paying for the lesson fees to the trainers.

The major difference between our project and the original project is whether this product is for private use or public use. The barbell subsystem in the original project allows the product to be used between several people. We substitute that with the wristband for the personal use only.

3.2 Analysis

Compared to the original project done by the team #32 in Fall 2019, the one major difference will be the targeted customers. Our product is more for the personal use than the public use. The original project uses a barbell subsystem, which can be used by anyone in the public space like a gym. The original project can be bought by the gym and the product can be shared for anyone doing the deadlift. Our product is opposite of that; the product is more for the personal use. The wristband is highly recommended to be used by one person at the time. Since we are in a difficult situation of where we need to avoid social contact, a personal device is more favorable than a shared device.

Instead of attaching the device on the barbell, wearing a wristband can prevent the balance issue when doing the deadlift. In the original project, the barbell subsystem is attached to the barbell itself, and this can possibly affect the balance of the barbell - causing poor deadlift form. A light-weight wristband can solve this issue and it reduces the amount of stuff to carry when going to the gym.

Since the product is for the personal use, we added the heart rate sensor on the wristband. Having too high heart rate can cause an issue when exercising. It is recommended to stop exercising when the heart rate is too high, and the wristband will emit a warning sound to enforce this. This sound alert will be different than the sound alert from the bad form.

The sound alert system is also a huge difference compared to the original project. The original project uses an LED indicator to inform the user. Yet, it is very difficult to see the LED indicator while doing the deadlift. The sound alert is much easier to notice even when the user cannot see the LED indicator.

We have mentioned two feedback systems in the above: the deadlift form feedback sound alert and the heart rate feedback sound alert. We have one more feedback system, which is a log of how well the user did for the entire workout. This will help the user track their improvements and motivate them to fix their forms. A percentage-based system on top of a binary good or bad alert system helps not only beginners but also slightly more experienced users to perfect their form over time.

The ease of set up is what distinguishes our project from the original project. The original project needs to attach a barbell subsystem on the barbell and the user needs to make sure the barbell is properly balanced. Instead of using a barbell subsystem, we are using the wristband subsystem which is very easy to set up. You just need to wear the wristband on the wrist. Also, the camera subsystem will be literally a camera with a tripod. This will be very small so that you can carry it inside a bag when going to the gym.

4 Cost and Schedule

4.1 Cost Analysis

We are expected to work at least 10 hours a week for 11 weeks during one semester. Our hourly rate is \$50 per hour. Putting everything into the equation shown below, the total labor cost is \$33,000.

$$3 \times \frac{\$50}{1 \text{ hour}} \times \frac{8 \text{ hours}}{1 \text{ week}} \times 11 \text{ weeks} \times 2.5 = \$33,000$$

Parts	Quantity	Unit Price	Cost
Pulse Sensor Amped	1	\$25.00	\$25.00
Microchip ATMEGA328 Microcontroller	1	\$2.08	\$2.08
Olimex HC-06 Bluetooth Module	1	\$2.99	\$2.99
Texas Instruments LP2985 3.3V Low-dropout Regulator	1	\$0.11	\$0.11
SparkFun Polymer Lithium Ion Battery 40mAh	1	\$4.50	\$4.50
Sony IMX219 Raspberry Pi Camera Module	1	\$29.96	\$29.96
Raspberry Pi 4 Model B	1	\$35.00	\$35.00
Adafruit 1669 Speaker	1	\$7.50	\$7.50
Adafruit 3627 LCD Display	1	\$2.95	\$2.95
Texas Instruments TPS82150 1A Switching Regulator	1	\$1.20	\$1.20
SparkFun Polymer Lithium Ion Battery 1Ah	2	\$9.95	\$19.90
Wristband	1	\$3.00	\$3.00
Total Cost:			\$134.19

Figure 4. Table of Parts, Quantity, Unit Price, Cost, and Total Cost

Considering the labor cost and the cost of all the parts, we expect total of \$33,134.19 to produce a single product.

4.2 Schedule

Week	Deniz Yildirim	Erik Jacobson	Sang Baek Han
1	Work with Sang to connect wristband subsystem to RPi	Begin familiarizing with OpenCV in Python	Begin working with Bluetooth hardware
2	Set up RPi with camera to prep for machine learning, pass off to Erik	Skeletal recognition basics with camera (on desktop computer)	Design PCB schematics
3	Begin working with Arduino IDE to create heart rate monitor code	Create Dataset of good/bad lifts and begin creating detection neural net	Design PCB board layout
4	Connect heart rate monitor with Bluetooth to previous RPi code.	Finalize neural net detection software for good/bad lift	Solder and Test PCB
5	Preliminary debugging of entire communication protocol		Revise PCB
6	Create beeping system within wristband assembly	Create preliminary models for assemblies	Finalize PCB
7	Test accuracy of Erik's skeleton detection and recognition software	CAD models for final assemblies	
8	Field test of entire system	3D-print final design for box and wrist band assembly	
9	Assemble camera/Pi into final assembly box and put together wrist band assembly		
10	Prepare for final demo and adjust and bugs or issues from the previous weeks.		
11	Present the final demonstration and finish final paper		

Figure 5. Project Schedule and Task Allocation

5 Ethics and Safety

The IEEE Code of Ethics #9 states that “avoid injuring others, their property, reputation, or employment by false or malicious action” [9]. In order to satisfy this Code of Ethics, this product aims to reduce the risk of injury and it is very important that it does not do the opposite by causing an injury. No matter how perfect a computer vision algorithm is it is prone to errors. If the user trusts the product completely, the user might injure themselves. We should make it clear to the user that they must pay attention to their form and proceed with care regardless of what the product says.

The other concern is the Lithium-ion batteries. We are using total of two Lithium-ion batteries: one on the wristband and one on the camera. The Li-on battery on camera is not a huge issue, but the Li-on battery on the wristband needs careful attention. Li-on battery is known for its potential risk of explosion, and we will prevent this by making sure there is no shorting of the circuit and the circuit has the protection to prevent over charging [10].

As we have chosen to design our product to be private use only, this also raise the concern with the IEEE Code of Ethics #1 where it states that “disclose promptly factors that might endanger the public or the environment” [9]. We are in a COVID-19 pandemic and the main modes of transmission for COVID-19 is the liquid transmission. The respiratory transmission, the aerosol transmission, and the contact transmission falls under this category [11]. When the user wears the wristband and exercises the deadlift, the user will eventually sweat. It is highly recommended that this product to be never shared with other people and we will make sure to warn this to the user.

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