

Countermovement Vertical Jump
Technical report 1

Countermovement Vertical Jump

Technical Report 1

Submitted by
Mina A. Eksnadrous
University of Southern California
3620 South Vermont Avenue, KAP 132
Los Angeles, California 90089-2533
Tel. (347) 283 0725
Email eskandro@usc.edu

Date: May 12, 2010

Work performed at USC

Countermovement Vertical Jump
Technical report 1

Abstract

This report focuses on anaerobic exercise which is a short-lasting, high intensity activity in which the body's demand for oxygen exceeds the oxygen supply available. During anaerobic exercises Lactic-acid, which is a by-product of producing energy, accumulates in the blood causing fatigue, and the purpose of such exercise is to make the body more efficient in handling the acid by producing a buffer to delay the fatigue. Anaerobic tests shape and develop muscles as to lead to a greater performance over a short duration of time. The most common test used for anaerobic exercises is the countermovement vertical jump. Up to now, this test has been mostly performed using chalk to mark the height of the jump, then taking the difference between the jump height and original height to find the distance and from that compute the power. Once the height of the jump has been found, it can be compared to previous results to detect improvements. Here we examine the countermovement vertical jump exercise digitally with the aid of an accelerometer to determine the maximum height, exerted force, and power. Such a system would be useful for Personal Trainers, Athletes and Physical Therapists.

Table of Contents

Summary	5
1. Introduction	6
2. Hardware architecture	6-7
3. Software	8
4. Performance measurements	8-15
4.1 Introduction	8
4.2 Raw and Filtered data	8-10
4.3 Processing Data	11-13
4.4 Force and Power	14-15
5. Marketability	16-18
5.1 Introduction	16
5.2 One-Degree of Freedom	17
5.3 Three-Degrees of Freedom	17-18
6. Conclusions	19
7. Distribution list	20

Countermovement Vertical Jump Technical report 1

Summary

Maximal strength and Power testing are common ways to evaluate the strength and power of a person. Anaerobic exercises are an important part of any athlete's training program because of their effectiveness in improving performance in high intensity activities during a short duration of time. An important test from this category of exercises is the countermovement vertical jump, which is a performance test commonly used to assess explosive power and predict athletic abilities. The same test can be useful for Physical Therapists in evaluating their patients' progress and response to different exercises. This test has been mostly performed by using chalk to mark the height of the jump, then taking the difference between the jump height and original height to find the height of the jump which is used to find the power.

The purpose of this project is to measure the peak power by a jumper in a one-dimensional countermovement jump digitally. The data acquisition system was attached to the belt of a jumper, and the readings of the accelerometer during the jump outputted to a data file. A code was developed to extract these data and filter them to obtain the height and velocity of the jumper during the jump. Once obtained the force impulse and the power outputted to perform the jump were calculated and graphed.

The importance of this test is derived from its simplicity and from the powerful results it outputs. Recently the USC athletics department requested a digital way to perform the test which indicates a potential market for professional athletes. Additionally, the device would be useful for Physical Therapists to examine the progress of their patients.

Furthermore, we recommended that a gyroscope be integrated to the current system because it will make it much more powerful. As the system currently stands it is able to calculate height and power only along one axis, however by integrating the gyroscope, the system will have three-degrees of freedom making it much more powerful and useful for a lot more exercises.

1. Introduction

One of the main anaerobic tests for athletes is the vertical jump. For decades it has been used as a momentary try-out of one's strength, speed, energy and dexterity combined because it solves in one equation all of his unknowns as Dr. sergeant¹ said, this equation is:

$$\text{Efficiency index} = \frac{\text{Weight [lb]} \times \text{Height jumped [in]}}{\text{Statue height [in]}}$$

