Remo measurement system

Development of a measuring system to assert on-water rowing performance

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Abstract

In crew rowing movement synchronisation is generally regarded as one of the main determinants of optimal performance. In my dissertation “[Coordination dynamics of crew rowing](#)” I conducted various studies to investigate rowers’ ability to coordinate their movements, both in traditional synchronised (in-phase) and the more innovative antiphase rowing, during which the rowers alternate their strokes (Cuijpers, 2019). To be able to measure crew coordination and the movements of the boat on-water, I developed a measurement system using open-source computer hardware and software that allows building digital devices and interactive objects.

The aim of this method paper is to provide insight in how this measurement system was developed and build. I hope that sharing our choices and considerations developing the measurement system will inspire you to think more freely about ways to measure and perhaps even to build your own measurement system.

Introduction

In rowing, the goal is to cover a course of 2000 meters as fast as possible, preferably faster than the opposing crews. This goal can be achieved by producing lots of power and effort, and/or by converting the power produced efficiently into boat speed (for a demonstration of these methods, see the final of the men’s pair at the 2007 World Cup with New Zealand yanking at their oars next to a comfortable, seemingly effortless rowing Australia). With margins as close as within hundreds of a second at World Cup level, it is evident that power is not enough (O’Brien, 2011). Only by perfectly coordinating their movements, rowers may be able to minimize velocity fluctuations due to turning movements of the boat and maintain maximum boat speed over the course of the race. Research in on-water crew rowing has been

done with specially equipped boats (see e.g., <http://www.peachinnovations.com> or <https://www.weba-sport.com/en/products/oar-power-meter-en>). However, these systems are expensive and cannot easily be switched to another boat.

In the study for which we developed this measurement system, we were interested in the relation between movements of the rowers (crew coordination) and the movements of the boat (e.g., yaw, pitch and roll; Cuijpers, Passos, Hoogerheide, Murgia, Lemmink, & De Poel, 2017). By combining a microcontroller to two potentiometer modules that measure the oar angle over time, and a MUP-6050 module that measures linear acceleration and angular velocity of the boat, a non-invasive and relatively cheap tool was developed to investigate the relation between crew synchronisation and boat movements. The use of Arduino-based microcontrollers and modules provide the opportunity to develop a non-invasive and relatively cheap measuring system to assert crew synchronisation. Using a module that captures linear accelerations and angular velocity in x, y and z-direction, boat movements such as fluctuations in boat speed and yaw, pitch, and roll are measured. Crew coordination is asserted using a potentiometer on the oarlock of each rower. The potentiometer measures the oar angle for each rower over time, from which the consistency and accuracy of crew synchronisation can be derived in terms of relative phase. The resulting time series allow for calculating continuous phase relations between rowers, which relates directly to coordination from a dynamical systems perspective (Cuijpers, 2019; De Poel, De Brouwer, & Cuijpers, 2016). As both the potentiometers and the accelerometer module are connected to one microcontroller, data is obtained in a synchronised fashion.

While the measurement system was developed for scientific research, it can also be used in training practice to analyse crew technique and the effects thereof on boat behaviour for the benefit of crew performance. For a nice illustration of that, see Sève, Nordez, Poizat, & Saury, (2013).

Method

The objective was to develop a non-invasive and relatively cheap measuring system to assert crew synchronisation and its influence on boat behaviour. In order not to interfere with crew coordination and balance, the device had to be as light as possible. As rowers have their individual riggings, such as the height of the oarlock, it would be preferable to design the system in such a way that it can be mounted on different boats without changing the rigging. Most evident, the device should be waterproof, as rowing is done on water. For the same reason, the system needs to be portable and able to measure for at least one hour straight. Finally, in order to obtain enough data over time to draw accurate conclusions from, a minimum sample frequency of 50 *Hz* is required.

