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# Portable tracker for neurophysiological research of sport shooting

V. M. Antipov[a,b], A. A. Badarin[a,c], V. V. Grubov[a,c], V. B. Kazantsev[a,c,d], and A. E. Hramov[a,c,d]

[a]Neuroscience and Cognivite Technology Laboratory, Center for Technologies in Robotics and Mechatronics Components, Innopolis University, Universitetskaya Str. 1, Innopolis, 420500, Russia
[b]Laboratory of advanced methods for high-dimensional data analysis, Lobachevsky State University of Nizhni Novgorod, 23 Gagarin ave., Nizhny Novgorod 603950, Russia
[c]Center for Neurotechnology and Machine Learning, Immanuel Kant Baltic Federal University, A. Nevskogo ul., 14, Kaliningrad, 236016, Russia
[d]Neurotechnology Deparment, Lobachevsky State University of Nizhny Novgorod, 603022 Nizhny Novgorod, Russia

## ABSTRACT

In this work we present the development process of a wireless portable module. It is developed to record various characteristics during sport shooting, such as automatic detection of the moment of shot and barrel movement during aiming, taking into account the peculiarities of its use in neurophysiological research. We propose an approach allowing to synchronize devices in a wireless local network with high accuracy (synchronization accuracy was 2 ms), as well as a method of logging the recorded data at a sampling rate of up to 2 kHz on an onboard flash drive.

**Keywords:** neurophysiological research, personal training, shot detection, sport shooting, sensors, device synchronization

## 1. INTRODUCTION

The problem of individualization of the training process remains one of the most important and urgent tasks not only in top performance sports but also in the fitness industry. Solving this problem is impossible without monitoring and correcting the psychophysiological state of the athlete. Proper and effective training must include not only load but also adequate recovery – neglecting this principle will inevitably lead to a decrease in performance and possible health problems.

Note that one of the key factors in building an individual and effective training is the objective detection of fatigue. Since the activation of peripheral muscle fibers involves the transmission of signals from the central nervous system, it is necessary to distinguish not only physical fatigue but also mental fatigue. Mental fatigue can contribute to decreased ability of cognitive control, accompanied by less effective behavioral activity.[1–8] Another important and interrelated problem is the current lack of portable and non-restrictive systems for recording multimodal data during training. One possible solution to these problems is to conduct comprehensive research aimed both at developing methods adapted to the individual characteristics of athletes, based on the analysis of signals of different modalities, in particular, signals of brain activity,[9–15] muscle activity,[7,16–18] behavioral characteristics[16,19]) and at developing a multimodal monitoring system. Note that the role of neuroimaging in exercise and sport and the interaction between behavior and the brain has also been highlighted in.[20]

Further author information:
A.A. Badarin : E-mail: Badarin.A.A@mail.ru
V.M. Antipov : E-mail: vantipovm@gmail.com

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Such a comprehensive approach to solving the training process individualization problem should allow creating an optimal assistive multimodal athlete monitoring system, the application of which will lead to a significant increase in the effectiveness and safety of training.

Here it is important to note that when conducting and planning neurophysiological experiments, external factors should be taken into account and controlled.[21–25]This becomes especially relevant when conducting such studies during sports training, as they are accompanied by high physical activity.[16] Such activity creates a large number of different external factors, which, in particular, generate artifacts and noise in the experimental data. To solve these kinds of problems, additional devices are being developed to measure and control the influence of external factors in the experiment. Note that a key aspect in multimodal data recording is accurate synchronization between the different recording devices. It is necessary for a correct comparison and analysis of the data obtained as a result of the study.

In this paper, we consider air rifle shooting as a sporting activity. Sport shooting is a sport discipline in which competitors compete in accuracy of hitting targets with different types of weapons. For this sport, it is necessary to measure the movement of the weapon while aiming and shooting. One also requires an ability to accurately measure the precise moment of the shot. From an ergonomic point of view, the device must not interfere with a person's natural movements. Within the framework of this work, a wireless portable module was developed, taking into account the peculiarities of its use during neurophysiological research, which allows to measure the parameters of shooting and synchronize with various devices in a wireless local network.

## 2. MATERIALS AND METHODS

### 2.1 Principal scheme

To measure the necessary parameters of sport shooting, a wireless portable module has been developed to automatically detect the moment of shot and barrel movement during aiming. It allows to log data from sensors such as inertial measuring unit (IMU), Microphone and synchronize with other devices in the local network with an accuracy of up to 2 milliseconds.

