Similarities of motion patterns in skateboarding and hydrofoil pumping

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Abstract. Like skateboarding acceleration in surfing on a hydrofoil with muscle power is achieved by a constant sinusoidal motion. Both are challenging sports to begin with because learning the complex up and down movements takes time, skill and reflexion. The interplay of rotating joints and applying forces at the right time is hard to perceive, understand and to transfer into muscle memory.

Since the motions in skateboarding on pump tracks and hydrofoil pumping are similar, we are comparing both motion sequences with inertial measurement units and 3D pose estimation. We postulate that learning the physically challenging and expensive hydrofoil pumping can be improved and accelerated by training with skateboards. Therefore, we are capturing forces with inertial measurement units and validate them with 3D pose estimation. Finally, we are comparing and visualizing the motions and forces of the boards and the skeleton to show the similarities within the y- and z-momentum.

Keywords: Machine Learning, Data Visualization, Pose Estimation, Interactive Systems.

1 Introduction

Hydrofoil pumping is a rather new sport with its first commercial boards being made after Mango Carafino developed the first hydrofoil surfboard in 1999 [7]. Since then, the sport sparked the interest of surfers and athletes around the world, who had no access to surfable shores, beaches or rivers. Despite the low requirement - an open water area, that's deep enough for the mast to fit - the technical entry barrier is quite harsh: Successfully riding a hydrofoil surfboard and staying afloat requires decent experience, a certain amount of technical skill and some sort of sense or understanding of the board's physical behavior. In our previous research [12] we noticed a similarity between the motion sequences of hydrofoil pumping and skateboarding. With our research we want to empower athletes and those to gain a better understanding of the board and accelerate their training progress.

At the current stage of our research, we are further comparing the motion sequences of these sports to gain insight on how to elevate the training experience of learning how to foil pump.

2 Related Work

2.1 Hardware Sensors

There is a range of small and integrated systems with 32-bit microcontrollers and sensors available with onboard machine learning functions like the BHI260AP [11]. The Arduino Nicla Sense ME [2], that we are using in our project, features a BHI260AP self-learning AI sensor with integrated IMU, a BME688 environmental sensor, a BMP390 pressure sensor and a BMM150 magnetometer. On the cheaper Adafruit Feather nRF52840 Sense we find an LSM6DS3TR-C accelerometer/gyroscope, an LIS3MDL magnetometer and a BMP280 temperature and barometric pressure sensor next to other sensors. Both microcontrollers can be programmed with the widely used open-source Arduino C++ in its own development environment with a very large community and libraries.

Unlike the mentioned development boards MBIENTLAB MetaMotionS [14] is a ready to use product with a gyroscope, accelerometer, magnetometer, barometric pressure sensor communicating like the forementioned devices via BluetoothLE.

We also worked with integrated solutions like Apple Watch and Google Pixel Watch but did not include the data at this time. Apple's latest Watch features several sensors like optical/electrical heart sensor, temperature sensor, blood oxygen sensor, GPS, compass, accelerometer and gyro sensor.

For our applications the Arduino Nicla Sense ME is currently one of the best solutions. With only 22x22x4 mm, the development board fits under a skateboard truck and on a foil mount under a surfboard.

2.2 3D Pose Estimation

Machine learning based 3D pose estimation approaches eliminated the need for special hardware like time-of-flight cameras in favor of standard cameras. Carnegie Mellon University's OpenPose [4] is a robust solution for 2D and 3D skeleton reconstruction delivering 3D skeleton data in the BODY_25 pose topology. MeTRAbs Absolute 3D Human Pose Estimator [10] is also featuring 2D and 3D position data of the skeletons' joints in the SMPL-24 topology. As part of the Mediapipe framework BlazePose [3] (currently transitioning to Gemini branding) delivers 33 3D landmarks in the COCO [9] topology superset GHUM3D and also a background segmentation mask.

