Lean Green Skating Machine

Report No. 1

Submitted by
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Abstract

Long distance pumping refers to the act of riding one's skateboard for a prolonged distance on flats or inclines without ever putting a foot on the ground. Instead, the skater continually displaces his/her weight so that momentum is conserved, or gained. This technique was supposedly developed hundred of years ago by Hawaiian and Polynesian surfers, and is quickly gaining popularity as the sport of longboarding continues to grow. Nevertheless, many people, and even skaters, are still unaware of how to pump a longboard, or what pumping even is. Pumping is a very advanced technique, and very difficult to master. There are no step-by-step instructions because the optimal pumping method is unique to every board and every rider. While many websites and forums dedicated to long distance pumping try and explain "proper" pumping techniques, the best way for a skater to learn how to pump is by going out and trying it for him/herself. The Lean Green Skating Machine is designed to help skaters recognize when they are accelerating the board by pumping so that they can internalize that motion and find their own optimum pumping technique.

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Summary

This report includes the details and design of the Lean Green Skating Machine, a device that will be used to help skaters reach their full pumping potential. Background and history of skateboards, as well as an explanation of the physics of pumping, was only briefly touched on in this report, as it was a heavy focus during the presentation. Instead, the focus of this report is on testing, results, commercialization, current issues and future improvements for the product.

A majority of time on this project was spent writing the MATLAB code, and then testing it to make sure that it worked. Using MATLAB, the Lean Green Skating Machine is able to find the frequency components of the different acceleration parameters on a skateboard, and filter out frequencies that are above a certain threshold to reduce noise from the signal. Despite the substantial amount of time spent on this portion of the project, there were still several problems with calibrating accelerations to ignore the acceleration due to gravity and approximating the integral of a set of data points.

There were some problems with testing the product as well. Originally, the testing method picked up too much high frequency noise from being placed directly on the skateboard, and could not be reconstructed into a usable signal. After trying different methods of calculating the acceleration and filtering the signal, I was finally able to record signals that could be used to process and identify the relation between the oscillation frequency of a pumping skateboard and its forward acceleration.

From the results, we find that the oscillation frequency and the forward acceleration do in fact have a direct relationship, but not one that can be mathematically derived at this time. While it was observed that when traveling at faster speeds, higher frequency pumping oscillations are needed to maintain momentum, the main thing that the results confirmed was that the optimum pumping motion is different for every board and every individual.

Finally, this report expands on the future improvements needed for this product to become commercially viable. Still, a lot more testing must be done in order to better understand the relationship between oscillation frequency and forward acceleration, but the Lean Green Skating Machine is designed to use previously recorded data to make a more educated guess regarding this relationship.

1. Introduction

The goal of the Lean Green Skating Machine is to promote a fun, clean and healthy mode of transportation and recreation: longboarding. This device helps longboarders perfect their long distance riding skills by finding a pumping technique that will result in maximum acceleration. The Lean Green Skating Machine uses an accelerometer to measure both the displacement of the board due to pumping, as well as the forward acceleration. It continually collects and stores data while the skater rides, and determines the optimum pumping motion for that specific skater. This means that as you ride with the Lean Green Skating Machine, both you and the device become better at determining the your best pumping motion.

2. Testing

Original Test: When initially gathering data for this experiment, the accelerometer was placed in the middle of the heel-side of the skateboard to measure the angular displacement of the board from the horizontal axis, caused by the shifting of the skater's weight from side of the board to the other. This was measured by the Z-axis acceleration, while the overall speed of the board was measured by the Y-axis acceleration.

Riders:
- James Kelly, sponsored by Loaded
- Louis Pilloni, sponsored by Sector 9

Skateboard Decks and Setup:
- Flex 3 Loaded Vanguard, Randal 180mm trucks, Purple Orangutang In Heats wheels, 85a Khiro Cone Bushings (Figure 1(a))
- Flex 1 Loaded Dervish, Randal 180mm trucks, Orange Orangutang Freerides, 80a Venom bushings (Figure 1(b))
- Sector 9 custom-cut prototype, Paris 180m trucks, Sector 9 Slalom Wheels, 80a Venom bushings (No image available)

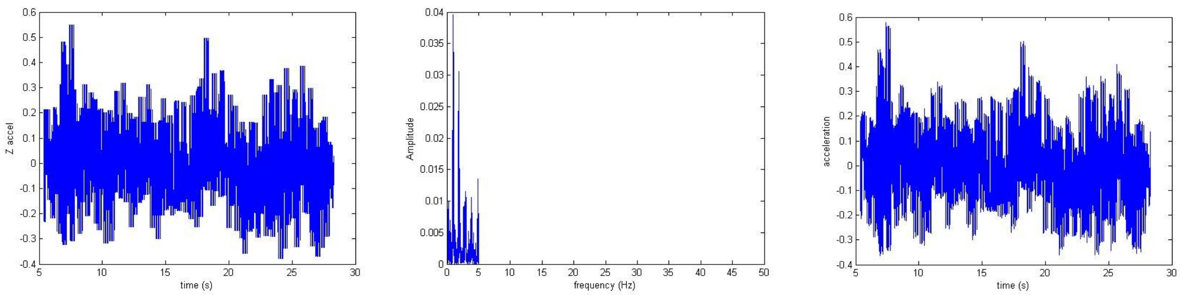
(a) (b)

Figure 1: (a) a Loaded Vanguard (b) a Loaded Dervish. Boards are made of bamboo and are unique because of their combination of flexibility and strength. Note: These are pictures of the same decks, but not necessarily of the entire setup used in testing. Board setups are important because every feature can have a substantial effect on one's pumping ability.

