Interface for Measuring Force Transfer Between Limbs and Vehicle

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***Abstract*—This paper focuses on technique of strain gauge measuring forces, which are transmitted between human and vehicle. In this paper, the theoretical analysis of acting forces and their effect to the vehicle is presented. This is followed by the second part, which deals with the practical realization of measuring the equipment and designing our own measuring device. Finally, the last section includes a description of the experiment and the analysis of the collected data.**

***Index Terms*—Force; Measurement; Strain Gauge; Accelerometer.**

This work focuses on measuring the forces transmitted between the user and the vehicle. In this case, vehicles suitable for these measurements are two-wheelers vehicles, which are represented by motorcycles and bicycles Although the method of measurement can be applied on any type of vehicles, a bicycle was used for the experimental measurement. The measurement focuses on forces, which are transmitted between the upper limbs of the user and the handlebars of the bike [5,10,12]. The work also includes a draft of possible solutions for measuring the position of the limbs, which is based on the determination of the angle that grips the cyclist's arm at the horizontal axis (reps. axis of movement direction) and the acceleration measurement on the limbs.

The determination of the said parameters results in an opportunity to analyze the musculoskeletal system stress of a cyclist or a motorcycle driver. With these acquired information, adjustments can be made to the settings of the bike (height and the position of the seat, angle, height and shape of the handlebars etc.). The appropriate settings allow for improvement, for example the weight distribution on the bike resulting from the improvement of the overall ergonomics of riding. This can be useful for long and time-consuming routes. Incorrect ergonomics can lead to poorer performance, back pain or cause problems associated with elbow nerve and carpal tunnel.

I. Transmission of Forces Between Human and The Vehicle

A person riding a bike has three basic points of contact – the seat, pedals and handlebars. A different force is drawn from each point. The forces are shown in Figure 1. F_S is the force acting to the seat, F_P to the pedals and the F to the handlebars. A rider applies a force on the handle bars through both hands. The amount of force from the left and right hand is affected by pedaling since during the pedaling process, the rider shifts his/her weight from one leg to another, which subsequently has an influence on the decomposition of acting forces to the sides of the handlebars.

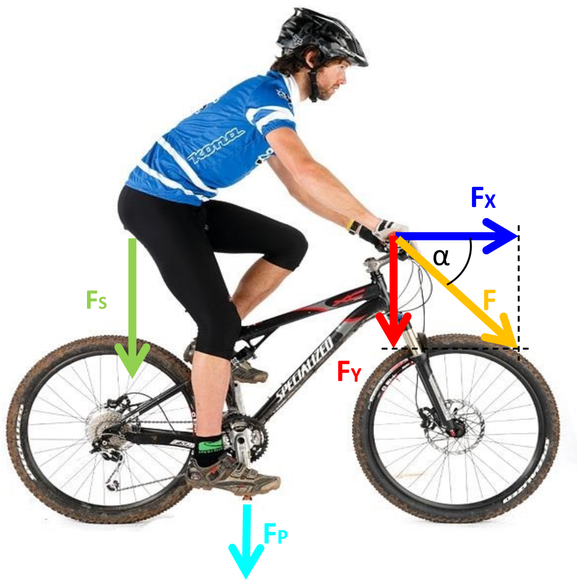

Figure 1: Forces between human and the vehicle

A. *Effect of the forces*

The acting force on the side of the handlebars causes the bending moment, which is presented by the tensile and compressive stresses. Further, their distribution and size depend on the bending radius. The material lying at the outer radius is stressed by the biggest tensile stress, while the material at the inner radius is stressed by the compressive stresses. Thus, this situation results in the bending of the handlebar, in the direction of the acting force. It follows that the transmitted force can be measured directly on the handlebar.

II. Force Measurement

In general, the measurement of force is based on their deformation effects. As stated above, the forces, which are transmitted between the human's limbs are acting to the handlebars. These forces subsequently cause a bend of the handlebars. The amount of the force can be measured by sensors, which are deformed together with an object., Strain gauges (strain gauge sensors) were chosen for this application. The sensor consists of a flexible support surface (foil or paper) and a metallic foil pattern or thin wire is placed on its surface. The principle of these sensors is based on the changes of their electrical resistance, which depends on the deformation. The deformation is presented by tension (the length of sensor shortens) and compression (the length of sensor extends) in the measuring axis. Due to these deformations, the dimensions of the metal are changed. The change of resistance of the strain sensor depends on the amount of deformation, the material and sizes of each sensor. These two parameters are included in the constant of each sensor. The changes of resistance are usually measured by using a Wheatstone bridge.

