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Lethal Force Encounters - Yet Another Opportunity for Engineering Education

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Abstract

Interdisciplinary research at Minnesota State University, Mankato and the cooperation of Tempe Police Department has made it possible to develop instrumentation and to establish baseline performance metrics for the evaluation of human performance in extreme encounters. A Motorola MC68HC11 microcontroller board was adapted by two Electrical Engineering graduate students who had no previous computer interfacing experience to control 27 Light Emitting Diodes (LEDs) and to track the trigger position of a modified training pistol. Software to control and support the system came from integration of commercial packages and student authored code. The system created was used to test over 100 Tempe police department officers during the summer of 2003. The measurements obtained by this testing have made it possible to establish both how quickly the "average" officer can pull the trigger given a "go" signal and also how long it takes for the "average" officer to quit firing the weapon given a "stop" signal under a variety of cognitive load conditions. This research has created an environment in which graduate students have learned about hardware design and integration, software engineering and validation, and compressed design cycles. Students involved in this research have also learned that research schedules are many times driven by factors outside of their control.

Introduction

Currently there are at least three police officers in this country facing homicide charges because of a shooting incident. During the past four years the second author of this paper has provided expert testimony on human performance in 20 civil cases, 9 criminal cases, 17 grand juries, has been featured twice on Court TV and has been involved in numerous arbitrations. Scientific research spanning engineering and human performance is being used to obtain information to appropriately evaluate lethal force encounters.

This paper will describe current research efforts by the Tempe Police Department and faculty and students from Minnesota State University, Mankato. The equipment developed and information obtained from these efforts has significant implications in evaluating an officer's performance in shooting situations, establishing shooting training protocols and scenarios, and demonstrating to students the relevance of an engineering education.

The Team

Research on reaction time was first begun in 1850 by astronomers and first published by psychologists in 1850[1]. Since that time, thousands of researchers have published tens of thousands of articles and textbooks on the topic. An interesting question is -- why hasn't this treasure trove of information made its way into a more scientific understanding of officer involved shootings? We believe that the answer to this question is fairly simple -- prior to this time a team with a commonality of purpose didn't exist that had expertise in computer based instrumentation, human factors and performance, and a readily available group of subjects in the law enforcement community.

The current research team is comprised of Sgt. Craig Stapp, Fire Arms Training Officer, Tempe Arizona Police Department; Dr. Bill Lewinski, professor of Law Enforcement, Minnesota State University, Mankato; and Dr. Bill Hudson, associate professor of Electrical and Computer Engineering and Technology, Minnesota State University, Mankato. Sgt. Stapp and Professor Lewinski have a long history of collaboration. The final member of the team, Dr. Hudson, was approached and recruited by Dr. Lewinski in the spring of 2003 to provide computer expertise in the research effort.

Dr. Lewinski has been researching human performance in law enforcement events for over twenty five years. Dr. Lewinski felt the next logical step in his research was to evaluate the response time of police officers under a variety of simple, non-threatening situations. His request of the Department of Electrical and Computer Engineering and Technology was to create a system that could display certain visual patterns on a Stimulus Box and record an individual's response time to that visual stimulus by measuring the trigger pull on a training pistol. To accomplish this Dr. Hudson enlisted the assistance of two Electrical and Computer Engineering graduate students, Darwin S. David and Ross Loven.

The Graduate Students

The graduate students were completing their second semester of their Master's Degree study. Both students had completed their Bachelor's degrees in Electrical Engineering at Minnesota State University, Mankato in the previous year. The students had both completed the many prescribed laboratories and their cumulative design experiences in both the single semester Junior design and the year long Senior design sequence. Both students also had completed the required Microprocessor design course in which they completed a multitude of assembly language programming exercises. The students had project design experience at the device level but had little experience in system integration and designing using commercially available subassemblies. Also previous to this activity, the students did not have significant research experience.

Research Timeline

Because of officer availability, the team was required to complete the system during a period of three months. The system was designed to support experiments proposed by Dr. Lewinski. Because of the time restrictions tradeoffs were made in software and hardware. Where possible, the graduate students were encouraged to use commercially available software, such as Excel and HyperTerminal, and to integrate commercially available hardware systems. This experience was significantly different from the students previous design experiences and they had to be reminded on occasion that it was time that drove many of the design decisions. The equipment developed to support the testing of the police officers will be described in the next section of this paper.

