International Journal of Digital Information and Wireless Communications (IJDIWC) 4(4): 408-417
The Society of Digital Information and Wireless Communications, 2014 (ISSN: 2225-658X)

Wireless Sensor Network (WSN) based Automatic Firing Practice System (AFPS) for Training of Law Enforcement Agencies (LEAs)

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ABSTRACT

The critical importance of an efficient infantryman in special operations force, tactical paramilitary and Law Enforcement Agencies (LEAs) is insurmountable. One of the many vital aspects of an effective solider is excellent marksmanship which requires extensive training at sophisticated firing ranges. Modern firing ranges are supported by Automatic Firing Practice Systems (AFPS) and this paper presents the design and development of such a system based on WSN. AFPS provide an automatic bullet-impact count during firing training session and is modular scalable in design for multiple of eight concurrent shooters. The system is versatile and flexible allowing for different small-arms and firing training modes and supports night firing exercise. AFPS comprises of two major components, the automatic target-box and a commander console. Automatic target-box has a motor & gear assembly, target sheet, bullet-impact sensor, control board, and WiFi communication module. Commander console is a ruggedized sunlight readable 10.4” Tablet PC, which with a built-in WiFi acts an access point. The automatic target-boxes equipped with embedded WiFi modules form sensor nodes of a WSN. The paper presents the complete System Development Life Cycle (SDLC) of the firing practice system and associated WSN. The AFPS and bullet-impact sensor was extensively tested on Firing Ranges for accuracy of bullet-impact count. The results showed a bullet-impact count accuracy of over 97 percent.

KEYWORDS

WSN, WiFi, Bullet-impact Sensor, Commander Console, Firing Practice System

INTRODUCTION

The infantryman still plays a critical role in the outcome of battles in modern warfare especially with the advent of weapons of mass destruction (WMD) where wars between equally adversaries are high improbably. Proficiency in effective shooting and excellent marksmanship is one of the many vital characters of a well-disciplined and efficient solider. Instilling this character into new recruits require the need of dynamic shooting ranges for training of small-arms Law Enforcement Agencies (LEAs), paramilitary and military [1]. Firing practice systems used in developing countries are predominantly manual or semi-automatic systems [2]. These semi-automatic systems have inaccurate bullet-impact count and had to be manually and tediously counted by the on-duty staff. Automated shooting practice systems developed by leading defense companies are cost intensive and are beyond financial budgets estimate of most of LEAs in the developing world [3]. The proposed automatic firing practice system has been developed to achieve the following objectives:

- WSN based AFPS provides instant bullet impact count update for each target plate,
- Provisioning of different firing training & exercise modes,
- Comprehensive training scenarios for LEAs, Para-military and military organization,
- Firing results database (FRD) for data analysis and provision of trend and statistical analysis.

Commander Console acts as an access point (AP) while 24 Field Boxes (FBs) form WiFi sensor nodes for AFPS-WSN.

This paper presents the complete System Development Life Cycle (SDLC) of the Automated Firing Practice System (AFPS) from concept to development and manufacturing. The paper is divided into four parts, description of AFPS, development of Target box assembly, commander console (CCon) & WSN, and finally the on-site test results of AFPS.

DESCRIPTION OF AFPS

Automatic Firing Practice System (AFPS) provides recruits of LEAs with better training environment and achieves a higher degree of skill more rapidly. Since AFPS is reconfigurable to different shooting training module that can be incorporated via software from the CCon, AFPS has a robust structure that allows it to adapt to different terrains and environments. The architecture of AFPS is shown in Fig. 1.

