Augmented Real-time Biofeedback Application for Precision Shooting Practice Support

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Abstract—Training at shooting is one of the most important training courses in public or private structures, such as police, military, security companies and the like. Shooting is a discipline where accuracy is the most important. Technologically supported shooting training brings more benefits for trainees and organizations. Trainees spend less time on average for training, but the organization can save funds for shooting ranges, coaches and materials. We designed an application that measures the movement of the gun during aiming, firing, and post firing phases of shots. The acquired sensor signals are evaluated using recorded hits in the target. Measurements comprise 32 subjects of different ages and different shooting skills. The results indicate that the movement of the arms during the aiming phase is strongly related to the accuracy of the shooting. On the basis of the above results, applications with real-time feedback systems and trainers are being developed. A precise shooting practice that includes real-time biofeedback applications or a trainer will lead to accelerated learning, reducing the number of poorly executed shots, and consequently saving time, resources, and money.

Keywords—wireless sensor, augmented biofeedback system, real-time application, precision shooting practice, coach support system

I. INTRODUCTION

In recent years, sensor technology has made remarkable progress. Many new sensors or sensor devices were invented and developed; many of them have also become miniature, lightweight and inexpensive [1]-[2]. The most numerous are sensors based on microelectromechanical systems (MEMS). They found numerous applications in various fields of human activity. For example, in mobile applications running on smartphones, different sensors are already used; from simple tracking applications for recreational sports, where their quality is often not so important, to complex applications for the detection of the human condition in e-health systems, where the correct human state detection and perception is of the outmost importance [3]-[4].

Sensors provide measurements of various physical and physiological quantities of humans such as acceleration, rotation, speed, heart rate, and temperature. Those measurements are in most cases accurate and precise enough for their intended use and more often than not much more frequent, detailed, and minute as observations made by the human observer (trainer, instructor, coach, etc.).

A. Motivation

Our motivation is several-fold; the two primary objectives of our augmented biofeedback application are accelerated learning and higher quality training of the precise shooting with the pistol. Success in any or even in both of the abovementioned objectives leads to shorter learning or training time. This may result in lower number of used bullets, shorter time for renting the shooting range, better shooting precision, and probably also in some other material or non-material benefits. For example, in professional police force training, where shooting practice is essential, such sensor system with real-time biofeedback application could prove very valuable to save resources and valuable time of all the involved parties.

B. Research questions

We were interested in a research question about the usefulness of sensor systems and applications in precise shooting. Although knowledge of firearms can be considered as one of the most important factors contributing to the overall security and effectiveness of law enforcement personnel, previous surveys clearly show that police officers have limited marksmanship skills [5]. This is therefore a key point of interest of a professional (and scientific) community that recognizes the need to develop and use the most effective training methods and equipment for its development. In connection with the above, we have designed an advanced sensor system and software to support accurate shooting practice.

II. METHODOLOGY

We have designed and implemented a biofeedback application that operates in two different scenarios; concurrent (real-time) feedback and terminal (coach) feedback [6]-[7]. In the real-time biofeedback scenario, represented by solid arrows in Fig. 1, the application follows the actions of shooters and warns them about any unwanted or excessive pistol movement that could cause a poor shot result or even a target miss. The same application can also present complete shooting results to the coach, i.e. sensor signals, parameters, statistics, and others. The coach gives terminal feedback (advice) to the shooter. This scenario is represented by dashed arrows in Fig. 1.
The application measures pistol movements during aiming, firing, and post firing phases of each shot. Each fired shot is recorded according to the standardized shooting target; the shot result in numeric values from 0 (miss) to 11 (inner most target centre), see Fig. 2(c). The acquired sensor signals are evaluated through recorded target hit results.

We tested the application by performing real-world precision shooting measurements that were carried on in the spring of 2018. Shooting was carried out in the shooting range under the standardized conditions. The shooting distance was 6 m with the standard pistol shooting position using both hands to support the pistol during all phases of each shoot, regardless of the individual shooting stance preference, see Fig. 2(a). The aiming time was not limited. All subjects used the pistol model CZ99 for shooting in the standardized target shown in Fig. 2(c). The orientation of the sensor coordinate system is set as shown in Fig. 2(b).

All shootings were realized according to the ISSF (International Shooting Sport Federation) firearms use regulations. The results of all shootings and individual shots as well as all sensor signals were recorded with the developed application.

III. RESULTS

The application measures pistol movements during aiming, firing, and post firing phases of each shot. The first results are based on 32 subjects of different ages and different shooting skill levels that performed 70 shooting episodes. Each episode included 5 shots, yielding 350 shots being fired in total.

