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Wireless cycle power-meter system with load cell

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Abstract— This article describeswireless power-meter system detectingthe force on the cycle pedals.The system consists of two specialized pedals for the left and the right foot, build from identical mechanical and electronic parts. We used commercial type MTB pedals with mounted therein load cell model MLC929B-75KG.The electronic part is composed of instrumentation amplifier for each pedal, one microprocessor Arduino Pro Mini, one XBee communication module, respectively for the left and right pedal, a module that reads the rotation of the pedals - also built with XBee communication. All signals are integrated through a receiving XBee module connected to a microprocessor that transmits the received data to a PC. The software - PLXDAQ-Recorder enters data directly into an EXCEL spreadsheet, where you can make various statistical and graphical analyzes. Signals from each pedal are transmitted to the receiving unit every 100 ms. The speed with which the pedals are rotating per minute (RPM) is also being directly entered in the spreadsheet. The system was evaluated at a pressure on each pedal from 0 to 60 kg. Every kilogram meets certain "arbitrary units" that are from 0 to 1024. The relation between the pressure power and the "arbitrary units" is described by a function which is a polynomial of the third degree.

Index Terms— Arduino, cycle, force, microcontroler, pedals, power, torque, deformation, angle velocyty, cycle power-meter system, instrumentation amplifier, load cell, vector of force

Introduction

Cycling is one of the most popular physical activities. In some cases, it is necessary to accurately measure the power of the work performed. The most common approach for measuring the force applied to the pedals is by measuring the deformations in their structure as a result of the applied pressure. For this purpose, the most commonly used are strain gauges due to their low cost and their easy usage compared to other sensors [5]. The strain gauges are placed in areas where the greatest deformation of the material is.

In sports practice power-meters are considered to support the training process. The accuracy of most of these devices is not tested in scientific reports and the information from the manufacturers is scarce. Quite few studies are necessary to confirm the validity, accuracy and reliability of such systems under various experimental conditions [1], [5]. These trading systems measure the total torque and total power in both legs, used in the training process. The better management of the training, however, requires monitoring of the forceand the power generated by both legs separately, which is something that these power-meters cannot do. These systems are not suitable for more accurate training process as well as for scientific researches.

At the moment MEP® system [1] and Garmin-Vector 2 (www.garmin.com/Vector) are supporting calculation of the torque at the crank arm for left and right foot. The systems include specialized, highly integrated pedals with a relatively high price. The disadvantage of these systems is that they do not allow displaying data in digital form and its entry into different operating systems and different statistical programs for further analysis by the researcher. These systems are not suitable for scientific research with a wider scope.

Another approach for measuring the force is the use of strain gauges mounted at various locations inside the pedals [2], [3], [4], [5], [10]. This allows measurement of the three orthogonal components of the resultant force (Fy-normal, Fx-front-back and Fz-media-lateral) [5]. An analysis of the systems measuring the force of pressure on the pedals and crank torque shows that most of them measure Fx and Fy component, while the systems measuring the three components or only Fy component are fewer [1]. In such systems the force of pressure on the pedals is measured separately for each leg. Unfortunately, they are too complex and space consuming to be used easily in practice. The positive side is that they allow analysis of the asymmetry in pedaling, which has many areas of application in sports as well as in medicine. It has been found that the asymmetry in pedaling varies greatly between individuals, and that individuals may show different systematic changes in asymmetry, depending on the speed of rotation of the pedals [6]. Similar results are also reported later by other authors [7], [8]. Perhaps the asymmetry in the produced power of both legs changes with the exhaustion level.

In this article we are describing a system for accurately recording the resultant force of pressure on both pedals separately, the torque and power for each pedal as well as their speed of rotation (RPM). The integration in standard pedals of the system described makes it easy to fulfill and relatively inexpensive. The data obtained is in such format that it can be analyzed in different operating systems and different statistical packages depending on the

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needs of the researcher, which is not possible in the commercial systems.

Materials and methods

The system consists of:

Specialized pedals for left and right foot, built identical from mechanical and electronic parts.

- Mechanical section. We used commercial pedals type MTB, in which we installed load cell model MLC929B-75KG manufactured by "MANYYEAR TECHNOLOGY" company - CHINA. We chose this type of pedal because of the greater free space and the easier and more securely mounting of the cell. The comprehensive error of the cell was 0.2%. Unlike most of the specialized pedals with strain gauges we used a load cell, which has certain advantages. First, it is the measurement of the resultant force applied to the pedal with just one sensor. As shown in Fig. 1 and Fig. 2. the structure that we offer allows indirect effect on the cell through a metal plate attached to the front end of the pedal through axle. The metal plate is connected to the pedal by a model of a lever of first class. So regardless of the direction of the vector of the force on the metal plate it impacts the cell only perpendicularly and reflects the resultant force. This is shown in the scheme for distribution of the pressure on the pedals in Fig.3.