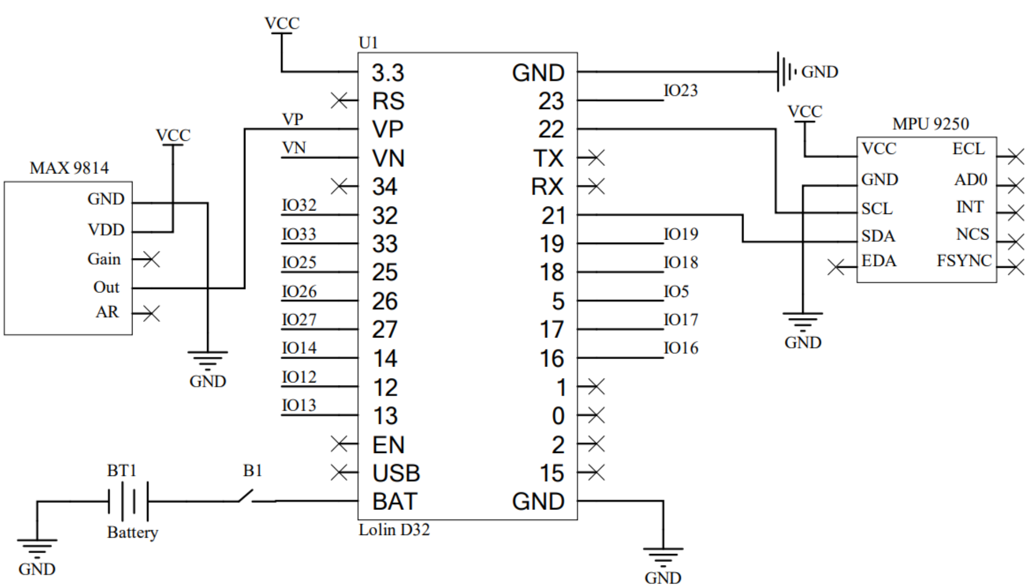


Figure 1. Schematic diagram of a portable measuring module for automatic detection of the firing moment and barrel movement during aiming. Here, MAX9814 - microphone module, MPU 9250 - inertial measuring unit, Lolin D32 - used platform based on esp32 microcontroller.

The device is based on microcontroller "Espressif esp32" with built-in Wi-Fi and Bluetooth modules. Main parameters of microcontroller are shown in table 1. This microcontroller is installed on the platform "Lolin D32 pro" which has: a built-in lithium-ion battery charging module, a USB-UART converter, a connected MicroSD connector, and also a stabilizer of the input supply voltage.

Table 1. Main characteristics of the esp32 microcontroller.

| | |
|---|---|
| Processor | Tensilica Xtensa LX6 |
| CPU bits | 32 bit. |
| Number of cores | 2 cores. |
| Frequency | 240 MHz. |
| SRAM | 520 Kb. |

A case for this module was designed and printed on a 3d printer. The case contains a 1500 mAh battery, a lolin d32 platform, an IMU module, and a microphone. The wiring diagram of the sensors is shown in Fig. 1. More details about the installed sensors are described in the Section 2.2. The module is mounted on the front of the sporting gun and secured with the integrated mount, see Fig. 2.


Figure 2. Example of module mounting.

Embedded software was developed for this module, consisting of the following modules: NTSClient - synchronization module, SDLogger - module to work with MicroSD flash drive, TCPClient - module for remote control of various aspects of the tracker, Settings - module to work with settings in the EEPROM memory via UART protocol.

## 2.2 Sensors

An inertial measurement unit (IMU) is used to measure the movement of the rifle during aiming. IMU unit is a module on which several chips are installed, such as gyroscope, accelerometer, magnetometer, temperature sensor, barometer (functionally). The module is built as a PCB board with convenient connection pins 2.45 mm. Usually, such modules have several interfaces for connection to an external microcontroller, e.g. I2C, SPI, UART, etc. The orientation of the coordinate axes of each chip is usually aligned, which facilitates data processing. The direction of these axes is usually shown on the silkscreen as arrows by the developers.

In this work we chose module mpu 9250, see Fig. 3a. This module was chosen due to its ease of use, high functionality, and accuracy. This module is powered from 3.3 to 5 V and can connect via I2C and SPI interfaces. The module also has low power consumption: gyroscope - 3.2 mA, accelerometer - 450 uA, magnetometer 280 uA, which is especially relevant when used in a wireless mobile device. For the connection the I2C interface was chosen, which uses only two pins: SCL (clock line), SDA (data line).

