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Identification of Hand Tremor Levels in Shooting Activities Under Different Shooting Positions Using a Low-Cost and Portable System

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ABSTRACT

The accuracy level is important in shooting activities and depends on many factors, such as hand tremors as body vibration and shooting position. Achieving high accuracy in different shooters is challenging, especially in the case of different shooting positions. However, there is a lack of information about the influence of shooting positions and experiences on a shooter's body vibration and accuracy levels. Thus, this study aims to develop a portable and low-cost hand tremor measurement device (as a function of body vibration) to identify the influence of hand movement on shooting accuracy. For this purpose, low-cost accelerometer sensors and a microcontroller were used as the measurement kit. Three different shooting positions (squatting, standing, and prone) were analyzed. The shooters were classified into novice and expert groups. Each group had five participants with standard fire guns and accelerometer kits. These participants were asked to shoot the target to get their best accuracy. Besides, the hand tremor level data from the self-developed kit were recorded to investigate the hand tremors. The results show that the novice participants have more hand tremors in all shooting positions. There are significant differences between the squatting, standing, and prone positions in hand tremors for novice and expert participants. In the expert group, the prone and squatting positions have the least vibration level, indicated by the least acceleration (0.01 - 0.04 m/s^2 for the expert group and 0.02 - 0.11 m/s^2 for the novice group). The best accuracy for all positions is also obtained from expert shooters. It can be concluded that different shooting positions are related to the body vibrations. The expert shooters have a lower body vibration than the novice participants. The hand tremor levels may influence the accuracy level since different shooting positions and experiences have different vibration and accuracy levels.

Keywords: Accuracy; Hand tremor; Hand vibration; Shooting position

NOMENCLATURE

I2C : Inter-Integrated Circuit
CSV : Comma-Separated Value
BV : Body Vibration

1. INTRODUCTION

Static sports, such as shooting, rifle competition, or a simulation-based activity, are mainly conducted to obtain the best target acquisition process[1]. The best target acquisition indicates the performance of the shooting activity itself. Generally, three levels or stages influence the acquisition process: individual gross movements, fine-tuning portion, and the final position after pulling the trigger[2]. These stages are known as the aiming procedures. Individual gross movement is related to the shooter and the firearm positions according to the aiming point. In physical science, it is known as the magnitude and the velocity factors[3]. The second stage, the fine-tuning portion, becomes the critical aiming window identified from the movement's reduced magnitude and velocity. The third stage, the final position after pulling the trigger, represents the received effects of the recoil process consisting of sudden movements[4-5].

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The identification of the acquisition process result can be interpreted as an accuracy level[6]. As one of the shooting performances, the accuracy level is related to many parameters, such as a stable stage and a stable movement[7]. A stable stage and a stable movement reflect good stance, trigger control, breathing, grip position, experience, and even the shooter's emotions. A previous study indicates that unpleasant emotions influence shooting accuracy (up to 70%)[8]. The next factor, breathing, is a proper breathing technique (inhale, pause, and exhale) that may keep a stable muzzle condition while shooting. It means that the breathing stage alters the body movement and stance, which affects the shooting aim and shooting accuracy[9]. The next factor is the grip position, a condition about griping the firearm perfectly. This point is relatively different among persons. The grip position is also influenced by the fire gun type, for example, in a light or a heavy-based fire gun. A certain fire gun with a correct, specific, and comfortable grip position helps someone get proper trigger control and has a significant role in the shooting vibration[10]. The shooting vibration related to the body movement is known as BV (body vibration)[11–13]. BV can be classified into vertical and horizontal vibrations[14]. All these factors have important roles in shooting activities and are interrelated. These factors also occupy a very important position in the defense system, the army, or similar military bases.

Body movement while shooting can be explained by movement stability, aiming accuracy, and firing fluency. Thus, shooting movement stability influences accuracy and other shooting performance[15]. In line with this, there is a need to analyze the probable sources of body movements since body movement significantly influences the accuracy level. As reviewed in a previous study, postural stability and balance play significant roles in shooting activities[16]. Balance is related to postural stability and depends on the stimulation, sense, and situation[17].