Experimental Apparatus

This research effort has developed a microcontroller based stimulus board and instrumentation system that can connect to a computer by way of a serial RS232 connection. A modified Glock training pistol is connected to the microcontroller board by a two conductor cable. The data acquisition system can determine with great accuracy how quickly an officer can pull the trigger given appropriate stimuli. Equally important the design of the data acquisition system also determines how quickly an officer, given a stop firing signal, can quit firing the gun.

The stimulus board is a black metal box with a pattern of clusters of lights on the face. There are 9 clusters of lights in a 3 by 3 pattern. Each has three lights (red, yellow and green.) The lights are instant on/off, light emitting diodes. The clusters of lights are spaced equally with 3.25 inches between clusters. The stimulus box front panel is a 10 inch black square. The stimulus board can be seen in Figure 1.

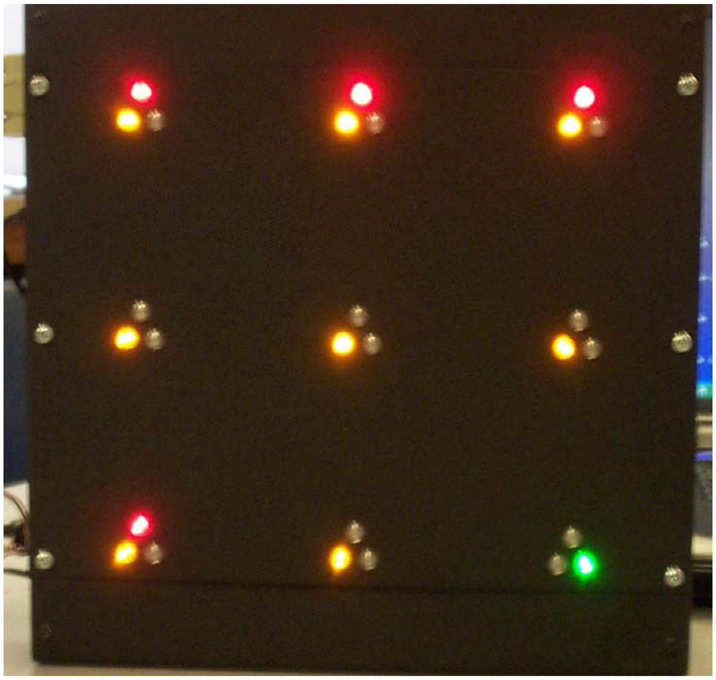

Figure 1 – Stimulus Board

The second piece of the experimental apparatus is a modified training pistol. Initial modifications to the weapon were made by the weapon's manufacturer, Glock[2]. The manufacturer's modifications to the weapon included the removal of the firing pin to prevent the use of live ammunition and the addition of a spring to recycle the weapon. In a normal weapon the recycling (preparing for the next shot) occurs in response to the bullet explosion. The modifications to this weapon resulted in a trigger pull of just under 10 pounds and a slightly longer trigger motion; these changes are not viewed as significant factors in changing the response time of officers. This training pistol was then outfitted with an external frame to support both a potentiometer and a mechanical linkage from the trigger. The movement of the trigger was mechanically coupled to the potentiometer. The potentiometer was part of a voltage divider network which was monitored by the microcontroller data acquisition system this arrangement allowed determination of 120 trigger positions. The modified training pistol can be seen in Figure 2.