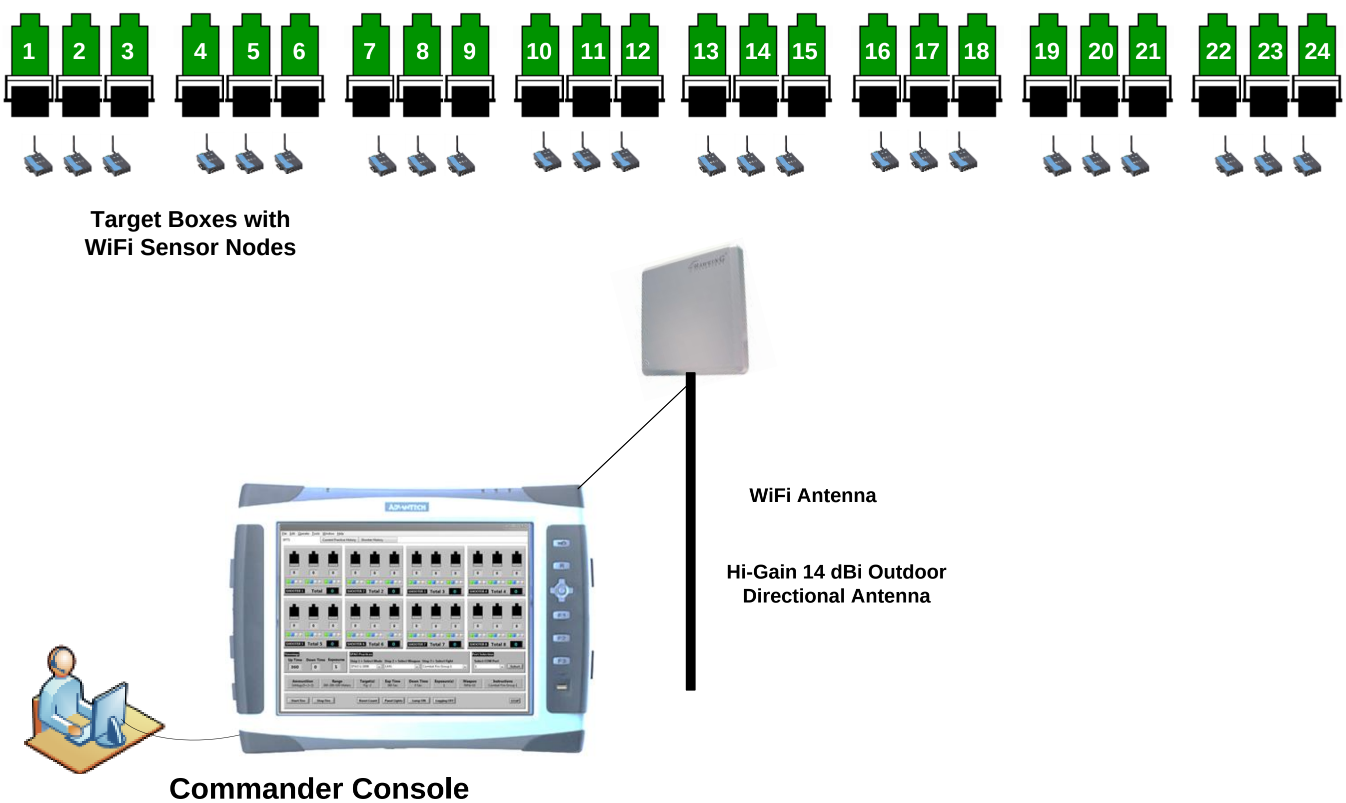

Figure 1: Architecture of AFPS

The main features of AFPS are accurate bullet-impact count, rejection of false-impact (a ricochet or stone), wireless connectivity and a ruggedized CCon. The main modules of AFPS are defined as:

1.1 Target Box Assembly

Target boxes were designed for a ruggedized deployment. Aluminum boxes were casted & machined to develop boxes that housed motor, gear assembly, target-sheet frame, counter-weights, limit switches and linkages. LED light was installed on the box for night firing mode capability. Target boxes were Powder Coated with automotive grade paint for all-weather operational requirements. The target boxes were made IP67 compliant [4].

1.2 Commander Console

Commander console for AFPS was designed based on a ruggedized 10.4” Tablet PC, with a WiFi Link to 24 Target box units to form a WSN. A WiFi local area network was established at the firing range, between CCon and target units within a range of 1000 meters with clear line-of-sight [5].

The target units connect to the commander and provide update on their current status. All the target units are synchronized to same starting position before firing practice.

DESIGN OF TARGET BOX ASSEMBLY

The Target box assembly comprised of a target-sheet & frame with bullet-impact sensor attached and a target-box housing motor gear assembly & a control board. The WiFi communication module is also placed inside is target-box.

1.3 Mechanical Designing of Target Box

The target plate and enclosure was designed and modeled using Pro-E, market leader CAD/CAM software [6]. The designs were evaluated and revised/updated recursively to meet the design criteria. Specialized gears were used that had 'heat-treated long-life' capability, having less wear and tear prolonging its service life for a specific duty cycle. Lithium grease was used to ensure smooth operation of gears [7]. The AFPS enclosure was properly sealed to ensure ruggedness. The final Pro-E design is shown in Fig. 2.

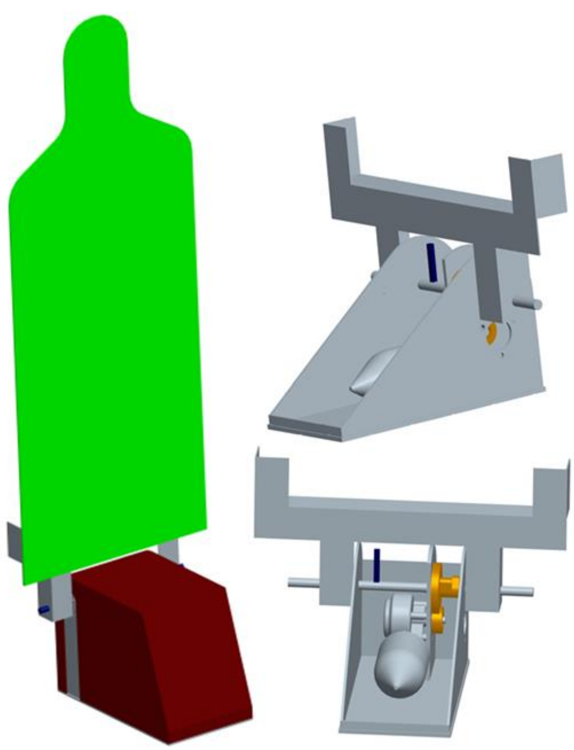

Figure 2: Automatic Target Box

1.4 Target Box Assembly

Target box assembly was designed & developed considering the harsh environmental deployments. AFPS is to be operated in open-air firing range under all weather conditions. The components selected or developed are:

- Bullet-Impact Sensor: The most critical module within the AFPS is the Bullet Impact Sensor (BIS), based on an piezoelectric Vibration Sensor PKS1-4A1 from OEM Murata was used in AFPS [8].
- DC Motor: +24V High Torque Motor was selected from a local source [9].
- Gear Assembly: Worm-gear assembly was designed to provide high torque [10].
- Switches & Connectors: Limit-switches were installed to provide motor over-shoot protection. Ruggedized mil specs circular connectors were selected for the WiFi Antenna & Power cable connections [11].
- LED Light: +12V LED light was installed to enable night firing mode operation of AFPS [12].
- Control Board: Piezoelectric Vibration Sensor (PVS) PKS1-4A1 from Murata was interfaced to a microcontroller AT89c2051 based control board [13]. BJTs & FETs based motor driver was designed to drive the DC motor [14]. Limit switches were interfaced to the microcontroller to provide safety for motor/target-sheet frame over-drive. The control board has its own SDLC which included developing the microcontroller firmware, design and fabrication of the PCB, procurement of Bill-of-Materials (BOMs), stuffing of the PCB, its quality assurance and finally its functionality testing.
- Target Sheet: Different materials of Target Sheet were assessed and tested for hardness and elasticity at firing ranges for endurance testing. The repairing methods were also evaluated for ease of maintenance and care. Fiber glass was finally selected as the material for target sheets, other advantages also include cost effectives and easy availability thought out Pakistan [15].

The finalized environmental tested and the final target box assembly is shown in Fig. 3.

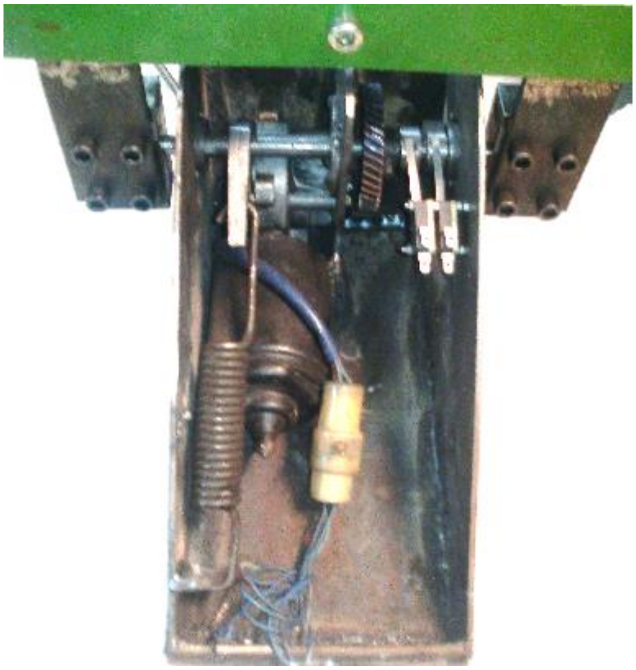

Figure 3: Target Box Assembly

Target box with mil specs circular connectors is shown in Fig. 4.

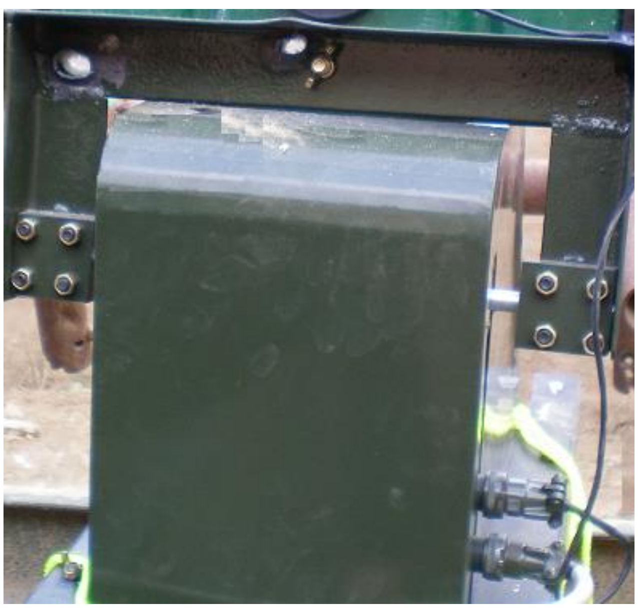

Figure 4: Circular Connectors for AFPS Target Box

1.5 Bullet-Impact Sensor

A special enclosure was designed for Piezoelectric Vibration Sensor (PVS) PKS1-4A1. The bottom of the target sheet where the PVS is located was covered with additional armor plate, to ensure the safety of the sensor. The sensor was placed longitudinal to axis of shock wave propagation. The placement of Bullet-Impact sensor is shown in Fig. 3.

Figure 5: Bullet-Impact Sensor Mechanical Placement

Target enclosure has a base-box and a target sheet. The shape used for Target Plate (TP) is a standard humanoid figure used commonly at Fire Ranges [16]. The height of the TP used for the AFPS is 42 inches and was developed using Fiber-Glass. The TP fitted with Piezoelectric Vibration Sensor PKS1-4A1 was then subjected to rigorous firings in order to record the bullet-impact responses.

Initial results were subjected to detailed statistical signal analysis and a subsequently an algorithm was developed in Matlab to distinguish between impact signals of the bullet-impact, other objects impact and bullet-ricochet signals [17]. The PVS interface circuit was revised for improvement and with the addition of with an installation of noise filter, and with an implementation of hardware and software de-bouncers, better results were achieved, thus PVS sensor was finalized for the AFPS project.