Hardware

The measurement system consists of two modules connected to a microcontroller. The MUP-6050 module measures linear accelerations and angular velocity in x, y and z-direction. From these data, boat movements such as fluctuations in boat speed and yaw, pitch, and roll, can be derived. Crew coordination is asserted by two potentiometer modules that measure the oar angle for each rower in time. In order to synchronise these modules, both are connected to an Olimexino-328. The obtained data is written into a text file on the micro-SD card in the SD-shield mounted on top of the Olimexino-328. Figure 1. shows the schematic setup of the system. The weights of the separate parts are shown in Table 1., resulting in a total weight of 1520 g for the complete system. Specifications of the designated parts are discussed in the sections below.

Table 1. Weights of the separate parts of the system.

Part	Weight (g)
Potentiometer module (excl. cable)	167
Potentiometer module (incl. cable)	462
Slide (large)	88
Slide (small)	75
Box (incl. 6 1,5 V batteries)	420

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Figure 1. Schematic overview of the Remo Measurement System.

Olimexino-328

The Olimexino-328 (Figure 2.) is a microcontroller development board based on Arduino™. The board has a build-in support for different types of data signals, such as digital, analog, SPI and 12C. Via the UEXT module the MUP-6050 module can easily be connected and read. The Olimexino-328 can be connected to a laptop (USB) and battery holder. In addition, the board is equipped with a pushbutton and led light, which are used to stop and start the recording and to indicate if the system is recording (see software).

Figure 2. Olimexino-328 Microcontroller Development Board (A) and MPU-6050 Module (B).

Potentiometer Module

The potentiometer module was custom made by the UMCG Research Technical Service (UMCG Research Instrumentmakerij, see <http://www.rug.nl/umcg/diensten/instrumentmakerij/>). A continuous turn 10 $k\Omega$ potentiometer type 6639) was made waterproof by casting the potentiometer and connection to a wire (3 core, 20 AWG) in silicones. The potentiometer is attached to an oarlock so the resistance of the potentiometer changes as the oarlock moves around the pin. The preferred rigging can be maintained by moving the potentiometer up and down the slide according the height of the oarlock and by replacing the pitch bushings the required oarlock angle is achieved (Figure 3.).

Figure 3. Potentiometer Module. By adjusting the height on the slide (A) and replacing the pitch bushings (B) in the oarlock the preferred rigging can be maintained.

MPU-6050 Module

The MPU-6050 module (Figure 2B) is a 3-axial gyroscope and accelerometer on the same silicon die together with an onboard Digital Motion Processor™ (DMP™) capable of processing complex 9-axis MotionFusion algorithms. MPU-6050 is equipped with an I2C interface and can be connected to the Olimexino-328 with UEXT.

SD-shield and Micro SD-card

The SD-shield (Figure 5.) is populated with a microSD socket, red power indicator LED, and a reset button. Communication with the microSD card (MicroSD 4GB Kingston Class 10 + SD Adapter p/n SDC10/4GB) is achieved over the SPI interface.

Figure 4. SD-shield, micro SD-card and SD adapter.

Power Supply

The system is energised by 6 1.5 V batteries in a housing connected via a 9 V battery clip (snap connector) to a 2.1 mm power plug (see Figure 5.).

Figure 5. Battery Holder, Battery Clip and Power Plug.

Housing and Connectors

Except for the potentiometer module, all the above-described parts are situated in a waterproof box with a see-through cover (Figure 6), so one is able to see whether the system is recording without opening the box. The connection to the potentiometer modules runs through waterproof connectors, i.e. multicom 2CT3002-W03400 and multicom 2CT3004-W03400. Both connectors have an IP rating of 67, indicating that no water enters the connector when holding it under water for 30m at a depth of 1 meter.

Figure 6. Waterproof housing and connectors.

Software

The software for this measurement system (see Remo_Measurment_System Code - L.S. Cuijpers.pdf) is written in IDE. To upload the script, the board (Arduino Duemilanove w/ATmega328) and serial port ('/dev/tty/usbmodem1421' or '/dev/cu/usbmodem1421') must be specified.

