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A smartphone based system for kite and board measurements in kitesurfing

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Abstract

This study introduces a smartphone based measurement system to obtain dynamic parameters of board and kite during kitesurfing. A built-in GPS receiver tracked the path and speed of the kitesurfer. Orientation values from inertial sensors in the smartphones attached to the kite were used to visualise kite movement patterns through projection onto the surface of a sphere. Ring transducers on kite lines measured forces acting between the kite and kitesurfer. The measurement system was tested with one participant. The total distance covered was 6654 m at an average speed of 8.17 m/s. Accelerations during a jump were evaluated to estimate jump height and duration. Board orientations and kite movements were found to be reasonable and in alignment with video recordings. Kite steering and lift force traces comprehensibly described the interaction between kitesurfer and kite. Jump parameters were in agreement with visual observations.

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Keywords: Kiteboarding; instrumentation; GPS tracking; kite position; board orientation

1. Introduction

Kitesurfing or kiteboarding is considered as an extreme water sport in which a kite harnesses the power of the wind to propel the kitesurfer over the water on a board. Kitesurfing is a relatively new sport but has experienced tremendous growth since the first series of commercially available kites for kitesurfing were introduced in 1995.

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The number of kitesurfers was estimated at 1.5 million in 2012 and furthermore, kitesurfing was temporarily voted to replace windsurfing in the Olympic Games 2016 in Rio.

Little academic research has been done in the field of kitesurfing to date. Conducted investigations mainly focused on injuries and biomechanical aspects during kitesurfing (Lundgren et al. (2011), Lundgren et al. (2007)), while Valsecchi *et al.* (2010) examined the effects of vibrations on the human body during kitesurfing using inertial measurement units (IMUs) and GPS. A mobile pc and accelerometers in a waterproof box attached to a board were used to investigate vibrations and board orientation. Furthermore, a consumer GPS device collected information about path and speed of the kitesurfer during the experiment. In a similar study for snowboarding performed by Holleczek *et al.* (2010), a system with GPS receiver and an IMU containing a gyroscope and an accelerometer was used to obtain movements and orientation of a snowboard. A mobile pc in a backpack captured data via Bluetooth, which were used to detect riding characteristics such as turns and different techniques.

As an alternative to the custom-made measurement systems as used in these studies, Harding and James (2010) investigated the usability of commercially available tracking devices for performance assessment in snow and board sports. These devices contain GPS modules and a variety of integrated sensors and allow a reconstruction of performance characteristics of jumps and other manoeuvres. Although providing a high number of sensors with a user interface in a compact and light design, these devices seem to be unsuitable for use in academic research due to their high price, non-transparent data processing and lack of customisable data analysis.

Most recently developed smartphones contain high numbers and various types of sensors and offer a competitive alternative to other commercially available devices and custom made measurement systems. They accommodate GPS, power supply, data storage, camera(s) and communication capabilities in a very compact and robust design. In academic research, smartphones are already in use e.g. to detect human movements such as walking or running patterns (Grankin et al. (2012), Saha et al. (2010)). However, a considerable disadvantage of smartphones is the restricted range of their IMU sensors like accelerometer (e.g. ±2 g) and gyroscope, which is sufficient for their original purpose of determining static orientation and gestures, but may not be suitable for highly dynamic sport applications.

As previously stated, little academic research has been conducted in kitesurfing, with no studies investigating performance characteristics. Furthermore, there have not been any studies which include the most important equipment of a kitesurfer: the kite. This technical report introduces a measurement system applied to kitesurfing, which uses smartphones as data capturing and primary measurement devices. The principle feature of this tool is to track board and kite during kitesurfing which allows analysis and comparison of a variety of manoeuvres performed by the kitesurfer such as transitions, tacks and jumps. Acquired information from internal IMU sensors, GPS and ring transducers mounted at the kite lines will provide novel insights into the dynamics of the sport. To demonstrate possible functions and assess the performance of the system, an experiment was performed and different manoeuvres were analysed.

2. Methods

2.1. Measurement system

Two tablet computers (Samsung Galaxy Tab 2 7.0 Android 4.2) were inserted into waterproof cases and attached to the centre of a board and on top of the central inflatable strut of a kite respectively. An Android application was developed to obtain data from the built in tri-axial accelerometer and magnetometer, as well as from Android provided rotation angles and their associated 3x3 rotation matrix with a sampling rate of 50 Hz to determine global device orientations. Additionally, GPS information (latitude, longitude, altitude, time and accuracy) were recorded with the maximum available sampling rate of 1 Hz to receive locations of board and kite. The device attached to the kite additionally recorded video using its front facing camera with VGA resolution at 15 FPS for purposes of documentation and visual validation. Remote control via WiFi-Direct ensured a synchronisation of the data collection for both devices.