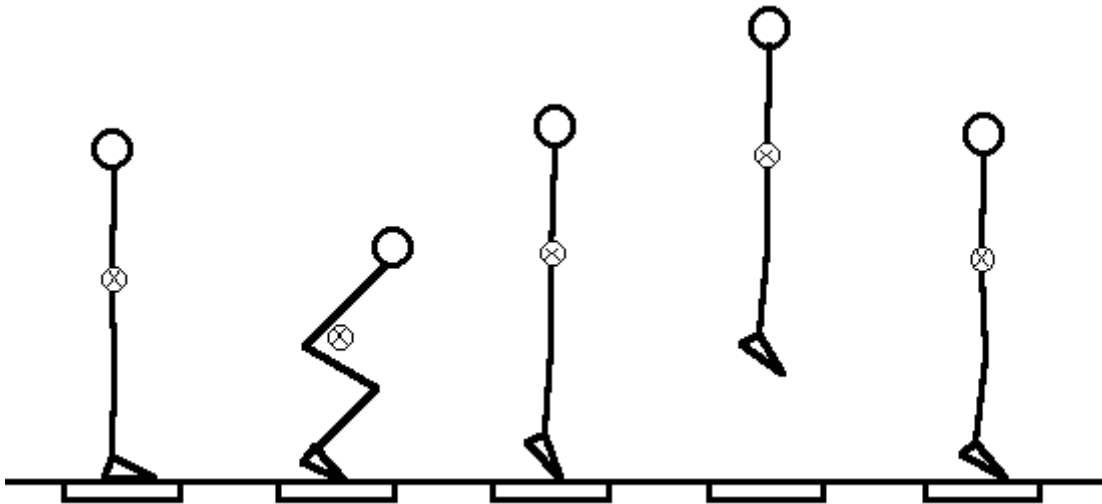


Fig 1.1: Countermovement jump

In this project we intend to measure the maximum height and exerted power by the body to reach that height digitally using the aid on an accelerometer. The measured acceleration is to be filtered, and processed to reach that goal. The data collected by the accelerometer is to be multiplied by 9.8 to convert it from units of [g] to [m/s²]. When the program is run, it asks the user to enter the mass of the 'jumper' in Kg, and uses this value in the computations of force and power. We encountered some problems with the data acquisition system probably due to insufficient computer/acquisition system speed, and another problem was the possible inaccuracy in the accelerometer readings.

The importance and popularity of this test is derived from its simplicity and the significance of its powerful results. Recently a research was published in the 'Journal of Strength and Conditioning Research' about the significance of the countermovement jump test; the research, that included several NCAA Division 1 football players, compares it to a jump from a stationary-stance position. The purpose of the research was to push for standardization in the test, mainly in the distance that the jumper can dip before the jump so that results would be comparable between different athletes.

2. Hardware architecture

We used a micro-controller data acquisition system shown along with its block diagram in Fig 2.2 and Fig 2.1 respectively. The system consists of five sensors; a 3-axis accelerometer, MMA7260QT, capable of sensing relative acceleration with a sensitivity of 1.5 or 6 g, a light sensor, TPS852, that consists of a single photocell, a pressure sensor, MPXA4250A6U, that uses piezoresistive transducer, and a humidity and temperature sensor HTM1735. Along with the sensors the system includes a micro-controller, PIC8F2410 which is an 8-bit, 16K flash and 768 RAM micro-controller, for controlling the devices and an FTDI chip for interfacing with USB.

¹ Sargent D. A.: "The Physical Test of a Man". American Phys. Educ. Rev.26: 188-194