Testing conditions:

- Rider pumps skateboard in straight-line along level surface for predetermined distance
- Rider has three kicks to initially build speed, but cannot remove feet from board after initial kicks
- Wear backpack containing laptop, which is running software to analyze data collected by accelerometer in real-time
- Whichever rider is not being tested follows and films test subject

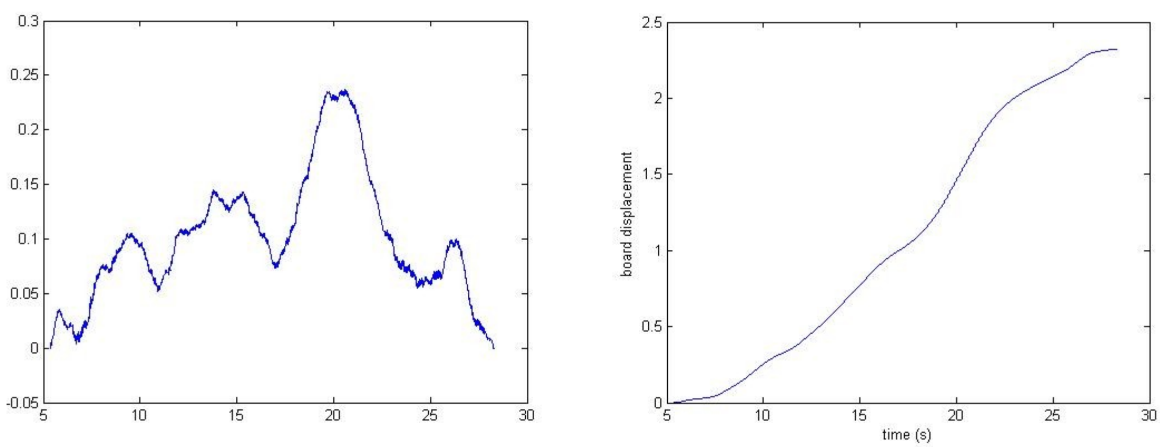
Most of the data collected during these trials was inaccurate due to the immense amount of high frequency noise picked up by the accelerometer, resulting from the vibration of the skateboard while riding. Because of this, the data was unable to be filtered down to a signal that could be used for analysis. As seen in Figure 2, the filtered data was still very difficult to process.



(a) **(b)** **(c)**

Figure 2: (a) Unfiltered Z acceleration in time domain (b) filtered Z acceleration in frequency domain (c) filtered Z acceleration in time domain. The filtered Z acceleration looked remarkably similar to the unfiltered plot until the cutoff frequency of the lowpass filter was as low as .3 Hz. This is too small to be the value of frequency oscillation when pumping a skateboard. The figures shown are filtered to pass all signals less than 5 Hz.

Also, the values of Z acceleration were inaccurate because they included acceleration due to gravity. Since the accelerometer was rotating on an axis, the acceleration due to gravity in the Z direction was not constant. Since the effect of gravity could not be efficiently calibrated for, the values of Z velocity and Z position as a result of integrating the Z acceleration values were inaccurate. See Figure 3.



(a) **(b)**

Figure 3: (a) plot of Z velocity vs time (b) plot of Z positions vs time. These plots are supposed to be sinusoidal in shape, like that of Z acceleration, but due to the inconsistent effect of gravity the data is not accurate.

The original goal was to compare the frequency of oscillations in the displacement of the board along the horizontal axis with the resulting forward acceleration, but this was impossible with the given data.

New Test: For the new test, the accelerometer was placed directly on the hip of the skater, in order to reduce the high frequency vibrations in the signal that were picked up when the accelerometer was placed directly on the board. Also, since the skater's body remains relatively perpendicular to the ground at all times, it was easier to calibrate for the effect of gravity. For this experiment, the oscillations of the skater's body were measured by the acceleration on the Y-axis, while the overall speed of the board was measured by the acceleration on the negative Z-axis. Same testing parameters were used, but the professional riders originally used in testing were out of town for competition and not available for second test so new riders and longboards were used.

