COMPARISON OF OPTICAL AND ELECTROMECHANICAL METHODES FOR EVALUATION OF THE ORIENTATION OF A BICYCLE PEDAL USING SIMI-MOTION® RESP. A CAPACITIVE MEMS TILT SENSOR

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1 Abstract

For a qualitative pedaling analysis the progression of the pedal's angle is important.

This paper compares to different methods to measure the change of pedal angles during pedaling cycles.

The used methods area a tilt sensor and video motion analysis.

Both measurement methods were used at the same time while a test person pedaled on a stationary ergometer bike.

For the video motion analysis two markers were placed on the test person's shoe to get defined points to calculate with. At the same time the tilt sensor was mounted on the downside of the pedal.

It was expected that there would be an angular phase shift between both angle curve progressions. Another fact that was expected was that measured maximum and minimum angles would correlate well.

The phase shift could be verified, the good correlation for maximum and minimum values not.

2 Introduction

"Visual analysis of human motion is currently one of the most active research topics in computer vision. This strong interest is driven by a wide spectrum of promising applications in many areas such as virtual reality, smart surveillance, perceptual interface, etc. human motion analysis concerns the detection, tracking and recognition of people, and more generally, the understanding of human behaviors, from image sequences involving humans." (Liang Wang, 2003). While video analysis methods have proven to be adequate for evaluating parameters such as position, speed, acceleration or angles concerning reliability and quality, other upcoming measurement methods often provide more flexibility and are less time and setup equipment extensive. Current developments are more and more into devices and instruments of smaller size. So called MEMS (micro-electromechanical systems) are state of the art and will probably soon be replaced by NEMS (N for nano). Apart from the smaller size and thus easier to place such devices also provide advantages regarding dynamic applications meaning there are less moved masses to contribute to measurement failures. But not all of the new miniature sensor technology is suitable for every application depending on their functional design and way how they work.

In stationary ergometer bicycling under test conditions video motion analysis is today's state of the art to study pedaling techniques. In fact it's mostly used to analyze vertical movement of hips and horizontal movement of knees.

On the other hand MEMS are not recognized in pedaling technique analysis at the moment.

Due to the mechanical tie of orientation of applied force and pedal angle, the pedal angle plays an important role in evaluating the quality of different pedaling techniques. Sanderson stated that comparing competitive to recreational cyclists the force application response of a cyclist due to changed load conditions (and therefore the orientation of the applied force) will make a major contribution to the resulting output differences (Sanderson, 1991). For application under outdoor conditions, which would be the original interest of such investigations, video motion analysis methods are unsuitable because of a huge coordinative and technical effort. Alternative tools, which are easily adaptable and mountable are needed to suit these demands.

Concern of this study is to determine whether a common capacitive sensitive MEMS tilt sensor will be able to present a fully applicable solution for outdoor measurement of bicycle pedal angle. While video motion analysis is an approved measurement method for such applications under stationary conditions the system will act as a quality benchmark for this investigation to assess whether the solution is practicable or not. A good and widely acknowledged instrument for the correlation of two data series or curves is the correlation coefficient (CC) according to Pearson. This CC has a range from -1 to 0 and from 0 to +1, where -1 and +1 mean a 100% correlation and 0 means no correlation. The literature states that with a CC of at least 0.8 the values are treated as to be nearly identical. For this investigation a CC according to Pearson of at least 0.8 will be one of the major quality criteria, as well as the minimum/maximum pedal angle values to be identical and an optical assessed similarity of the plotted data.

The hypothesis is that the ten times higher data recording of a MEMS compared to a camera brings different curve progression, in fact an angular phase shift because the MEMS recognizes a change of an angle earlier. Maximum values of angles should correlate very well.

3 Methods

One male student participated in this investigation. S1 (22 years, weight 68 kg, 178 cm tall) is physically healthy, free of any lower extremity disorders and competes in triathlons on a national elite level.