Countermovement Vertical Jump Technical report 1

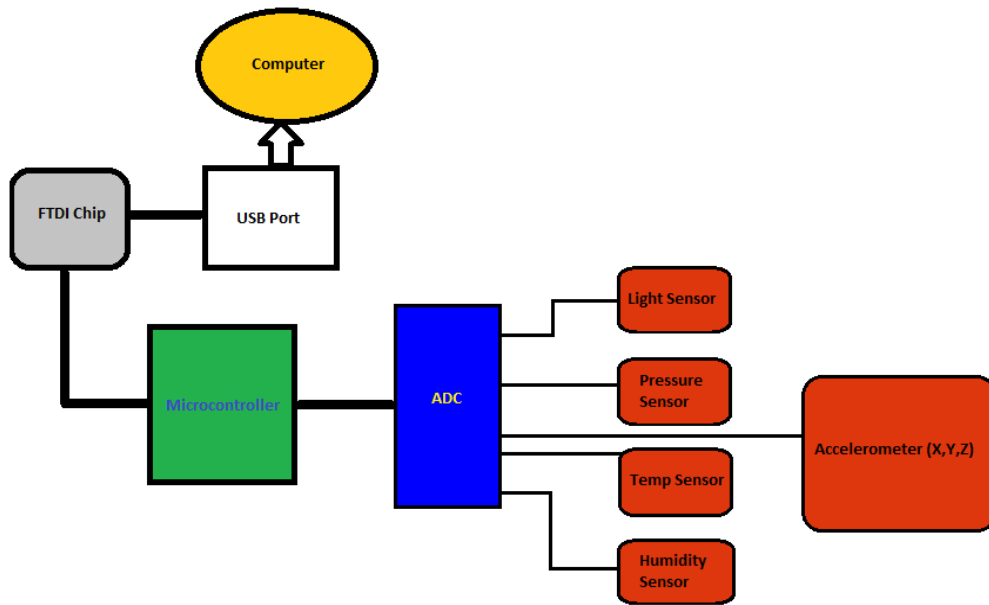


Fig 2.1: A block diagram of the data acquisition system

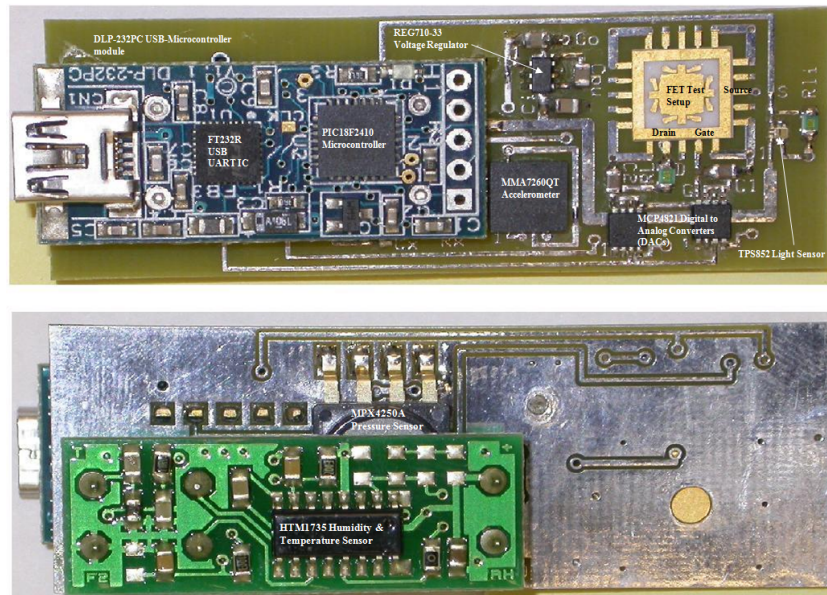


Fig 2.2: A top and bottom picture of the data acquisition system

3. Software

Software included two Matlab m.files; the first was a general code written Mr. Philip Seliger and provided by Professor A.F.J.Levi to extract data from the sensors, and we developed the second code to use these data to execute our task. Only the output raw data from the first code were used and a separate band pass filter was developed in the second code. For the first code, the user has to enter the COM port number, the desired sensitivity (either 1.5g or 6g), and lastly the desired acquisition time. The second code is designed to extract the acceleration data gathered by the first code, determine the highest 2^n data points available and use it to find the Fast Fourier Transform (FFT), filter it, and find the height, force, and power. Some alterations might be needed in the second code on a case basis to change the parameters of the filter to include only the desired frequencies and minimize noise; however, a compromise can be achieved by reasonably widening the range of frequencies to include an assumed possible range for the specific purpose of this program, which is countermovement vertical jump. For example, in the frequency domain, it is very unlikely that we are going to have a high amplitude frequency anywhere beyond 15Hz, and consequently we can filter the data on that basis. A band pass filter was used instead of a low pass filter to exclude the relative acceleration that the accelerometer measures, which will become clear in the next section.

4. Performance measurement

4.1 Introduction

The following sections include graphs and analysis of the collected raw data, filtered, and processed data to find the maximum height, force and power. Basic computations were needed using Newton's laws of motion for constant acceleration. Even though the acceleration were not constant over the time span of 10 seconds, which was used, by breaking it into really small intervals of approximately $8.2667e-004$, the acceleration can be regarded as constant for each interval, and consequently these basic laws can still be used.

The basic laws that were used:

$V=V_0 + at$	(EQ.1)	* Find final velocity
$X=X_0 + V_0t + \frac{1}{2} at^2$	(EQ.2)	* Find final position
$V_2=V_0 +2ad$	(EQ.3)	* Find take-off velocity
$F=ma$	(EQ.4)	* Find force
$P=FV$	(EQ.5)	* Find mechanical power

4.2 Measurement: Raw and Filtered Data

The displayed set of data was collected over a period of approximately 8 seconds, during which the acquisition system was attached to a belt that the person who performed the vertical jump was wearing.