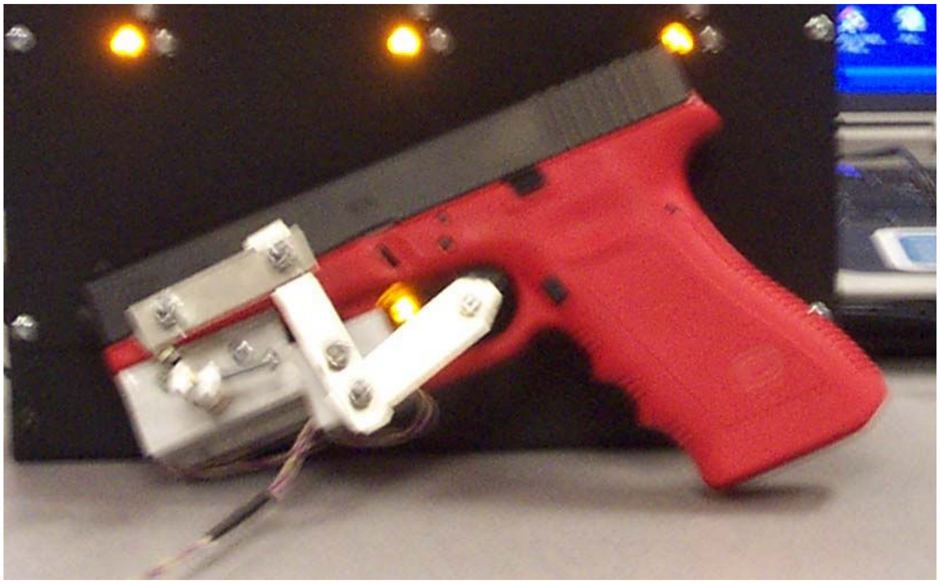

Figure 2 – Modified Glock Training Pistol

A MC68HC11 microcontroller board is used for both control of the stimulus box LEDs and for data acquisition. Software was written for this microcontroller by the graduate students in a manner consistent with their previous training. They found that the simple techniques taught in their undergraduate course work left them ill prepared for this effort. The software to create the stimulus lights and to control the analog to digital converter was written in assembly language. Based on previous training this task was very time consuming because of a lack of understanding of the benefits of software engineering and code sharing.

Because of time constraints the microcontroller board was purchased from Axiom Manufacturing (Part #CMD-711EX)[3]. Driver limitations on the Axiom system required the addition of a buffer board and an additional power supply to support the 27 LEDs. This section was fabricated by the graduate students and they were forced to address issues of packaging and ease of connections – something that previous projects had allowed them to ignore. The microcontroller board and associated interconnects can be seen in Figure 3.