Set up

In the first section of the code, a number of libraries are opened and variables are initialised. In order to communicate with the SD-library, the SD-card must be formatted to FAT-32. To do so, open Disk Utility, select Erase and choose MS-DOS (FAT) as format. The SD-library assumes that the CS pin of the SD-shield is broken out to the D10 pin. On the SD-shield that is used in the system, the CS pin is broken out to the D8 pin, so this needed to be specified in the set up.

Creating Files

When the button on the side of the Olimexino-328 is pressed, a new recording is started. First, the code checks if the SD-card is present. If this is the case, a new file is created with the name 'DATAXXXX.TXT' depending on which files are already in use on the SD-card. When the recording is stopped and then started again, the text file the incoming data is appended to the current file. If the system is reset by pushing the reset button or by interrupting the power supply, a new file will be created when starting the recording. While the system is recording, a led light is activated.

Data Registration

The Olimexino-328 reads the incoming data from the two potentiometer modules and MPU-6050 sensor. In addition, the time in microseconds is registered. The Olimexino-328 reads the sensor values every 5000 microseconds and writes these values into the text file, separated by columns. This results in seven columns per row at a sample frequency of 200 Hz:

- time (μs)
- resistance potentiometer 1 (mV)
- resistance potentiometer 2 (mV)

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- linear acceleration x-direction
- linear acceleration y-direction
- linear acceleration z-direction
- angular velocity x-direction
- angular velocity y-direction
- angular velocity z-direction

Converting Raw Data

Once the text file is loaded onto the laptop, the raw sensor values must be converted. The angle of the oarlock is reflected in the resistance of the potentiometer. In theory, the potentiometer values range from 0 to 5V, corresponding with 360°. However, the rowing cycle amounts a maximum of 160° within one cycle of the potentiometer, suggesting only a selected part of the range in mV is used. Therefore, the potentiometer module was calibrated from -80° until +80° in steps of 10° to calculate the relation between angle (°) and resistance (*mV*) (see Figure 7.). As such, the change in resistance of the potentiometer module can be converted into change in angle of the oarlock by the following formula:

$$\Delta angle (^{\circ}) = \Delta mV/3 \quad (Eq. 1)$$

which means that a change of 1° corresponds with a change of 3 *mV*.

Figure 7. Calibration data from both potentiometer modules.

The full-scale range of the MPU-6050 accelerometer sensor is set on FS1, which means that the module can register values between -2 and 2 g at a LSB sensitivity of 8192/g. In order to convert the accelerometer-gyroscope data into m/s², the following formula is used:

$$acceleration (m/s^2) = (sensor\ value/LSB\ sensitivity) \times 9.81 \quad (Eq. 2)$$

The full-scale range of the MPU-6050 gyroscope sensor is set on FS0, which means that the module can register values between -125 and 125°/s at a LSB sensitivity of 131°/s. In order to convert the accelerometer-gyroscope data into °/s, the following formula is used:

$$angular\ velocity\ (^\circ/s) = (sensor\ value/LSB\ sensitivity) \quad (Eq. 3)$$

Results and Discussion

The objective was to develop a non-invasive and relatively cheap measuring system to assert crew synchronisation and the effects thereof on the movements of the boat. Figure 8. shows an example of the resulting time series, from which the oar angles (A) and movements of the boat in terms of velocity fluctuations (C) and yaw, pitch and roll (D) can be related directly. The resulting time series of the oar angles allow for calculating continuous phase relations (B) between rowers, which gives indications on the consistency and accuracy of crew coordination.

Figure 8. Example of resulting time series: A) oar angles ($^{\circ}$), B) relative phase ($^{\circ}$), C) linear accelerations (m/s^2) and D) angular velocity ($^{\circ}/\text{s}$). Dotted lines indicate catch and finish of the stroke.