**Countermovement Vertical Jump
Technical report 1**

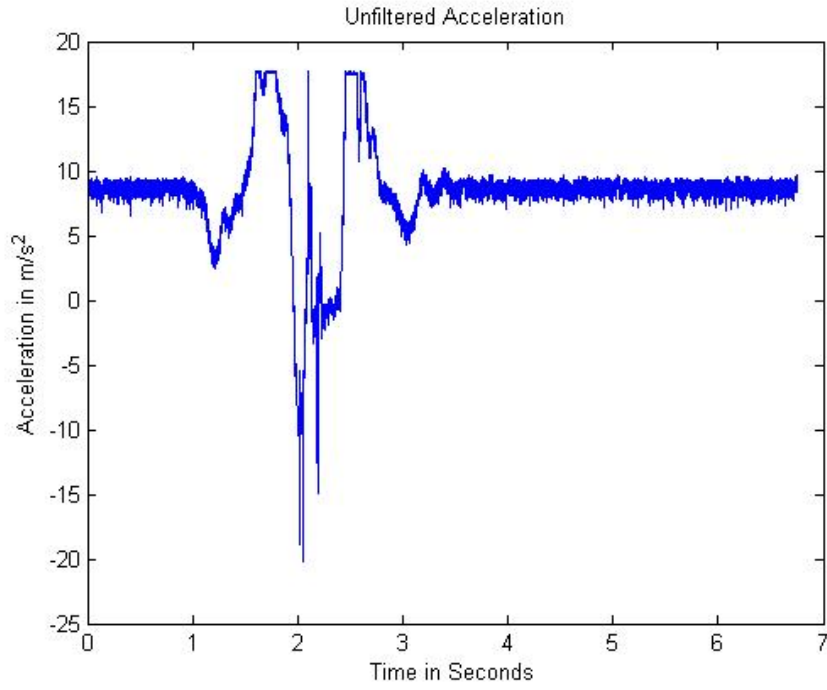


Fig 4.1 unfiltered Acceleration

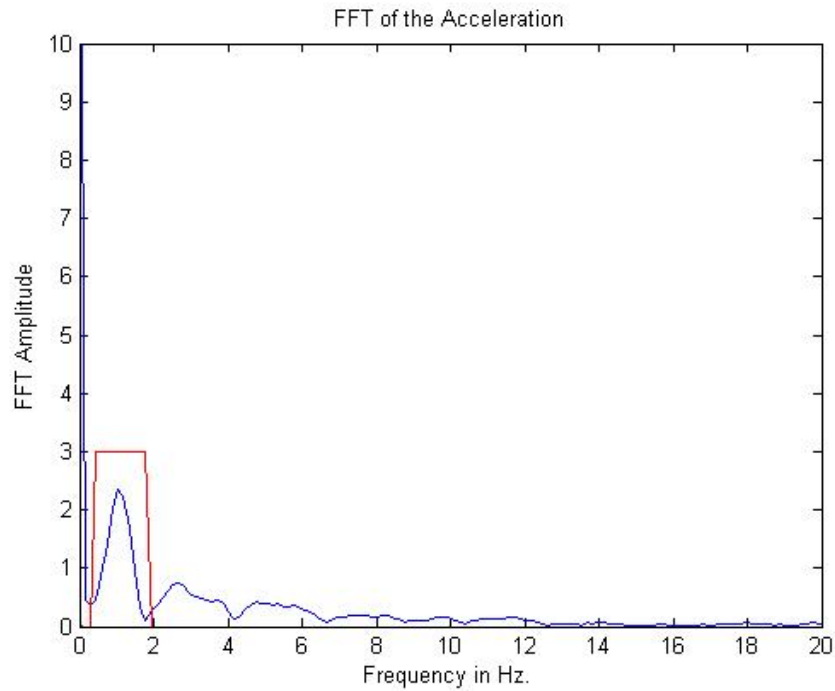


Fig 4.2 Frequency and Filter

Countermovement Vertical Jump Technical report 1

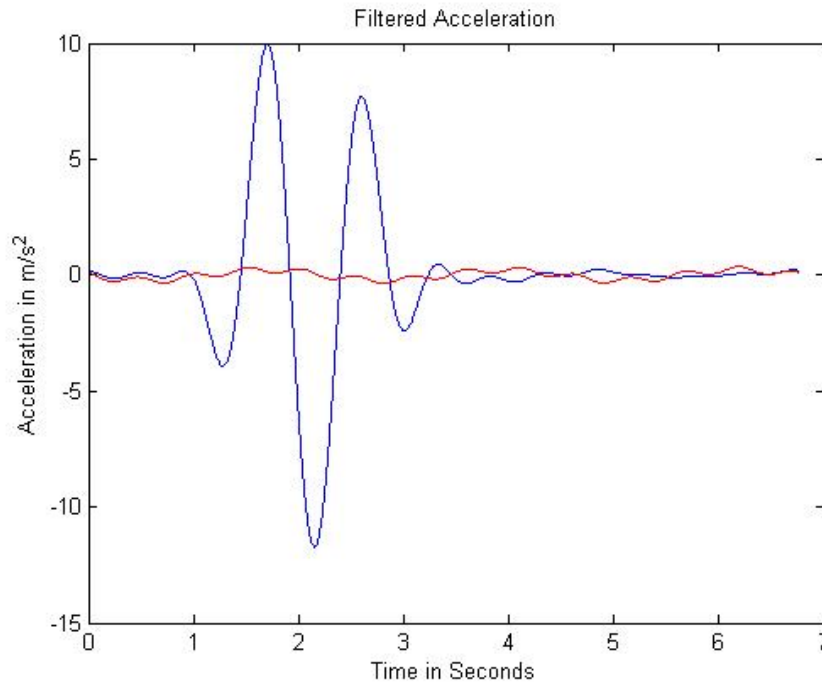


Fig 4.3 Filtered Acceleration

By closely inspecting figure 4.1, the unfiltered data, the readings show it is starting at -10, this is due to that the accelerometer measures the acceleration relative to gravity, in the frequency domain this is caused by a high amplitude and very low frequency approximately around 0.1 ~ 0.3 Hz. That was taken into account when constructing the filter as shown in figure 4.2, and in figure 4.3, which displays the real and imaginary part of the signal we can see that the filtered data is normalized to approximately zero. Also by inspecting figure 4.1 we can see that the acceleration saturated at the maximum value of the signal, which indicates that we should have used the 6g sensitivity instead of the 1.5g.

The data was filtered using the Matlab built-in FFT function; this required that the to-be filtered data be of 2^n size. This was achieved by, first extracting the data from the text file, then comparing its size with 2^n in a while loop and increasing n by 1 for every iteration until the maximum n that would fit in the data was found. Moreover, once the data were taken into the frequency domain, we can see from figure 4.1 that the amplitude of the fundamental frequency is close to 3, so we set the limit of the band pass filter to be 3 within the range of the desired passed frequencies. So by filtering the data we multiplied the original amplitude by 3, and consequently to get the original amplitude we divided by 3 before taking the inverse FFT, and since the Fourier Transform is a linear operation it does not matter if the division takes place before or after the transformation occurs.

Countermovement Vertical Jump Technical report 1

4.3 Measurement: Processing Data

After the data was filtered, a for loop was constructed to calculate the velocity and position. First, the velocity and position vectors were initialized to zeros and every output value was used as an input for the next iteration. Until all calculations were completed and graphed.