An example of recorded accelerometer signals is shown in Fig. 3; for a better readability of the graph, only signals between samples 500 and 850 are plotted. Signals shown in Fig. 3 represent the absolute value of the acceleration of the pistol in all three dimensions. The application records four seconds of sensor signals for each fired shot; given the sampling frequency of 250 Hz, that amounts to 1000 samples. Each shot is divided into three parts: (a) the aiming phase before sample number 750, (b) the pistol firing moment at sample number 750, and (c) the recoil phase after the sample number 750. In the aiming phase slight movements of the pistol can be noticed and an abrupt change in the pistol acceleration is evident at the firing moment, see Fig. 3. The pistol firing moment is detected by a threshold trigger that calculates the difference between two consecutive accelerometer samples and sets that moment at sample number 750.
Results for gyroscope signals are presented in Fig. 4; the horizontal axis represents achieved shot results and the vertical axis represents the standard deviation of angular velocity given in deg/s. It can be noticed that the highest variability of rotations is expressed around the X-axis and the lowest around the Z-axis. It is also evident that the curves presented in Fig. 4 express the negative trend towards the higher shooting results. A linear and power regression line is drawn against each axis angular velocity plot and shown as a dashed line of the same color.

IV. BIOFEEDBACK OPTIONS

The results presented in the previous section clearly indicate that the shooting result is related to the movement variability of the hands during the aiming phase. More specifically, the shooting result is inversely proportional to the standard deviation of hand accelerations and rotations. In other words, less hand movement and/or rotation, the better result is achieved. These results offer us more options for implementing biomechanical biofeedback applications for precise shooting.

The Sensor System for Shooting Evaluation application [8] was developed to upgrade from the basic measurement and analysis tool to the real-time biofeedback application for precise shooting learning and training. A new version of the SSSE application will be able to obtain and analyze sensor signals in real time. Based on the results of the analysis, the shooter will receive concurrent feedback. For example, when the application detects an excessive movement of a hand in a given predetermined time period, an acoustic or visual signal is given to the shooter indicating the suggested interruption of the current aiming phase. The shooter starts over after a short rest period.

It is expected that such applications of real-time biofeedback will have many advantages in precise learning and training. For example, in a learning scenario, the shooter will immediately be aware of the situations that lead to adverse results (a low score), which will most likely lead to a shorter learning time. In the training scenario, experienced shooters can get valuable information about the degree of their concentration or fatigue. Thresholds for different scenarios will be set to different levels and various variables can be used. The
settings and fine tuning of these parameters is the subject of future research and experimentation.

An interesting research topic in precise shooting is the influence of the grip strength and overall physical fitness on the result of shooting. Among firearms trainers there is a broadly accepted belief grip strength influences marksmanship due to better stabilization of the weapon while depressing the trigger, better recoil absorption [9], and the fact that the handgrip strength is in a positive relation to other relevant muscle groups and overall body strength [10]-[14]. Such studies are important for biofeedback application developers, especially for the proper and proper interpretation of signals and the setting of biofeedback system parameters.

V. DISCUSSION

Gained results clearly indicate that the shooting result is correlated to the variability in hand movement during the aiming phase. More precisely, it is inversely proportional to the variability of hand accelerations and rotations; the less the hand is moving and/or rotating, the better result is achieved. Results for the variability of gyroscope signals, expressed by standard deviation measure, are shown in Fig. 4. It is clearly visible that larger variability produces lower shooting result.

Results shown in Fig. 4 are, as mentioned, results acquired from the initial set of measurements. The achieved result frequency is shown in Fig. 5. As it can be noticed, the shot frequency for shot results below 5 is low. Consequently, the statistics for the shot results below 5 in Fig. 4 is less relevant, which is expressed in the oscillating plots. More shooting data will have to be acquired to get results of higher quality.

![Figure 5. Shot frequency for all possible shot results; 435 shots are included into the statistics.](image)

VI. CONCLUSION

The first results obtained with the presented application indicate that the designed sensor system is suitable for use in real-time biofeedback applications. Movement variability, calculated as the standard deviation of the sensor signals during the aiming phase, expresses a good correlation with the result of the shooting.

But there is still a lot of work to be done. The first step is to acquire a larger set of data that includes many more subjects and many more shots being measured and recorded. These data will be the basis for more reliable analyzes, which, hopefully, will bring additional parameters suitable for inclusion in the biofeedback application. The next step we are planning is also the use of machine learning techniques to extract additional features and identify the most influential ones. We are convinced that the real-time biofeedback system will be useful for accelerated learning of precise shootings for beginners and a useful tool for experienced shooters.

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