Measuring Accurate Timings in Outdoor Sports Using Photoelectric Sensors and Ultrasound

Project plan

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Motivation

For the personal training in sports that require time measurements, there are no cheap systems available to measure the time for a fixed segment accurately. The systems used in competitions are too expensive and too complicated to set up for regular personal use.

Furthermore, for small hobby competitions with friends, an accurate time measuring system that is cheap, easy to set up and portable would be useful. There are apps like Strava that use GPS data to time segments, but this is very inaccurate and cannot be used to get reliable timings.

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1 Project Description

Goals

- Cheap and easy to set up and use
- Compact and lightweight
- Accuracy comparison with professional systems
- Multiple users at once (small groups of friends)
- Not for official competitions (users can be trusted)

Approach

There are two general approaches to be considered: Measuring the time on the athletes themselves and measuring the time with devices at the start and finish line.

Time measuring on athlete

The simplest method is to detect the crossing of start and finish line with the smart phones the athletes are carrying themselves. With GPS, no device is necessary at the start and finish line. Apps like Strava are using this method, but the timings are not accurate enough. With devices at start and finish, a variety of sensors of a modern smart phone can be used. With the magnetometer or NFC, the detection distance is problematic. Using WiFi or Bluetooth signal strength, a high accuracy is difficult to achieve and the signal detection might not be fast enough while running or riding bicycles.

For a reliable detection, the microphone seems to be a good candidate. An ultrasound with a high-pitched inaudible frequency could be emitted by the device and detected by the smart phone using a Fourier transform.

Time measuring at start and finish

A different approach is to do the time measuring with the devices at start and finish. Thereby, a data transmission between start and finish device is needed and the clocks have to be synchronized. Furthermore, if multiple athletes should use the setup at the same time, the recorded times have to be linked to the corresponding athletes.

Systems that are used in competitions use this setup with long-range RFID sensors as it offers high enough accuracy and athlete identification at the same time. These long-range RFID sensors are really expensive and therefore not suitable for most private uses or training.

A much cheaper device could use a photoelectric sensor (light barrier) to detect a crossing, but like this a direct identification is not possible. If there is enough space between the athletes, the recorded GPS data of all the athlete's smart phones could be used to link the recorded timestamps

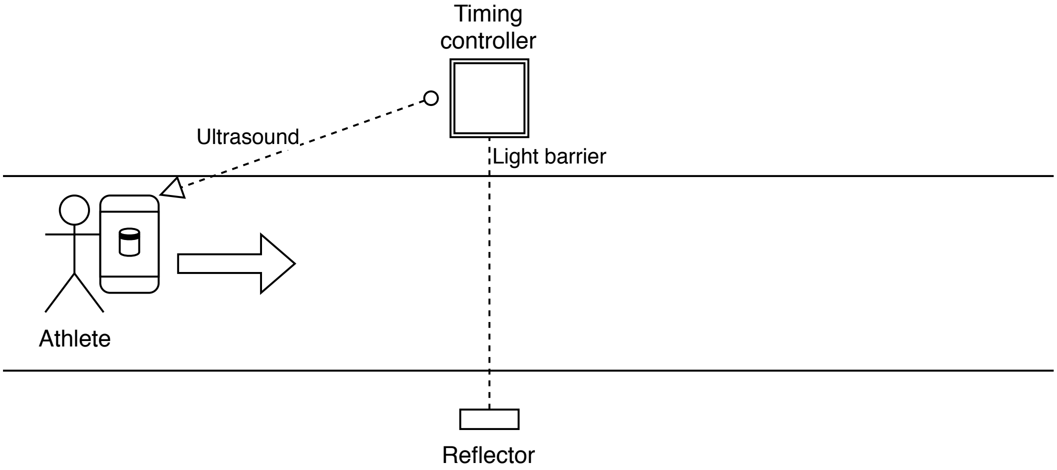

Figure 1: Combined timing approach

of the start and finish devices to the athletes. For this, a decent GPS signal is necessary and all devices need to be in a network.

Combination of both approaches

To increase the accuracy of the first approach, it could be combined with the second approach. The devices at start and finish use a light barrier to detect the crossing accurately and signal the exact time to the smart phone by a frequency change. The smart phone can record an exact timestamp as soon as it detects the frequency change. This concept is depicted in figure 1.