3. Hardware

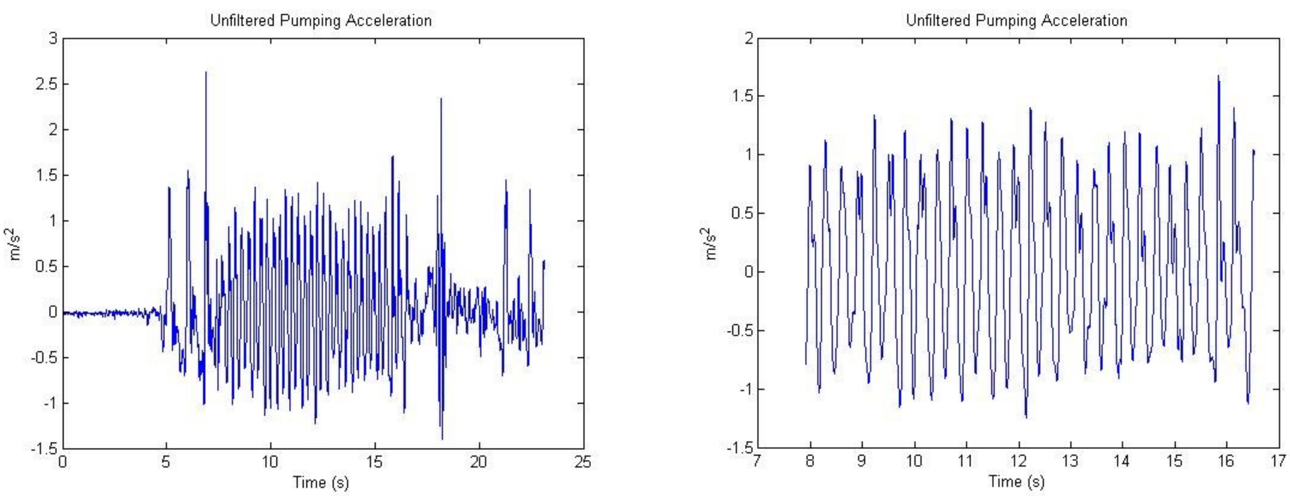
Figure 4

Computer: Asus Eee PC netbook (See Figure 4). Features a low price, fully compatible, laptop that runs Windows 7 and has a solid-state drive. Comes with 1 GB of RAM and 120 GB HD. Since this was carried around in a backpack while skating, the fact that it is lightweight with substantial battery life was very important.

4. Software

MATLAB code:

```
M = dlmread('avg aaron pump 1.txt', '', 2, 0); %read avg file for y acceleration and time
rows = length(M(:,1)); %calculates number of rows in M

time = M(9580:20042,1);  %filters out data correspoding to times during which rider was not pumping
Z = -M(9580:20042,4); %define row vector of Z acceleration
Y = M(9580:20042,3); %define row vector of Y acceleration
```



(a) (b)

Figure 5: (a) unfiltered acceleration of skater's oscillations for all values of Y (b) unfiltered acceleration of skater's oscillations for values of Y during which the skater was pumping. Note that both of these plots have already been calibrated to account for gravity. This interval is found by syncing the video with the recorded data and determining at what times pumping began and ended. It is also fairly easy to tell where pumping began and ended by simply looking at plot (a). The numbers 9580 and 20042 are the rows that correspond to the time values at which the skater started and stopped pumping, respectively.

```
avg = mean(Y);
Ycal = Y - avg; %calibrate Y to account for gravity
plot(time,Ycal);
xlabel('Time (s)');
ylabel('m/s^2');
title('Unfiltered Pumping Acceleration');

Yfft1 = fft(Ycal); %FFT of Y accel
```

```
maxfreq = 1213; %define sampling parameters (maxfreq = 1/steptime)
minfreq = maxfreq/length(Z);
freq = (0:minfreq:maxfreq);

hr = zeros(1,length(Z)); %create initial vectors for impulse response
hi = zeros(1,length(Z));

hf = 3.711; %cutoff frequency for filter
kf = hf/maxfreq*length(Z); %cutoff freq scaled to step time
```