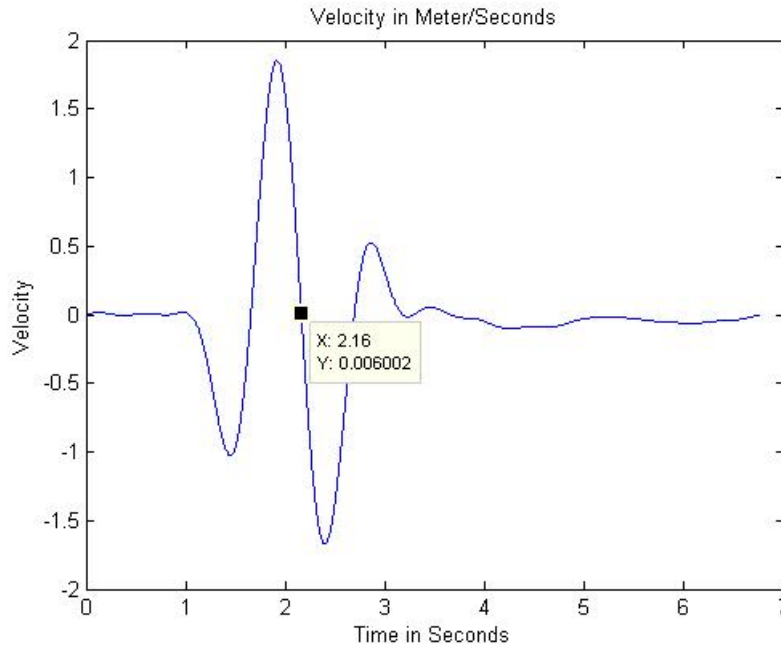


Fig 4.4: Velocity

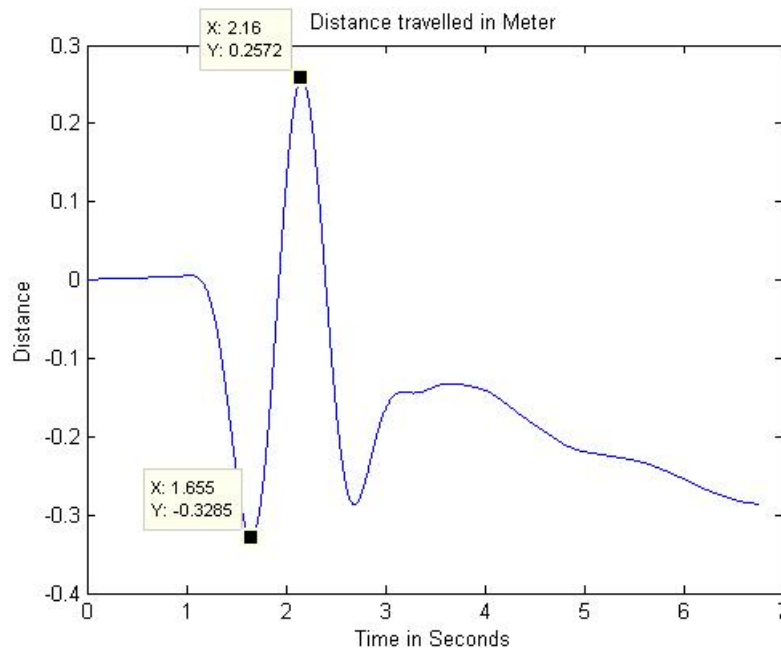


Fig 4.5: Position

For the data that were collected, simple steps can be taken to find how high the 'jumper' was able to reach; $height = \max(y_{pos})$, $height = 0.2350$ m. It is also evident from the graph that the jumper

**Countermovement Vertical Jump
Technical report 1**

dipped before jumping and the length of that dip can be easily found as 0.3287m below the starting position.

Also by inspecting figures 4.4 and 4.5 we can see that the moment that the jumper reaches the highest point in his trajectory is the same point where the curvature of the velocity changes as it sits momentarily at approximately zero because the jumper comes to momentary rest.

To find the take off velocity: (let c=the dip length= 32.85 cm)

$$\Sigma F=ma$$

R-W = ma; where R is the ground reaction force, and W is the weight of the jumper

$$a = \frac{R-W}{m} = \frac{g(R-W)}{W}; \text{ substituting this in EQ.3}$$

$$V^2 = \frac{2g(F-W) c}{W}; \text{ take-off velocity}$$

The countermovement vertical jump test became one of the athletic industry standards. Tests are performed by athletes and their results compared to average values. An example of such table is shown in the next page.

Fig 4.6 a typical jump height comparison table¹

Vertical Jump Scores		
Sport / Position	In.	cm
NCAA Div I College Football		
Split ends, strong safetys, offensive and defensive backs	31.5	80
wide receivers, outside linebackers	31	79
linebackers, tight ends, safetys	29.5	75
Quarterbacks	28.5	72
Offensive guards	27	69
High School Football Players		
Backs, receivers	24	61
Linebackers, tight ends	22	56
Linemen	20	51
NCAA Div I College Basketball		
Players (men)	28	71
College basketball players (women)	21	53
College baseball players (men)	23	58
College tennis players (men)	23	58
College tennis players (women)	15	38
Recreational college athletes (men)	24	61
Recreational college athletes (women)	15	38
Sedentary college students (men)	16-20.5	41-52
Sedentary college students (women)	8-14	20-36

Figure 4.6 is a typical jump height table for different sports and positions; it provides a reference point that based upon and based upon his previous results an athlete can be evaluated. And based on these results, a set of training exercises can be recommended to improve future results.