$$\Delta R = R \cdot k \cdot \varepsilon \tag{1}$$

where:
ΔR = change in resistance [Ω]
R = initial resistance strain gauge [Ω]
k = the constant of strain gauges
ε = the relative elongation measuring grid

A. *Measured vectors*

The angle which is formed by the acting force depends on many things, for example the height of the biker, settings of the bike, and surface type (uphill, downhill). Due to this fact, it was assumed that the force can be decomposed into two components, which form the right angle. The decomposition is shown in Figure 1. The force labelled as F_X represents the component of the force that has the same direction as the motion of the bike. The force labelled as F_Y represents the vertical component. These forces were measured separately and the resultant force can be found during the post processing.

B. *Strain sensor location and application*

For the best response of the sensor, it is recommended to place them at the location where the effect of acting force is the highest. In this case, dealing with measuring on the handlebars was the best solution to place the sensors close to the canter of the handlebars, near to the handlebars holder. For this experimental measurement, the original handlebars were replaced by the straight stainless tube (diameter 15mm, wall thick 2mm), as shown in Figure 2.

The total number of strain gauges is four, two for each axis. The deformation of the handlebar's tube in one of the axes leads to the deformation of the two sensors. The strain gauge on the outer radius of the bend is stretched out, while sensor on the opposite side is shortened. The sensors are connected in a Wheatstone halfbridge.

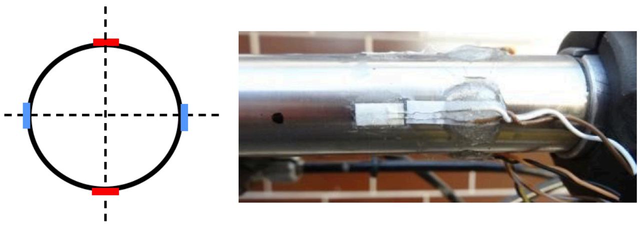

Figure 2: Detail and placement of strain gauges and detail

For the measurement, strain gauges with a paper surface with these parameters were used:

- Type: SM120
- Ohm. value: 120.8 + - 0.25%
- Sensor constant: 1.98 + -2%
- Manufacturer: MIKROTECHNA Prague

For the application of strain gauges, glues namely Locttite454 (for strain gauges) and Locttite3430 (for fixation wires) were used. The space under the bare wires was protected by self-adhesive paper to prevent short circuits, occurred when the wires accidentally touch the metal surface of the handlebars. The sensor's supply cabling is a twisted pair of cables for interference suppression signal, which are induced in the wires. To ensure accurate measurements, it was necessary to assure precision during the application. The longitudinal axis of the handlebar's tube and the axis of sensors has to be identical. Additionally, it is important to ensure that the each strain gauge from the end of handlebars and the regular spacing of 90° has the same distance.

Figure 3 shows the handlebars with the installed equipment used for the measurement. The strain gauges are glued at the left side, while the camera is placed on the right side for better orientation in the measured data for the post processing.

Figure 3: Bike handlebars with measuring equipment

III. MEASURED DEVICE

Data from the sensors were obtained from two methods. The first method used the measuring card NI 9237, manufactured by National Instruments. The card is designed for bridge measurements. However, the mechanical attributes of the card (weight with module cca 620g and size cca 194x88,7 mm) does not fulfil the requirements for the normal operation of a vehicle.The second method used a measuring device, which was designed and created for this experiment. The motivation for designing our own device for measurement was our intiative to replace the measuring card.

A. *Created electronic device*

The principle of performing the measurement with strain gauges is based on measuring the differential voltage between two midpoints of the Wheatstone bridge. It fallows that the main component of the measuring circuit is A/D converter with differential inputs. A/D converter was selected based on the results of the test measurements with a measuring card. Those measurements showed that the upper limit 5 kHz for sampling frequency is sufficient. The selected A/D converter is AD7192, ultralow noise, low drift, 24-bit sigma-delta converter manufactured by Analog Devices.

The converter is placed on the printed circuit board together with other components, as shown in Figure 4. The sizes of the board are 50x60mm. The converter is powered by 3.3 V from ADP3303, voltage regulator, which is included on the board. This regulator allows to powering the circuit by the voltage source from 3.3 V to 12 V. The constant voltage 3.3 V from the regulator is also used for powering the measuring bridges. It can also be used for powering all measuring parts (microcontroller with bluetooth module). Not all output/inputs pins of converter are used in this application, but they are wired and prepared for potential use (for example the external crystal clock). The board is divided into two sides. Connectors for power supply, communication and the other pins of A/D converter are placed on the left side of the board.