Aluminium ring transducers (outer diameter: 50 mm) with a Wheatstone full-bridge containing four strain gauges were mounted to all four lines in order to record line forces and hence obtain information about the interaction between kite and kitesurfer. Wires for power supply and sensing lines were arranged along the kite's bridle lines and leading edge and were connected to a 4 channel differential amplifier board and a power supply in a waterproof box. An IOIO-OTG input/output board (SparkFun Electronics Inc., DEV-11343) sampled the amplified signals with a resolution of 10 bit and sent the information via Bluetooth to the tablet attached to the kite.

Environmental conditions such as wind speed and temperature were recorded using a handheld vane anemometer (TechnoLine, EA3010).

2.2. Data collection

The measurement system described above was operated in an experiment near Greatstone-on-Sea (Kent, UK). A 12 m² kite (Naish, Park 2011) with 26 m lines and a kiteboard (Liquid Force, Influence LFX 2012, 138 cm x 42 cm) were equipped with the two tablets, ring transducers and circuitry. A volunteer participant (age: 38, mass: 83 kg, height: 183 cm) with 4 years of kitesurfing experience was instructed to perform several sets of different manoeuvres after familiarization with the equipment. Onshore wind (north-north-east) with an average speed of 7.4 m/s and occasional gusts of 8.5 m/s were measured. A temperature of 25 °C and frequent breaking waves with heights of 20 cm were recorded over the duration of the experiment. Furthermore, important events such as turns and jumps were listed during the trial.

2.3. Data analysis

The data recorded were processed and analysed using Microsoft Excel (Microsoft Corporation), Matlab (MathWorks Inc.) and Google Earth (Google Inc.).

The board's GPS data were used to determine speed, total distance travelled and tack directions. Global orientations of both tablets, expressed as Tait-Bryan angles (yaw, pitch and roll), were calculated from low pass filtered rotation matrix values. Decomposed orientation parameters follow a ZXY convention in the world coordinate system with range restrictions for yaw [-180 – 180°), pitch [-180 – 180°) and roll [-90 – 90°).

The orientation values were used to visualise board characteristics during a nose side transition following its GPS trace. The corresponding kite movement was reconstructed by determining the kite position as projection on a surface of a quarter of a sphere using yaw, pitch and roll angles, which describe the kite's rotations around Z, X and Y axes (Fig. 1a). This approach is based on the assumption that the kite can only move along the surface of this sphere, which represents the kite's wind window whose centre is formed by the kitesurfer. Furthermore, this concept was used to compare differences in kite positioning in up and downwind tacks.

An alternative approach to receive kite position in the wind window using GPS positions of board and kite was also examined but rejected due to unacceptable inaccuracies.

Additionally, jump characteristics were determined from global board accelerations. Jump duration was obtained by time difference between distinctive signal characteristics, while jump height was determined by double integration of vertical gravity-compensated accelerations between take-off and landing. Furthermore, board vibrations were analysed and compared to previous findings.

3. Results

A distance of 6654 m was covered in the experiment with an average speed of 8.17 m/s (maximum speed: 14.32 m/s).

Board orientations were obtained throughout the trial. Fig. 2a shows board illustrations projected on the board's GPS trace during a nose-side transition with a frequency of 3 Hz. The change of tilt from the front side edge to the back side edge with a simultaneously performed roughly 180° rotation clockwise around its Z-axis shows the change of direction first downwind and ultimately again perpendicular to the wind.

Fig. 2b shows reconstructed kite positions during the same transition. Circles represent kite positions on the ground inside the wind window. The graph shows the kite first rotating clockwise on the left side (illustration 1-4), moving over the zenith to the right side of the wind window (5-13) and drifting lower (14-16). The number of illustrations was manually reduced to approximately 12 Hz for reasons of clarity.

The difference of kite positions during an upwind and a downwind tack with little kite steering was determined. Fig. 1b illustrates the average position over the duration of 20 seconds in both directions, with the darker object representing the position during the upwind tack and the brighter object during the downwind tack. It can be seen that the kite position is lower and slightly closer to the edge of the wind window for the upwind tack.