The sensor installed on the AFPS is Piezoelectric Vibration Sensor (PVS) and was extensively tested for various types of shocks and vibrations [18]. An amplifier circuit was designed for PVS to provide a suitable gain to its signal. PVS was attached to a target sheet and live rounds were used for testing. Amplified PVS signals were recorded on a digital oscilloscope for various ammunition types and provide calibration benchmarks, for e.g. an amplified bullet-impact response is shown in Fig. 6.

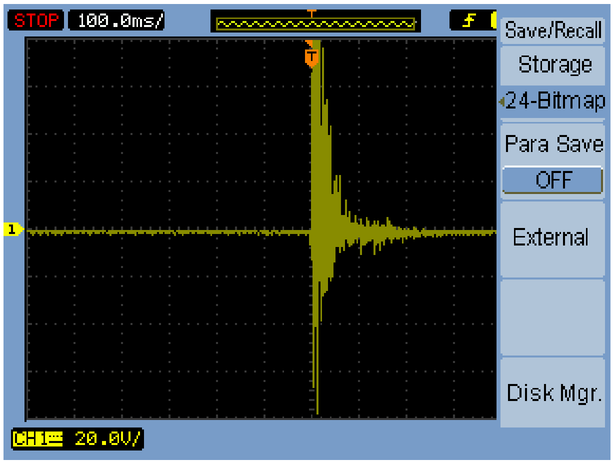

Figure 6: Amplified Response of Bullet-Impact Sensor

The finalized system was installed at 10 different places across Pakistan and bullet-impact results for 10,000 bullets were collected. The responses were of five different types of ammunitions, fired from a distance of 200 to 500 meters. The results were once again subjected to detailed statistical analysis and minor adjustments were made in the algorithm.

The bullet-impact detection algorithm was fine-tuned and was tested on the recorded 10, 000 bullet-impacts. The results of the Matlab bullet-impact sensing algorithm showed accuracy over of 97 percent.

1.6 Control Board

An 8051 microcontroller based control board was designed for AFPS. The control board had a Bullet Impact Sensor Interface, Motor Driver Circuit, and Light Control Circuits. The Proteus ISIS [19] design of Control Board is shown in Fig. 7.

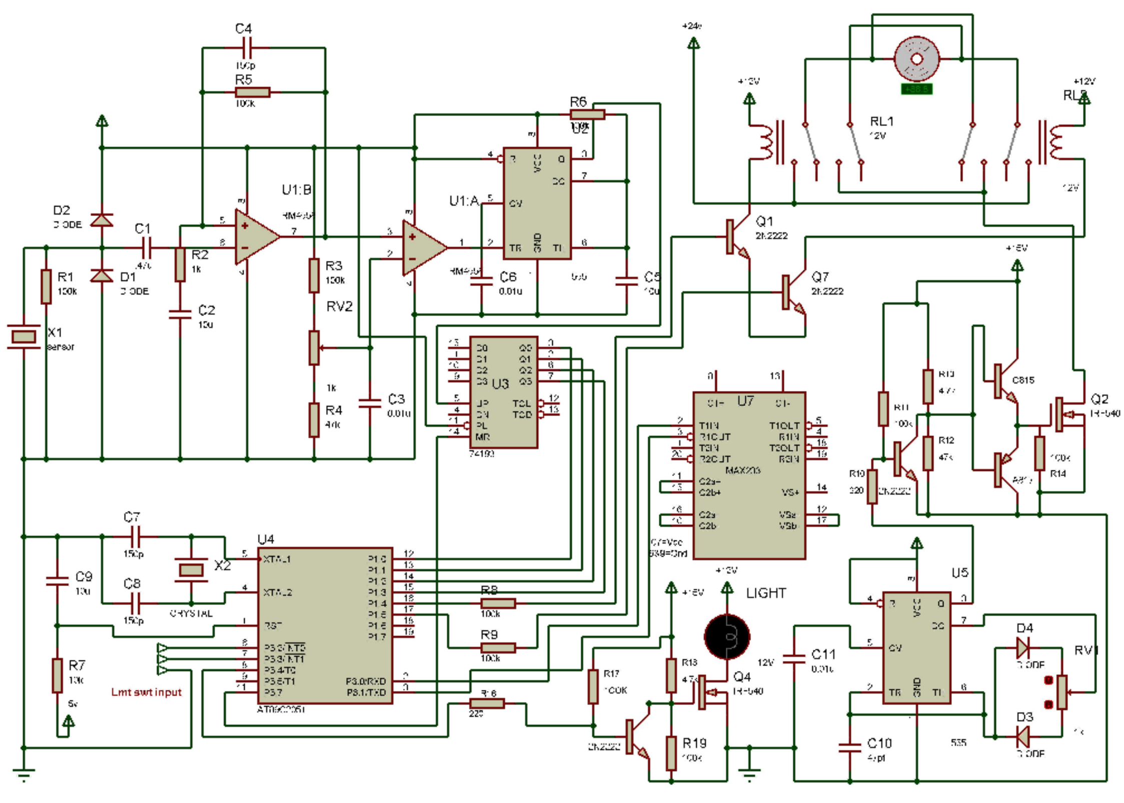

Figure 7: Control Board Circuit Design

The main parts of Control board circuit are:

- Bullet Impact Sensor Interface: Piezoelectric Vibration Sensor PKS1-4A1 was interfaced with the Control Board
- Bullet Impact Counter: Analog comparator based bullet-impact counter circuit was designed. The design of Bullet Impact Counter was revised over recursive design iterations.