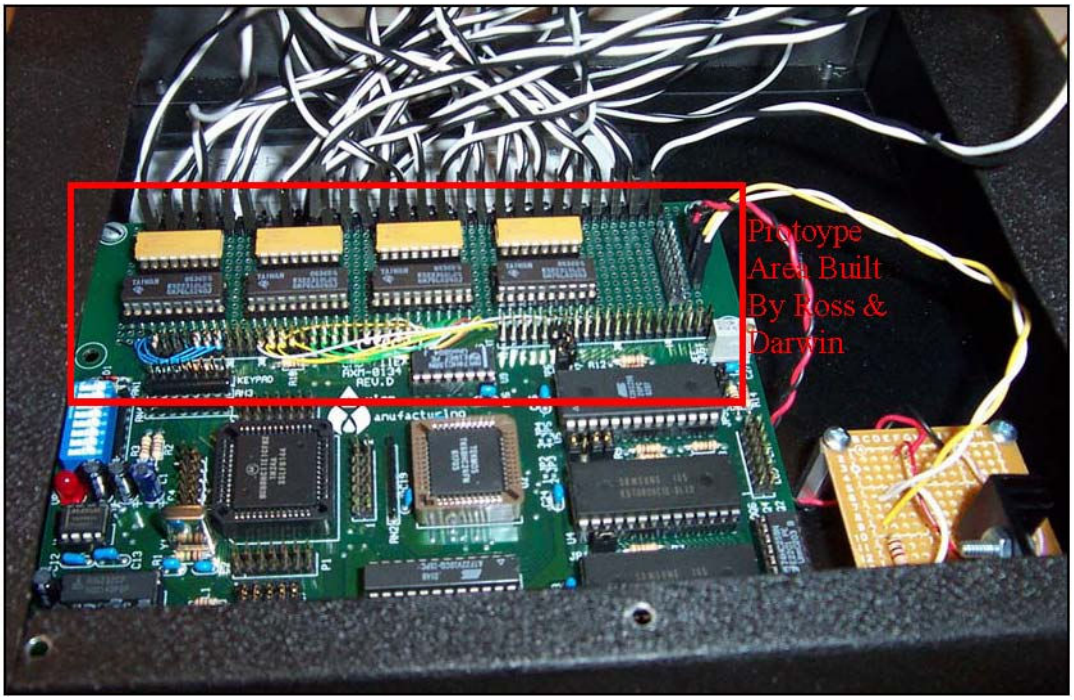

Figure 3 – Microcontroller Board and Interconnects

Current operation of the experimental apparatus requires a host computer. The microcontroller board runs the Buffalo Monitor system which allows the downloading of code to the microcontroller. This host computer is responsible for downloading the assembly code for each experiment to the microcontroller board and also receives the data from the microcontroller at the conclusion of each experiment. Current software requires the user to save the data from each experiment on the host computer. Because of development time restrictions the commercial HyperTerminal[4] program was used rather than create custom code to support communicating with the Axiom board. This decision while reducing development time created a system that requires more operator intervention to operate. The five experiments conducted using this equipment will be described in the next section.

The Experiments

The experiments were designed to evaluate human performance under a variety of cognitive load conditions. Some of the experiments were simple reaction time tests to determine how quickly a police officer could respond when a light turned on while other experiments required the officer to look for patterns. Additionally, the rate at which an officer could stop pulling the trigger was also measured. In all five different experiments were developed and each officer was tested five times on each of the experiments.

The first experiment proposed was to determine basic reaction time. Most research studies on reaction time in law enforcement are done using a simple auditory stimulus, such as a buzzer. Traditional research informs us that a reaction to a visual stimulus is slower than a reaction to an auditory stimulus and the more complex the visual stimulus is, the slower is the reaction.

Because the majority of officer related shootings involve visual response it was decided that the first experiment would be to measure the officer's reaction time to the stimulus of a single light turning on. The first experiment determines the length of time it takes an officer to pull the trigger on a training pistol once a single light is turned on. Individuals are to pull the trigger only once each time the test is run.

In the second experiment the subject's response time is measured to determine how many trigger pulls can be accomplished after a single light is turned on. Additionally, this experiment is designed to determine how quickly an individual can stop firing the gun once the stimulus is removed. In this experiment the reaction time before the first trigger pull, the number of trigger pulls inside the stimulus boundaries, and the number of trigger pulls outside the stimulus boundaries are being measured. It is necessary to count the number of trigger pulls outside the stimulus boundaries to determine how long it takes an individual to stop pulling the trigger after the stimulus has turned off. Individuals were encouraged to focus on the light and to fire as rapidly as possible when the light was on – but only while the light was on.

The third experiment is designed to increase slightly the cognitive load on the test subject. The test subject is now instructed to pull the trigger in response to three lights being turned on – false stimuli distracter patterns force the test subject to think in addition to react. That is, when one full cluster (all three LEDs) are turned on the subject is to pull the trigger only once. This test involved only the upper row of LEDs on the Stimulus Box. In this experiment the reaction time from the onset of the stimulus to the start of the trigger pull is measured along with recording of any false trigger pulls or any missed trigger pulls. A false trigger pull is when a test subject fires when they are not supposed to, where a missed trigger pull occurs when a test subject does not fire when they are supposed to.

In experiment four the reaction time of the officer is measured after they see three green LEDs appearing in a row anywhere on the stimulus box. This experiment also measures how many trigger pulls can be completed while the lights remained on. In this experiment both the reaction time before the first trigger pull and the number of trigger pulls that can be accomplished are being measured. This experiment was designed to increase the cognitive load on the subjects by forcing them to look for visual patterns in the presence of visual distracters.

In the last experiment the officer's single shot response time to a build up to three LEDs in a row is measured. During this test the subject is presented with many patterns of LEDs that appear to be building to the desired "go" signal. Many of these buildups do not result in a "go" indication. These false encouragements lead the officers in a sense of false expectation. In this experiment the reaction time from the onset of the completed stimulus to the start of the trigger pull is measured along with any false trigger pulls or missed trigger pulls. This experiment is designed to both increase slightly the cognitive load and to also introduce the element of expectation into the decision process.