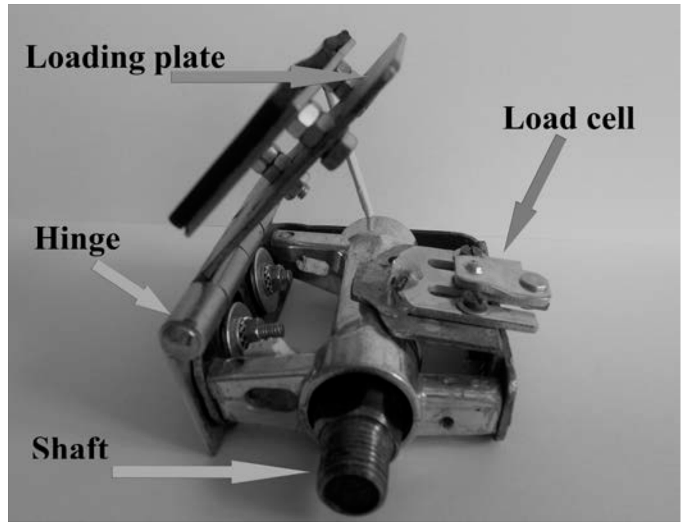

Fig. 1 Pedal – side view

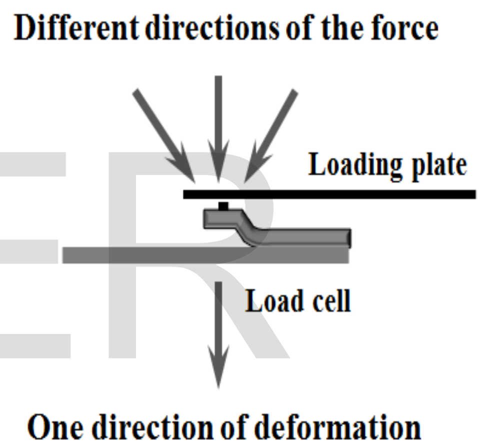

Fig.3Scheme for distribution of the pressure on the pedals

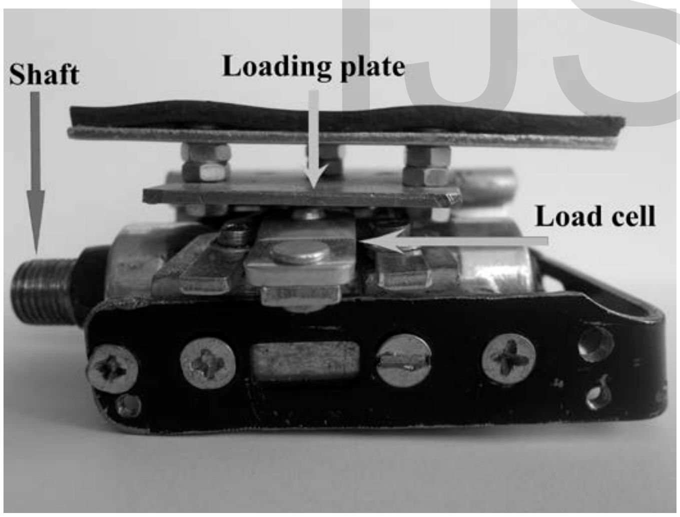

Fig. 2 Pedal-back view

Another advantage of the cell is that constant calibration is not necessary. This happens once in a production process. The simple construction which provides higher reliability and could be easily constructed is also an advantage.

- The electronic part is consist of:

Two identical electronic analog channels for left and right pedal. Load cell represents a strain sensor with two resistive arms that are incorporated under the scheme of Wheatstone bridge. The difference in the voltages of the two arms of the cell is amplified by instrumentation amplifier implemented with INA 125. Every electronic channel has a microprocessor Arduino Pro Mini and a communication XBee module, respectively for the left and right pedal. The amplified signal from the instrumentation amplifier is submitted to one of the analog inputs of the microprocessor where it is converted into digital. The digital signal is submitted to the XBee module by TX and RX pins on the Arduino. Fig.4 presents one of the electronic analog channels.