- Motor Driver: IRF540 Power MOSFETs were used to drive the DC motor [20].
- Light Control: IRF540 Power MOSFET was used for LED light control.

1.7 WiFi Communication Module

Serial to WiFi module NPort W2150A by Moxa with WiFi antenna was used for Target side communication [21]. The W2150A effectively forms sensor node part of WSN. W2150A provides a RS232-to-WiFi interface enabling the Control Board microcontroller to CCon over WiFi shown in Fig. 8.

Figure 8: Moxa WiFi Communication Module

DESIGN OF COMMANDER CONSOLE

Ruggedized Tablet PC MARS-3100R from Advantech was used with sunlight readable LCD and back-up battery [22]. CCon Firmware was developed in Labview with Microsoft SQL Server database. Wireless capability is introduced with a WiFi Antenna attached to an Antenna-mast also acting as the Receiver Station [23]. Customized and proprietary communication Protocol for commander and target communication was designed & developed. The WSN formed with CCon & 24 Target units provides instant bullet-impact count and provides a dynamic deployment advantage to the AFPS.

1.8 Graphical User Interface of Commander Console

CCon software is primarily used for conducting firing practice and monitoring shooter score. The GUI is designed in Labview [24]. The software is equipped with a Microsoft SQL Database to provide the capability of detailed firing practices results storage and analysis. The layout of CCon GUI is shown in Fig. 9.

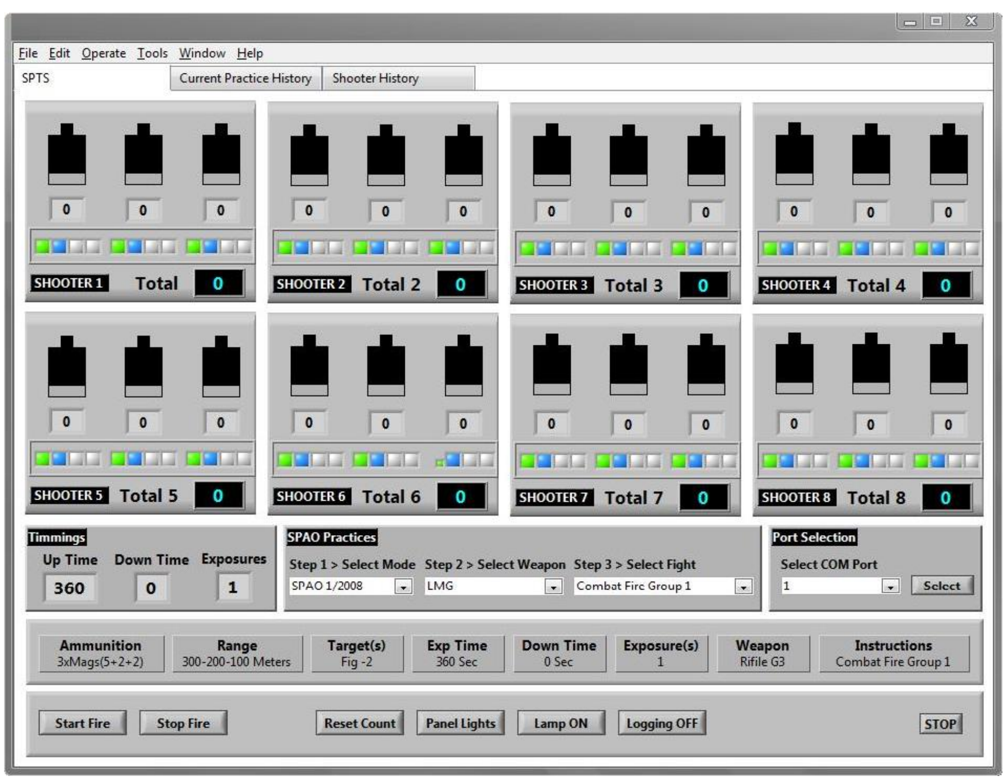

Figure 9: Commander Console Labview GUI

The main features of CCon software are:

- The software/GUI is divided into eight sub-areas. Each sub-area represents each target unit
- A bullet-impact is immediately reported to the CCon and shooter score is update on the GUI in real-time
- GUI shows individual score of each target plate
- AFPS' CCon supports night firing mode.

The CCon is 10.4" ruggedized tablet MARS-3100R by Advantech and provides portability to the commander. CCon has a supporting stand to place it on table with a USB keyboard and mouse for conventional Desktop like usage. The commander console is shown in Fig. 10.

