Sensor system for agility assessment: T-test case study

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***Abstract*—Measurement of the relevant basic and sport specific physical abilities of athletes is one of the most important elements in the system of sport. Agility, i.e. the ability to rapidly change direction is one of these abilities and various agility tests are regularly included in sport test batteries. This paper presents a state-of-the-art approach to measuring agility using infrared and kinematic sensors. The combination of precise timing, position detection and motion recording enables the acquisition of previously inaccessible kinematic and temporal variables. The evaluation of the athletes' agility can be more objective and acquired with much greater certainty than it would be possible with current equipment and methods. The presented sensor system can be used in different sport settings and types of tests, including the frequently used T-test, which serves as our case study.**

***Keywords*—agility, photocell, IMU, sensor system, synchronization, sensor fusion, T-test**

I. Introduction

Throughout history, athletes have used technology to improve their performance. Nowadays, the use of scientific knowledge in sport is even more remarkable. The introduction of new technologies is one of the important elements that have contributed to the general improvement of performance in various sports. These technologies are used not only in competitive sports, but also in recreational activities, personal fitness monitoring and physical rehabilitation. The introduction of new sensors and sensor systems in sports is particularly remarkable and profound in competitive sports, as the meticulous observations and detailed knowledge can provide a significant competitive advantage. This is mainly due to the fact that new systems and solutions provide coaches and sports scientists with previously inaccessible information, as well as the higher measurement reliability achieved [1]. In sport, competitive performance depends largely on the effects of long-term preparation on the physical performance of athletes. It is not surprising that athletes are monitored permanently and periodically by using different test batteries. Agility, i.e. the ability to change direction quickly, is one of the skills that is very important in many team sports such as basketball and football, but also and especially in individual sports such as martial arts. Various agility tests have been developed and regularly used as part of both the basic and sport-specific test batteries. Performance in these tests is usually measured as the time taken to complete the movement task. While this is useful, it does not provide information about the movement kinematics of the athletes during the test.

Nowadays, objective sports tests should not be subject to human error and observations of a coach. In this paper the evaluation of the athlete's agility using the "T-Test" is presented. At present, T-test agility is done almost exclusively by means of a stopwatch and the trained eye of a trainer. We have opted for an engineering approach with the design, development and implementation of a versatile, easy to use, integrated multi-sensor system. It provides a reliable method for measuring and testing agility in sports. When developing this T-test solution, our main concern was the universality of the system. Its elements - sensors, sensor devices, synchronization and communication protocols, basic application logic, etc. - should also be usable for other agility tests. With the proposed system, we address the issues of precise timing during the various test phases, synchronization of a number of sensor devices contained in the system and reliable sensor data transmission. The merged temporal, spatial, and kinematic data obtained in this way will allow an in-depth analysis of the athlete's performance during the test and will significantly improve the quality and usefulness of the information for coaches and athletes.

The main contribution of this paper is the new technological approach to measuring agility. The paper presents new methods to obtain agility data and to present the results to athletes and trainers with high accuracy.

The structure of this paper is as follows. In the Section II different techniques for measuring and evaluating agility are presented. The detailed architecture and operation of the designed sensor system is explained in Section III. Testing and evaluation of the system are described in Section IV, and we conclude with Section V.

II. T-test Basics

Agility is often equated with the ability to change position quickly and efficiently, i.e. the speed at which a person changes direction (CODS). It is associated with trainable physical characteristics such as strength, power and technique as well as cognitive components such as visual scanning techniques, visual scanning speed and anticipation [2].

Agility cannot be measured using only one specific task, but by a combination of movements performed in rapid succession. Therefore, agility is assessed by measuring the time taken to complete a series of predefined tasks. Even if the measuring path is predefined, each instructor gives different commands to the athletes and measures time subjectively. This makes the measurements taken by different trainers less comparable.