¹ <http://www.sport-fitness-advisor.com/powertests.html>

Countermovement Vertical Jump Technical report 1

4.4 Measurement: Force and Power

From Newton's Law, we know that $\Sigma F = ma$.

The external forces acting on the body of the Jumper are:

- I. His own weight (W)
- II. The ground Force Reaction (R)

Then by taking our coordinate system to be positive in the 'up' direction we have

$$R - W = ma$$

$$\text{Then: } R = m(a+g)$$

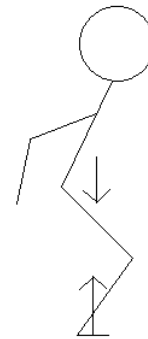


Fig 4.7

Also power can be calculated from (EQ.5): power = Force * Velocity.

So by constructing a for loop similar to the one that was used to calculate the velocity and height, both force and power can be easily calculated and graphed. Here are the results

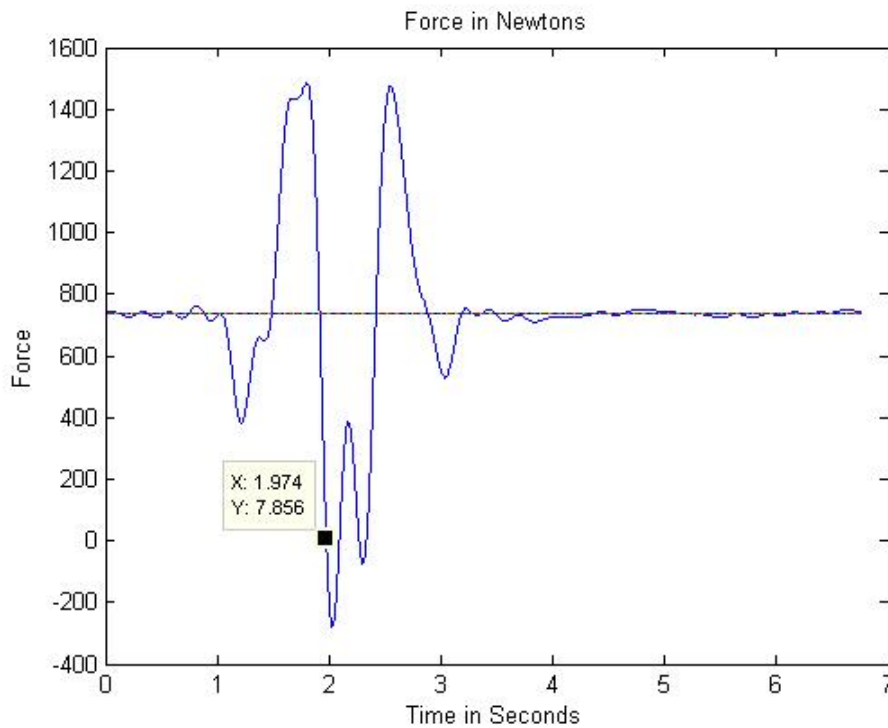


Fig 4.7: Force Vs. Time

Countermovement Vertical Jump Technical report 1

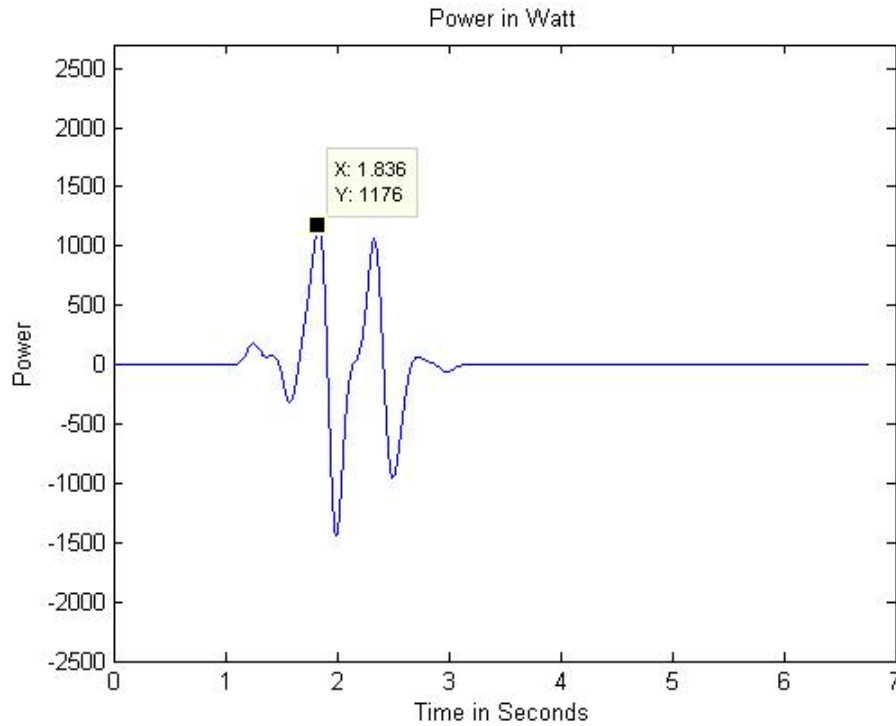


Fig 4.8 Instantaneous Power Vs. Time

The straight horizontal line in figure 4.7 represents the weight of the jumper, for this specific case, it was 735 Newton ($75 \text{ Kg} * 9.8$). By analyzing the graph we see the ground reaction force fluctuates above and below the weight, as the jumper is 'dipping' the reaction force goes below the weight and as the jumper is in the propulsion phase his reaction force exceeds his weight. The area between the reaction force and the weight in the propulsion phase represents the force impulse applied by the jumper. Also, the coordinates of the point indicated on the graph represents the point at which the jumper 'takes-off' because at this point the ground reaction force becomes zero and the jumper is no longer touching the ground.

5.0 Marketability

5.1 Introduction

Maximal strength and power testing are common assessments that are used to evaluate the strength and power of a person which makes them a necessary component of the evaluation of the progress of an athlete or a physical therapy patient.

The data acquisition system is intended to be sold for Personal Trainer, Athletes and Physical Therapists who want to measure the progress of an athlete or a patient. Moreover, a modification to the current system might include a 3-axis, eliminating the limitation of the device to only one-dimension measurements. Below is a list of components to assemble the device for both the one and the three dimensions measurements. Both prices; the miscellaneous and the cost of the board are approximations. Miscellaneous will depend on the final schematics and layout of the PCB, and the cost of the board will depend on both; how many boards are being produced and on the layout and dimensions of the board.

Items	Quantity	Digi-key part #	Price
3-D accelerometer	1	497-6969-1-ND	7.63
300° Gyroscope*	1	497-10138-ND	9.55
Microcontroller	1	P8X32A-Q44-ND	7.99
EEPROM ₁	1	24LC256-I/MF-ND	1.62
LED Power/ Heart Beat	1	511-1287-1-ND	0.31
USB MiniB connector	1	A31727CT-ND	1.29
3.3V Regulator ₂	1	576-1135-ND	2.23
Miscellaneous ₃			5
Cost of the Board ₄			20
Total 1-D			46.07
Total 3-D*			55.62

* Necessary for the 3-D calculations