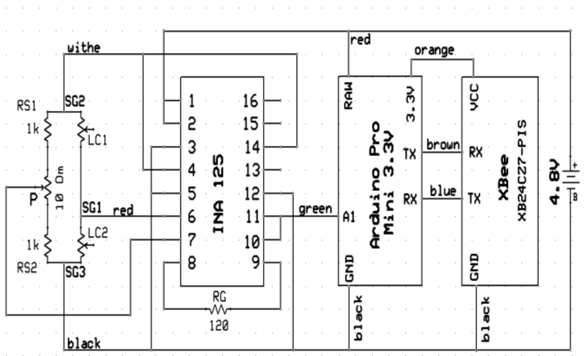

Fig.4 Scheme of one analog channel

Digital channel. It indicates the rotation of the pedals. It is built by a Reed switch connected to one of the digital inputs of the XBee module. The reed switch is located on the body of a stationary bike on the trajectory of the right crank, to which a permanent magnet is fixed. So with each pass of the magnet along the Reed switch to the microprocessor a rectangular pulse with amplitude 5 V will be reached. The principal scheme of this digital channel is shown in Fig. 5. It is simply arranged and together with the software it reads the forefront of the digital signal.

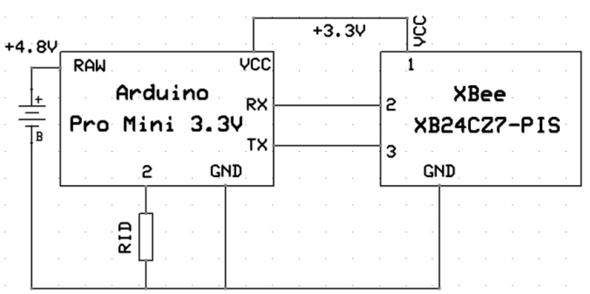

Fig.5Scheme of digital channel

Receiving module - One XBee receiver is connected to a microprocessor "a-star 2.0", which transmits data received via USB2 interface to the computer. Due to the voltage difference of logic levels and the power supply of the XBee we used XBee Explorer. Diagram of the receiving module shows in detail these connections (Fig. 6)

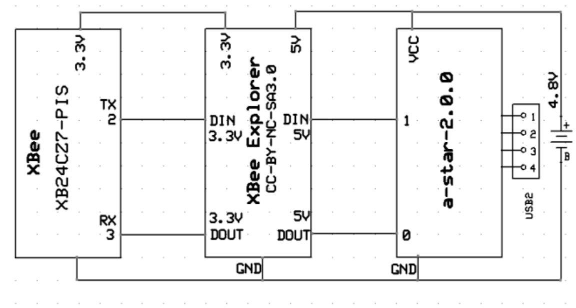

Fig.6Scheme of receiving module

Software receiving and visualizing the data programmed on two levels.

- A program for the microprocessor of Arduino board. It was written in a language similar to C ++ which comes from the manufacturers of Arduino. It is stored in the microprocessor and processes the data coming from the differential amplifier which is then being passed to the XBee module. The software for programming of Arduino modules is free.

- PLXDAQ-Recorder written for Windows XP / 7. It records the data which is transmitted to the XBee coordinator from the Reed switch and both pedals directly into an EXCEL spreadsheet. Depending on the recorded macro commands, data can be processed and displayed online or offline. It is an open source program and is also free.

The described system composed of mechanical and electronic components requires examination of the relation between mass, which acts on the pedal expressed in kg, and the readings of the electronic channels expressed in arbitray units, called for us - "Arduino units" from 0 to 1024. The force which impacts on the pedals and the rotation speed give the torque and power of the performed work. The technical task is to link the pressure on the pedals with the Arduino units defined by the software and the angular velocity of rotation of the pedals. For this purpose, was created a test bench where the pedals were exposed to varying force. The test bench is shown in Fig. 7. It consists of a shell in which a tube slides. In the upper end of the tube we have mounted platform. On this platform are placed different weights. The lower end of the tube has a mounted foot thattransfers the weight onto the load plate of the pedal. The shell is connected with props resting on a solid base (e.g., concrete). The pedal is also placed on the base.

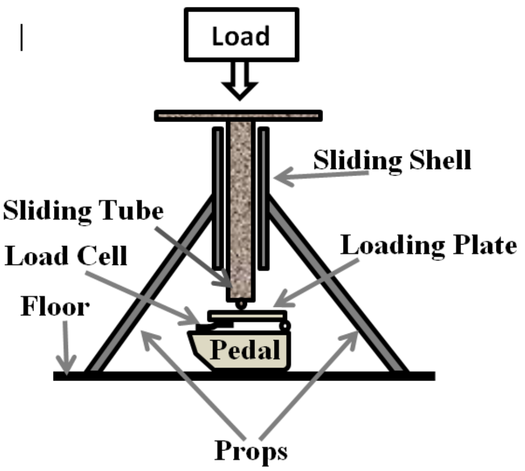

Fig. 7Test bench

Each pedal has been studied with the established test bench at weight 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50 and 60 kg. We did an average of 30 measurements for each weight. This approach was necessary because each pedal is a complex, multi-component system composed of many mechanical elements which have different response to deformation. Therefore, the study of the mechanical properties of this system had to be conducted experimentally and the results to be used to correlate between the force with which the pedal is pressed, and "Arduino units' recorded by the presented equipment.