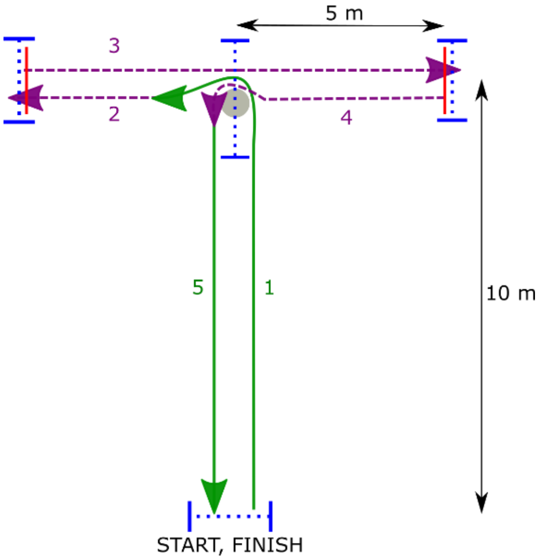

Figure 1 Diagram showing T-test execution, the lines (green, red) and cones (gray) and movement of the athlete (green, violet) are displayed. The T-test is performed with a straight forward sprint (1, green), lateral movement (violet) to the left (2) and right (3), back to the cone (4) and a backward sprint (5, green) to the starting point. The dotted lines (blue) represent the measuring points (optical gates) of the proposed system.

There are different standardized tests for assessing speed and agility [3], [4]. We have studied the tests used: T-test, X-test, Illinois test, and Sprint run test. Each of them has its own characteristics when you look at the athlete's performance, more precisely; each of them evaluates different aspects of agility. The widespread use of the T-test in assessing agility in various sports prompts us to use it as our case study. It is simple but complex enough to be carried out and learned by the athletes, and it allows us to address any technical problems that we might encounter later in other agility tests. The T-test, as shown in *Figure 1*, is performed by a (straight) forward sprint from the start line to the center cone. As the athlete crosses the central cone, he changes the direction of movement and jumps sideways to the left and then to the right line. When he reaches the right side, he returns sideways to the central cone and finally sprints backwards to the start line [5], [6]. The use of markings in the form of ground lines or cones depends on the equipment available.

Experts in this field advised us on characteristics and aspects they try to evaluate in the testing of athletes. We came to the conclusion that, in addition to the total time required to complete the test, spatio-temporal and kinematic parameters during movement would be beneficial to the athletes. At present, they only use the measurement of total time for agility assessment and the system we are proposing builds on top of that.

III. Sensor System

A. *Architecture*

The architecture of our solution is shown in *Figure 2*. On the one hand, there are optical gates for measuring precise timing of an athlete at a specific location. The second is a portable kinematic sensor for measuring kinematic variables, which is attached to the athlete. Thirdly, there is a synchronization protocol which

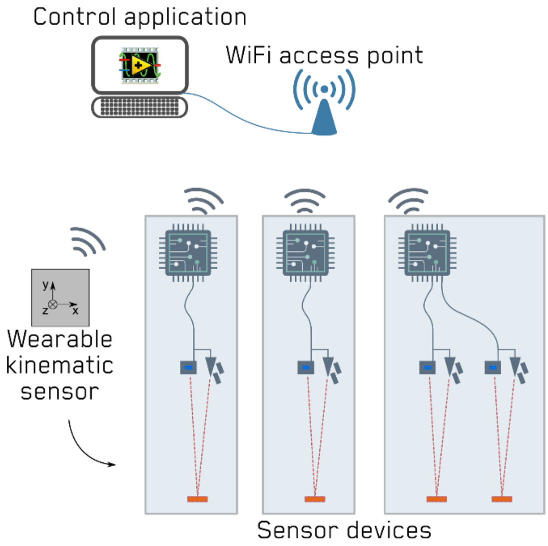

Figure 2 Architecture of the system. Devices and sensors are connected to the LabVIEW control application via Wireless access point. Wearable kinematic sensor is mounted on the athlete. Optical gates are located at specific positions as required by the test. Each sensor device can support one or multiple optical gates.

synchronizes the internal clocks of all the devices. The fourth is the transmission protocol via the wireless network. And the fifth is a dedicated control application written in a LabVIEW environment.

B. *Operation*

All system elements must be connected to the same local wireless network. This is achieved with a single access point, as shown in *Figure 2*. Optical gates are spatially arranged as shown in *Figure 1* , and marked with blue markings. A portable kinematic sensor is attached to the athlete's lower back using a special belt. Once all the equipment has connected through the wireless access point, an operator initiates a synchronization process using a control application on a computer (server). When this process is complete, the measurement can begin. The received data packets are processed, they can be logged, and stored in a database. The results can be used for immediate feedback to the athlete or processed later for more in-depth analysis.

C. *System Elements*

Optical gates

There are 4 regions that interest us during the T-test: the starting position, the center, the left and the right turning point. When crossing these points the movement should be observed and recorded. There is an optical infrared gate at the start, left, right, and center, as shown in *Figure 1*. This allows us to determine the location, the direction of approach and the timing, but also to obtain partial results for each specific task (forward and backward sprint, left and right lateral movement), which gives us much more information for assessing an athlete's agility.