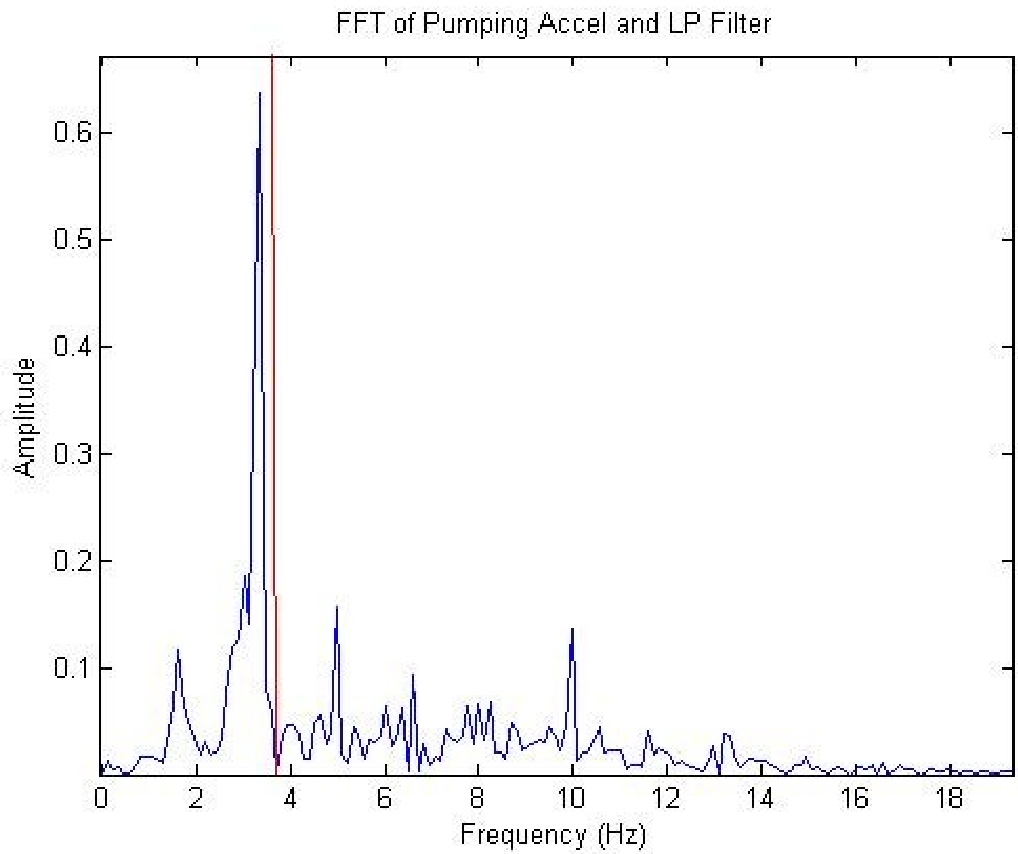


Figure 6: The unfiltered FFT of Y acceleration values with low pass filter shown in red. Cutoff frequency of low pass filter is manually determined by analyzing the unfiltered plot. The cutoff frequency will be slightly higher than the frequency under 5 Hz with the greatest amplitude. Anything with higher frequency than 5 Hz will be too fast to be a product of the skateboard pumping.

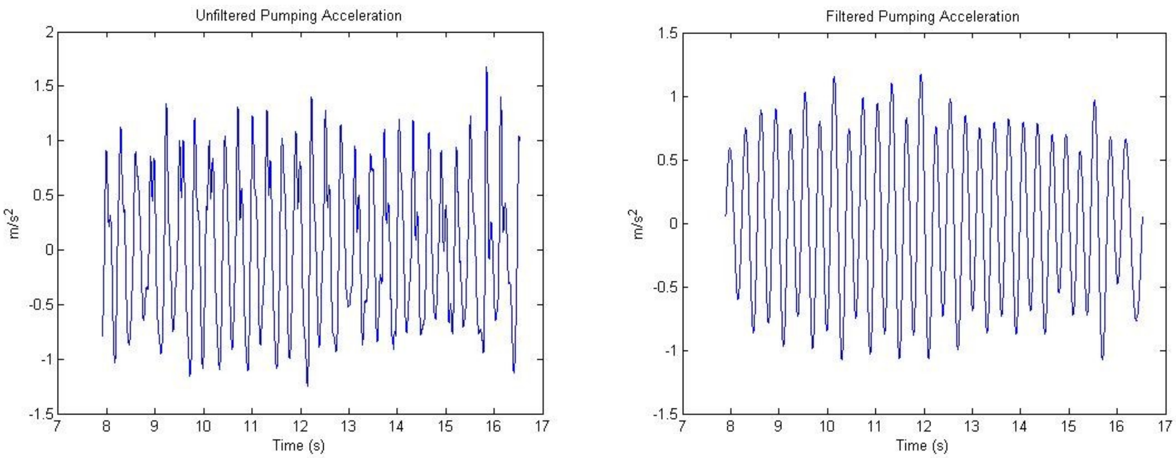
```
for k = 1:1:kf %create lowpass filter
    hr(k)=1;
    hr(length(Z)-k+1)=hr(k);
end

h = complex(hr,hi);

figure;
plot(freq(1:length(Z)/2), abs(2*Yfft1(1:length(Z)/2)/length(Z)));
hold on;
plot(freq(1:length(Z)/2),real(h(1:length(Z)/2)),'r')
xlabel('Frequency (Hz)');
ylabel('Amplitude');
```

```
title('FFT of Pumping Accel and LP Filter');

Yfft2 = h'.*Yfft1; %send FFT through LP filter

figure;
plot(freq(1:length(Z)/2), abs(Yfft2(1:length(Z)/2)/length(Z))); %plot filtered signal in freq domain
xlabel('Frequency (Hz)');
ylabel('Amplitude');
title('Filtered FFT Pumping Accel');

Yaccel = ifft(Yfft2); %inverse fourier transform
Yaccelr = real(Yaccel); %only need real values of iff


figure;
plot(time,Yaccelr);
xlabel('Time (s)');
ylabel('m/s^2');
title('Filtered Pumping Acceleration');

figure;
plot(time,Z);
xlabel('Time (s)');
ylabel('Acceleration');
title('Unfiltered Forward Acceleration');

ar = zeros(1,length(Z)); %initial vectors for impulse response
ai = zeros(1,length(Z));

af = 1.799; %cutoff frequency for filter
bf = af/maxfreq*length(Z);

for k = 1:1:bf
   ar(k)=1;
   ar(length(Z)-k+1)=hr(k);
end
a = complex(ar,ai);

Zfft1 = fft(Z); %calculate FFT of Z acceleration

figure;
plot(freq(1:length(Z)/2), abs(2*Zfft1(1:length(Z)/2)/length(Z))); %plot FFT of Z accel
hold on;
plot(freq(1:length(Z)/2),real(a(1:length(Z)/2)),'r')%plot low pass filter
xlabel('Frequency (Hz)');
ylabel('Amplitude');
title ('FFT of Forward Accel and LP Filter');

Zfft2 = a'.*Zfft1; %send FFT through LP filter

figure;
plot(freq(1:length(Z)/2), abs(Zfft2(1:length(Z)/2)/length(Z))); %plot filtered signal in freq domain
xlabel('Frequency (Hz)');
ylabel('Amplitude');
title('Filtered FFT of Forward accel');
```

```
Zaccel = ifft(Zfft2); %inverse fourier transform
Zaccelr = real(Zaccel);

figure;
plot(time,Zaccelr);
xlabel('Time (s)');
ylabel('m/s^2');
title('Filtered Forward Acceleration');

Zvel = cumtrapz(time, Zaccelr);

figure;
plot(time, Zvel);
xlabel('Time (s)')
ylabel('m/s');
title('Forward Velocity');

Zpos = cumtrapz(time,Zvel); %define Z position by integrating Z velocity

figure;
plot(time,Zpos);
xlabel('Time (s)');
ylabel('meters');
title('Total Distance');
```