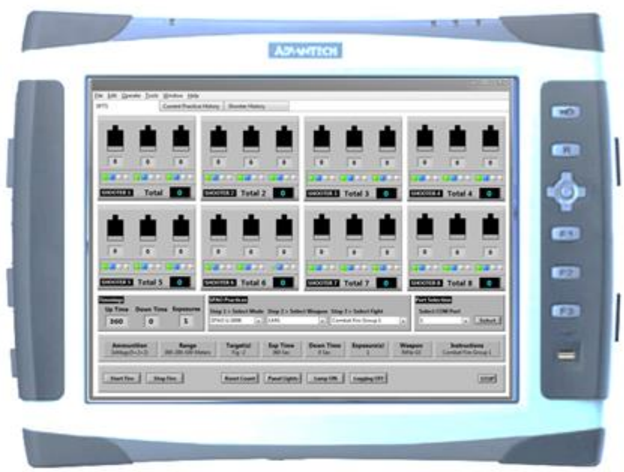

Figure 10: AFPS – Commander Console

1.9 WiFi Communication Protocol

AFPS WiFi Communication Protocol is defined as:

- Configuration: CCon assign IDs to address of targets a, b, c … w, for 24 Targets
- Get Target Status: Commander reads the status of Target
- Set Target Status: Commander sets the current status of Target to Up or Down with LED Light On or Off
- Get Bullet-Impact: Target immediately reports to Commander the Bullet Impact
- Bullet-Impact Acknowledgement: Commander's Acknowledgement of the reception of Bullet-Impact
- Hit Down Mode: Command to put Target in Hit Down Firing Practice Mode. Target will go down on every hit and will remain in such position until command for popup is issued
- Pop Up Mode: Command to put Target in Pop-up Firing Practice Mode. The target will go down on each bullet hit but popup again automatically and immediately
- Still Mode: Command to put Target in Still Firing Practice Mode. Target will remain static even when hit
- Time Mode: Command to put Target in Time Firing Practice Mode. The target should appear 5 times for 6 seconds at intervals of 5 or 6 seconds
- Command Acknowledgement: Commands reception acknowledgement sent by Targets to Commander Console

Communication between CCon and Targets is secured through built-in security features of WiFi like WEP, WPA, and WPA2.

1.10 +24V Regulated Power Supply

Power requirement for 24 AFPS units was calculated. +24 Volt Regulated Power Supply was designed & developed for AFPS units. Power requirement for AFPS Target Boxes (with WiFi Module) was calculated to be 5A at +24V. A +24 Volt, 150A regulated DC Power Supply was designed and developed to power-up 24 AFPS Target Boxes.

AFPS Testing & Results

The preliminary field trial of AFPS showed over-counting of the bullet-impacts. The reason for over-count was identified and the bullet-impact circuit was critically analyzed. The bullet-impact signal was producing sustained vibrations which were causing a false-count. The design of bullet-impact counter circuit was reviewed and de-bouncer was added both in hardware and software. The bullet-impact over-count & Corrected signals are shown in Fig. 11.

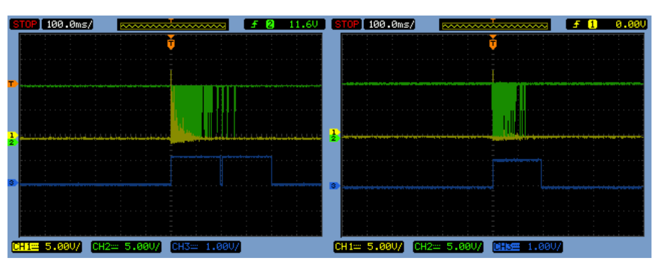

Figure 11: Bullet-Impact Over-Count & Corrected Signal

A testing methodology was established in which the performance of the AFPS would be critically analyzed during the live testing phase and error corrections will be incorporated for the improvement of the final system. A complete setup of AFPS was assembled at the firing range with a CCon and three target units.

In the first phase of the live firing test, on a clear day, 100 bullets were fired on each of the three target units, from a distance of 200 meters. First firing test produced an average accuracy of 82.5%. First firing results are shown in Fig. 12.

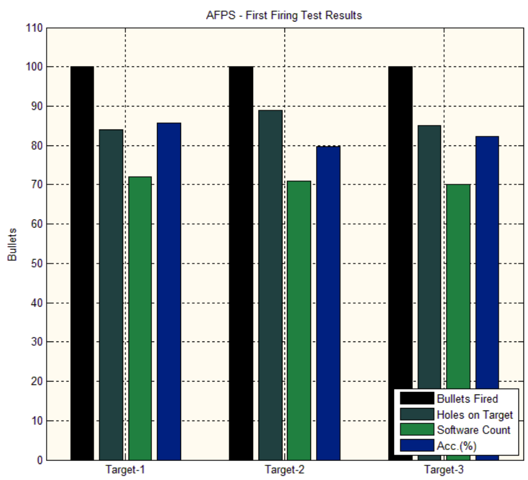

Figure 12: AFPS - First Field Testing Results

Bullet-Impact sensing circuit was improved after the first trail. During the second phase of the live firing test, on a clear day, 100 bullets were fired again on each of the three target units, from a distance of 200 meters. Second firing test produced an average accuracy of 92.1%. Second firing results are shown in Fig. 13.

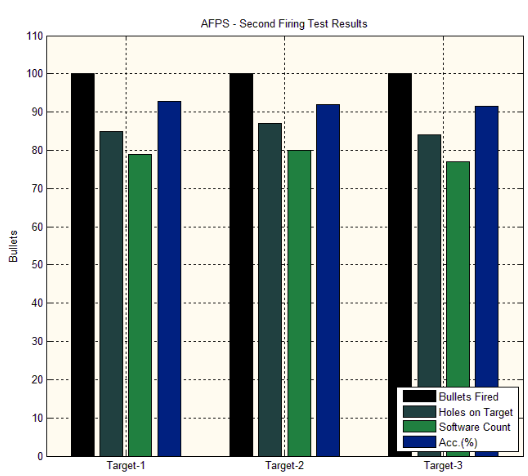

Figure 13: AFPS - Second Field Testing Results

To further improve the efficiency of the AFPS, temperature compensation was added to the bullet-impact sensing circuit. Third firing test showed a greater improvement with an average accuracy of 94.7%. The results of third field firing are shown in Fig. 14.