When designing the gate, we considered several types of optical sensors. There are two main types: reflective with transceiver, and transmitter-receiver. Since the users of this system have to assemble the system themselves, the design should require as little technical knowledge as possible. A simple and inexpensive solution that uses reflectors and works at the required distance of 2 meters is used in our system. A simple integrated circuit *IS471F* [7], which is mainly used in urinals, fits our needs perfectly. We have coupled this sensor with a suitable infrared LED (light- emitting diode). We tested LEDs with different beam sizes and found that a viewing angle of 10°-15° is suitable for our desired distance. The beam of this angle is optimal for the arrangement of the sensor and can be easily "directed" to the reflector. When developing a circuit, we were aware that LED and photosensor should be as close as possible, so we shielded the receiver from the transmitter to prevent direct transmission of the signal. The use of the integrated circuit IS471F is advantageous because the modulator in this circuit controls the IR LED. This couples the modulation and demodulation of the signal. The modulation of the signal reduces the noise from other IR sources, which allows the use of this sensor when exposed to sunlight and other light sources.

The IS471F sensor is connected to an *Adafruit Feather M0 WiFi with ATWINC1500* [8] microcontroller board. Since the output of this sensor is an up or down state. Any digital input can be used. And multiple sensors can be connected to a single microcontroller. The microcontroller uses interrupts to monitor the change of state on each input. If an interrupt is triggered, the program works according to the transmission protocol 0.

Wearable kinematic sensor

Wearable sport devices are common in both leisure and professional sports. The combination of motion sensors (accelerometer, gyroscope, magnetometer) is generally accepted that a well-placed kinematic sensor can be used to measure motion [9]–[12].

We measure kinematic parameters with a single sensor device attached to the athlete [11], [12] at a sampling frequency of 200 Hz. We use a *MinIMU-9* sensor with integrated accelerometer and gyroscope (*LSM6DS33*) and magnetometer (*LIS3MDL*) [13]. This sensor is precisely attached to *Adafruit Feather M0 WiFi with ATWINC1500* [8] to form an autonomous wearable sensor device with a Li-ion battery. The sensor is connected to the microcontroller via the I^2C protocol. Data is sampled and processed on a microcontroller and then transmitted to the LabVIEW application over the wireless network.

Synchronization protocol

For correct and reliable operation of the sensor system, time synchronization of all remote devices is required. We concluded that the use of wired methods and manual synchronization of internal clocks using interrupts is the most accurate method, but is impractical for anything other than laboratory testing.

So we created a solution that works over IEEE 802.11 wireless networks. The timeline diagram of the protocol is shown in *Figure 3*. The protocol itself is simple and uses the broadcast address of the Internet Protocol (IP). How the protocol works is as follows:

1. The server requires all devices to synchronize using the broadcast address. This means that all devices receive this packet practically at the same time.
2. When the devices receive this request, they set the synchronization clock variable to zero and send a unicast message back to the server confirming that synchronization is complete and iterating the local counter.

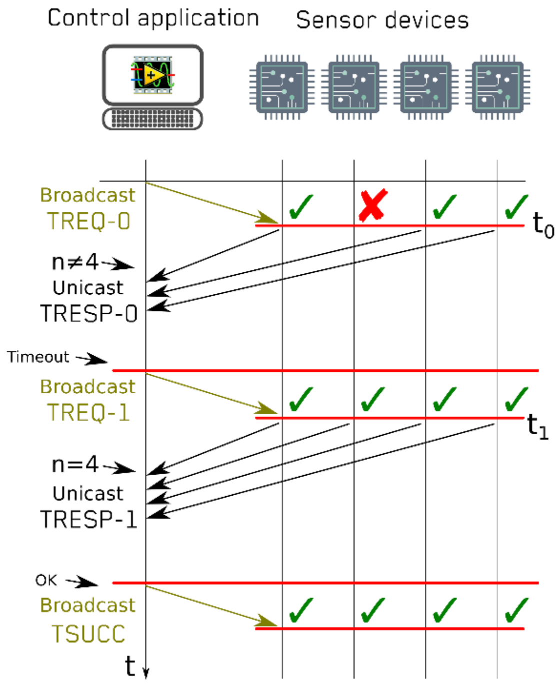

Figure 3 Synchronization protocol diagram. Server sends request (TREQ-m) to all the devices on the same network using a broadcast address. Devices respond with TRESP-m message. If server does not receive the response from all the devices, it starts the synchronization cycle *m*+1. When all devices successfully confirm the synchronization, the server broadcast a successful sync message (TSUCC) indicating to the devices, they can start streaming data.