In our prior research [13] we evaluated these human pose estimation solutions in different sports situations. We found that OpenPose and MeTRAbs performed best regarding accuracy recognizing close and far bodies and correct approximation of hidden body parts. BlazePose unfortunately only works accurately on bodies closer than 4 meters. In our experiment we were using MeTRAbs since the OpenPose model repository is not existent anymore.

2.3 Skateboarding

Physics of skateboarding are well documented since the 1970s. In an early publication Hubbard et al [6] where analyzing the skateboard and rider parameters and described them with stability criteria in experimental validations. Kuleshov [8] constructed a mathematical model of the skateboard, describing the motion of the rider on a skateboard.

Several publications are describing on the detection and classification of skateboard tricks. There are algorithm-based approaches using IMU-sensors [5] and more recent machine learning-based classifications [1].

2.4 Hydrofoil Pumping

The history of hydrofoil surfing since the 1960s and the popular mechanic principles are well summarized by Red Bull [7] in an article about hydrofoil surfing. In a recent publication Kirill Rozhdestvensky [9] describes a simplified mathematical model of a pumped hydrofoil surfboard elevated above water. An in-depth description of the physics of a surf foil by analyzing the physical concepts behind hydrofoils using the principles of aircraft design and aerodynamic wing theory was published by Robin Chahal et al [4].

3 Experiment Setup

3.1 Skateboard Track Facility

For collecting the skateboard data, we choose a skate park close by featuring a concrete pump track ideal for our measurement. The pump track consists of a drop in to gain speed to start the run, then two waves and a quarter at the right end (figure 1). Since the skate park is new the quality of our measurements benefits from the smooth concrete surfaces.

The skateboarder starts on the left side of the track. He drops in, stretches his legs and gains speed while moving downwards to the right. Climbing the first wave he loses speed while catching the momentum by bending the knees. This sequence repeats on the second wave and until the turn / exit on the end of the track.

We are using a skateboard with a standard popsicle shaped deck, trucks and soft wheels to dampen uneven ground and thus minimizing noise in the measurements.

Fig. 1. A skater riding the concrete pump track.

3.2 Hydrofoil facility

As stated previously, the only requirement of hydrofoil pumping regarding the location is water with a decent scale to ride and enough depth to not hit the ground with the mast and foil. We choose a natural public pool without any other visitors, which featured a footbridge at the edge of the pool for a good starting position.

The surfer starts on the footbridge, jumps on the board and begins with up and down body movements to create a forward momentum with the foil under water (see Fig. 2). He surfs a linear path while he is recorded and measured. Unlike in the skateboard setup the surfer on the hydrofoil has no terrain but must create the uniform sinusoidal path himself. Uneven curves, stalls or collisions with the water surface are interfering with the quality of the forward momentum.

We are using a short (4’0) foil surfboard with a 75cm long mast and a wide carbon hydrofoil wing. Unlike in other hydrofoil sports in muscle based pumping a wide wing with a large surface is needed.

Fig. 2. A hydrofoil surfer "pumping" on a lake.

3.3 Hardware

In our setup we are using two different sensing devices for motion data acquisition: One Arduino Nicla Sense ME and one Apple Watch Series 9, which was only used for background data validation in this paper at this time. The Apple Watch is worn by the athlete on the back foot's ankle facing inside. To ensure watertight and firm positioning of the microcontroller to the boards we designed and 3D-printed one universal case and two different mounts – one for hydrofoil boards' mast box (see Fig. 3) and one for skateboards in front of the back truck (see Fig. 4). For both boards the microcontroller is placed at the bottom directly under the athletes back foot when standing on the board, to minimize angular offsets in the data.

The microcontroller runs custom Arduino code logging the sensor data connected via BLE. For field recordings we are using an off the shelf Android smartphone which connects to the controller via WebBLE in a web-browser to trigger start, stop as well to receive the data. We captured the data of the sensors with different intervals of 20 and 60 Hz during several takes.

To better compare, validate and understand the motion sequences we additionally capture the skateboard runs with a GoPro Hero 5 Black at 1920×1080-pixel resolution and 60 frames per second and the hydrofoil runs with a DJI Mini 3 Pro at 2688×1512-pixel resolution and 60 frames per second.