Non-invasive

In order not to interfere with crew coordination and balance, the device had to be as light as possible. The complete measurement system weights 1520 g. Assembling the potentiometer module to the rigger will create a momentum, influencing balance. Rowers have their individual riggings, adjusted to i.a. boat type and the strength, length and preferences of the rower. Some of the variables in rigging are the angle and height of the oarlock. In order not to interfere with these individual riggings, the potentiometer module was equipped with an oarlock that is compatible

with Hudson, Filippi and Empacher shells, which are the three most used boat builder companies in Europe. As such, by simply replacing the pitch bushings of the oarlock and adjusting the height of the potentiometer on the metal slide (Figure 4.), the potentiometer module can be assembled on the boat while the preferred rigging is maintained.

Waterproof

As rowing is done on water, it is evident that the device should be waterproof. In order to achieve this, the majority of the parts (i.a. microcontroller and MUP-6050 module) are situated in a waterproof housing. The potentiometer module was made waterproof by casting the potentiometer and connection to the wire in silicones. By the use of waterproof connectors, the connections between the potentiometer modules and the microcontroller in the housing were made waterproof.

Portable

As the crew will be rowing out on the water during the measurements, the system had to be wireless. To achieve this, the data obtained are written in a text file to a micro SD-card placed in a SD-shield mounted on top of the microcontroller. As such, the obtained data can be transported after the measurements via an SD-card reader to the laptop, after which the data can be read and analysed. Power is provided by a 6x1.5 V battery holder with 6 1.5 V batteries.

Data acquisition

As the recording must be started on land and calibration may take some time, one of the requirements was that the system is able to record over a minimum time span of two hours, which was attained during the pilot study. Finally, in order to obtain enough data over time to draw accurate conclusions from, the sample frequency was set at 200 Hz.

Conclusion

The aim was to develop a measurement system to investigate the relation between crew synchronisation and boat movements. We developed a system that is light, non-invasive, waterproof and portable at a total cost of around 400 euro. The system can measure over a time span of 2 hours and samples data at a rate of 200 *Hz*. As such, the system meets the requirements to investigate crew coordination and boat movements. While the measurement system was developed for scientific research, it can also be used in training practice to analyse crew technique and the effects thereof on boat behaviour for the benefit of crew performance (see Sève et al., 2013).

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References

Cuijpers, L.S., Passos, P.J.M., Hoogerheide, A., Murgia, A., Lemmink, K.A.P.M., De Poel, H.J. (2017). Rocking the boat: does perfect crew synchronisation reduce detrimental boat movements? *Scandinavian Journal of Science and Medicine in Sports*, 1-8. DOI: [10.1111/sms.12800](https://doi.org/10.1111/sms.12800)

Cuijpers, L.S. (2019). Coordination dynamics in crew rowing. University of Groningen, Groningen, The Netherlands. DOI: [10.33612/diss.94906482](https://doi.org/10.33612/diss.94906482)

Cuijpers, L.S., & De Poel, H.J. (2017). Antiphase crew rowing on water: a first case study. In: *Complex Systems in Sport, International Congress: Linking Theory and Practice*. Editors: Torrents, C., Passos, P., Cos, F. *Proceedings of the 5th Complex Systems in Sports Conference*, October 5-6th, 2017, Barcelona, Spain.

De Poel, H.J., De Brouwer, A.J., Cuijpers, L.S. (2016). Crew rowing: an archetype of interpersonal coordination dynamics. In: *Interpersonal coordination and performance in social systems*. Passos, P., Chow, J.Y., Davids, K., editors. Routledge, 140-153.

O'Brien, C. (2011). Effortless rowing. In: Nolte, V. (Ed). *Rowing faster* (p. 173-182). Champaign: Human Kinethics.

Sève, C., Nordez, A., Poizat, G., Saury, J. (2011). Performance analysis in sport: contributions from a joint analysis of athletes' experience and biomechanical indicators. *Scandinavian journal of medical sciences in sports*, 1-9.

Appendices

Remo_Measurment_System Code - L.S. Cuijpers.pdf