Out of the five experiments, experiment three seems to be the hardest experiment in terms of the cognitive load and a person's ability to react to the stimulus. On the other end of cognitive load, experiment one appears to be the easiest as it is a simple go no/go decision process. The reader needs to be cautioned -- this research is done in a controlled laboratory situation. The stimuli are simply lights. They are unaffected by issues of race, sex, economic status, experience or emotional status of the officer etc. This research is only interested in measuring reaction times of officers in very neutral situations. The goal of this research is to establish simple base rates of reaction times for a variety of simple situations. The officers were encouraged to react as quickly as they could.

Analysis Software

Data from the microcontroller board was sent to the host computer in an ASCII format – formatted to allow easy importing into commercially available spreadsheet programs. All original data analysis was conducted using the spreadsheet programs and visual inspections. An example of one of the original spreadsheets can be seen in Figure 4. This handling of data did require additional labor but allowed for rapid development of the system. The graphical presentation of the information from the spreadsheets proved to be informative. Officers who were trying to "half pull" the trigger could be easily identified. It was also easy to identify the officers who were able to stop a trigger pull. While this visual information has been helpful it has also become clear that the software for this project will need to be revised to streamline data analysis when larger populations are tested. An example of preliminary work on automatic data analysis conducted by graduate student Jeremy Casper in support of this research effort[5] can be seen in Figures 5 and 6. This is one of many new research efforts occurring as a result of this interdisciplinary teaming.

