EMG-Based Squat Form Indicator

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***Abstract*—Squats are one of, if not the most popular exercise around the world. Not only do squats have evidence for improving lower body strength and endurance, but it is also an exercise that is easily replicable in day-to-day life. After building strength in the lower body and core muscles, it will also improve balance, posture, and prevent future injuries. However, it is shown that 22% of all injured participants stem from doing squat or squat related exercises. Proper form is vital to maximize both safety and strength throughout the entire exercise. Although the risk of squats remains evident, squat correction and prevention techniques still remain relatively unknown. Therefore, a bioinstrument that emphasizes the importance of risk prevention is created to correct proper form in exercise use for squats. The device uses electromyography (EMG) signals to measure muscle activation and corresponding form techniques to ensure the user is provided with the proper feedback to maximize muscle growth and prevent injury. If an attempt is made but without proper form, a buzzer will trigger to indicate that the repetition was not deemed complete. With a fast feedback response, this bioinstrument will be able to minimize injury and allow appropriate feedback for correction to optimize muscle growth and endurance.**

Keywords—Squat, EMG, Low Pass Filter, Rectifier, Hysteretic Comparator, Inverted XOR Gate

I. INTRODUCTION

Many researchers and performance trainers view squats along with deadlifts as some of the riskiest weightlifting movement exercises that are currently used in modern weightlifting techniques and competitions [1]. It is widely researched and known that squats put tremendous stress on the lower back if not down properly, especially at higher weights [2]. Therefore, all athletes and weightlifters must be properly trained and aware of the risks that stress on the lower back has, both immediately and chronically. Maintaining proper lumbar curvature, shown in Fig. 1, throughout these exercises is crucial and vital for injury prevention and maximizing muscle growth and endurance.

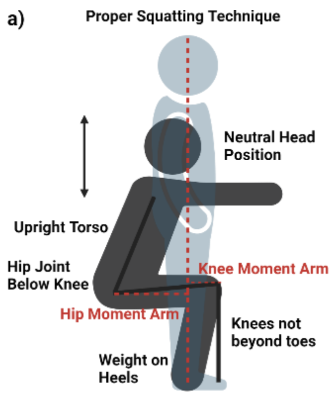

Fig. 1. Proper squatting technique to be deemed a full repetition. Created with Biorender.com

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Providing focused feedback into the proper form and full range of motion has proven beneficial in the long run. It is important to see a completed squat as studies show deeper squats lead to superior muscle growth when compared to shallow squats [3]. Therefore, real time feedback on muscle activity will ensure consistent and safe squat technique.

Given the danger to high injury rates and importance that deep and proper squats provide, a bioinstrument that will empower to train smarter and effectively by prioritizing form and injury prevention is created. Through the design of this bioinstrument, it is planned to capture the EMG signals created during the squat, refine the signal quality, identify initiation and completion of each squat repetition, and provide feedback if an incomplete squat repetition occurs. With this methodology going forward, the overall goal can be achieved.

II. METHODS

A. *Assumptions*

A key assumption made in our design is that squats in all humans are largely uniform in the EMG signal produced by activity of the rectus femoris quadricep muscle. This means amplitudes of the EMG signals retain their shape even as the person performing the squats begins to fatigue at around a standard 10 μV to 100 mV range, and that the desired signal frequency range is approximately 0~100 Hz.

B. *DESIGN AIMS*

Our device attempts to fulfill four key aims:

Objective 1: Capture electromyography (EMG) signals during squats

Objective 2: Refine signal quality by eliminating noise

Objective 3: Compare signals with thresholds to identify the initiation and completion of squat repetitions

Objective 4: Provide auditory feedback for incomplete squat repetitions

A successful implementation of these aims results in an EMG signal that is amplified, conditioned to get rid of artifacts, and ultimately accurate in determining proper squat form.