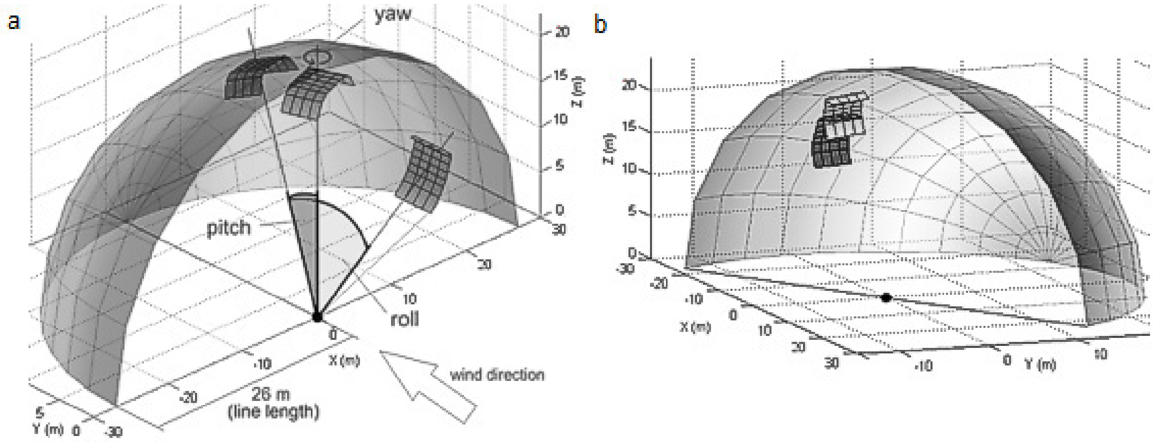

Fig. 1. (a) kite position determination; (b) kite positions during an upwind tack (dark) and a downwind tack (bright).

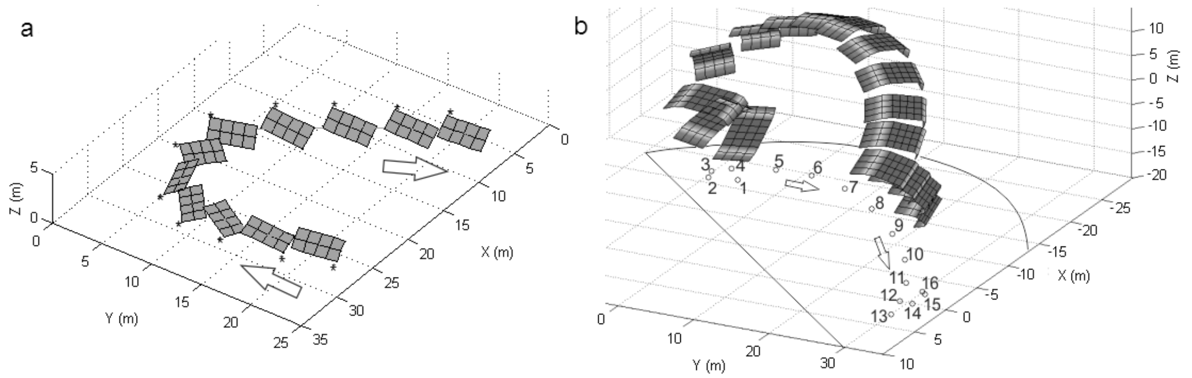

Fig. 2. (a) board orientation during a transition following its GPS trace; (b) kite movement pattern during a transition.

Line forces of the kite are presented on a normalised scale in Fig. 3a. The graph represents the force signals during a water start to the right and the following tack in the same direction. Combined lift forces from the two power lines are represented by the bold curve. Peak lift forces were obtained shortly prior and during the water start (1 & 2). Peak forces on the right steering line were detected shortly prior to the water start (1), while peak forces on the left steering line were detected during the water start (2).

A selected jump has been analysed to receive jump height and duration from board acceleration data. Fig. 3b shows global board accelerations. Obtained jump duration was in accordance with estimated air time of 3.3 s, which was determined using video analysis. A Jump height of 4.6 m was observed, which is comparable to the estimated height of 5 m, which was noted during the trial.

