# Wireless Remote Shooting Training Controller with Multiple Targets Using Impact Vibration Analysis

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***Abstract*—This paper presents an advanced automatic firearm shooting control system for the military training ground. To detect the correct hit and bounded bullet or soils impact, the impact energy and impact signals are analyzed. The proposed two-level impact comparator and the resettable impact energy detector are used to classify the correct hit or un-correct hit from the crash vibration. The low level and high level comparator from the vibration sensor generate a different signal patterns according to the crashed materials to the target such as hit bullet, sand or scattered small stones. The signal patterns are compared to the correct hit pattern then, the determination of the hit is classified in the proposed system. The 3-groups 72 targets are wireless communicated to the main controller with group router using Zig-bee to reduce the installation cost and more expandability.**

**The designed automatic firearm shooting control system can detect the correct hit shot with the 99.7[%] accuracy in the test.**

***Index Terms*—Firearm shooting control, Impact signal analysis, Hit shot determination, Zig-bee wireless communication**

## I. INTRODUCTION

In recent, various combat capabilities monitoring systems are adopted to improve the shooting skill of soldiers. The personal assault rifle is the basic arm of the soldier. Various training systems are investigated to improve the shooting skill of the soldier [1-4]. And the Personal firepower can be reported by the firearm shooting system. For the accurate statistics of the firing skill of each soldier, an accurate hit shot monitoring system is required. In order to measure the fire shot skill, the automatically controlled training hit target which can move up and down with piezoelectric vibration sensor is used [5-7]. When the fired bullet is passed the target, a penetration impact vibration can produce the electrical vibration signal by the piezoelectric sensor. Then the MCU (Micro Control Unit) can determine the hit state of the bullet by the detection of the vibration signal[8-9]. A conventional hit detecting system which uses a vibration sensor just compares the sensor signal to the pre-fixed vibration level to determine the hit state of the bullet and target surface. This system is very simple and robust, but cannot determine the correct hit impact and the impact of the reflected bulled by the ground or scattered materials by the bullet such as crashed stones and soil. In order to monitor the correct hit of the bullet and un-correct crash impact, a complex signal analysis should be implemented in the MCU. To diagnose the practical vibration and impact signal analysis methods are used in the various field [10-14]. By the pre-signal processing, the impact source location can be estimated [10]. And the electric machines such as motor and turbine generator can be monitored by the vibration signal analysis [11, 13-14]. These signal analysis technologies can be used to characterize the vibration sources of the target surface.

In order to improve the decision accuracy of the correct hit or un-correct crash, an advanced shooting control system is presented in this paper. Various impact vibrations should be analyzed to classify the impact sources of the target surface.

The proposed system uses the three-axis vibration sensor to detect crash impact from the bullet passing and other impact vibration. As well known, the moving bullet is fast rotated in the air, and the vibration of the correct hit passing the target is generated to the two-axis with z-axis by the fast rotating. But, the other impacts make complex signal patterns. To analyze the vibration characteristics of the crash impact on the target surface, three-axis vibration signals are measured simultaneously. And the three-axis impact signals are separated as 3-parts which are high impact signals, low impact signals and integrated energy signal of impact. All signals are analyzed by the impact time, time intervals between the signals and impact patterns. Then the MCU compares the analyzed data to the standard patterns of the correct hit data. When the analyzed patterns are in the standard impact range, the impact is judged as the correct hit. From this data comparison, un-correct impact such as

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sand, soil and scattered broken stones by the reflected bullet on the ground has different signal patterns to the standard impact pattern of the correct hit shot. The accurate judgment can be done by these complex data comparison. Furthermore, the designed system has Zig-bee wireless communication to reduce the installation cost. The 72 targets are classified as three groups, and connected to the router with Zig-bee module to transfer command and state data to the main controller.

In order to verify the proposed system, the practical shooting test is done in the firearm shooting ground. In the practical test, the proposed system has over than the 99.7[%] accuracy to determine the correct hit shot.

## II. Shooting Training System

Fig. 1 and Fig. 2 show the hardware configurations of the designed automatic shooting control system and the configurations of the each target system. The 72 targets are classified as 3-groups which has same PAN (Personal Area Network) ID. And the main controller is connected to the 3-routers by RS-485 wire communication.