Logically, there is a different body movement between novice and expert shooters. Qualitatively, it can be examined from a simple observation. However, it is important to identify the exact difference level between a novice and an expert shooter quantitatively. Theoretically, different body movements are obtained from different postural and balance levels. As explained in a previous study, professional shooters can control their balance by managing the muscle strength and posture stage. It is very different with a novice shooter[18]. Hence, an expert or a trained shooter will have a better shooting performance due to better and experienced body responses[19].

Interestingly, the factors that affect the shooting acquisition process are quantitatively examined in a laboratory scale instrument and indoor system (laboratory benchmarking). In contrast, its affecting factor of shooting accuracy should be studied carefully in real conditions, especially for an army (using a real fire gun). This is because of the different conditions between a real shooting emotion and a laboratory-scale experiment. Moreover, the use of a fire gun not only produces recoil but also the force, torque, and many parameters that reverse the shooter and influence the body vibration level. In line with this, the factors influencing the body vibrations should be investigated, such as shooting positions, stance, and ambient conditions.

1.1 Related Work

In terms of the stance and vibration, these factors are related to the body posture and shooter position. As a crucial factor, fixing the stance helps to get the proper and better grip position and to decrease the vibration while shooting (such as in hand tremor cases in most armies). Stance is one kind of shooting condition for the shooting sport. The body posture determines the firearm control and the vibration and ensures an accurate shooting result. The stance also depends on the shooting positions. Shooting objects or targets in prone, standing, squatting, and running positions needs different shooting stances since all these positions may generate different vibration frequencies[20]. Thus, these positions directly influence shooting accuracy since a stable stance allows the shooter to control the recoil and sight[21]. However, no specific and detailed information exists about the probable correlation between body vibration and shooting position. The previous background indicates that shooting accuracy is related to shooting errors. Many shooting errors (such as hand movement or body vibration) are obtained from different shooter experiences. That is why a real measurement regarding the body vibration, stage or postural position, and shooting position should be further analyzed.

There are many vibration meters or vibration measurement tools that can be used to measure or analyze the acceleration on a vibration source. They are used for identification, measurement, or vibration testing equipment. The biggest problem with a vibration meter is the size, dimension, and price. All of them are expensive and not portable. Moreover, there is no specific vibration meter for a shooting test that can be installed on a firegun.

1.2 Aim of the Study

There is an urgent requirement to identify the most probable error in shooting activities, such as body vibration and accuracy levels. However, there is no specific or detailed information and also a specific tool (portable) to identify body vibration levels more easily. There is also a lack of information about the correlation between a shooter's body vibration levels and accuracy. Thus, this study aims to develop a portable and low-cost hand tremor measurement device (as a function of body vibration level) to identify the influence of hand movement on shooting accuracy. For this purpose, the device was also tested by different shooting positions and shooter's experiences (novice and expert or trained shooters).

2. METHODOLOGY

2.1 Hardware Implementation

The study used a microcontroller (Arduino Nano board) and a minimum system for the data acquisition process. The sensors (ADXL345) were connected to a microcontroller using an I2C (inter-integrated circuit) data communication as the sensing elements of the hand movement levels. ADXL345 is a digital accelerometer (a low-cost sensor) with sensitivity levels of +/- 2g, +/- 4g, +/- 8g, and +/- 16g (1 g = 9.8 m/s^2). The main principle of this sensor is capacitance and a special micro-machined structure on a silicon wafer. This structure is suspended by polysilicon springs that can deflect in any direction and change the capacitance. The sensors were activated using a direct current voltage (5 Volt) in a parallel signal to obtain the mean hand acceleration levels (as a function of hand tremors) in three different positions (Fig. 1). All components were installed inside a device box. This box was then placed on the fire gun to measure the hand tremor levels and calibrated for the data acquisition[22–26]. The sensor data were recorded (Python-based software) in real-time conditions and stored as a CSV file (comma-separated value).