1 To program the Micro-controller

2 USB's output = 5V, while the accelerometer and gyroscope use 3.3V

3 Approximate prices of necessary resistors, capacitors and other miscellaneous parts

4 Varies by number of PCB's to be produced

One issue to keep in mind while marketing this device; is the filter parameters. Every athlete or rather every jump will have its own frequency, these frequencies might be very close to each other but will shift left or right from time to time. To obtain the best results will require that the filter parameters be changed for every jump to suppress noise and obtain the cleanest single possible to calculate the power. One solution for this problem is to set the filter to pass a band of possible frequencies while eliminating any signal outside of this range, the trade-off in this solution would be that some noise would be included and the results might be a little off than the actual ones.

5.2 One-Degree of Freedom

The system as it stands right now has proved that it is effective in calculating the force impulse and the power exerted by the jumper as well as the height of his jump. As mentioned before, this system can replace the current techniques. The schedule shown above assumes that the unit price of this one-dimensional model will cost approximately 46.07 dollars to produce; this price is not exact and can be cut down. The first item that can be cut down from that system is the 3.3V regulator. Even though the voltage output from any USB is 5V, using a voltage divider with well calculated resistances we can produce the desired output voltage necessary to operate the Accelerometer at 3.3V. The other two approximate prices, as was mentioned previously, the miscellaneous and the cost of the board. Potential customers for this system include Physical Therapists and Athletic Trainers, who are interested in one-Dimensional exercises. Examples of such exercises are, but not limited to, the countermovement vertical jump, the standing jump and the squat jump which are shown in order in figure 5.1 below.

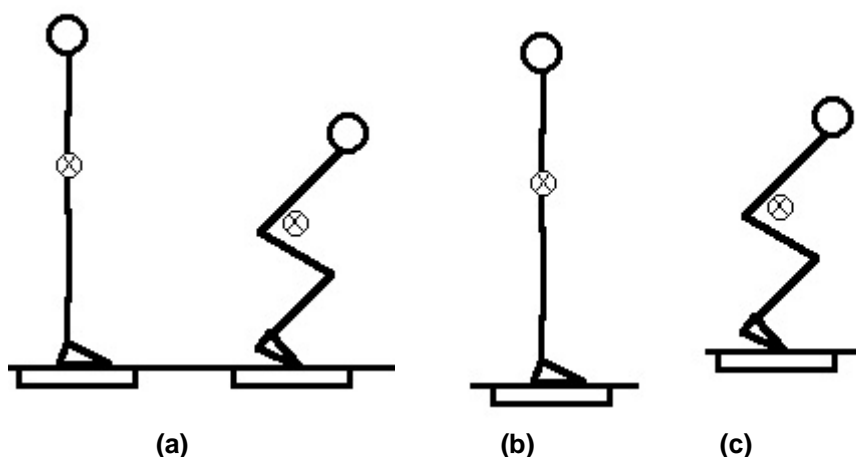


Fig 5.1 initial position before jumping (a) Countermovement vertical jump, (b) Standing jump, (c) squat jump

Using the device athlete can track their improvement or lack-off digitally, to determine the best course of action to improve their power output. Also Physical Therapists currently lack a measurable and sensible way to determine the improvements of a patient but rather rely on answers given by the patient but how much pain they are feeling by doing a certain exercise and how they feel. The device will calculate and output the power and force exerted by the patient and will provide the doctor with a sensible and physical number for both the power and force which makes his task a lot easier in evaluating the patient progress. Selling the device for 53 dollars will comprise a 15% profit, and it will be marketed to doctors mainly physical therapists as well as trainers and coaches in colleges and the professional sport's arena.