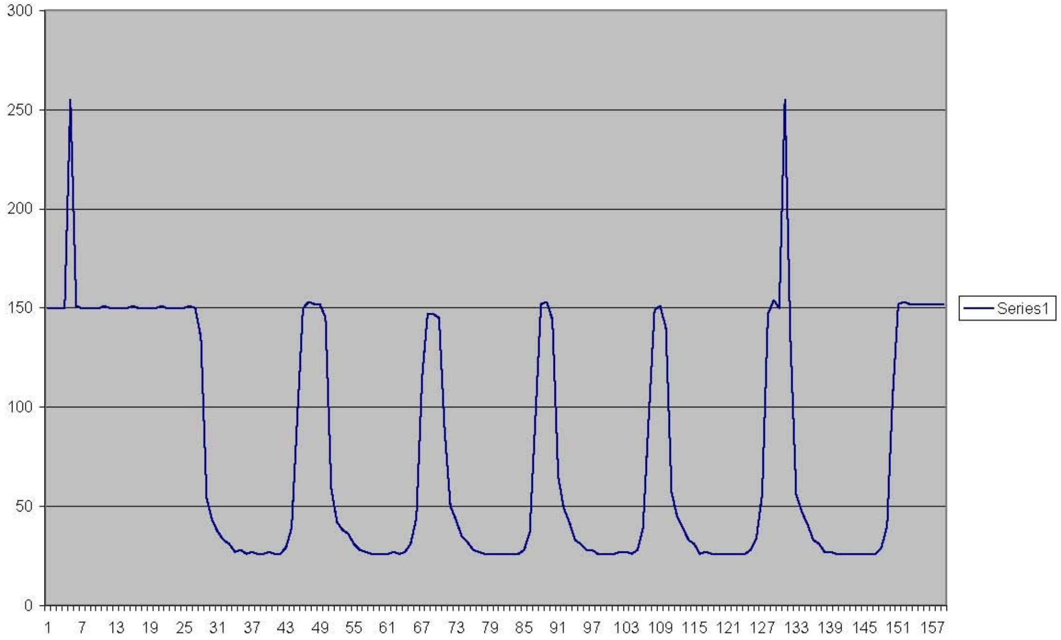

Figure 4 – Graph of Trigger Pull Reaction Time

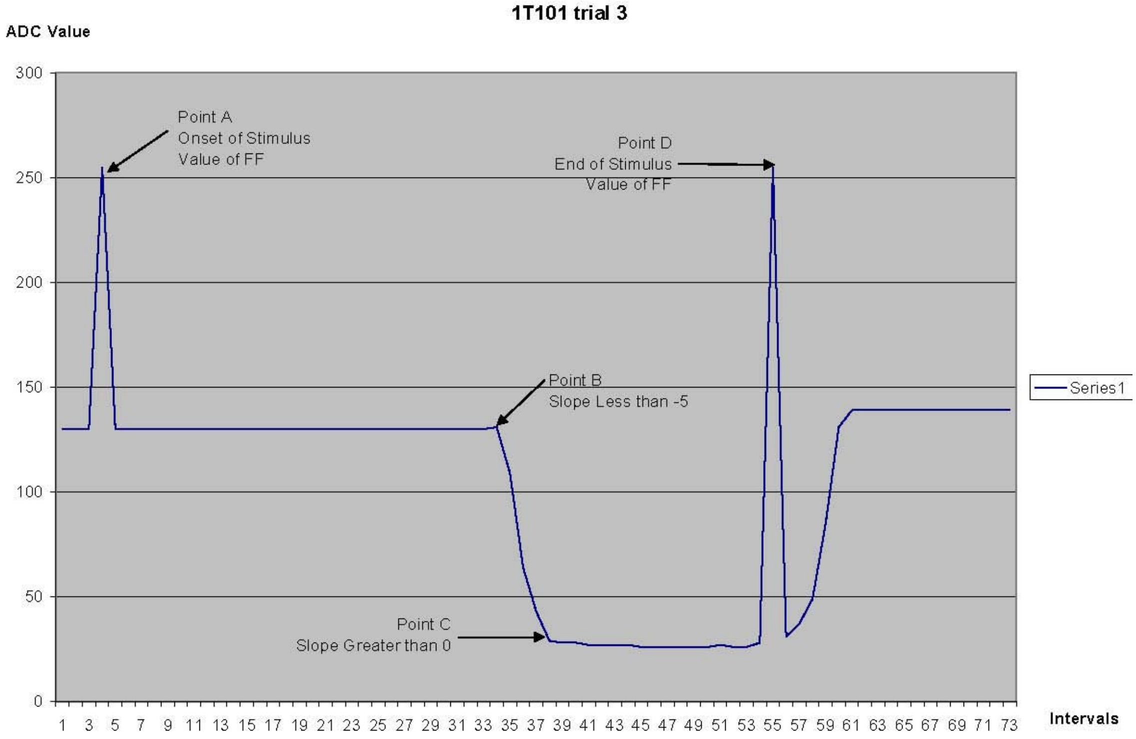

Figure 5 – Preliminary Algorithm Design

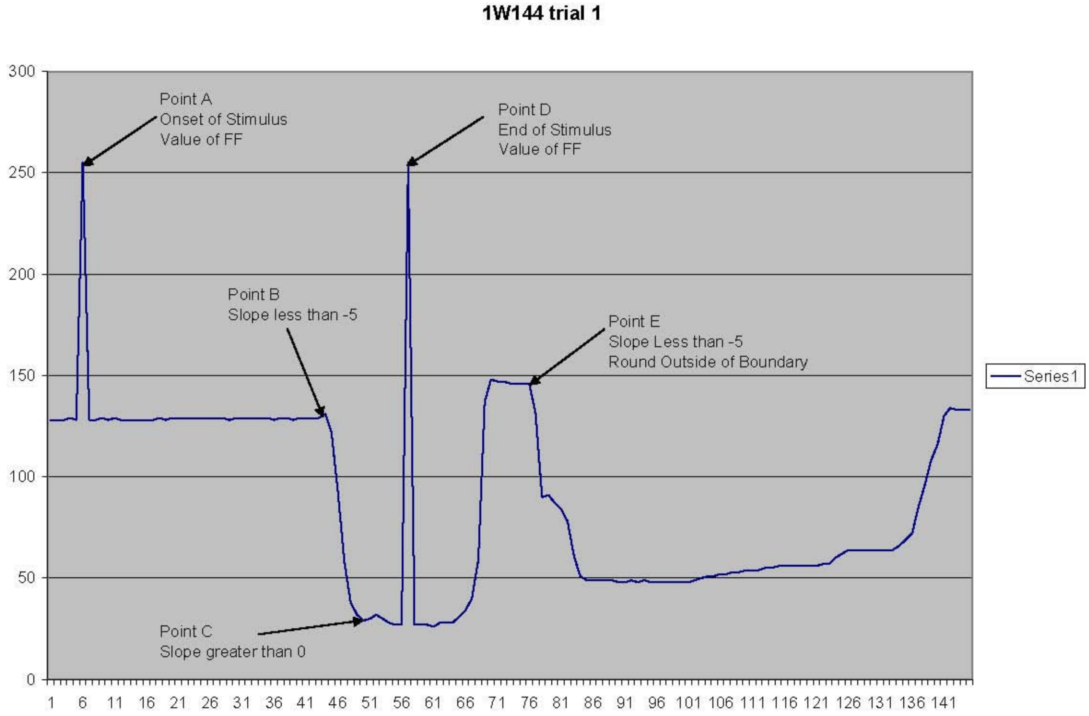

Figure 6 – Preliminary Algorithm Design

Results

The system developed has been used to test the reaction times of over 100 police officers in the Tempe Police during the summer of 2003. This testing has shown the average time to pull the trigger for an officer responding to a simple stimulus (experiment 1) is $31/100^{ths}$ of a second. Of this, on average, $25/100^{ths}$ of a second is information processing time and $6/100^{ths}$ of a second is the delay associated with the trigger pull motion. And, using experiment 2 it has also been possible to determine that on average the officers tested required $35/100^{ths}$ to stop pulling the trigger. And, it should be noted that in a significant number of the officers tested this delay was over a half second. The implications of this if the officer is using a semi automatic weapon are profound – corresponding to many additional rounds being fired after the stimulus to fire is removed.

As the cognitive load increased so did the observed reaction time. In experiment three 68 percent of the officers tested reacted to the stimulus in between $44/100^{ths}$ and $69/100^{ths}$ of a second – the reaction time was doubled by the slight cognitive load addition of simple pattern recognition. Additional research will be required to determine how real world visual processing loads impact reaction time – the expectation is that reaction times will increase even more.

Conclusions

This interdisciplinary research effort has resulted in a variety of positive results. The success of the research has resulted in the formation of the center for the Study of Human Performance in Extreme Encounters at Minnesota State University, Mankato. This center is a cooperative effort between the College of Science Engineering and Technology and the College of Social and Behavioral Sciences and provides an efficient method to continue this interdisciplinary collaboration.

Through this research two graduate students received financial support that allowed them to more easily complete their graduate studies. In addition the research described in this paper has been used to assist in the evaluation of current and past shootings to determine in a scientific manner if those involved acted in an appropriate manner. For students seeing their research being used in such significant applications provides very real educational reinforcement.