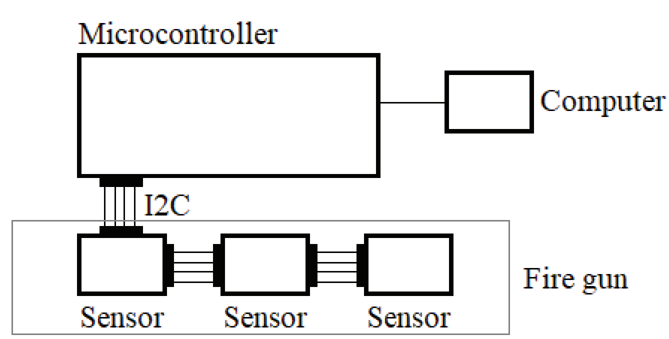


Figure 1. Schematic circuit of the hardware.

2.2 Participants

Tenarmies participated in this study as participants (n = 10). The participants were chosen using a random purposive sampling technique and divided into two categories: novice shooters (A, inexperienced shooters) and trained shooters (B, expert shooters). Group A consisted of five participants with common shooting performances (novice shooters, beginner level). Group B had five trained shooters (expert level). They were asked to shoot in three positions: standing, squatting, and prone. All shooting variations were repeated three times to get the best value.

2.3 Test Apparatus

This study used a standard assault rifle of the Indonesian armed forces for the shooting devices (SS2-V1 type, manufactured by PT. Pindad, Indonesia). This assault rifle has 4.16 kg of mass (gas-operated, rotating bolt). Each participant tried to aim for the best target to identify the accuracy level (three repetitions per person, using a laser for aiming and pointing) in three shooting positions (Fig. 2). The position variations were standing, squatting, and prone. All processes were conducted in a semi-indoor room to eliminate the influence of air velocity (0.1 m/s to 0.2 m/s) around the test location (room temperature = 24.5 °C to 25.5°C, humidity = 70.2-71.2%). All procedures were conducted without a real bullet to avoid recoil and other environmental parameters.

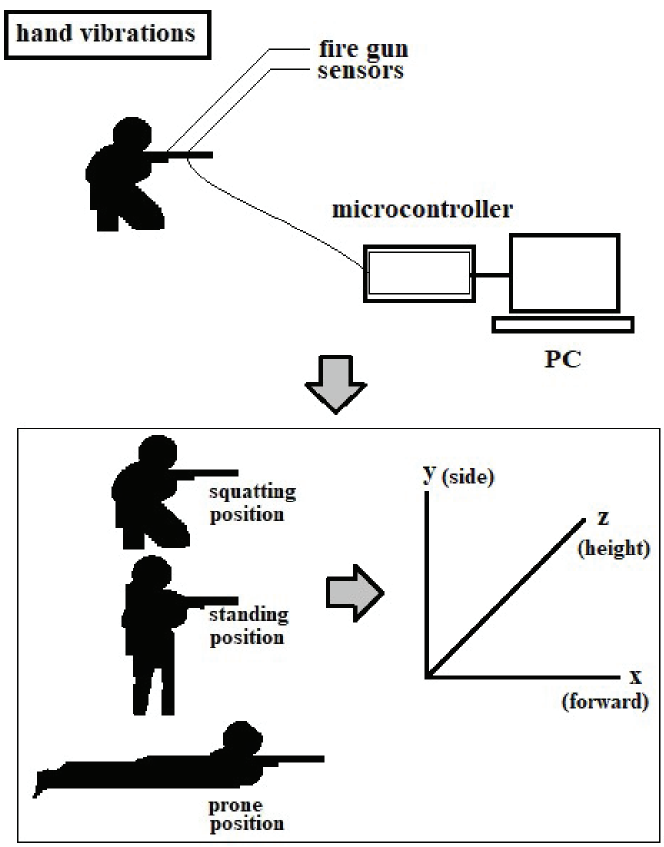


Figure 2. Hand tremor measurement using an accelerometer and the fire gun.