C. *SIGNAL COLLECTION, Amplification, and preprocessing*

The first primary component of this device serves to receive and amplify the signal. Our setup, shown in Fig. 2, consists of an instrumentation amplifier, a high pass filter, an operational amplifier, and then a low pass filter, attenuating our signal collection range to frequencies of 0.07 Hz to 100 Hz in accordance with our assumed raw signal frequencies. The electrode placements onto the user will be shown in Fig. 3. We will record and send the EMG signals from the

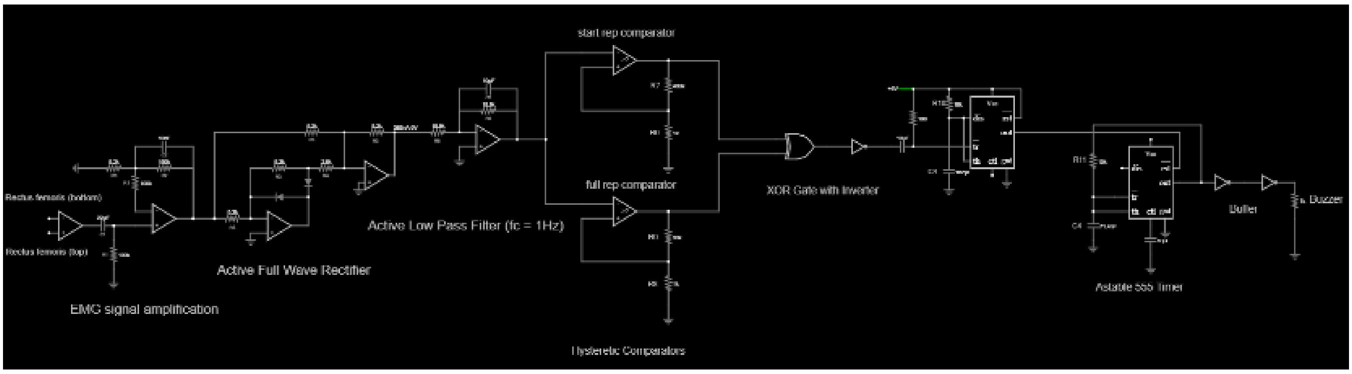

Fig. 2. Full Circuit Schematic

electrodes directly to the instrumentation amplifier through an open loop to the positive and negative inputs with a reference node to ground. The instrumentation amplifier and operational amplifier in our model are the AD622 and LM741 respectively, where their gain values can be calculated using equations (1) and (2).

$$G_1 = 1 + \frac{50.5}{R_G} \tag{1}$$

$$G_2 = 1 + \frac{R_2}{R_3} \tag{2}$$

This resulted in a total gain of approximately 900V/V for all received input.

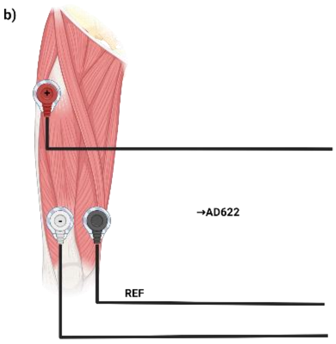

Fig. 3. The electrode locations on the rectus femoris muscle. Created with Biorender.com

This signal is processed through an active full-wave rectifier in a two-stage process which achieves two things: implements a half-wave rectification of all positive input and inverts all negative voltage input to complete the full wave rectification. The first stage has a gain of 1, as shown in Fig. 4 by the equal resistor values, R_3/R_3. The second stage has a gain of 2 relative to the input, as shown in Fig. 5 by the resistor relationship R_3/R_4.

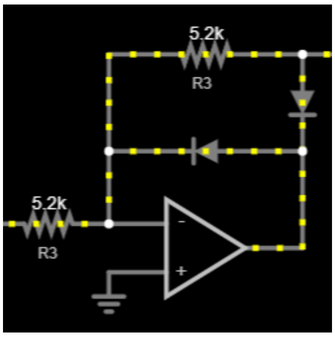

Fig. 4. Half-wave rectifier.

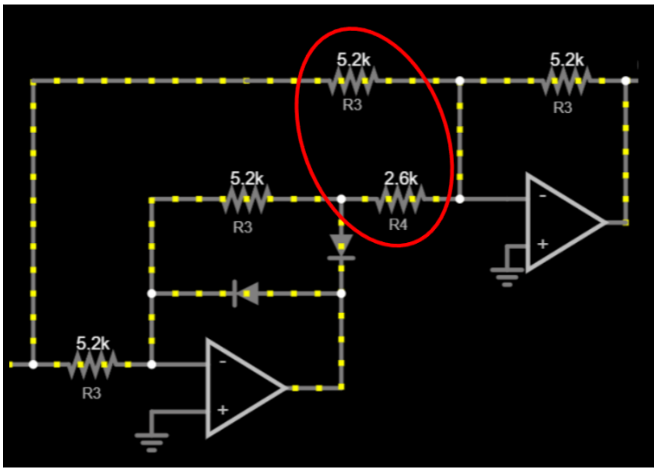

Fig. 5. Full-wave rectifier. This modified signal now containing only absolute voltage potentials recorded from the EMG is then sent through an active low-pass filter with a cutoff frequency of 1 Hz to eliminate DC drift and unwanted artifacts from wire movement.