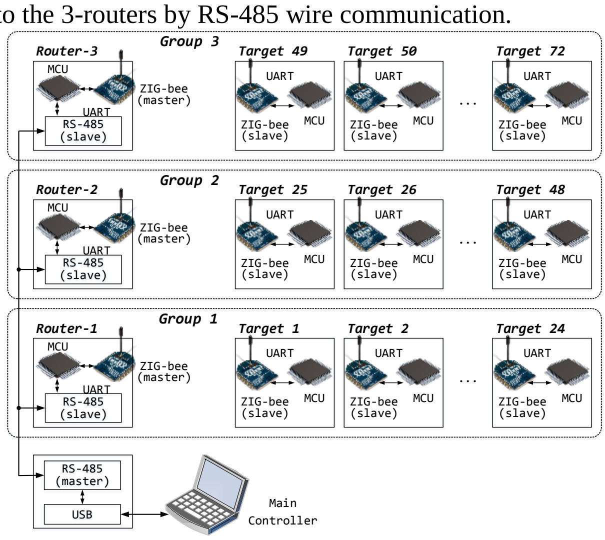



Figure 1. Hardware configurations of the designed system.

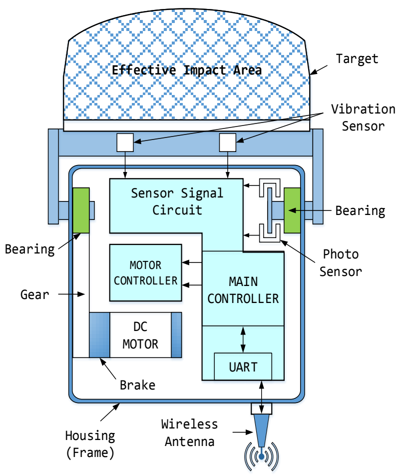



Figure 2. Hard-ware configurations of the target system

Each routers have two UART(Universal Asynchronous Receiver/Transmitter) channels to connect the main controller and wireless target devices. The Zig-Bee module is used as a wireless communication which has 2.4[GHz] frequency band. Each target system can receive the control commands such as up, down and state check from the main controller though the router. And the target sends hit and target state to the main controller through the router.

In order to protect wireless confusion between groups, each group devices have different channel with different PAN ID. Zig-bee module can select 12-channels which have different frequency in the 2.4[GHz] band. From the separated channel, the group1 signal is not confused to the group2 or group3 devices.

When the main controller sends control command and state check command to the router, the selected router transmits the received commend to the targets. Then the target analyzes the received command by the address matching method. If the received command is matched to the own address, the target follows the received command. In every 250[ms], selected group states can be monitored by the wireless communication.

Fig. 2 shows the hardware configurations of the target system. As shown in Fig. 2, two vibration sensors are attached to the back of target support. In the conventional system, only one piezoelectric sensor in the center is attached to detect the crash impact of the bullet. Due to the attenuation of the vibration transmission to the sensor, two sensors are symmetrically placed, and can detect the crash impact of the target by the passing bullet and other materials.

The vibration signals from the hit impact of the target are transferred to the sensor signal circuit and main controller of target system. The DC motor and motor controller can move the target up and down direction according to the communicated command through the wireless antenna. When the target is moved to the proper up position, the electrical brake can fix the target in the proper position. Similarly, the brake can fix in the down position from the photo sensor signal.

## III. The Proposed Vibration Analysis Method

Fig. 3 shows the basic configurations of the designed system. As shown in Fig. 3, the fired warhead of the bullet is flying to the target with fast rotation. In the training ground, the target system is placed under a trench. Only the target can be shown to the people when the target is up state. In the down state of the target, the target is hidden to the trench to protect the undesired breakdown from bullet.

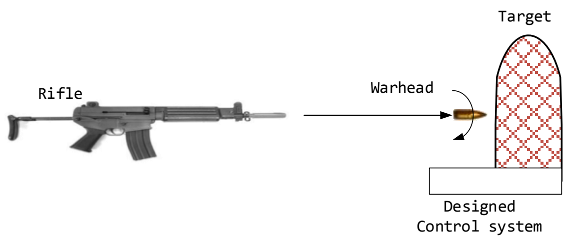



Figure 3. Rifle and warhead trajectory in the system

When the bullet passed through target correctly, the moving energy of the bullet is changed from the crash. Since the mass of bullet is not changed, the velocity of the bullet is changed, then, the changing energy is transferred to the target. Fig. 4 shows the various conditions of the target crash of the bullet in the practical system. In case ①, the correct hit bullet with mass $m_1$ and velocity $v_1$ is passed the target, then the mass of bullet is $m_2$ and the velocity is changed as $v_2$.