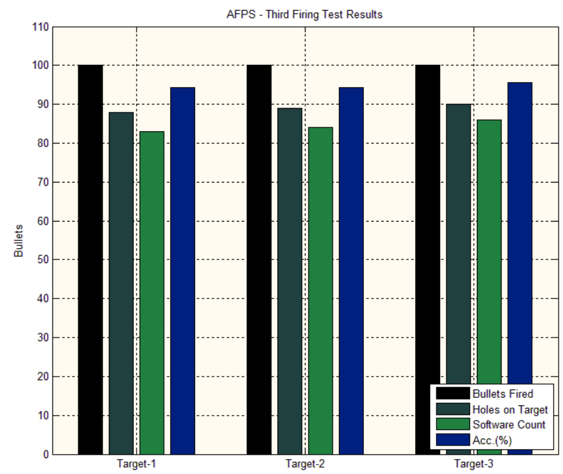

Figure 14: AFPS - Third Field Testing Results

A software de-bouncer was added in the bullet-impact detection logic. Software de-bouncer brought a significant improvement further to the system. Fourth firing test showed even greater improvement with an average accuracy of 97.6%. Results of fourth field firing of AFPS are shown in Fig. 15.

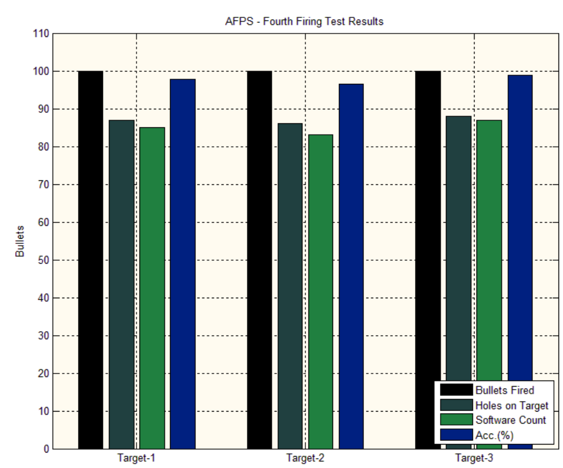

Figure 15: AFPS - Fourth Field Testing Results

The four phases of AFPS field testings and improvements made on the basis of the results obtained from these field testings brought the average Software Count Accuracy to a astonishing figure of 97.6%. The overall achievement from a 82.5% to 97.6% mark shows the success of the development procedure and cycle. The graph of average Software Count Accuracy percentage is shown in Fig. 16.

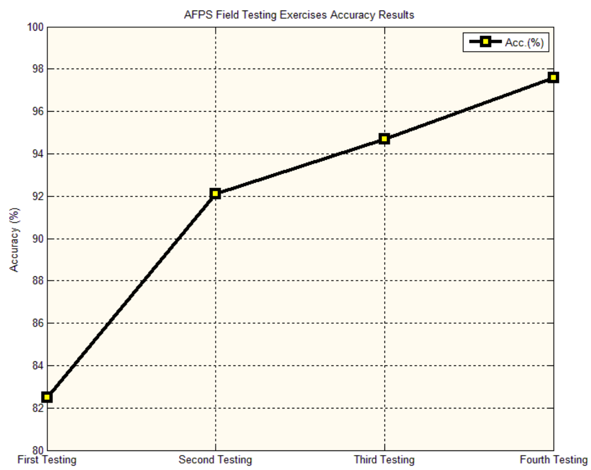

Figure 16: AFPS – Average Software Count Accuracy Percentage

CONCLUSIONS

A firing practice system has been designed and developed to automate the existing manual or semi-automatic firing ranges. WSN based AFPS provided real-time bullet-impact count wirelessly adding a greater level of flexibility for the Commander for conduct of dynamic firing exercise scenarios. The complete SDLC of the system has been presented including mechanical and electrical design of different parts of AFPS with revision and improvement through different development stages. The improvement process continued during the field trials phase as well, till a 97.6% Bullet-impact count accuracy was achieved. The system is controlled through a wireless (WiFi) commander console. The power to the target units is powered by a DC power supply. The next version of the AFPS will be battery-powered, wirelessly controlled, completely portable system for versatile shooting practice scenarios.

REFERENCES

[1] S. Li, "The Design and Implementation of Shooting System Simulation Platform for Police College," *International Conference on Scalable Computing and Communications; Eighth International Conference on Embedded Computing, 2009. SCALCOM-EMBEDDEDCOM'09.*, pp.566-570, 25-27 Sep. 2009.

[2] F. Ali, and A.B. Mansoor, "Computer Vision based Automatic Scoring of shooting targets," *IEEE International Multitopic Conference, 2008. INMIC 2008*, pp.515-519, 23-24 Dec. 2008.

[3] J. Sun, F. Zhang, Y. Li, and S. Wang, "Research on key technologies in automatic target-reporting," *International Conference on Automatic Control and Artificial Intelligence (ACAI 2012)*, pp.1732-1735, 3-5 Mar. 2012.