To measure the exact moment of the shot, a capsule microphone module with a built-in amplifier based on the MAX9814 chip was chosen, see Fig. 3b. This module allows amplifying the signal from the microphone up to an amplitude of 1.25 V. (output range 0 - 2.5 V) and has built-in noise reduction. The module also has a built-in AGC - automatic gain control, which equalizes the volume of soft and loud sounds. The supply voltage

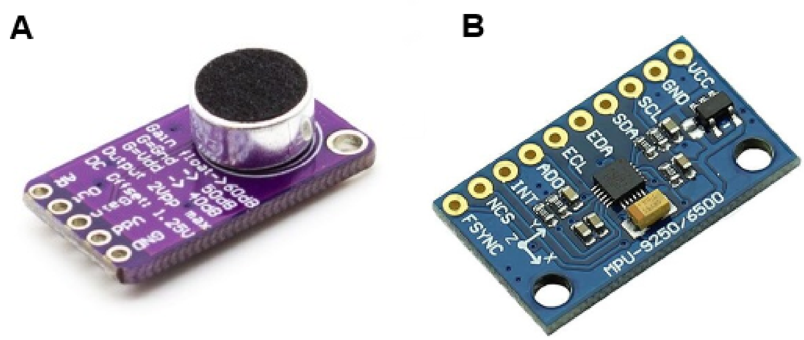


Figure 3. Sensors used in the portable tracker: a) - capsule microphone module with the built-in amplifier on the chip max9814, b) - inertial measurement unit based on the chip mpu 9250

of this module is 3 - 5 V. The gain range can be adjusted by connecting the Gain pin to different pins: GND - 50 dB, VCC - 40 dB, Noun - 60 dB. Also, the module allows adjusting the sound compression by connecting the AR pin: VCC - 1:2000 ms, GND - 1:500 ms, 1:4000 ms.

### 2.3 Synchronization

Any neurophysiological experiment requires precise synchronization of measuring equipment. The need for synchronization is related to the fact, that the clocking devices used in non-specialized equipment (quartz resonators) technologically cannot be identical to each other. This difference generates small deviations in the clocking on different devices, so, for example, when comparing the time on a personal computer relative to some reference point with the time on a microcontroller, after some time a significant error can be noticed.

There are many different synchronization technologies to solve such problems, the most popular is NTP. This technology allows synchronizing time in local networks with high accuracy. However, due to the complexity of the algorithm, the hardware requirement increases. Since the used microcontroller does not have large computational power, this technology can not be applied. This is because the measured data is written at a sampling rate of about 2 kHz, which takes about 80% of the CPU resources.

To solve this problem, a simple and efficient algorithm was developed and tested to synchronize the time of devices in the wireless LAN with an accuracy of up to 2 milliseconds. The algorithm is based on the use of UDP datagrams. This protocol was chosen because it has no arbitration as opposed to TCP. This saves the resources of the microcontroller for additional checks, thus the algorithm is often used in real-time systems. Each datagram has two 32-bit fields: the server time ($T_{server}$), and the datagram key. The datagram key is necessary to identify the correct response from the server since there is no message arbitration in UDP. After receiving the response from the server, the algorithm compares the sending time $T_{sp}$ and the receiving time $T_{rp}$.

$$\begin{cases} dt = T_{rp} - T_{sp} \\ dt <= 1 \text{ (ms)} \end{cases} \tag{1}$$

If the condition 1 is not true, the algorithm creates a new datagram key and sends a second request. Then the operation is repeated with the interval set during initialization.

If the condition 1 is true, the new estimated server time $T_{ns}$ is calculated according to equation. (2).

$$T_{ns} = T_s + (T_{rp} - T_{mc}) \tag{2}$$

where $T_{mc}$ is the time of the microcontroller at the last successful synchronization, $T_s$ is the server time since the last synchronization. Since latency is not nondeterministic, the “time offset” $T_{os}$ is calculated if equation 3 is true.

$$T_{os} = T_{ns} - T_{server}, \text{ if } T_{ns} > T_{server} \tag{3}$$

where $T_{server}$ is the actual server time obtained within the datagram.

After successful synchronization, the current time can be obtained from the equation (4).

$$\begin{cases} T_s, \text{ if } (T_{client} - T_s) < T_{os} \\ (T_{client} - T_{mc}) + T_s, \text{ else} \end{cases} \tag{4}$$

where $T_{client}$ is the current time of the microcontroller in milliseconds. This algorithm significantly offloads the microcontroller chip and RAM, allowing a more efficient allocation of computing resources.