Table I provides the values of components used in the first and second stages of the circuit design.

TABLE I. COMPONENT VALUES

Component	Value
R_1	100 kΩ
R_2	150 kΩ
R_3	5.2 kΩ
R_4	2.6 kΩ
R_5	15.9 kΩ
R_G	1.7 kΩ
C_1	22 µF
C_2	10 µF
C_3	10 µF

D. SIGNAL COMPARISON AND IDENTIFICATION

The next phase of the design consists of two hysteretic comparators, an inverted XOR gate, and a monostable 555 timer, as displayed in Fig. 6.

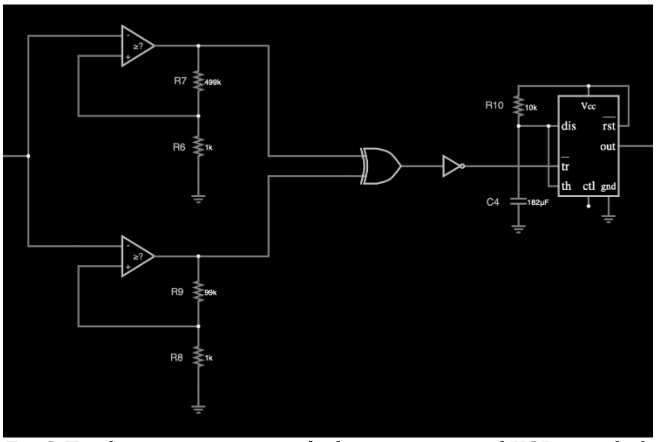

Fig. 6. Two hysteretic comparators feeding into an inverted XOR gate which then feeds into the trigger pin of a monostable 555 timer.

Beginning with the implementation of two hysteric comparators, the amplified and processed EMG signal from the low pass filter output is compared to the respective threshold values of each comparator. Consequently, they provide the initial step in determining if auditory feedback, in the form of buzzer, will be initiated. In the setup, one of the comparators (start rep) determines if the EMG signal signifies the beginning of a squat rep. The threshold voltage for this comparator was experimentally determined to be around 10 mV. If the EMG signal is greater than 10mV, the output voltage will transition to 5 V. If the signal is less than 10mV, the output will transition to –5 V. The other comparator (full rep) determines if an initiated squat rep is fully completed. The threshold voltage for this comparator was experimentally determined to be around 50mV. If the EMG signal is greater than 50mV, similar to the start rep comparator, the output voltage will transition to 5 V. If the signal is less than 50mV, the output will transition to –5 V. The resistance values of the voltage dividers of both comparators were dependent on each comparator's respective threshold voltages, which is displayed by equations (3) and (4).

$$V_{comp\ thresh,\ start\ rep} = \frac{R_6}{R_6+R_7} \cdot V_{cc} \qquad (3)$$

$$V_{comp\ thresh,\ start\ rep} = \frac{R_8}{R_8+R_9} \cdot V_{cc} \qquad (4)$$

Table II provides the values of components used in this portion of the circuit design.

TABLE II. COMPONENT VALUES

Component	Value
$V_{comp\ thresh,\ start\ rep}$	10 mV
$V_{comp\ thresh,\ full\ rep}$	50 mV
$+V_{cc}$	5 V
$-V_{cc}$	-5 V
R_6	1 kΩ
R_7	499 kΩ
R_8	1 kΩ
R_9	99 kΩ
R_{10}	10 kΩ
C_4	182 µF

Following the two comparators is an inverted XOR gate that receives and combines the output signals of the comparators into a single output. This digital logic gates outputs true when both inputs are the same and outputs false if the inputs are different. In the context of this design, the inverted XOR gate will output 5V if its inputs are both +5 V or both -5 V. These input possibilities signify the start and completion of a full rep and no attempt at a rep, respectively. Conversely, if one of the inputs is +5 V and the other is -5 V, then the logic gate will output 0 V. This represents an incomplete rep attempt. Table III summarizes the corresponding inputs for each inverted XOR gate output in a truth table.