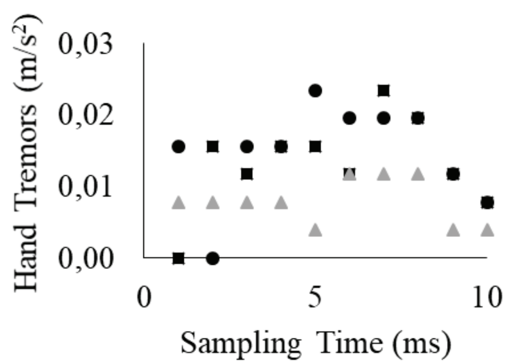
2.4 Statistical Analysis

The stored data were projected into a three-dimensional target for the analysis step. The resulting projection was determined using the vector calculation from all axis movements[27]. The Accuracy level was calculated by comparing the shooting scores in three repetitions. All data were interpreted as mean ± standard deviation from three repetitions. A Student's t-test was used to identify the differences between the two groups. A value of p< 0.05 was considered as statistically different[28].

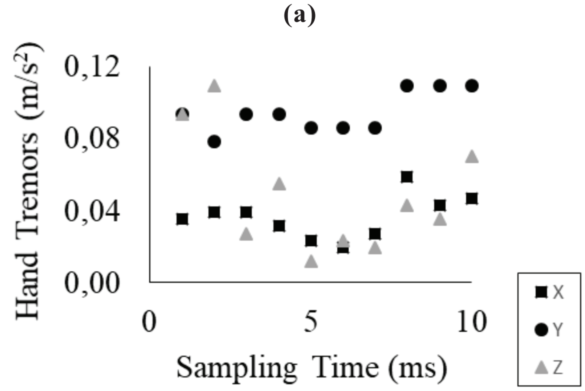
3. RESULTS

3.1 Prone Position

In these variations, the identification focuses on the hand vibration levels between two groups: trained and novice. The figure below interprets the results of the prone position measurement. This figure shows that all participants have similar results. As seen in Fig. 3a, the expert participants (n = 5) in the trained group have vibration changes of <0.03 m/s^2. The most change is measured from the y-axis (side acceleration). The vibration or tremor levels in this axis are 0.04453 m/s^2 to 0.06797 m/s^2. The calculated changes are 0 to 0.02 m/s^2. The x-axis (forward acceleration) shows the second position, with a vibration change of 0.01 m/s^2 to 0.02 m/s^2. The least difference can be seen in the z-axis (height acceleration). This axis has vibration levels of 0.07687 m/s^2 to 0.08468 m/s^2 (the change is only 0.01 m/s^2). These values are relatively more constant than the x-axis and y-axis. The hand vibration levels fluctuate for the novice group (n = 5). The highest change is obtained from the y-axis, resulting in 0.08 m/s^2 to 0.11 m/s^2. The measured vibrations are 0.11875 m/s^2 to 0.15 m/s^2. Interestingly, the z-axis also has a high vibration change (0.01 m/s^2 to 0.11 m/s^2).



(a)



(b)

Figure 3. The hand tremor or hand vibration levels measured at the prone position: (a) Expert participants; and (b) Novice participants.

As presented in Fig. 3(b), this measurement point has up to 0.10 m/s^2 of the vibration change, indicating a similar result as the *y*-axis. As expected, the *x*-axis does not reflect a significant movement since the hand tremor change is 0.02 m/s^2 to 0.06 m/s^2. The novice participants have more hand tremors than the expert participants. For all axis measurements, the trained participants have less vibration than the novice participants, indicating a more stable position while aiming and shooting. Moreover, the motions, or the hand vibrations, are highly measured on the *y*-axis. These results indicate that the hand vibrations are dominated by the side acceleration (right-left movements) for both stable and unstable psychological emotion conditions.

3.2 Standing Position

Figure 4 interprets the hand tremor levels for the second (standing) position. Theoretically, this position has more vibrations or hand tremor levels than the prone or squatting positions since standing while shooting needs a more stable stance. As seen in Fig. 4(a), the *x*-axis from the stable psychological emotion conditions has hand tremor changes of 0.01 – 0.04 m/s^2. These values are lower than the data from the prone position, confirming a lower vibration on the *x*-axis. The hand tremors are 0.04891 – 0.08406 m/s^2. On the *y*-axis, the changes are 0.01719 m/s^2 to 0.06406 m/s^2. Compared to the *x*-axis, the measurement point has a lesser shift. The changes are < 0.03 m/s^2. As expected, the *z*-axis representing the height hand tremor has the most vibration. The measurement point has a hand tremor change of 0.01 m/s^2 to 0.05 m/s^2. These values are even higher than the prone position data, which indicates that the standing position has more vibration than the prone position for the stable participant's conditions.