The hit impact energy $I_h$ of the bullet can be explained as follow.

$$I_h = m_1 v_1 - m_2 v_2 \quad (1)$$

$$I_h = F_h \cdot \Delta t \quad (2)$$

where, $m_x$ and $v_x$ are the mass and velocity of impact material. And the $F_h$ is the transferred force to the target by the impact energy. In the correct hit case, the impact energy is somewhat regular due to the fast rotating and unchanged mass of the passing bullet even if the environment temperature is changed.

However case ②, ③ and ④ shown in Fig. 4, are un-correct hit cases. In Fig. 4, case 2 shows the reflected bullet from the ground. And the case ③ and case ④ are the reflected scatter such as broken stone and sand or soil. Unlike the correct hit case ①, the hit impact energy is not regular due to the changing velocity by the ground reflection. Since the rotating velocity is not same as the correct hit case, and the blunt conflict is occurred at the target. Sand or soil crush in front of the target makes some impact energy, but the peak force is very lower than the correct hit case. Furthermore, the crush signal is not one due to the scatters. In case of gravel or broken stone, they make a high impact due to the blocking impact by the target.

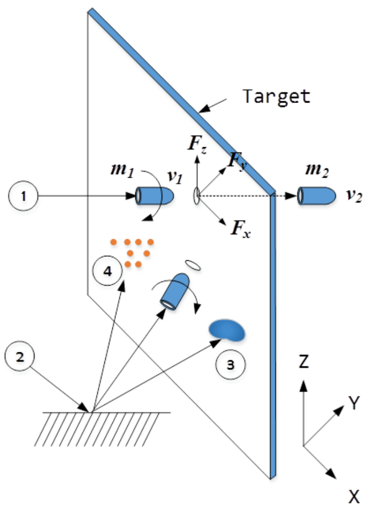



Figure 4. Hit condition of the practical target

The transferred vibration signals are very complex according to the crash materials and crashed point on the target. However, the designed system is used in the specialized condition such as training ground for the solider. And the system is installed with the standardized condition such as cement trench. So, the crash materials are limited such as soil, small stone and warhead of the bullet.

In order to determine the correct hit shot from the vibration sensor, two-level impact comparator and resettable impact energy integrator is proposed. Fig. 5 shows the proposed sensing signal conditioning circuit. The vibration sensor makes output impact signals in x, y and z-axis which are proportional to the impact energy. The output signals are passed through the designed BPF (Band Pass Filter) which has 200 to 2[kHz] frequency. The pass band frequency is designed by the target material and correct hit impact propagation characteristics. The passed signal is compared with two-level comparators.

The high level comparator is for detecting the correct hit state. The low level comparator is to detect the low impact state such as soil or sand by the bullet crush to the ground. In the correct hit case, the high level output $S_{SH}$ and low level output $S_{SL}$ can be high simultaneously. However, high level comparator may be shortly high or remains low state in the scatters impact such as sand or soil. In the proposed circuit, the comparing voltage $V_{SH}$ and $V_{SL}$ are fixed by the actual refile shooting tests.

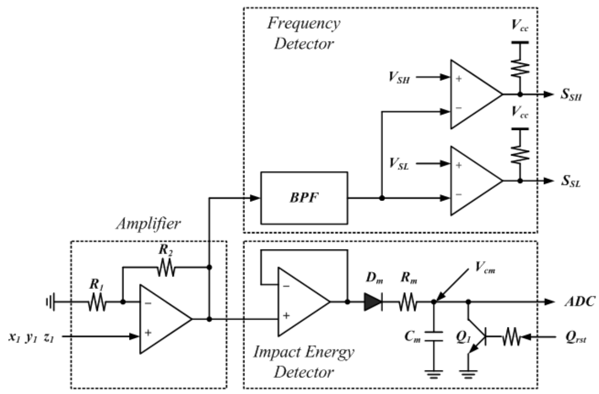



Figure 5. The proposed sensing signal conditioning circuit

The designed resettable integrator can be used to detect impact energy maintenance characteristics according to the impact pattern. We can know the signal variation characteristics by the detected voltage $V_{cm}$ in the integrator. The integrator is reset after hit condition determination by the transistor signal $Q_{rst}$ in Fig. 5.