The test routine included five sets of pedaling exercises to perform consisting of three pedal cycles each. The sets were done at low load of 50W and a cadence of 30 rpm, which, of course, does not represent competition conditions but was chosen to provide better terms for the tilt sensor to follow the motion. S1 was wearing his casual footwear and not clipless bike shoes for easier mounting of the sensor. Sets were executed with a recovery time of one minute in between. S1 was asked to carry out the cycles in a natural way of his own discretion. The used ergometer was equipped with a two-sided pedal providing a platform on one side, which was chosen for exercise and a clipless SPD system on the other. The side of the ergometer body facing the camera was oriented perpendicular to the camera axis and prepared with black adhesive tape to provide a proper background contrast for the motion analysis video. The camera used for recording was a Sony DCR-TRV80E (Sony Corp., Tokyo, Japan) mounted on a tripod Cullmann Alpha 2000 (Cullmann, Langenzenn, Germany) and positioned about 1.5m from the capture plane represented by the outer surface of the pedal. The calibration was done via the use of a white sheet of paper of DIN A3 size acting as calibration object. The camera recorded 50 half frames per second deinterlaced to 50 frames. To improve tracking of markers and video quality additional lighting was used. Two spherical reflective markers with 10mm diameter were positioned on the subject`s right shoe. The markers were attached to the outer sole in the regions of phalanges proximales V and the proximal part of calcaneus. Data was recorded using SIMI-MOTION® software version 7.5.304 (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany). Also the marker tracking and marker position computations were done in the SIMI-MOTION software. To achieve adequate starting and ending events for each full crank turn (360 degrees) an additional single (only visible for one frame) tracking point was set at the appropriate frame in the video (12 o'clock position of crank = 0° crank angle) which made divisions of the measured data into single pedal cycles possible. Furthermore a visible event represented by a battery powered led module was placed in the capture setup. This event was triggered manually by a switch and was later on used for synchronization with the data gathered from the tilt sensor. The marker position data were imported and further processed in MatLab (V7.11.0 (R2010b), The Mathworks Inc., Natick, MA, USA). To compute the angle between the line connecting the two tracking markers and the x-axis of the coordinate system of the calibrated video equation ($\varphi = cos^{-1}\left(\frac{\vec{a}*\vec{b}}{|\vec{a}|*|\vec{b}|}\right)$ (1) was used.

$$\varphi = cos^{-1}\left(\frac{\vec{a}*\vec{b}}{|\vec{a}|*|\vec{b}|}\right) \qquad (1)$$

where $\vec{a}$.. vector between marker points, $\vec{b}$.. x-axis

The tilt sensor was mounted on the side of the pedal facing the ground oriented in a way that the axis marked as "roll" was sensitive to pedal angle alterations. The used tilt sensor CXTA02 (MEMSIC Inc., San Jose, California) a capacitive sensitive sensor of MEMS type, provides a linear voltage/tilt-angle characteristic within a range of +/-20° and a full measuring range of +/-75°. A maximum band of about 40° (-10 to 30°) during motion was expected (R. R. Neptune S. A., 2000) causing a sensor output range of 2.15 to 3.6V under consideration of the sensors sensitivity (35mV/°). Both devices, the tilt sensor as well as the synchronization led were connected to analog inputs (voltage measuring) of a 11-bit (for differential wiring) A/D-converter. With use of an calibration run the DC offset of the tilt sensor in zero pedal angle position was evaluated. The NI USB-6008 (National Instruments Corp., Austin, Texas) is connected to a PC via a USB interface and can be responded using the software LabView (National Instruments Corp., Austin, Texas). Due to the limited voltage supply provided by the AD-converter (max. 5V) the tilt sensor (6 to 30V) had to be supplied separately using a regulated lab power supply (type PS2032-025, EA Elektro-Automatik GmbH&CoKg, Viersen, Germany). Data recording was performed at 500Hz and the resulting data were exported for further computations to MatLab. The resulting mV-signal is converted to an angle value following equation ($\varphi = \sin^{-1}(\frac{\pi}{180} * \frac{(V_{out} - V_{DCoff})}{s})$ (2).

$$\varphi = \sin^{-1}(\frac{\pi}{180} * \frac{(V_{out} - V_{DCoff})}{s}) \quad (2)$$

where: V_{out} .. outputvoltage, V_{DCoff}.. DC-offset voltage in zero angle pos., s.. sensitivity [mV/°]

According to the event signal both data series (SIMI and sensor data) were synchronized and with use of the starting/ending markers of each crank turn applied in SIMI-MOTION where then stripped into five by three (15) single cycle data series for each measurement type. Each of these, all in all, 30 data series represented a full crank turn (360°), 15 for SIMI-MOTION and 15 for the tilt sensor data. All of the data were interpolated to 0 to 360 degrees (of crank angle). The 15 data sets for each measurement type were averaged and the resulting mean value vectors (one for each measurement type) were low-pass-filtered with the MatLab filtfilt-function for zero phase shift and compared to each other. The filtering was especially necessary for the sensor data because the signal was polluted with high frequent noise. Of interest for comparison were values and position (crank angle) of minimum and maximum mean pedal angle, the correlation coefficient between the two vectors and the qualitative progression of both curves (optically assessed).

4 Results

The results break down in three parts. First the analysis of the angle curve progressions of both measuring methods. Second the comparison of the maximum angles and third a comparison of the crank angles where those maximum values are measured.

