Steps Towards Adaptive Psychomotor Instruction

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Abstract

Marksmanship is a core skill required of every Warfighter yet the approaches and effectiveness of marksmanship training can vary by instructor. Even the U.S. Army's Engagement Skills Trainer (EST) marksmanship simulator, which provides detailed data about every shot fired, is only as effective as the instruction based on this data. The authors discuss a marksmanship simulator enhanced with an intelligent tutoring system in order to help instructors provide more efficient, consistent and accurate diagnoses and feedback to trainees. This paper presents the brief history of adaptive psychomotor skills training and a 3-phase plan for the development of an adaptive training system for marksmanship, which is a relevant approach for other types of adaptive psychomotor training.

Introduction

The skills of marksmanship have become fundamental to the success of military operations (Yates, 2004). Marksmanship, however, is a complex psychomotor skill demanding high physical and mental coordination. To strike a small target at distance, a Soldier must have a combination of proper breath control, body positioning, motor control of the muzzle and trigger squeeze, and sight alignment between the sights/target (Pojman et al., 2009).

Psychomotor training has a long history in psychological research, with three primary findings into motor skills training and practice (Salmoni, Schmidt, & Walter, 1984). The first is that rote practice is effective in promoting long term retention. The second is that the addition of "right/wrong" information is extremely helpful in lessening the overall error rate. The third is that the knowledge of results, confirming right/wrong information, lowers overall error and improves retention.

In the U.S. Army, Basic Rifle Marksmanship (BRM) training consists of instruction on the fundamentals of marksmanship with a culminating qualification event. Traditionally, the training portion includes education in the classroom, practice on the Engagement Skills Trainer (EST), a simulator which supports many types of firearms training, and live fire on outdoor ranges. On a live range, an instructor reviews a target after a shooting session and applies expertise and feedback on shooter errors. On the EST, an instructor replicates this process with additional information such as aim trace, trigger pressure and weapon cant, provided through weapon-embedded sensors. However, when using sensors on the EST simulator, instructors must take time to review and interpret the data before providing individual recommendations to the remedial shooters. This is a challenging environment due to the large number of trainees and the limited number of instructors. While simulated marksmanship training with realistic noise/recoil can serve the purposes of weapons qualification (White, Carson, & Wilbourn, 1991), it lacks instructional ability of a hands-on coach. The Army simply does not have the resources to provide individualized coaching and coaches for each trainee.

While remedial individualized feedback is available to Soldiers, the instructor often doesn't immediately have the data to effectively diagnose errors and some instructors simply misunderstand parts of marksmanship doctrine and/or inconsistently apply training techniques and procedures (James & Dyer, 2011). Regardless, Chung et al, found that individualized instruction based on errors related to shot placement, body position, breathing, trigger squeeze and muzzle wobble was effective in improving shooting skills (Chung, Nagashima, Espinosa, Berka, & Baker, 2009). However, a human coach was used to review the data and diagnose errors. In an ideal situation, a training system would automatically review the data and diagnose the errors consistently. Research is needed in this area to examine modeling approaches within the domain and to evaluate their effectiveness in a training context.

One method of ensuring reliable, individualized diagnosis and instructional feedback is through the use of an intelligent tutoring system (ITS). With research providing evidence of ITSs as effective tools for improving learning (VanLehn 2011), a marksmanship ITS could

instantly assess trainee performance and provide feedback. This could help standardize error diagnosis and ensure trainees receive consistent training. Further, by addressing trainee errors immediately, an ITS could help improve the efficiency and lower the cost of marksmanship training.

A prototype has been assembled to test the application of ITS technology in the BRM domain, using the U.S. Army Research Laboratory's Generalized Intelligent Framework for Tutoring (GIFT) (Sottilare, Brawner, Goldberg, & Holden, 2013). GIFT provides a means to collect/analyze data relevant to model construction along with tools to assess performance and provide remediation.

Collection Apparatus

The experimental testbed is an integrated system of software and hardware which will be discussed at a component level. The software items are the SCATT marksmanship training software (SCATT Shooter Training Systems, 2013) and the GIFT (Sottilare et al., 2012). The hardware components are a simulated M4 rifle, a trigger pressure sensor, a weapon orientation sensor, and a physiological monitor (see Figure 1 and Figure 2).

SCATT WS1 is used for fixed target marksmanship training and includes an electronic optical sensor which is fixed to the weapon barrel. The shooter aims at the SCATT electronic target while the system logs aiming data measured through the optical sensor. When the weapon trigger is activated, the point of impact is recorded, and this data is logged for post-hoc analysis.