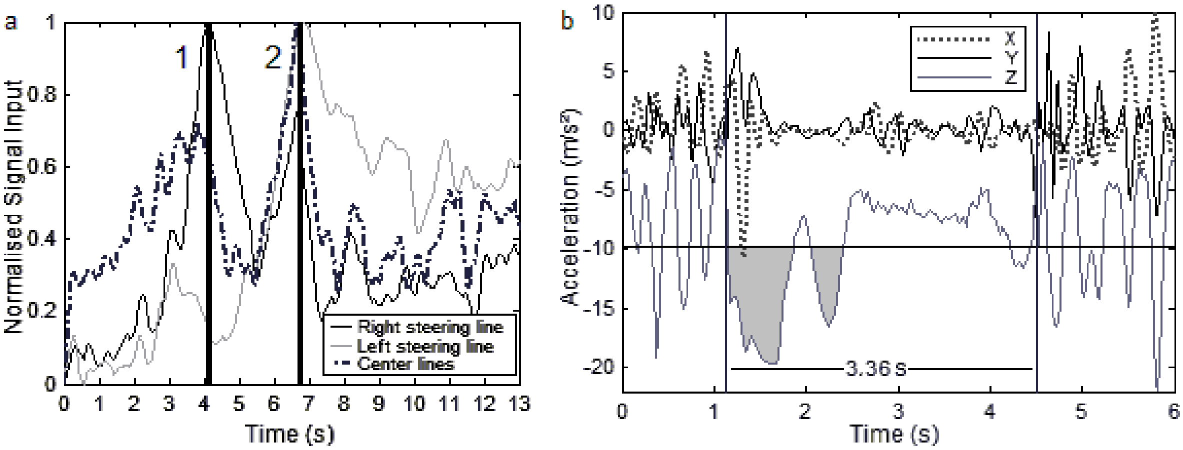

Fig. 3. (a) Normalised line forces during a water start; (b) global board accelerations during a jump.

4. Discussion

The key objective within this study was the implementation of board and kite tracking during kitesurfing with commercially available tablet computers.

The main novelty introduced within this study is the ability to track the kite during a trial, which offers insights into dynamics and technique differences in kitesurfing. The obtained kite movement pattern presented in Fig. 2b appeared to be reasonable and has been qualitatively verified using video recordings. It is important to mention, that this visualisation is solely based on the assumptions made previously and shows only the kite movement pattern and not absolute positions of the kite. The introduced feature has been further used to analyse differences in kite position during an up- and downwind tack (Fig. 1b). The observed lower position slightly closer to the edge of the wind window for the upwind tack is reasonable and commonly taught in kitesurfing: A lower kite position allows maintaining a larger resistance against the kite using the board and the water ("edging"), which is crucial to be able to go upwind. The accuracy of the kite position measurement has not yet been determined, but the findings indicate the potential to detect differences in kite orientation and resulting position.

Line forces provide useful information about steering input from the kitesurfer and kite response. The analysis of a water start to the right, illustrated in Fig. 3a, shows a peak force at the right steering line shortly prior to peaks of centre lines and left steering line. These characteristics were found to be in agreement with the video recordings. The kite was steered aggressively from the zenith down into the right side of the wind window, which was effected by the steering input on the right steering line (1). Due to the fast movement, the kite exerted the required lift to pull the kitesurfer out of the water and in the direction of travel, which can be observed by peaks on all lines (2). The following force traces suggest only minor kite steering input during the tack, which was supported by the video recordings.

In addition to the investigation of kite parameters, captured GPS information and IMU data at the board were used to track the path of the kitesurfer and to obtain board orientations throughout the trial. The GPS recordings show a reasonable path without inconsistencies. A recording frequency of 1 Hz seemed to be suitable for applications in kitesurfing, due to comparably slow changes of directions and predominantly continuous movements in one direction. Furthermore, board orientation sequences during tacks, turns and jumps can be analysed by projection onto the GPS trace. The presented orientation sequence during a front side transition in Fig.

2a was supported by video recordings and appears to be reasonable. However, acquired board orientations were found to be very noisy and biased at times, especially during upwind tacks while cutting through breaking waves. Fig. 3b indicates the extent of this noise prior and after a jump. These vibrations exceeded the accelerometer range of ±2 g, which presumably lead to errors in calculating the board orientations.

On the contrary, the tablet computer's IMU sensors appeared to be very suitable to calculate height and air time of jumps. As obtained from the global accelerations shown in Fig. 3b, distinctive signal characteristics allow the observation of accurate jump durations (3.36 s vs. 3.30 s from video recordings) and reasonable jump heights (4.6 m vs. 5 m from protocol).

Altogether, the findings suggest that IMU sensors in smartphones generally seem to be suitable for applications similar to the one introduced in this study.

Limitations of this study are outlined above. Improved results for obtaining board orientations might be obtained using devices with gyroscopes and a higher accelerometer range. Better accuracy in determining kite position could be achieved using modern devices with GPS and GLONASS (Global Navigations Satellite System), in combination with integrated temperature and atmospheric pressure sensors. Furthermore, calibration and validation procedures have to be established to provide accurate results for different setups and conditions.

5. Conclusion

A smartphone based measurement system to obtain characteristics in kitesurfing was introduced. The system offers GPS tracking and analysis of board parameters during transitions and tacks using built-in IMU sensors. This was used to analyse orientation sequences during a transition as well as jump height and duration. Furthermore, a method to observe kite movement was introduced, which uses the orientation of a tablet computer mounted to the kite to define kite positions on a sphere. This was used to investigate differences of kite positions during two tacks in different directions. Additionally, acquired line forces were used to analyse steering input and kite response during a water start.

It was concluded that smartphones generally seem to be suitable for the introduced application, with some limitations due to strong vibrations, which exceeded the accelerometer range and caused errors. Further investigations have to be conducted regarding kite position determination and board orientation in noisy conditions.

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