## 3. RESULTS

We conducted a series of experiments in which we shot at targets with a sporting rifle with the developed module for automatic detection of the moment of shot and barrel movement during aiming. In particular, Fig. 4 shows the signal recorded by the capsule microphone module during firing.

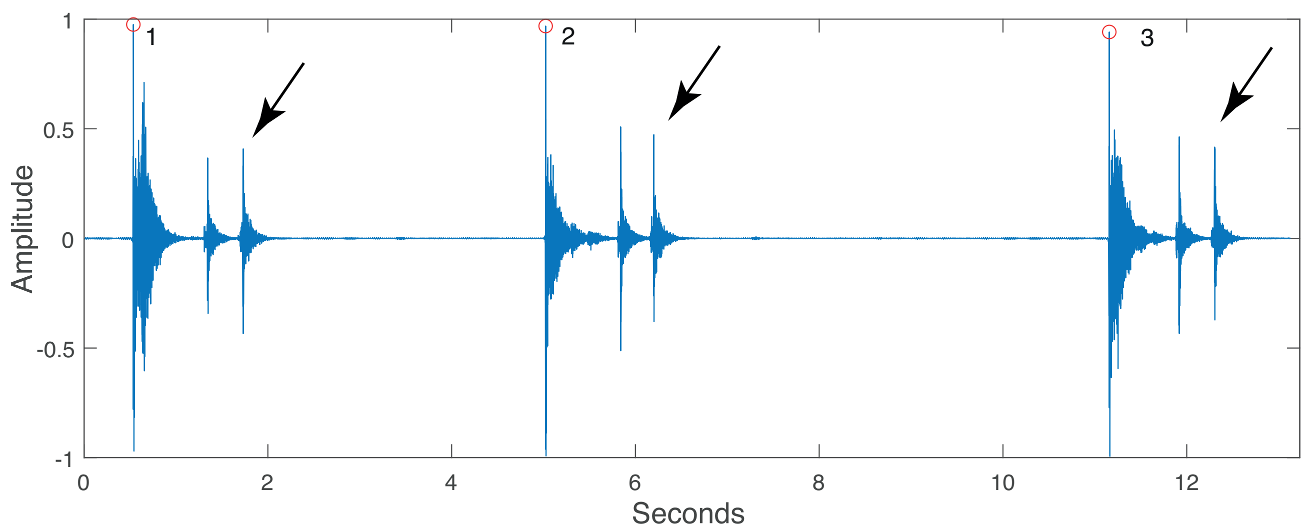


Figure 4. The signal, recorded by the capsule microphone module, for three shots. Numbers and red circles indicate the moments of the shot threshold trigger. The arrows indicate the fragments of the signal corresponding to the bolt movement of the sporting rifle during reloading.

It can be seen that the beginning of the shot is accompanied by a sharp increase in the amplitude of the signal. Therefore, to detect the shot, we used a threshold trigger, which is triggered when the signal amplitude exceeds a certain threshold value. In Fig. 4 the red circles indicate the moments of triggering of the threshold trigger, and the arrows indicate the fragments of the signal corresponding to the movement of the sporting rifle bolt during reloading.

In table 2, N (dt > 10) is the number of recorded shot moments with an error greater than 10 ms; $dt_{max}$ is the maximum error. Here, the graph Single synchronization corresponds to a single synchronization of the devices at the beginning of the experiment; Wireless Trigger - transmission of information about the moment of the shot over the wireless network immediately after its detection; Our approach to synchronization - the proposed method of synchronization described in Section 2.3; From table 2 it can be seen that the proposed approach provides high synchronization accuracy and thus can be used in neurophysiological experiments.

Table 2. Results of time delay measurements for a series of 100 shots.

| | N (dt > 10) | $dt_{max}$ |
|---|---|---|
| Single synchronization | 83 | 150 |
| Wireless Trigger | 21 | 98 |
| Our approach to synchronization | 0 | 2 |

## CONCLUSION

Thus, in this report we present the development process of a wireless portable module. We have developed the special sensor for recording the various characteristics during sport shooting, such as automatic detection of the moment of shot and barrel movement during aiming, taking into account the peculiarities of its use in neurophysiological research. We propose an approach allowing to synchronize devices in a wireless local network with high accuracy (synchronization accuracy was 2 ms), as well as a method of logging the recorded data at a sampling rate of up to 2 kHz on an on-board flash drive.

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