Fig. 3. Arduino Nicla Sense ME mounted to the bottom of the hydrofoil board.

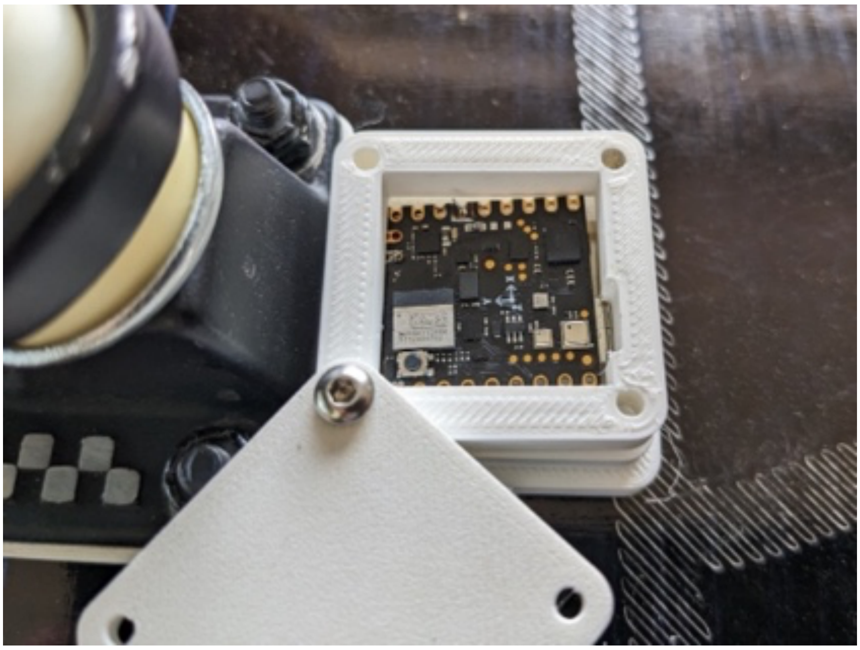

Fig. 4. Arduino Nicla Sense ME mounted to the bottom of the skateboard.

3.4 Pose Estimation

To get an even better understanding of the recorded datasets and for validation of the data points we then analyzed the recorded videos with the MeTRAbs pose estimation model. The skeleton data we received from the algorithm could then be combined with the sensory data to visualize the athletes' movements and corresponding forces (see Fig. 5). The visualization shows the forward momentum (red arrows) and the skeleton joints of the front hip, knee and ankle (grey lines and circles) on top of a rotoscope image of the video. The relation and angle of hip, knee and ankle represent the pushing movement with the up and down motion of the skater's body.

Fig. 5. Visualization of the captured data combined with the pose estimation data.

4 Results and Interpretation

4.1 Data quality optimization

When we started to evaluate the recorded data, we noticed noise in the skateboard data which turned out to be originating from the different riding surface although we were using soft wheels to dampen the noise from the surface. Small gaps in the concrete and little stones created acceleration peaks. The unevenness of the concrete can be observed on the skateboard IMU data (see Fig. 6). In the hydrofoil board recordings are very smooth without noise, as the flow through the water only creates minor noise from the vibrations of the hydrofoil wing and mast which are also audible.

To compensate this issue and further refine data and the later plotted graphs, we applied a standard Kalman Filter algorithm with the process noise variable R at 0.01 and the measurement noise variable Q at 3 to the datasets. The resulting data exposes the sinusoidal motions. The noticeable difference in amplitude is resulting from the track dimensions for skateboarding and from the mast height and overall size of the hydrofoil board.

4.2 Visual interpretation

In the following graph plots we would like to substantiate our thesis of the similarity in the motion patterns of skateboarding on pump tracks and hydrofoil surfing and the outlook of using it for training purposes. The graphs are displaying the filtered (foreground) and unfiltered accelerometer data. Color codes are distinguishing the axes of the accelerometer. The y axis of the graph displays the force measured in G. On the x axis the time of the take is visible in milliseconds from start.