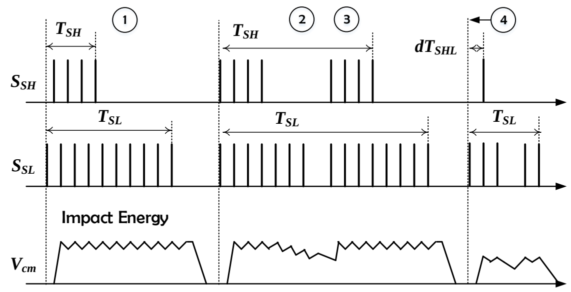



Figure 6. Signal patterns according to the impact cases

Fig. 6 shows the various signal patterns in the correct hit and un-correct hit case. The signal $S_{SH}$ and $S_{SL}$ denote the comparator output of the high level comparator and the low level comparator. And $V_{cm}$ is the voltage of the integrator. In the correct hit case ① shown in Fig. 6, the regular signal pattern of $S_{SH}$ and $S_{SL}$ can be obtained. The MCU(Micro-Computer Unit) can detect the maintenance time $T_{SH}$ and $T_{SL}$ with energy variation $V_{cm}$. Furthermore, the delay time of $S_{SH}$ and $S_{SL}$ to detect the other material impact after the first impact. When the reflected bullet by the ground or broken stone by the bullet is crushed to the target, $T_{SH}$ and $T_{SL}$ are much longer than the correct hit case. In the case ② and ③, twice impact are occurred in the target from scatters by the bullet crush to the ground. In case ④ shown in Fig. 6, sand or soil is crushed to the target. A short high level impact signal or low level signal is produced by the crushes of scatters. From these signal pattern and impact energy variation, we can determine the correct or un-correct hit shot in the automatic shooting control system.

Fig. 7 shows the signal detecting and hit state determination process of the proposed method. The start and end of the target operating are commanded by the wireless Zig-bee communication of the main controller shown in Fig. 1. When the target is up state, the two timers are operated. The one is to check the up state time of the target. When the time is over than the commanded up state, the target is moved to down direction. The second timer is started by the first hit signal after up-state. Then this timer records the hit states of x-axis, y-axis and z-axis. Simultaneously, the impact energies of each axis are recorded by the 10bit ADC module which is embedded to the micro-processor. After 200[ms] from the first hit signal, the proposed method compares all timer data and impact energy data with the memorized correct hit range. Then the result can be determined and saved to the memory.

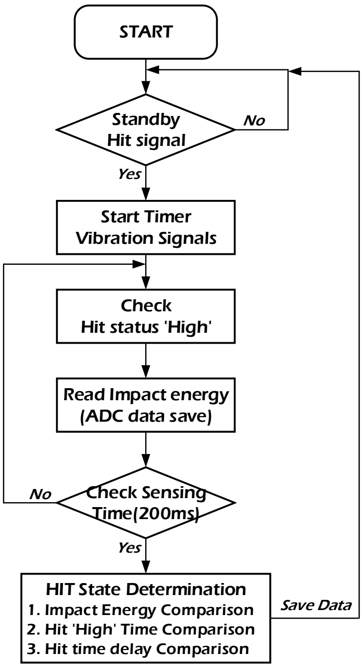



Figure 7. Flow chart of the proposed detecting method

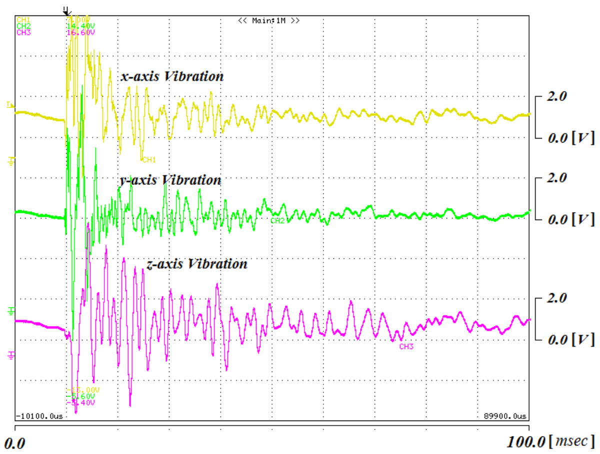
## IV. Experimental Results

In order to verify the proposed system, the practical experiments are implemented in the actual shooting range. The tested firearms are 5.56mm and 7.62mm NATO standard bullet are used to measure the real impact vibration. The target distances are 100, 200 and 250[M] are tested.