5.3 Three-Degrees of Freedom

One important addition to the current system is the gyroscope; which is device that measures orientation based on the principle of conservation of angular momentum. The advantageous achieved by including the gyroscope is that instead of having a one-dimensional system, we now have a three-dimension one. By including the gyroscope, the unit price becomes 55.62 dollars, however using the same reasoning mentioned above this price is approximate and can be cut down by eliminating the 3.3V voltage regulator and using a voltage divider instead, also the cost of the board will depend on the board's layout and the number of boards being produced.

This device would be a better buy for the same group of customers mentioned above; Physical Therapists, and Athletic Trainers simply for its ability to measure the performance in a much wider group

Countermovement Vertical Jump Technical report 1

of exercises. So in addition to all the exercises mentioned above it can also measure the power and force in exercises that are not just limited to one dimension; for example like, the running high jump, which measures an athlete ability and efficiency in converting his kinetic energy into potential energy, the standing broad jump, the long jump.

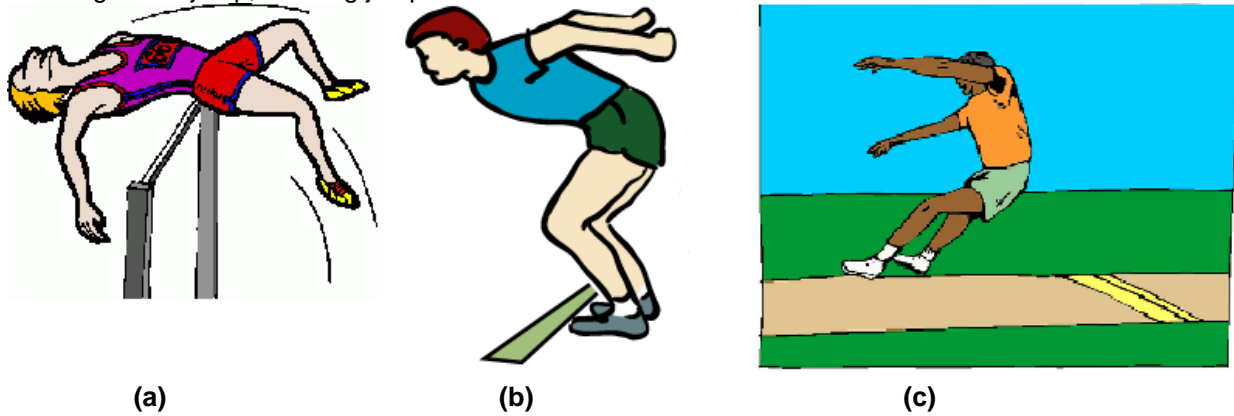


Fig 5.2 (a) running high jump, (b) standing broad jump, (c) long jump

Similar to the one-dimension device, athlete can use this device to track their improvements digitally. Also Physical Therapists can use the device to track the improvement and progress of their patients. Selling this device for 64 dollars will attain a 15% profit as well. However instead of having both devices in the market, it would be a wise decision to have just one, the three-dimension one, because it can perform all the possible functions of the one-dimension device.

Finally, we would like to conclude by saying that the market exists for this device, for example the USC athletic department requested the development of such a device. Similarly other schools and professionals would be interested. Also, we previously mentioned that Physical Therapists would be interested in the device to measure the progress of their patient. In the case of Physical Therapists, the device will not have to go through to intensive FDA approval process, since it is for external use.

6. Conclusions

By performing the Countermovement Vertical jump test using the traditional way by using chalk, while recording the outputted data from the data acquisition system, the digital calculations were off the actual result by 3cm out of 28cm or exactly by 10.7%. at small distances this deviation is significant and more tests needs to be done to identify its cause and correct it.

The integration of a 3-axis gyroscope will prove to be very useful, because it will allow the device to be used for a variety of other exercises, and make its use practical for athletes and physical therapists.

As was mentioned before, the market does exist for this device, as the USC athletics department requested its development and its usefulness in evaluating physical therapy patients' progress. It would be a wise choice to only produce and sell the Three-Degrees of freedom system because of the wide range of exercises that it is able to measure the power output for.

6. Distribution list

Report number – Report title (1 copy total)

A.F.J. Levi
Professor of Electrical Engineering
University of Southern California
3620 South Vermont Avenue, KAP 132
Los Angeles, California 90089-2533

1 copy

Tel. (213) 740-7318
Fax. (213) 740-9280 fax
Email. alevi@usc.edu
Web. <http://www.usc.edu/alevi>