3. The server collects all responses. If the number of responses is equal to the number of devices used and the iteration counter of all responses is equal to the last one sent, synchronization was successful.

Otherwise, the server continues with synchronization requests until all devices respond to the same request.

Transmission protocol

We use *Adafruit Feather M0 WiFi with ATWINC1500* [8] as our microcontroller board. The advantage of this board is that it has two processors, one for core processing and another for networking. This makes time-dependent processing, such as signal sampling, less prone to errors.

We use UDP (User Datagram Protocol) as transport layer protocol. We send one packets for each sensor sample. Wearable kinematic sensor sends 200 packets per second. Optical gates detect and send only the change of state (beam interrupted or uninterrupted). Each packet carries its own internal clock, a synchronized clock and the sample number of carried data. All received data is arranged on a common time axis by the LabVIEW application according to the synchronization.

In wireless networks, there is a not insignificant possibility of packet loss. We try to minimize data loss through optical gates due to packet loss by implementing a data buffer. The device periodically sends a packet containing the last 10 state changes to the server, allowing data to be replaced from the lost packets. This minimizes the probability of losing the temporal and spatial information.

Control application

The control application is implemented in the LabVIEW environment. It is used to record and analyze sensor signals and data, control and monitor the system, execute synchronization and the data transfer protocol. This means that the system operator uses the application to synchronize the sensor devices and starts the measurement. After the data is received from the sensors, it is decoded and stored according to the synchronization time. The control application can also include real-time visual monitoring specific to the sport or use this data to activate a biofeedback system. But the implementation of visualization and biofeedback is beyond the scope of this paper.

IV. TESTING AND EVALUATION

The proposed system uses non-standard equipment and protocols, which means that they had to be evaluated in real measurements before they could be used. There are several variables, several devices, all of which are interconnected to create a system that is simple and complex as a whole. We evaluated the hardware operation of the optical gate sensor and tested the operation of the synchronization and data transmission protocol.

A. *Evaluation of the optical gate operation*

For the implemented optical gate we used off-the-shelf components as described in Section III.C This made it easy for us not only to build the optical gate, but also to consider only one datasheet when evaluating the optical sensor itself.

During the evaluation our main interest was the precision of the optical sensor. We came to the conclusion that in our case the precision corresponds to the internal sensor delays. Since we do not have any other optical equipment similar to the one we developed, we tested the sensor in a laboratory environment. We used reflectors of different sizes while using the smallest possible objects to trigger the sensor. The output of the sensor was connected to the oscilloscope. We found that the size of the object we could track was proportional to the size and shape of the reflector. Using tall but thin reflectors, we were able to detect changes as small as the finger passing the sensor. We concluded that the precision of the optical gate is more than sufficient for the sensor system designed for agility testing.

B. *Evaluation of the synchronization protocol*

For the synchronization protocol test we assume that optical gates and kinematic sensor are black boxes. Since we use exactly the same hardware for each optical gate and the same microcontroller boards for all sensor devices (optical and kinematic), we can assume that the internal delays within these black box devices are the same.

For the evaluation of the synchronization protocol we are interested in the different delays between the sensor devices. We have developed a setup that uses two sensors side by side, both using the same reflector. This means that if the IR beam is interrupted, they are triggered simultaneously. The synchronization is then performed on all devices, but we only monitor the time difference between the two devices using the same reflector. When sensors are triggered, we monitor time stamps from microcontrollers. The measured internal synchronization delays are between 0.5 ms and 1 ms. We consider this a success because the possible synchronization difference between two devices is about 0.5 ms, which allows us to measure time with an accuracy of 1 ms, which is sufficient for our intended tests and for most sports applications involving time measurements.

V. CONCLUSION

Agility tests are used to train and evaluate athletes. As in any other profession, athletes have various options for agility assessment. The system we present is universal, as it can be used not only for agility tests, but also for some other tests in sports training and evaluation.

We use modern technologies to make agility tests more precise and objective and to provide new, previously inaccessible information about the movement and performance of the test. Our solution integrates existing technologies and provides trainers with valuable new information. For the optical sensor, we have reused a simple, low-cost sensor, thus reducing the cost and complexity of the system.