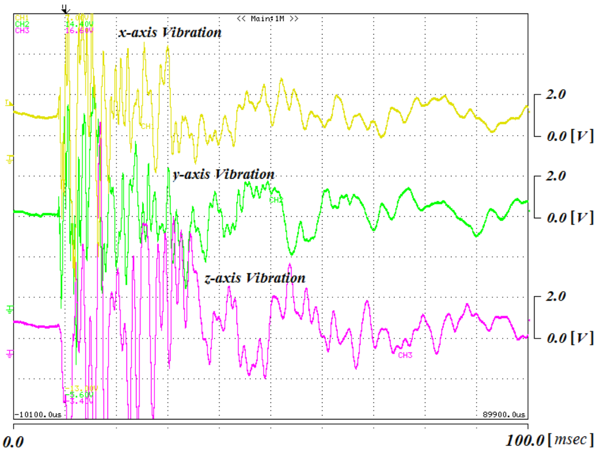
Fig. 8 shows the practical sensor output signals in x, y and z-axis in case of correct hit and un-correct hit case such as reflected bullet by the ground in front of target. As shown in Fig. 8(a), Fig. 8(b) and Fig. 8(c), the vibration waveforms are different according to the impact energy and crushed materials. Various correct hit data are acquired by the crushed points and environmental temperature. By these experiments, we can obtain the standard impact waveform at the correct hit case.

Fig. 9 shows the output signals of the proposed signal processing circuit in various cases. The output signals are the correct hit shot, reflected bullet and small scatters such as sand or soil respectively. In the Fig. 9, $V_{cm}$, $S_{SL}$ and $S_{SH}$ are the integrated impact energy, low level comparator and high level comparator output of the proposed circuit shown in Fig. 5. As shown in Fig. 9, the vibration signals have different intervals according to the impact cases. We can determine the correct hit case by the integrated impact energy $V_{cm}$ and signal durations of two-level comparator $T_{SH}$, $T_{SL}$ in x, y and z-axis.

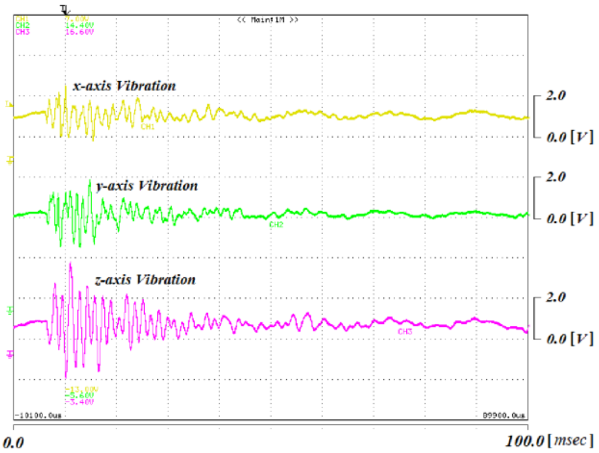
Fig. 10 shows the continuous fire-shot experiments. In every 200[ms], the MCU determine the hit shot or un-correct hit shot by the impact signal analysis. As shown in Fig. 10(a), the first hit impact is determined as correct hit shot. But the second hit impacts shows the twice hit during 200[ms]. This means un-correct hit case. In every 200[ms], the judgment signal shows the hit state. Fig. 10(b) shows the communicated signals between the target devices and router, main controller. As shown in Fig. 10(b), every 250[ms], the router can receive all states and scores of the 24 targets which are located same group shown in Fig. 1. And the received scores and states are transmitted to the main controller by the RS-485 wire communication method.