The applied nature of this research has also shown students that engineering is a problem solving discipline and as such, many times compromises must be made in design to meet time constraints and many times what is learned in class is only a starting point for "what you really need to know." Further, the fact that this equipment must be used by others also provides emphasis to student researchers about the need for quality documentation to support their design efforts.

The results obtained through this research have been published on two occasions in the Police Marksman[6,7]. While the publications have been significant, it has been the "positive press" students share about this research that makes it noteworthy for ASEE. Students through this research have found real world engineering problems and solutions to them. As students discuss these activities the excitement grows and so does student involvement. This original research is expanding. Student papers are underway that present software algorithms for automatic analysis of trigger pull data. Also because of a desire to enhance data collection and to increase stimulus flexibility new microcontroller systems are being designed by students around the ZiLOG[8] family of microcontrollers. Much of what is needed in the future to support this research will be measurements of test subject movements. As a result, students are developing systems to track movements using ultrasonics.

As time allows analysis of this data will continue. The results and their implications are significant for the fair evaluation of officers involved in shooting situations. Equally significant is the sense of accomplishment and focus that a project such as this can give to students. This project and cooperation across disciplines again show the great things that can be accomplished through teamwork and student efforts.

The authors would like to acknowledge and thank the Administration of the Tempe Police Department, and Minnesota State University, Mankato graduate students, Darwin David, Ross Loven, and Jeremy Casper for their contributions to this project.

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