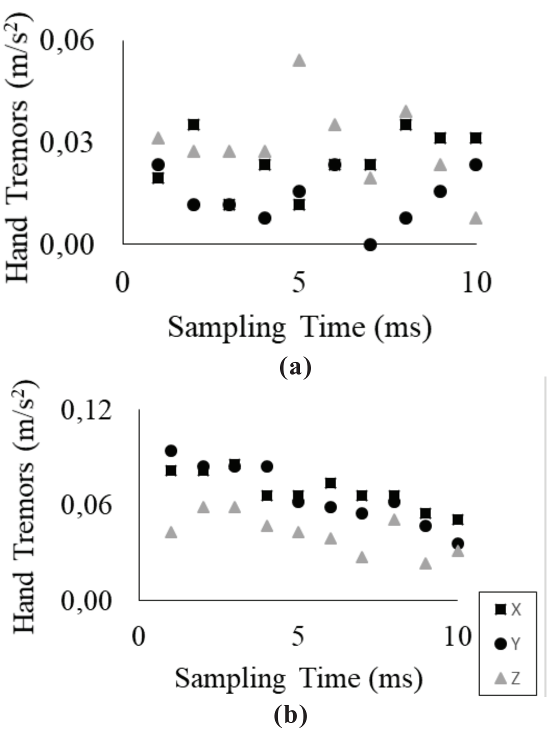


Figure 4. Hand tremor levels measured at the standing position: (a) Expert (b) Novice.

For the novice participants with unstable psychological and emotional conditions, Fig. 4(b(shows that the *x*-axis data has a maximum tremor level of 0.12312 m/s^2. The other two points have 0.12312 m/s^2 and 0.11593 m/s^2, respectively, for the *y*-axis and *z*-axis. The calculation data of the tremor changes for all points are 0.05 – 0.09 m/s^2 (*x*-axis), 0.04 – 0.09 m/s^2 (*y*-axis), and 0.02 – 0.06 m/s^2 (*z*-axis). These values show that the novice participants have the most vibration in the *x*-axis and *y*-axis for the standing position. These values are also higher than the trained group (0.01 – 0.05 m/s^2), confirming that the stable conditions have lesser hand tremors than the novice ones (in standing position).

3.3 Squatting Position

On the trained group in the last variation (squatting position, Fig. 5(a), the least tremor levels are measured and calculated on the *x*-axis and *y*-axis. Both of these positions only have < 0.03 m/s^2 of tremor changes. Compared to the other two positions above, squatting has little vibration. It is also confirmed by the z-axis data, where the vibration is measured in the range of 0 m/s^2 to 0.02 m/s^2. Fig. 5b shows the tremor change values of the squatting position for the novice participants. The *x*-axis data interpret the tremor changes are 0.04 m/s^2 to 0.09 m/s^2, which are the most changes or fluctuations among all shooting positions on the *x*-axis. On the *y*-axis, the resulting data are also the most changes among all shooting positions for the novice participants. The data from the *z*-axis show different results. This axis has no significant hand tremor changes (0.02 – 0.05 m/s^2).