5. Results

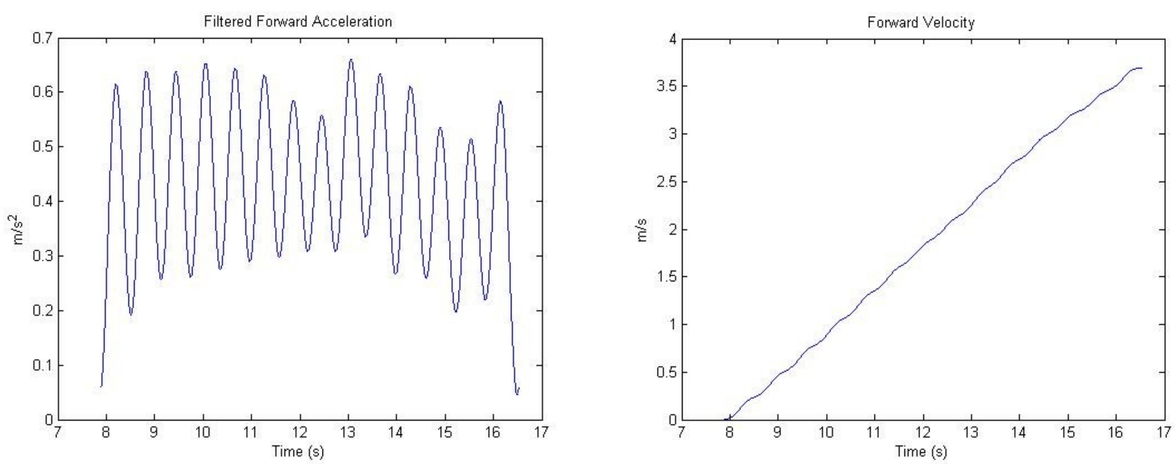
The second test was much more successful than the first in terms of gathering usable data. By putting the accelerometer directly on the hip of the individual, the high frequency noise in the signal was drastically reduced, making it easier to filter a signal that looks very similar to a sinusoidal wave. Also, the values of acceleration in the Y direction were more accurate because they did not have to constantly calibrate for different values of acceleration due to gravity. While the skater does have to lean forward and backwards slightly to create the pumping motion, this is primarily an upper body motion and therefore the plane of the skater's hips primarily stay perpendicular to the acceleration of gravity.



(a) **(b)**

Figure 7: (a) unfiltered Y acceleration signal (b) filtered Y acceleration signal. To get (b) from (a) signal is passed through the low pass filter from Figure 6. As you can see, there is not nearly as much noise in this sequence of data as there is in Figure 2.

Despite the fact that this second test was setup to reduce as much external noise as possible in the signal, Z acceleration should still be put through a low pass filter to further ensure that the values used to calculate Z velocity and position are accurate. Like the Y acceleration values, the Z acceleration values are transformed in to the frequency domain, and then any frequencies above a certain threshold are eliminated. The resulting signals representing filtered forward acceleration and the forward velocity are shown in Figure 8.



(a) (b)

Figure 8: (a) filtered acceleration of the skater and (b) velocity of the skater

From Figures 8(a) and (b) we can conclude that the skater not only conserved his momentum, but that he gained some as well. While the value of forward acceleration at time t oscillates around .4 m/s^2, the acceleration value never falls below the x-axis. This means that the skater is constantly accelerating, but just not at a constant rate. Each spike in the acceleration is a result of the centripetal force from the wheels pushing against the riding surface as they turn away from the center of the board's turning radius. Each drop in the acceleration corresponds to the creation of that centripetal force when the wheels turn in towards the board's turning radius. At this time, the board is still accelerating, but just not as quickly. The net effect of this oscillating acceleration is actually a fairly linear velocity function, due to the fact that the acceleration was oscillating around a constant value. The small ripples in the forward velocity are most likely a result of the longboard being affected by sideways components of acceleration from the centripetal force, which causes the rider to "slalom" around a straight line.