A short frequency change when detecting a crossing is a simple frequency modulation. This could be enhanced with a simple protocol and frequency-shift keying to transmit additional data. Like this, the measuring device can be identified enabling the use of multiple sensors and therefore multiple different segments at once.

If the speaker of the smart phone is suitable, this system could also be expanded to a half-duplex system or it could be reversed. In this case, the smart phone constantly emits an identifying signal that is detected by the measuring device. As soon as the crossing is detected, the timestamp can be saved with the identifier.

As this project is designed for personal training and hobby competitions, the data does not have to be processed centralised. The easiest method is to store and compute the times directly on the smart phone of the user. If there is an Internet connection available, the processed times can be sent to a server to compare results with friends and generate a leaderboard. Like this, the measuring device itself can be really simple and cheap. With solar power, these devices could even be installed permanently and used by everyone with the corresponding app.

2 Work packages

- **Research:**
  - **Existing products:** What options do athletes have for training already? How do these work? How expensive are they? How accurate and precise are they?
  - **Sensors to measure timings:** Which sensors can be used to detect a crossing of the start and finish line?
  - **Accuracy and precision:** What is required? What can be achieved? What is used in competitions?
  - **Ultrasonic data transmission:** Is it used in other applications? Are there any existing protocols? What is the reliability and range?
  - **Integration in existing software:** Do common GPS tracking apps offer API's? Can Strava segments be adjusted to the accurate recorded times?
- **Implementation:**
  - **Timing Controller:** Building a small circuit with a microcontroller, a sensor and a speaker. Programming the microcontroller to emit an inaudible frequency which changes when the sensor detects an athletes crossing.
  - **Timing App:** Developing an app to detect the frequency change of the controller and recording a timestamp. Calculating the time in between timestamps.
  - **Communication:** Implementing a lightweight communication protocol that can transmit identification data via sound between the smart phone and the measuring device.
  - **Data aggregation and analysis:** Combining recorded GPS data with the recorded timestamps. If identification is implemented, checking if the segments match. For multiple athletes, checking for close timestamps and trying to correct possible errors, for example detected crossings from another athlete.
  - **Visualisation and connectivity:** Displaying the measured data and combining it with segment data from existing services with API support.
- **Analysis:**
  - **Environment:** Tests in different real world environments (surrounding noise, smart phone in pocket or rucksack)
  - **Versatility:** Usability in different sports (cycling, mountain biking, running, sprinting)
  - **Precision:** Fixed and consistent smart phone movement with many iterations
  - **Comparison:** Test in direct comparison with a professional timing system at a real or a staged competition
  - **Evaluation:** Performance of the whole system
- **Documentation:** Written documentation of the completed work

3 Time Table

Month	April				May				June					July		
Calendar week	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Research and evaluation	■	■	■	■	■											
Implementation					■	■	■	■	■	■						
Analysis									■	■	■	■				
Documentation												■	■	■	■	■

4 Risk Analysis

Working with Android, developers have to deal with a huge variety of devices. Some smart phone manufacturers might use filters for inaudible sounds. On average, the used microphones usually have a roll-off around 22 kHz reducing the usable bandwidth. Furthermore, microphones have frequencies that are detected louder than others. There are many projects, that try to use ultrasound to integrate communication into existing platforms. Most of them failed because there were better alternatives or the achievable transmission rate was too low. For this project, the data that has to be transmitted can be reduced down to 1 bit just for signalling the crossing of the light barrier if further reliable communication is not achievable. If some smart phones have big problems detecting ultrasound, the crossing could still be signalled with an audible sound.

Another risk is that the detection is not fast enough and the frequency change cannot be detected while the smart phone is in range. Especially in cycling, crossing speeds can be high. In this case, there could be a fallback to the recorded GPS data which can be matched by the recorded times from the light barrier.

The light barrier needs to detect the crossing reliably. It should be positioned depending on the activity and the controller should have different modes. For example, for cycling, it can be positioned at the axle height and it should measure the first blocking of the light which is the tip of the front wheel. After that, it should have a timer to let the bicycle pass before watching for other crossings. This has to be optimised for different situations.

Looking ahead to a possible product, there could be statutory regulations regarding sound pollution, especially for high frequencies.

Due to the current Corona pandemic, it is not clear if the system can be tested in a real competition. There could also be issues with obtaining parts like a specific light barrier for the task. In this case, basic available parts need to be used.