The Hatalom Electronic Air Recoil (HEAT) is a simulated M4 weapon with the look and feel of the real U.S. Army M4 rifle. Using a standard carbon dioxide cartridge the HEAT is able to approximate the noise and feeling of weapon recoil without firing any projectiles. The HEAT rifle was modified for the inclusion of the SCATT STS Trigger Sensor, which is used to record applied pressure on the trigger before, during, and after the shot.

In addition to the SCATT optical sensor and trigger sensor being fit directly on the rifle, an OS3D weapon orientation sensor was installed. The OS3D uses magnetometers, gyroscopes, and accelerometers to measure absolute orientation of an object enabling pitch, cant, and yaw measurement. This information associates weapon position as held during shooting.

The BioHarness BT is a compact electronics module that is worn under the clothing and produces a metric of breathing intended to assess breath control concepts.

The GIFT modular architecture project is able to provide the context for adaptive training in a variety of areas of instruction. This generalized approach is used to be able to quickly construct and use ITSs in an experimental fashion.

Figure 1: The Experimental System. Pictured from left to right are the target, the weapon, the software and the physiological sensor systems.
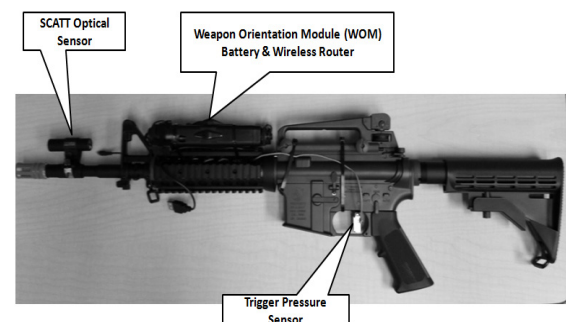

Figure 2: Detailed Instrumented Weapon--SCATT optical sensor, the weapon orientation sensor, and trigger pressure sensor.

A Plan for a Three-Phase Study

There are three distinct phases of experimentation linked to the development of an adaptive psychomotor training system. The first phase focuses on domain modeling and building representations of expert performance of the skills and abilities linked to BRM. The second phase introduces a pilot study including both novice performance and expert annotation. The outcome of these two phases will result in the development of a testbed to assess the impact of the different adaptive marksmanship modeling techniques.

Phase 1 of the study is the development of expert models linked to BRM fundamentals. The U.S. Army Marksmanship Unit (AMU) at Fort Benning provided expert data. AMU shooters are a representative sample of both the expertise required, and of instructional validity.

Eight AMU experts' worth of data was collected. During data collection, each subject was instructed to produce five-shot groupings over a twenty minute time window while wearing the physiological sensors. This procedure was executed across two stances: prone unsupported, and kneeling. Experts shot at their own pace and took self-

administered breaks to avoid mental/physical fatigue. A small sample size is typical for expertise, and it is hoped that data will align towards AMU instructional standards.

For model creation, this data is to be treated as unlabeled, as it does not have resolution on par with performance; there are more data points than shots. The fundamental action that can be taken on unlabeled data is trend discovery. Given the goal of the effort is to assign remediation feedback on one of the key fundamentals (position, aim, breath control, trigger pressure), the signals will be analyzed for discovery trends in these areas.

The expert data is expected to take a windowing approach for before-shot and after-shot features. Each data signal collected from the apparatus is expected to have a different window of time leading up to the shot where the data is valuable. For example, a marksman taking a shot raises the weapon, controls his breath, slowly squeezes the trigger, and fires. These sequences occur in a defined order, with different relevant time periods for each signal.

Trigger squeezing errors are predicted to be the easiest error to diagnose, as it should correlate with information from the pressure sensitive trigger alone. It is expected that experts slowly apply pressure on the trigger, as recommended in the BRM field manual and previous studies (Army, 2003; Berka et al., 2008). This may be represented as a low amount of signal variability or low signal power which can be calculated in real time via a sliding window technique. A small number of experts should be able to establish a suitable range of trigger squeeze variability, and a suitable window by which they commonly align. As with trigger control, the assessment on breath control may be isolated within a single sensor data stream. Breath control will also be analyzed for variability within a before-shot window, while investigating the question of whether there is significant deviation between the marksmanship standard and experts. The data will be assessed for trends of firing after exhaling, or during a held breath, as in Figure 3.
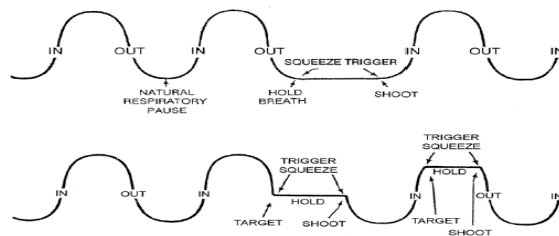