The first graph (see Fig. 6) is displaying the accelerometer data of one skateboard run on the described track. Most relevant for our thesis are the Y values of the accelerometer representing the forward momentum of the skateboard and the Z value representing the height position on the skateboard track.

We are observing a strong acceleration at the start and a clear downward movement followed by a slowdown while climbing the first wave repeating over the track. The length of the wave and the amplitude corresponds to the concrete structure of the pump track.

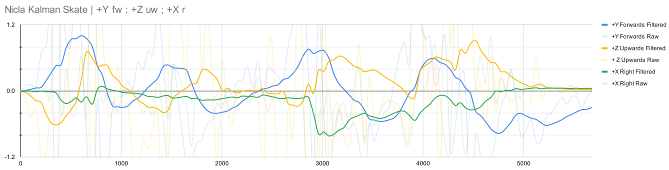

Fig. 6. Arduino Nicla Sense ME data of one skateboard run.

Figure 7 represents the motion patterns of the hydrofoil surfer on the lake. We are observing a similar sinusoidal pattern with a noticeable shorter wavelength and lower amplitude due to the physical characteristics of the foil mast and wing. The Z values are clearly displaying the motion path. The Y values representing the forward momentum are constituting the slower speed.

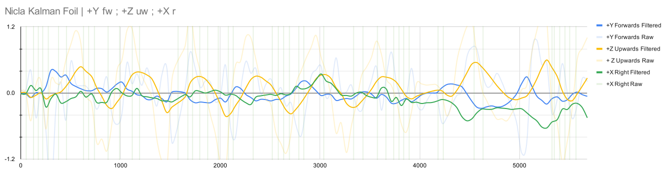

Fig. 7. Arduino Nicla Sense ME data of one hydrofoil board run.

In order to further compare the motion patterns, we combined in figure 8 the forward momentum and in figure 9 the vertical acceleration of the two sports. A clearer picture emerges and illustrates the similar patterns. Although there is noticeable a difference in wavelength and amplitude the sinusoidal patterns for generating forward momentum are clearly visible.

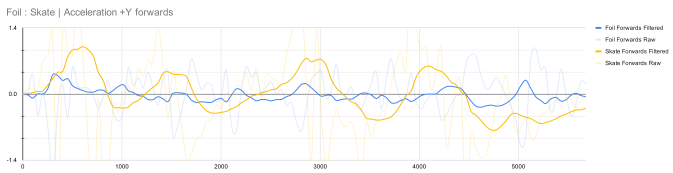

Fig. 8. Comparison of forward acceleration data of hydrofoil and skateboard. Positive equals forward acceleration.

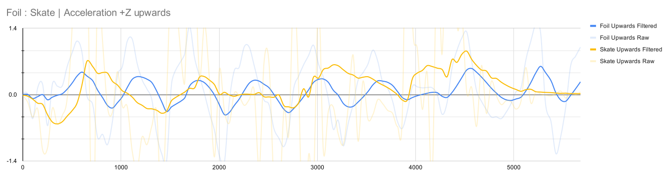

Fig. 9. Comparison of vertical acceleration data of hydrofoil and skateboard. Positive equals upwards acceleration.

5 Conclusion and Future Work

We recorded the acceleration forces of a skateboard in a concrete pump track and a hydrofoil surfboard in a lake and compared the resulting filtered data in combined graphs. Our theory of the similarity of the motion patterns of both sports and the emerging momentum is proven in the visualizations although differences in wavelength and amplitude.

In our next steps we will combine the acceleration data with the pose estimation data not only for visual validation but to automatically extend the observation on the motion of the bodies of the athletes. We will validate the data with additional sensors of smart watches on ankles and wrists. Our goal is to create complete models of the motion patterns.

With these models and embedded motion patterns we think we can create a watch application supporting the learning of the sports by drawing the attention on the different motions.

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