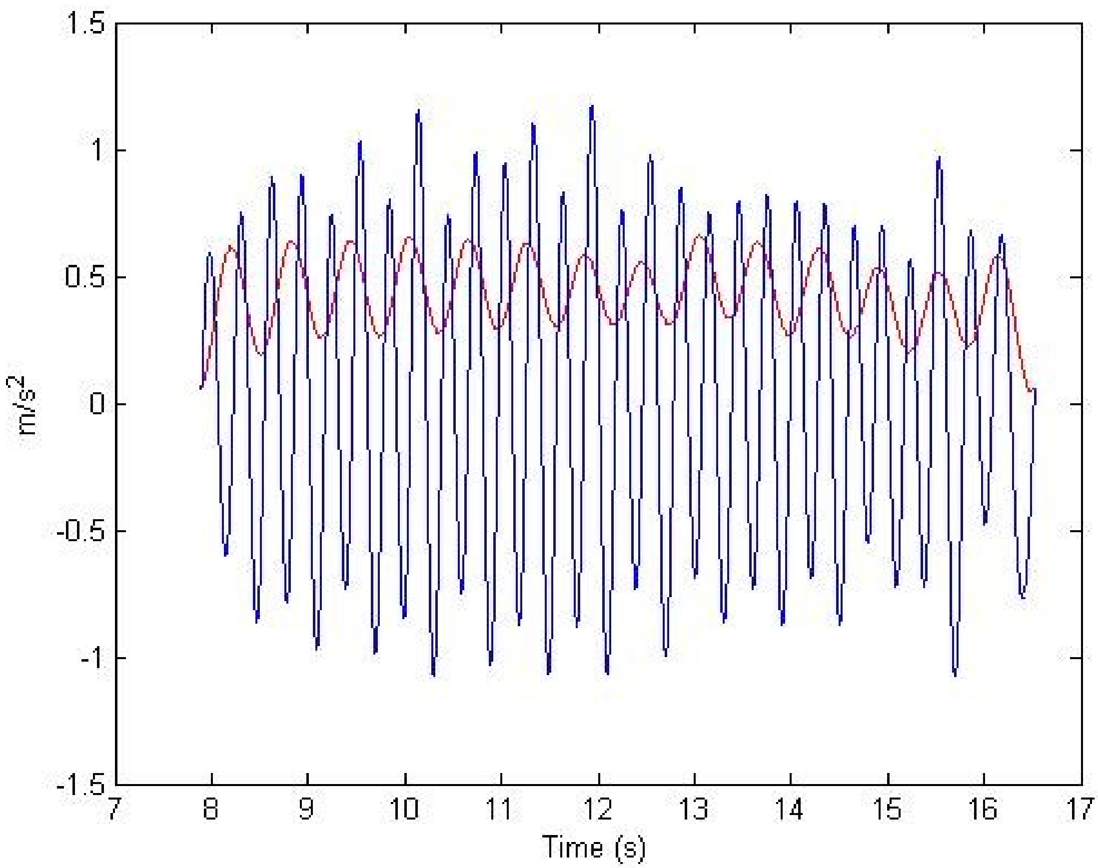


Figure 9: overlaps Figure 8(a) and 7(b) in same plot. Forward acceleration is in red and the pumping oscillations are in blue.

Figure 9 confirms that there is a relation between the board's acceleration and the frequency of the acceleration of pumping oscillations. This figure may be slightly confusing because the Figure 7(b) actually displays roughly twice the frequency of oscillation of pumping movements. Each spike in this figure represents a pump in the heel-side/toe-side direction, and the following spike represents a pump in the opposite direction. Since one full pump consists of a pump in the heel-side direction AND a pump in the toe-side direction, the period of each oscillation can be calculated by taking the difference in time values between two local maxima separated by only one local maxima in between them. This motion of alternating from toe-side to heel-side, and vice-versa, is what allows the board to continue to move forward rather than veering off to the side.

Although the second test was much more successful than the first in terms of data acquisition, much more data is still needed in order to accurately hypothesize the relation between these two variables. Because the data is only recorded for a short period of time (roughly 20 s per trial), and the amount of data that can be used to analyze the pumping motion is even less than that, we have very little variation in our frequency and acceleration values. In all trials, the frequency of oscillation remained reasonably constant (within a couple tenths of a hertz), and the incremental change in acceleration is reasonably constant, as indicated by the linear relation of velocity to time as seen in Figure (8b).

Despite the fact that the relationship between forward acceleration and the acceleration of pumping oscillations has not been defined with explicit mathematical figures, a few conclusions can still be drawn from the testing process. For example, when testing, we observed that at higher speeds, a higher frequency of oscillations was needed to maintain that speed, while at lower speeds, the frequency of oscillations needed to maintain that speed was much lower. From this, we can conclude that if pumping oscillations become more frequent, this will cause the rider to gain speed. On the contrary, carving can be thought of as pumping, but with extremely low oscillation frequencies. Carving is the act of taking wide, s-shaped turns in an effort to slow down and maintain control. This technique is very common amongst skiing, snowboarding and other board sports. While the goal of carving is the exact opposite of pumping, the same principles apply. Carving is like pumping at a very low frequency, which in turn causes the rider to slow down.