We conducted several tests with this system and confirmed that it meets the specified requirements. In this system we combined a wearable kinematic sensor with wireless optical gates that provide us with information that cannot be captured by either type of sensor alone. This system also provides us with a reference design that we can use in the future not only for creating new agility tests or other measurements, but also for sports biofeedback applications that require precise spatio-temporal information.

ACKNOWLEDGMENT

This work is sponsored by the Slovenian Research Agency within the research program ICT4QoL - Information and Communications Technologies for Quality of Life (research core funding No. P2-0246) and within the bilateral project between Slovenia and Serbia titled Sensor technologies as support systems for the detection and selection of talents in sport and monitoring the performance of athletes (research core funding No. BI-RS/20-21-023).

REFERENCE

[1] A. I. Cuesta-Vargas, A. Galán-Mercant, and J. M. Williams, ‘The use of inertial sensors system for human motion analysis’, *Phys. Ther. Rev.*, vol. 15, no. 6, pp. 462–473, Dec. 2010, doi: 10.1179/1743288X11Y.0000000006.

[2] J. M. Sheppard and W. B. Young, ‘Agility literature review: classifications, training and testing’, *J. Sports Sci.*, vol. 24, no. 9, pp. 919–932, Sep. 2006, doi: 10.1080/02640410500457109.

[3] T. J. Gabbett, J. N. Kelly, and J. M. Sheppard, ‘Speed, change of direction speed, and reactive agility of rugby league players’, *J. Strength Cond. Res.*, vol. 22, no. 1, pp. 174–181, Jan. 2008, doi: 10.1519/JSC.0b013e31815ef700.

[4] G. Sporis, I. Jukic, L. Milanovic, and V. Vucetic, ‘Reliability and Factorial Validity of Agility Tests for Soccer Players’, *J. Strength Cond. Res.*, vol. 24, no. 3, p. 679, Mar. 2010, doi: 10.1519/JSC.0b013e3181c4d324.

[5] K. Pauole, K. Madole, J. Garhammer, M. Lacourse, and R. Rozenek, ‘Reliability and Validity of the T-

Test as a Measure of Agility, Leg Power, and Leg Speed in College-Aged Men and Women', *J. Strength Cond. Res.*, vol. 14, no. 4, pp. 443–450, Nov. 2000, Accessed: Mar. 31, 2020. [Online]. Available: insights.ovid.com.

[6] P. F. Stewart, A. N. Turner, and S. C. Miller, 'Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests', *Scand. J. Med. Sci. Sports*, vol. 24, no. 3, pp. 500–506, Jun. 2014, doi: 10.1111/sms.12019.

[7] 'IS471F Datasheet(PDF) - Sharp Electrionic Components'. https://www.alldatasheet.com/datasheet-pdf/pdf/42903/SHARP/IS471F.html (accessed Mar. 31, 2020).

[8] A. Industries, 'Adafruit Feather M0 WiFi - ATSAMD21 + ATWINC1500'. https://www.adafruit.com/product/3010 (accessed Nov. 05, 2019).

[9] H. Zeng and Y. Zhao, 'Sensing Movement: Microsensors for Body Motion Measurement', *Sensors*, vol. 11, no. 1, pp. 638–660, Jan. 2011, doi: 10.3390/s110100638.

[10] C.-C. Yang and Y.-L. Hsu, 'A Review of Accelerometry-Based Wearable Motion Detectors for Physical Activity Monitoring', *Sensors*, vol. 10, no. 8, pp. 7772–7788, Aug. 2010, doi: 10.3390/s100807772.

[11] A. Kos and A. Umek, 'Wearable Sensor Devices for Prevention and Rehabilitation in Healthcare: Swimming Exercise With Real-Time Therapist Feedback', *IEEE Internet Things J.*, vol. 6, no. 2, pp. 1331–1341, Apr. 2019, doi: 10.1109/JIOT.2018.2850664.

[12] A. Kos, S. Tomažič, and A. Umek, 'Suitability of Smartphone Inertial Sensors for Real-Time Biofeedback Applications', *Sensors*, vol. 16, no. 3, p. 301, Mar. 2016, doi: 10.3390/s16030301.

[13] 'Pololu - MinIMU-9 v5 Gyro, Accelerometer, and Compass (LSM6DS33 and LIS3MDL Carrier)'. https://www.pololu.com/product/2738 (accessed Mar. 31, 2020).