(a) Flow chart of the proposed detecting method

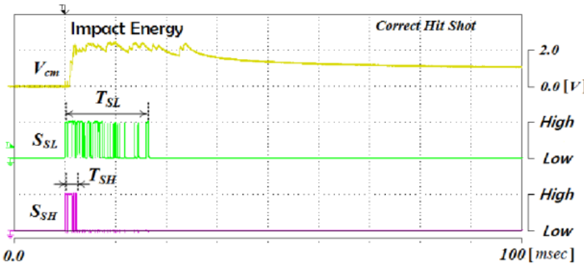



(b) Un-correct hit by reflected scatters

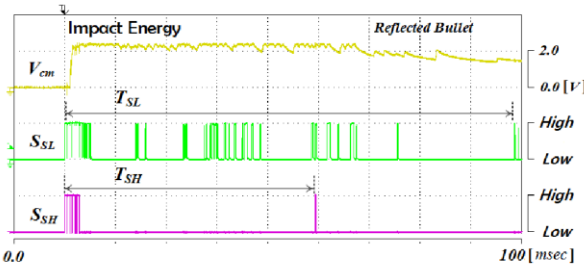



(c) Un-correct hit by sand, soil reflection

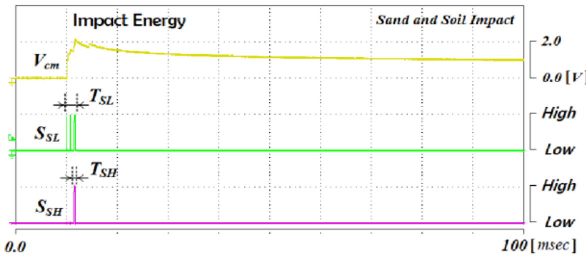
Figure 8. Actual vibration patterns according to the impact




(a) In the correct hit case

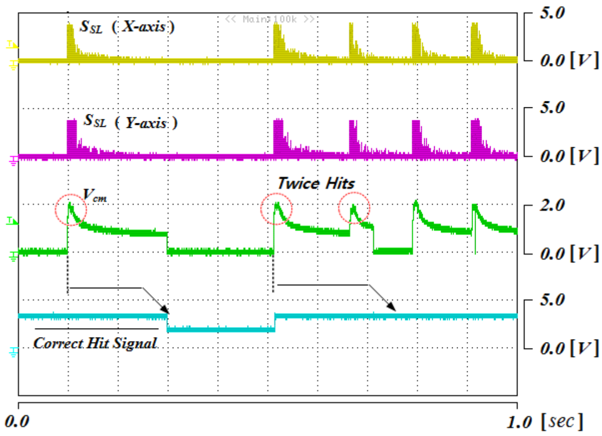



(b) In the un-correct crash by the scatters

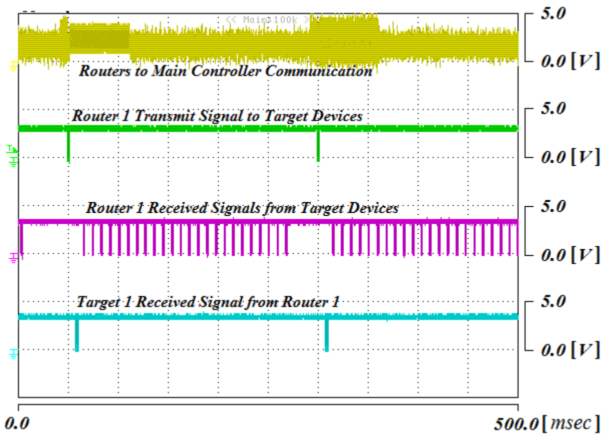



(c) In the un-correct crash by sand and soil

Figure 9. The output signals of the proposed circuit




(a) Correct hit determination by the impact signal




(b) Wire and wireless communications between router and targets

Figure 10. The hit determination and communication signals

In the practical experiments, the proposed method is verified that system has 99.7 [%] accuracy in the determination of the correct hit shot

## V. Conclusions

This paper presents an improved automatic shooting control system which can be used in the military training. For the easy installation of the system and maintenance of the system, Zig-bee wireless communication between the router and group targets is used. In order to improve the judgment accuracy of correct hit shot, the advanced signal processing circuit and judgment algorithm are proposed. The proposed method uses a two-level vibration signal comparator and integrated impact energy. According to the impact cases and materials, the vibration signals have different patterns. In the first impact signal, MCU detects the low level and high level signal durations with impact energy. Then the acquired data are compared with the standard memorized signal data to determine the correct hit shot. In order to satisfy the practical military training course, every impact signals are analyzed and judged in 200[ms].

In the practical experiments, the proposed system has 99.7[%] of accuracy in the correct judgment.

## ACKNOWLEDGMENTS

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