The right side is designed for the connection of measuring bridges. Outputs from each Wheatstone halfbridges are connected, through capacitor and inductor input filters to one pair of converter's inputs, which are set in differential mode.

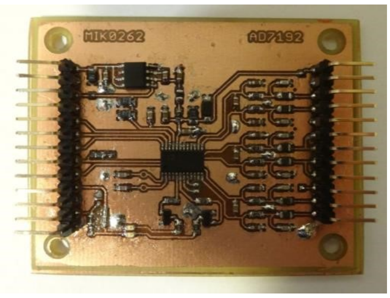

Figure 4: Electronic board with A/D converter for measuring

Since Wheatstone half-bridges, which consist of two sensors and two constant resistors are used in this application, the 120 Ω resistors are placed on the external interposer board, as shown in Figure 5. This solution ensures the universal usage of the converter; therefore, it can be used for any type of measuring bridge.

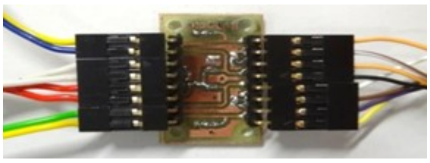

Figure 5: External board with Wheastone bridges's resistors

As shown in Figure 7, the final measuring circuit communicates via SPI (Serial Peripheral Interface) with the microprocessor cc2541 (based on microprocessor 8051), which controls the converter and sends measured data to PC by USART,

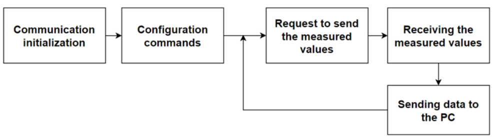

Figure 6: Communication block scheme

Used microprocessor is prepared for the wireless transfer over Bluetooth 4.0. This is the main advantage of this device because it allows the possibility to eliminate the cabling in the future [3, 4]. This fact brings space for more user-friendly alternative, which would be based on the usage of mobile phone. Mobile application (Figure 8) should be able to perform real time processing of measured data, simple visualization of acting forces and save data [7]. Saved data could be further sent to the external database through the internet for the long term analysis [1, 2, 6, 11].

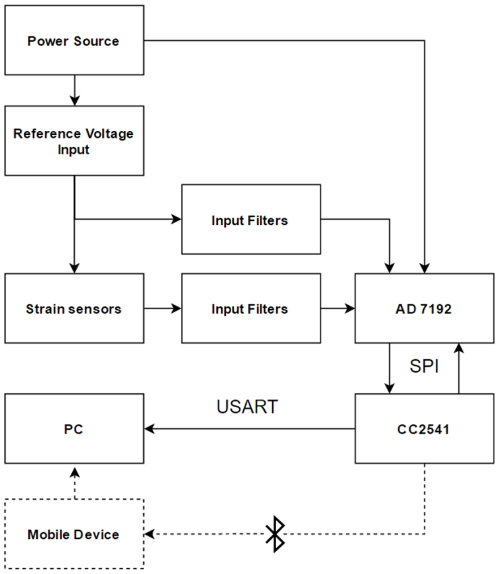

Figure 7: Measuring block diagram

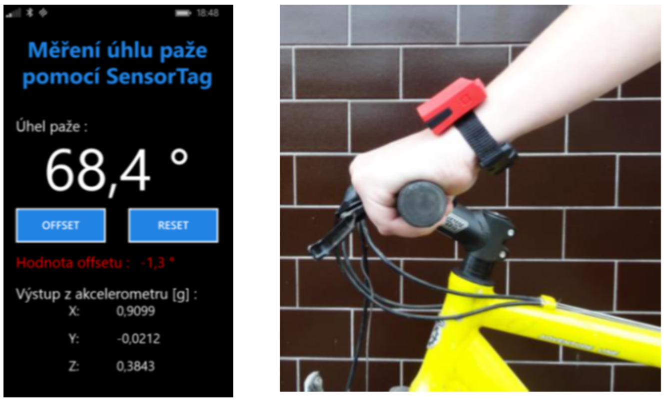

Figure 8: Example of mobile app's GUI and the position of the sensor

B. Limb position sensor

As stated above, data from the force measuring can be extended by the information on the position of the limb. For the experimental measurement, data were obtained by placing a sensor on the dorsal side of the forearm of the rider. The sensor includes accelerometer and gyroscopic sensor. The device, manufactured by Texas Instruments, SensorTag, communicates via Bluetooth 4.0. Data from sensor are received by creating mobile application for platform Windows Phone 8.1.