Figure 1 shows the angle progression of one pedalling cycle measured with a tilt sensor. In comparison figure 2 shows the same progression measured by marker tracking (video motion analysis). Noticeable is the fact that in figure 1 the curve never shows negative values. Also the standard deviation of figure 1 is much wider compared to figure 2. The curve in figure 2 is also much smoother than the curve in figure 1, although it is low-pass filtered.

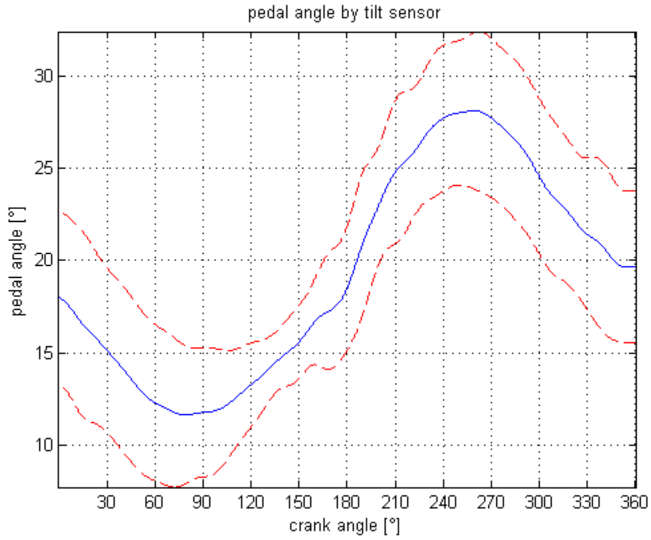

Fig 1: angle curve progression measured by a tilt sensor

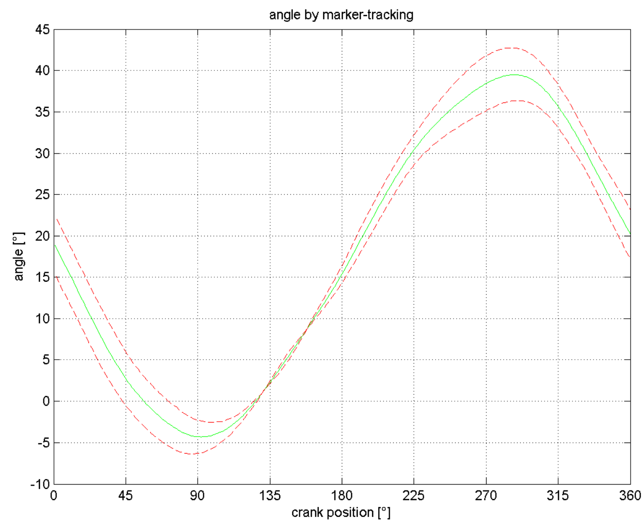

Fig 2: angle curve progression measured by marker tracking

Table 1 shows the maximum and minimum values for angles for each kind of measurement. As already explained the tilt sensor never shows a negative value, on the other hand the values by marker tracking do. Also the maximum angle is 40,5% higher with the optical measurement.

marker tracking	**Max Angle**
	39,50
	Min Angle
	-4,31
tilt sensor	**Max Angle**
	28,10
	Min Angle
	11,65

Tab 1: maximum and minimum values of each kind of measurement

Table 2 shows the pedal position where maximum and minimal angles where measured. The tilt sensor measures those values always earlier during a cycle. Maximum appears 17° earlier, the minimum 13°. Relating to part one an angular phase shift is determinable.

	Pedal Position [°]
marker tracking	287
	92
tilt sensor	
	260
	79

Tab 2: position of measured maximum and minimum angles of each kind of measurement

The overall correlation coefficient of both curve progressions is 0,96.

5 Discussion

The first part of the hypothesis could be verified, that an angular phase shift between both angle curves progressions is noticeable. The reason for this is answered by the recording rate of the measuring methods. The tilt sensor records ten times more often than the camera does. Thus changes of an angle can be detected faster and according to the crank position more exactly.

The second part of the hypothesis could not be verified. Maximum and minimum angles of the pedal correlate not well. Especially the fact that the tilt sensor does not show negative angular positions of the pedal is not acceptable because during the video motion analysis a negative angle could be optically assessed. A reason for this could be the limited measurement range of the sensor and the fact that this was a dynamic measurement. It could be possible that the pedalling velocity was still too fast for the sensor.

The conclusion is that this tilt sensor is not an alternative to video motion analysis. The curve progressions correlate well but the maximum and minimum values do not. The only positive fact about this sensor is the high recording rate and the exact position where the maximal and minimal angles appear. The marker tracking method works for this kind of measurement better because it has no limited range of measurement. To avoid an angular phase shift a higher recording data for the camera is needed.

6 References

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