TABLE III. INVERTED XOR GATE TRUTH TABLE

Input		Output
Start Rep Comparator	Full Rep Comparator	Inverted XOR
0	0	1
1	0	0
0	1	0
1	1	1

The inverted XOR gate output then feeds into the trigger pin of a monostable 555 timer. The inverted XOR gate will trigger the timer if it does not output successive 5 V input signals to the timer within a 2 second span. 2 seconds was determined to be the period for one squat rep to be fully completed and the timer's resistor and capacitor values were configured to satisfy the 2 second delay. In the case that the timer receives successive input signals within a 2 second span, the timer will reset the 2 second timer without being triggered. Equation (5) shows how the time is dependent on the resistor and capacitor.

$$t = \ln(3)\, R_9 C_4 \qquad (5)$$

E. TRIGGER BUZZER FOR INCOMPLETE REPS

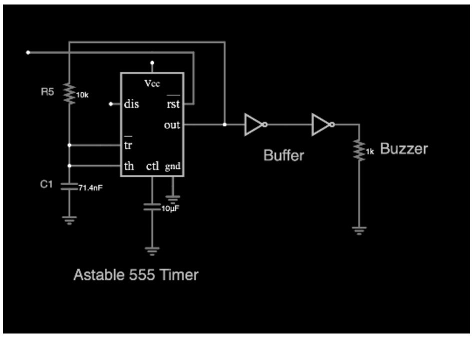

Fig. 7. An astable 555-timer feeding into a buffer which feeds into a buzzer.

To alert the user when their squat doesn't achieve full range of motion, we've devised a system employing a 555 timer alongside a buffer and buzzer as shown in Fig. 7. When activated, the 555 timer operates in astable mode, generating a 1000 Hz frequency signal for the buzzer. The buffer facilitates seamless signal transmission, ensuring that when the buzzer receives the 1 kHz frequency, it promptly sounds, alerting the user to their incomplete squat.

Equation 6 helps determine the optimal resistance and capacitance values to achieve the desired 1 kHz frequency for the buzzer:

$$f_{buzz} = \frac{1}{1.4R_{11}C_5} \quad (6)$$

Table IV provides the values of components used in this portion of the circuit design

TABLE IV. COMPONENT VALUES

Component	Value
f_{buzz}	$1\ kHz$
R_{11}	$10\ k\Omega$
C_5	$71.4\ nF$

III. DISCUSSION

A. Advantages

The development of an EMG repetition counter provides numerous benefits to athletes in strength training. Real-time feedback provides athletes with a valuable tool for immediate form adjustment. Athletes are able to receive near instantaneous cues regarding the depth and quality of their squats, and other movements, enabling them to quickly adjust on the spot. This feedback loop promotes continuous improvement and adjustment from athletes that maximizes their performance and likelihood of injury, staying safe in the process.

B. Limitations

However, while this device can alter athlete performance in a positive way, there are limitations regarding its applicability. Despite the ability to offer real-time feedback, the accuracy of the device may be susceptible to fatigue, electrode placement, and signal interference. Given that athletes slowly become more fatigued throughout their workouts, excess fatigue might be misconstrued as incorrect form or lack of range of motion. Also, surrounding muscles may interfere with specific muscle groups that are being examined, which can result in giving unreliable feedback. Additionally, while squats focus on a rather large muscle group, other individual and smaller muscle groups can be far harder to examine. This limitation can prevent athletes from addressing weaknesses in muscle groups that are more difficult to provide signals with through this device. Finally, while this device solely focuses on muscle activation, correct form and technique can become overlooked. Joint alignment and weight distribution are not specifically determined from a device that purely measures muscle activation.

C. Future Applications

Expanding the functionality of the EMG repetition counter beyond squats would allow athletes to track muscle activation and growth for other compound lifts including bench press and deadlifts. Also, utilizing the counter for physical rehabilitation would be another way of lessening the likelihood of injuries. Using the EMG counter as a way of educating athletes on how to complete specific exercises could then promote more effective workouts. Finally, by analyzing muscle activation patterns, form consistency, and exercise performance over time from different athletes, trainers could use the device to tailor workouts for specific athletes that optimizing their training style and individual needs. Training intensity, volume, and exercise selection could be determined for specific athletes based on previous data from other athletes.

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