The first part of the mobile application is ensuring communication between the device and the sensors. After choosing a suitable generic attribute (GATT) for the position of the sensors, the mobile phone sends command to activate and configure this group of sensors. Then, raw data were received from the accelerometer, magnetometer and gyroscope, which can be further processed and eventually the data are ready to be saved to a file. The current version of the application gives user the information about hand angle only through data from the accelerometer.

Bluetooth interface allows the usage of more connected devices, so this application can be extended by receiving data from the strain sensors. It can also be used in more devices with position sensors, which can be placed on any body parts.

IV. MEASURED DATA

The measurement used two differential inputs of A/D converter, each for different axis. The primary processing, real time visualization and saving of the raw measured data were done by using software LabView.

A. Description of measurement

The experiment consisted of continual measuring force during riding of a bike on different surfaces. Measured data were transmitted to the notebook placed in the rider's backpack. The tested surfaces were for example, straight flat asphalt, unpaved roads, asphalt's uphill and downhill, hitting the curb, and crossing two types of surface.

B. Recorded data

Data were recorded with frequency of 50 samples per second. From the saved measured data, shorter sections of data from each surface were chosen. The sections were chosen with the use of the video records and the Trend Viewer [8]. Further, the chosen data were post processed with Matlab, where they were computed using fast Fourier, and transformed to get the frequency spectrum.

V. RESULTS AND ASSESSMENT

Waveforms in the graphs below represent the changes of each acting force in time. The blue X-line represents the force in the horizontal direction, red Y-line represents the vertical component of the transmitted acting force. The graphs also contain FFT spectrum.

A. Straight Asphalt

The first measuring was done on a flat, straight asphalt surface. The experiment consisted of simple pedaling. The periodicity of the waveforms in Figure 9 is due to the strain sensors, which are placed only at one side of the handlebar and the rider is shifting his weight from side to the other side during the pedaling. The horizontal strain ranges are approximately from 0 N to 30N. The major frequency components are not exceeding 10 Hz.

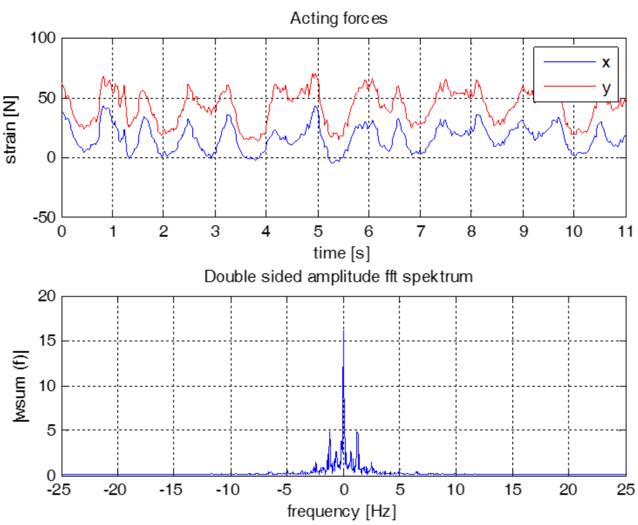

Figure 9: Straight asphalt measurement

B. Unpaved road

The following measuring was done on an unpaved surface, presented by gravel road. The main sign of waveforms in Figure 10 shows increased dynamics of acting forces, which is also evident in the FFT spectrum. The main components of the spectrum are reaching higher values, that is about 17 Hz. The amplitude reaches about 70 N, and the peak reaches up to 130 N.