Results

After investigation of the specialized pedals through the test bench designed and made by us fig. 7, we received the following results.

1) The measurements for each value of pressure on the pedal showed some variability. This is probably due to the high sensitivity of the differential amplifier connected to a Wheatstone bridge. The set of measurements for each weight were subjected to a test for normality of distribution, as we selected the tests of Kolmogorov-Smirnov and Lilienfors. It turned out that the distribution of measurement is not Gaussian, so we used the median as an indicator of the average trend of the measurements obtained for each weight, with which the pedal was tested.

2) We set the obtained medians in ascending order for each weight. The relation between the force of pressure and "Arduino units" is described by a function which is a polynomial of the third degree. The curve for both the pedals is similar but not identical. This can be seen in Fig. 8 and Fig. 9. On each of the graphics is written the polynomial function for the corresponding pedal. The type of the regression best describing the data entered by PLXDAQ-Recorder is determined by built-in EXCEL function - Trendline.

3) Through this function we determined how many kilograms of pressure on the pedal correspond to how many "Arduino units". This function is specific to a given pedal and is unique to it. This is due to the complex assembly of mechanical elements constituting the pedal which characteristics vary, even though within a small range. Moreover, it would be difficult to develop two completely identical in structure and properties mechanical elements.

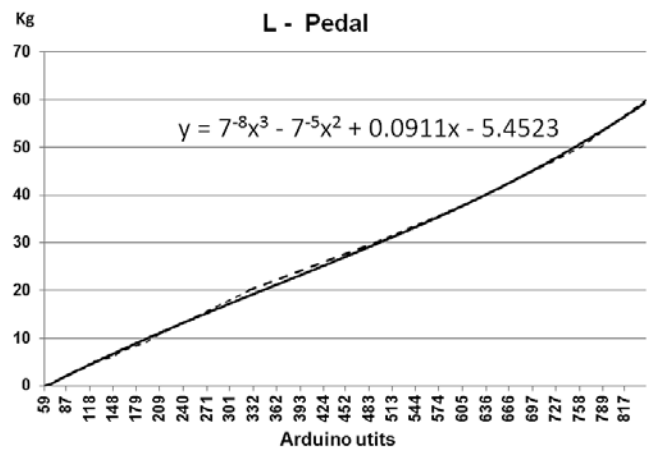

Fig. 8Polynomial function for the left pedal

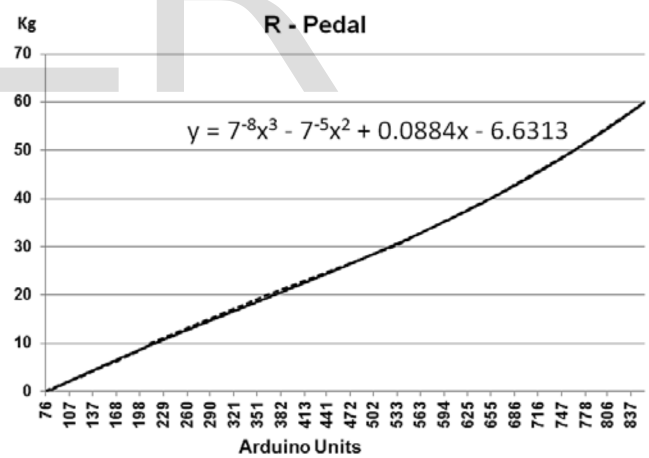

Fig. 9Polynomial function for the right pedal

Conclusion

The system described above is simply arranged, with standard mechanical and electronic components, which makes it easily reproducible. Each pedal made with this technology must be pre-tested trough the described test bench and be used after determining its characteristics. The differences highly depend on the selection of load cells and their electrical characteristics. Results are obtained in standard XLS-format, and then can be subject to any processing according to the willingness of the researcher. Data for the pressure on the pedal in kilograms is obtained every 100ms. This interval can be easily changed in the program of the microprocessor. For the purposes of our studies this interval was sufficient. Through the described system we define the beginning of each spin and its angular velocity. The force of the pressure on the pedals and the angular velocity can give us pedaling torque for each foot separately. The obtained results have statistically significant reliability for sports practice and can be used relatively easy by sports professionals. The wireless communication and data transfer is a great feature, which, depending on the selection of XBee modules may exceed 1.5 km.

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