Even though there was not much variation in the data, Figure 10, on the following page, accurately portrays this relationship between oscillating frequencies and the overall acceleration of the board. Figure 10 is a table of data collected from the experiment for one trial from each rider during the second test. The time column shows the times at which a local maximum occurs for pumping accelerations. The period is the time in between two local maxima, with exactly one local maximum separating them, in order to account for pumps to the heel-side AND toe-side. The velocity at time t is acquired from figure 8(b), and the acceleration is calculated by the difference in voltage at the beginning and end of a period divided by the length of that period. As mentioned earlier, the frequency and incremental acceleration values for all trials remain reasonably constant within their respective trials. In all trials, the rider also accelerated throughout the entire trial. Because the velocity continues to increase while the frequency of oscillations remain generally constant, however, the incremental acceleration does begin to slightly taper off, especially in the case of Aaron's trial. This is indicative of the previous conclusion drawn that that at a higher velocity, oscillations with higher frequencies will be needed to maintain acceleration. Note that this is not necessarily a true statement when different skaters and boards are compared with each other. While David's frequency of oscillation is higher than Aaron's throughout the entire trial, his average velocity and incremental acceleration are less than Aaron's. This could be for a variety of reasons, including loose mounted screws, rusted bearings, or maybe even weak kicks to start the trial. The best pumping technique will be different for every board and individual, but there will still be a relationship between oscillation frequencies and forward acceleration.

Figure 10

Aaron Pumping				
Time (s)	Period (s)	Frequency (Hz)	Velocity (m/s)	Acceleration (m/s^2)
8.013			0.065	
8.304			0.201	
8.617	0.604	1.656	0.303	0.395
8.940	0.636	1.572	0.465	0.415
9.248	0.631	1.585	0.581	0.440
9.535	0.595	1.681	0.731	0.447
9.844	0.596	1.678	0.849	0.450
10.140	0.605	1.653	1.006	0.455
10.450	0.606	1.650	1.130	0.463
10.740	0.600	1.667	1.282	0.459
11.040	0.590	1.695	1.406	0.468
11.330	0.590	1.695	1.553	0.460
11.640	0.600	1.667	1.684	0.464
11.940	0.610	1.639	1.828	0.450
12.260	0.620	1.613	1.958	0.441
12.540	0.600	1.667	2.092	0.439
12.850	0.590	1.695	2.213	0.432
13.150	0.610	1.639	2.381	0.475
13.470	0.620	1.613	2.520	0.495
13.760	0.610	1.639	2.679	0.488
14.060	0.590	1.695	2.791	0.459
14.350	0.590	1.695	2.935	0.435
14.650	0.590	1.695	3.053	0.444
14.940	0.590	1.695	3.174	0.406
15.230	0.580	1.724	3.277	0.386
15.530	0.590	1.695	3.381	0.351
15.870	0.640	1.563	3.509	0.363
16.180	0.650	1.538	3.629	0.380
16.570	0.700	1.429	3.779	0.385
David Pumping				
Time (s)	Period (s)	Frequency (Hz)	Velocity (m/s)	Acceleration (m/s^2)
7.137			0.119	
7.441			0.196	
7.708	0.571	1.751	0.255	0.238
8.004	0.563	1.776	0.320	0.220
8.276	0.568	1.761	0.406	0.266
8.548	0.544	1.838	0.465	0.267
8.819	0.543	1.842	0.552	0.269
9.095	0.547	1.828	0.607	0.259
9.354	0.535	1.869	0.694	0.265
9.630	0.535	1.869	0.750	0.267
9.905	0.551	1.815	0.840	0.264
10.170	0.540	1.852	0.903	0.283
10.430	0.525	1.905	0.980	0.266
10.690	0.520	1.923	1.050	0.283
10.960	0.530	1.887	1.128	0.280
11.220	0.530	1.887	1.200	0.283
11.480	0.520	1.923	1.277	0.287
11.740	0.520	1.923	1.345	0.278
12.010	0.530	1.887	1.424	0.276
12.260	0.520	1.923	1.491	0.281
12.530	0.520	1.923	1.581	0.302
12.780	0.520	1.923	1.651	0.308
13.040	0.510	1.961	1.730	0.293
13.310	0.530	1.887	1.805	0.289
13.570	0.530	1.887	1.883	0.288
13.820	0.510	1.961	1.950	0.286
14.100	0.530	1.887	2.026	0.270
14.350	0.530	1.887	2.106	0.294
14.600	0.500	2.000	2.161	0.270
14.830	0.480	2.083	2.227	0.251
15.110	0.510	1.961	2.310	0.293
15.380	0.550	1.818	2.389	0.296
15.670	0.560	1.786	2.468	0.281

6. Commercialization

As of now, there is nothing like the Lean Green Skating Machine on the market. The goal of this product is to measure your frequency of oscillations, as well as your acceleration while you are skating and then at the end of your ride, the Lean Green Skating Machine will provide a report of your pumping efficiency, which will be a measure of your actual acceleration for a certain period of time over your expected acceleration for same period of time. Since the exact relation of oscillation frequency to acceleration is still yet to be defined, the product would work by optimization. Each time you use the Lean Green Skating Machine, it will record and store your velocity, frequency of oscillations, and the resulting acceleration. Once the Lean Green Skating machine acquires enough data, it will be able to determine your expected acceleration based on your velocity and frequency of oscillations. At the end of your ride, the Lean Green Skating machine will provide a map of your route and identify during what parts of the route your acceleration was higher, or lower, than what was expected.