[4] R. Ahiska, H. Mamur, and M. Ulis, "The design and application of a LED driver and a LED armature with a thermoelectric generator," *Fourth International Conference on Power Engineering, Energy and Electrical Drives (POWERENG), 2013*, pp.902-905, 13-17 May 2013.

[5] A.K.M.M. Islam, A. Zeb, and K. Wada, "Communication protocols on dynamic cluster-based wireless sensor network," *International Conference on Informatics, Electronics & Vision (ICIEV), 2013*, pp.1-6, 17-18 May 2013.

[6] L. Yongfeng, T. Hongsen, Q. Tao, and L. Lianda, "Research on 3-D computer aided design of rapid manufacture for the movement system in diesel engine based on PRO/E," *International Conference on Mechanic Automation and Control Engineering (MACE), 2010*, pp.589-592, 26-28 Jun. 2010.

[7] J. Bryan, "Reducing downtime by proper motor lubrication," *Conference Record of 2013 Annual IEEE Pulp and Paper Industry Technical Conference (PPIC)*, pp.50-62, 23-27 Jun. 2013.

[8] M. Dubois, M. Farhat, E. Bossy, S. Enoch, S. Guenneau, and P. Sebbah, "Flat lens for pulse focusing of elastic waves in thin plates," *Applied Physics Letters* , vol.103, no.7, pp.071915-071915-4, Aug 2013.

[9] L. Zi-Yi, W. Sew-Kin, P. Wai-Leong, and O. Chee-Pun, "The design of DC motor driver for solar tracking applications," *10th IEEE International Conference on Semiconductor Electronics (ICSE), 2012*, pp.556-559, 19-21 Sep. 2012.

[10] L. D. Xu, C. Wang, Z. Bi, and J. Yu, "AutoAssem: An Automated Assembly Planning System for Complex Products," *IEEE Transactions on Industrial Informatics*, vol.8, no.3, pp.669-678, Aug. 2012.

[11] N. Greenough, and C.C. Kung, "A new high-efficiency stepper motor driver for old technology stepper motors," *IEEE 25th Symposium on Fusion Engineering (SOFE), 2013*, pp.1-4, 10-14 Jun. 2013.

[12] A.W. Louw, and C. Neethling, "Digital LED lighting solutions," *Proceedings of the 21st Domestic Use of Energy Conference (DUE), 2013*, pp.1-4, 3-4 Apr. 2013.

[13] X. Zhang and Z. Zhang, "Design on Sampling Circuit of EEG Signal Based on AT89C2051 Single-Chip," *Fourth International Conference on Innovative*

Computing, Information and Control (ICICIC), 2009, pp.454-457, 7-9 Dec. 2009.

[14] J. Xi, G. Liao, and W. Yang, "Study of Stepping Motor Subdivision Driver," *International Conference on Intelligent Computation Technology and Automation (ICICTA), 2010*, vol.3, pp.443-446, 11-12 May 2010.

[15] F. Yuan, L. Tsai, V. Prakash, D. P. Dandekar, and A.M. Rajendran, "Dynamic shear strength of S2 glass fiber reinforced polymer composites under shock compression," *Journal of Applied Physics*, vol.103, no.10, pp.103537,103537-8, May 2008.

[16] C. Huang, S. Wang, C. Chang, C. Huang, Y. Cheng and L. Fu, "An air combat simulator in the virtual reality with the visual tracking system and force-feedback components," *IEEE International Conference on Control Applications, 2004. Proceedings of the 2004*, vol.1, pp.515-520, 2-4 Sep. 2004.

[17] R. Mirshak, "Collateral damage risk: Quantifying the water surface bullet ricochet problem," *International Waterside Security Conference (WSS), 2010*, pp.1-7, 3-5 Nov. 2010.

[18] T. Matsuno, Y. Shima, T. Motoyoshi, K. Koyanagi, T. Oshima, and T. Fukuda, "Basic characteristics analysis of tuning fork structured piezoelectric vibration sensor and application for robot control," *International Conference on Mechatronics and Automation (ICMA), 2011*, pp.1532-1537, 7-10 Aug. 2011.

[19] X. Xiumei, and P. Jinfeng, "The simulation of temperature and humidity control system based on PROTEUS," *International Conference on Mechatronic Science, Electric Engineering and Computer (MEC), 2011*, pp.1896-1898, 19-22 Aug. 2011.

[20] M. S. Lee, and H. C. Lee, "Dummy Gate-Assisted n-MOSFET Layout for a Radiation-Tolerant Integrated Circuit," *IEEE Transactions on Nuclear Science*, vol.60, no.4, pp.3084-3091, Aug. 2013.

[21] R.D. Snow, J.R. Garner, and J.M. Whitaker. "Developing Load Cell Monitoring on the Mock UF6 Feed and Withdrawal System." *ORNL/TM-2013*, no.34, 2013.

[22] www.ruggedpcreview.com/3_slates_advantech_3100r.html

[23] M. Radek, and J. Zidek. "Application of synthetic instrumentation that applies the trend of software-based approach for measuring on the field of modern wireless transfer systems." *International Journal of Digital Information and Wireless Communications (IJDIWC)*, vol.2, no.3, pp.208-221, 2012.

[24] E. Wang, S. Zhang, and Z. Zhang, "A Study on GPS Signal Performance Analysis Platform Based on LabVIEW," *8th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM), 2012*, pp.1-4, 21-23 Sep. 2012.