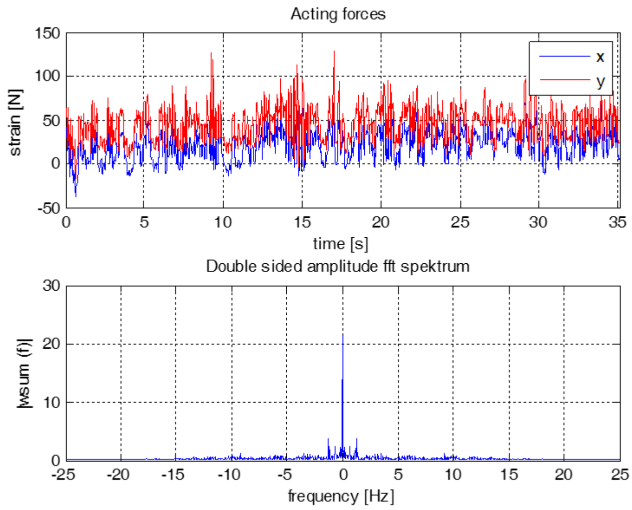

Figure 10: Unpaved road measurement

C. Crossing two types of surface

The next measurement was done to compare two surfaces. It was a combination of two surfaces from the previous measuring. The waveforms in Figure 11 illustrate the different dynamics of acting forces.

D. Hitting the curb

This measuring was done to analyze the acting forces during the riding over obstacles on the road. The experiment was conducted by hitting the curb by the road. Figure 12 shows waveforms that present the acting forces during the riding from the road to the sidewalk and back to the road. These events are evident in the graph as the two bouncing peaks with overshoot.

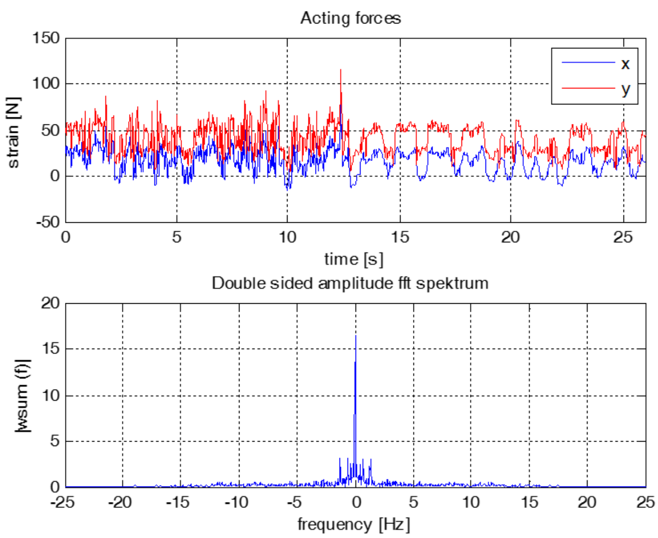

Figure 11: Crossing measurement

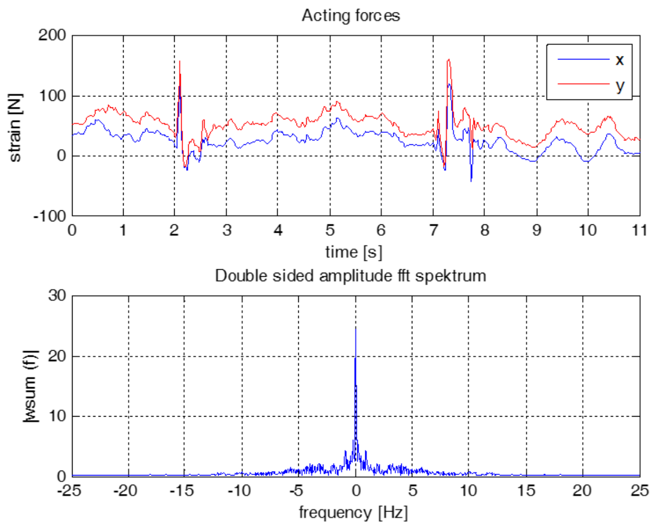

Figure 12: Hitting measurement

VI. CONCLUSION

In this work, we summarized the procedure for measuring forces, which are transmitted between human and a vehicle. The results show the function of the measuring equipment that allows the registering and measuring of the forces on the handlebars of a bike. The principle of the method is that the construction of the device and the shape of the sensors allow it to be applied at any part of any vehicle.

The presented method allows measuring not only the amount of acting of the forces, but also their dynamics. This fact can be used in the sports industry, mountain biking and motocross sport. Besides setting the controls, the data may be used for verifying and adjusting the appropriate settings of the damping and suspension.

Although the main advantage of this work is in the design of the wireless solution for complex collecting data from the interaction between human and vehicle, few similar measuring has been published.

The next steps in developing this measuring device is to completely replace the wiring. This would be based on using Bluetooth 4.0 for transmitting data from microprocessor directly to mobile device. After that, mobile application would be provided to user real time data visualization from strain sensors and position sensors. This would provide user a more comfortable way of measuring, during settings and riding as well as during the long-term measuring [9].

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