The target audience for this product would obviously be the longboarding community, and specifically longboarders who are enthusiastic about long distance pumping. Longboards have been popular in California and amongst college campuses for a long time, but in the last few years the longboarding community has extended its reach to people of each and every walk of life. Love for the sport is growing all around the world within people both young and old. Some people ride for recreation, others for transportation, and others, like the long distance pumpers, do it because it is what they love.

The Lean Green Skating Machine would also be a great product for individuals who are not familiar with the sport of longboarding. This device is meant to be a teaching tool to help people of all skill levels improve their skating, and specifically their pumping abilities. With increased pumping efficiency, in the future, the longboard could become the preferred mode of emissions-free transportation over the bicycle. The only fuel a longboard needs is kicking legs, but with the Lean Green Skating Machine, that may not even be necessary. On top of being clean, safe and good for the environment, longboarding is a great cardio and lower body workout, and the pumping motion greatly strengthens the core.

Despite the fact that the longboarding community is growing, and has the potential to get much bigger, there is still not enough demand to commercialize the Lean Green Skating Machine as a stand-alone device. While this device would be perfect for individuals who participate in long distance pumping, LDP is a very young sport, with only a few people around the world who are very committed. The device would be fairly expensive to produce, as it would need a microprocessor, memory, battery, and display just to name a few costs. In order to be most effective, the Lean Green Skating Machine should utilize GPS technology, or else the Lean Green Skating Machine would only be accurate when traveling along a straight line, which is very difficult to do when skating for long distances over extended periods of time. This would add to the potential cost even more.

Rather than trying to sell the Lean Green Skating Machine as a stand-alone device, this technology would be much more successful as an iPhone application. The iPhone already has an accelerometer and GPS built into the phone. It also has a display, battery, memory and a microprocessor. Also, testing this technology has proved that a device, like an iPhone, that could be attached to one's waistband or kept in one's pocket is much more accurate than placing the accelerometer directly on the skateboard to pick up all of the high frequency vibrations. Rather than offering this technology as an expensive product with limited demand but still lots of potential to be damaged, it can be sold for just a few dollars to anyone who knows how to use the internet. The cost and risk would be much less for both the consumer and the producer.

7. Future Improvements

The most important thing for the development of this technology would be more research. As explained earlier, through this experiment I observed the general relationship between oscillation frequencies and forward acceleration, but was not able to produce an explicit mathematical relationship between these two things. Because the optimum pumping technique can vary so much between boards and individuals, there may not be a mathematical formula to explain exactly how these two parameters interact, but more research would only be better for understanding of this relationship.

The issue of calibrating the acceleration values to account for the acceleration of gravity was a problem that arose several times throughout this project. In the future, it would be best to use a device that calibrates itself for the acceleration of gravity in real time. Due to the rotation and general displacement of the accelerometer during the testing process, the acceleration of gravity was not constant to any one-axis, making the data very difficult to process. Nevertheless, this is an important parameter that cannot be ignored. Detecting acceleration due to gravity is crucial in order to be able to determine if the skater is on an incline or a decline. Obviously the effects of pumping on an incline or a decline will be very different than pumping on a flat surface, but the Lean Green Skating Machine can simply use this as another parameter by which to estimate the skater's expected acceleration.

It would also be interesting to see if a similar relationship can be found between the forward acceleration of the board and the displacement of the board along the x-axis. In order for the calculations to be accurate, the testing route would have to be a straight-line, but it wouldn't have to be on a flat surface like when the oscillations are measured on the y-axis. If the gradient of the slope is known, the calibration for gravity can be accounted for, but the calculations would be difficult to complete in real time.

8. Conclusion

Based on testing completed for this project, it has been confirmed that there is a relationship between the oscillation frequency of a pumping skateboard and its forward acceleration component. We do not know the exact relationship between these parameters, but we do know that at higher speeds, the rider must pump the board at a high frequency of oscillation in order to maintain momentum. Conversely, carving causes a rider to lose momentum because his/her frequency of oscillation is too low for his/her current speed.

Although the second test was successful in gathering data that could help explain the relationship between the oscillation frequency and the forward acceleration component, a lot more testing still needs to be done before the Lean Green Skating Machine can be a financially viable product. Due to the limited time of the trials, there was not much variation in the data, making it difficult to do more than make broad generalizations about the relationship between oscillation frequency and acceleration. As of now, the Lean Green Skating Machine is simply designed to estimate the skater's acceleration based on his/her oscillating frequency and current velocity. But since these properties are based on assumptions from a fairly limited data set, no guarantees can be made that the Lean Green Skating Machine will be able to work accurately for an extended period of time. As more testing is performed, the Lean Green Skating Machine will improve at defining this relationship, and estimating the corresponding acceleration value.

While an accurate and reliable stand-alone product for the Lean Green Skating Machine is not anywhere in the near future, an iPhone application is. The iPhone, which already has an accelerometer, GPS and display, has all of the necessary components for the Lean Green Skating Machine to work. The only thing missing is the coding, and a lot of that was completed for this project. With continued testing and development, the Lean Green Skating Machine can eventual help more people learn how to perfect their longboarding skills, whether it be for recreation, transportation or perspiration.

9. Distribution list

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