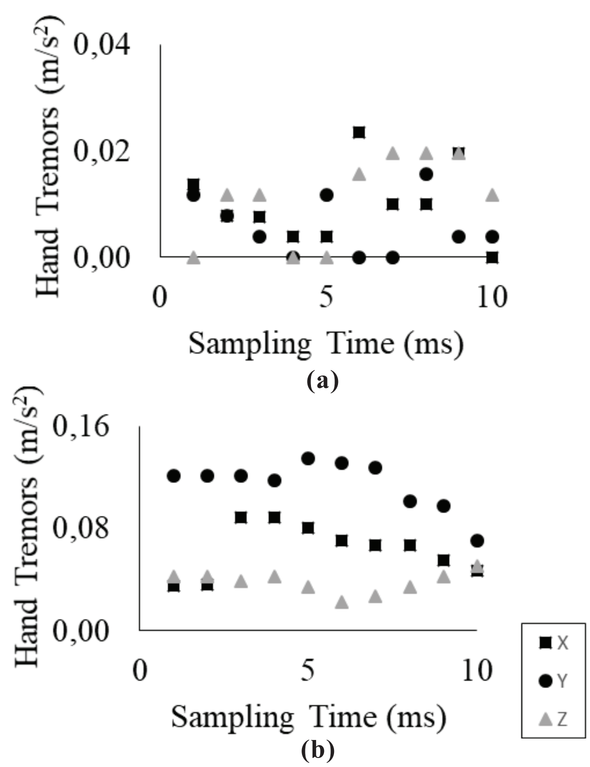


Figure 5. Hand tremor levels (squatting positions) of: (a) Expert (b) Novice.

3.4 Accuracy Levels

Table 1 shows the accuracy levels of all shooters from all shooting positions. This figure depicts the best accuracy obtained in Group B (up to 90 %). Group A has lesser accuracy levels at all shooting positions (74 % – 80 %). The trained participants have more focus on the center of the target. These participants were also calm and had lesser vibration than the novice group. Besides, the novice participants tend to leave the predetermined area, resulting in lower accuracy. The novice participants had higher movements, which indicated influential vibration in hand. In other words, the novice participants had random hand movements that were interpretedas hand tremors.

Table 1. Accuracy levels in all shooting positions

Positions	Accuracy Levels (%)	
	Novice (A)	Expert (B)
Squatting	74±10	90±7
Prone	75±9	93±7
Standing	80±7	94±5

4. DISCUSSION

All data show significant differences between squatting, standing, and prone shooting positions. It can be seen that the best option is the prone position. This shooting position has the lowest hand tremor level. Then, the data also show a difference between experienced and inexperienced shooters. As expected, the best performance with the least vibration is obtained from trained shooters. The best accuracy is also obtained at stable conditions (expert group).

Shooting sport is a precision activity that requires physical and mental skills and supporting infrastructures[29]. Moreover, the accuracy is also influenced by the shooter's brain responses[30]. The finding has proved that when novice shooters shoot to the center of the target to obtain the best accuracy, their tremors (body vibration) are higher than the expert participants. Especially in difficult shooting positions, the tremors increased while the accuracy decreased. Therefore, a question arises regarding the reason for the tremor increase under different shooting positions. In line with these previous studies, hand tremors might influence shooting accuracy since hand tremors can be classified into physical skill. Thus, the probable factor for these results is the riffle muzzle and hand positions. The data also show significant differences between squatting, prone, and standing positions. Moreover, shooting practice using a weapon (for example, a gun or a machine gun) is mainly related to the target acquisition process.The hull vibration is one of the dynamic processes of vibration that can be identified from displacement. This vibration includes linear and angular vibration, such as the influence mechanism of linear chassis vibration on firing accuracy in real vehicle experiments[31]. As previously studied, these vibrations include three aspects: (a) affecting the cross velocity of the projectile when out of the muzzle; (b) reducing the imaging quality of the aiming system; and (c) affecting the observation and aiming efficiency of the crew[32].

The vibration is also influenced by the body movement that generates noises, such as breathing. Another probable form of noise is the shooting technique used. Previous studies show significant performance deterioration occurs during stressful shooting moments involving psychological or physical stress[33], which might be also an important parameter in shooting performance. As an impact, many markers exist, such as rapid reaction, decreased accuracy and precision, and more false-positive decisions.

5. CONCLUSION

It can be concluded that different shooting positions are related to the hand tremor or hand vibration levels. The expert shooters have a lower vibration level than the novice participants. The hand tremor levels may influence the accuracy level since different shooting positions and physical-mental conditions have different hand vibration and accuracy levels.

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In the current study, he has carried out the formulation, instrumentation, and shooting procedures.

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