Figure 1: Diagram of Army recommended breathing

Positioning and aiming signals include the aim trace, the weapon cant, shot accuracy and consistency (over a group of shots). The system will use this information in conjunction with the work performed by James & Dyer (2011) on marksmanship diagnostics to identify consistency in performance and to evaluate an individual's ability to produce a set group of shots as required by Army standards testing.

Following completion of expert model development, the results will be used in *Phase 2* to develop a validation testbed to verify their utility in a training context. Expert models will be built on data trends, linked with task concepts, and assessed from novice deviations. The GIFT software is equipped to assess these deviations (Domain Module), create performance records (Learner Module), assign instructional strategies (Pedagogical Module), and deliver feedback (Domain Module).

The last task for execution before having a fully functional testbed is to develop instructional tactics and interventions for diagnosed errors. For this purpose, we will use video-based instructional interventions based on previous work from Chung et al (2009). The videos will include a SME covering the fundamental BRM components of the diagnosed error. For this phase of the study, this will be the only type of instructional tactic used. It is important to note that the feedback delivered will be fairly general. This is because the model will only be able to identify individuals not performing similar to experts, rather than root error cause.

With an updated version of experiment, Phase 2 will result in an experiment using novice first-time shooters. This experiment will provide pilot data to test and validate the expert model's ability to interpret novice performance in real-time and diagnose errors based on outcomes. This will enable a thorough follow-on analysis to compare novices against experts and to locate common differences between both populations, as seen in Berka et al. (2008). In addition, this experiment will provide initial evidence of whether individualized feedback autonomously delivered by an ITS is an effective tool for BRM training.

As the initial expert models generated can be used to dictate what an individual is doing differently, these models do not have the ability to accurately determine what is truly causing the error, which limits the system's ability to provide detailed feedback. With a goal of improving the models used to diagnose error, this phase will also include SMEs in BRM to observe novice performance. The data from witnessing experts on the use and validation of the models of marksmanship and associated feedback will be used to develop a buggy–performance library of errors made. The generation of a *subjectively labeled* dataset that identifies types of trainee error will be beneficial to the research, and able to be compared to the expert-based models. As James and Dyer (2011) note, subjective labeling can lead to discrepancies in diagnosis as SMEs in this domain are inconsistent in the tactics and procedures they teach along with their

understanding of the concepts involved in the task. At this point, two competing models will be in existence, without the knowledge of relative superiorities.

Based on the outcomes from Phases 1 and 2, *Phase 3* will begin with modifications to the GIFT testbed previously developed. The expert model parameters will be adjusted based on observations from the Phase 2 study. In addition, the buggy-library models will be incorporated into the GIFT domain representation for assessment purposes. The distinction between the models must be noted, as one is based solely on data generated from experts doing what they do best, while the other model is based on data from novices and the errors they commit as deemed by a panel of SMEs. In an ideal situation, the most effective tutor will recognize specific errors being made so as to intervene with detailed feedback. However, if there are extreme inconsistencies between error annotations, this approach will lead to inaccurate assessments.

Once development is final, an experiment will be conducted to determine which model of performance leads to better overall learning, or if a hybrid approach is the best way to proceed. The model produced in Phase 1 is based on unlabeled data, expert performance, and marksmanship manual knowledge. The model produced from Phase 2 is based on labeled data, novice performance, and expert annotation of trainee error. Each model has limitations to the feedback it can support. Because the expert model can only provide information on what the trainee is not doing, feedback can be structured in a general fashion to cover the fundamentals violated. In a bug library, specific errors can be identified, enabling a more focused intervention on what went wrong, rather than on what they should try and do correctly. We will determine whether expert data and base knowledge are enough to build an effective psychomotor tutoring system, or whether expert annotation aids in overall performance outcomes.

Conclusion & Future Directions

This work is naturally aligned with the Department of Defense's ongoing interest in marksmanship training. The U.S. Army has already fielded hundreds of EST marksmanship simulators around the globe which are currently deployed without ITS technology. Adding a proven ITS capability to those simulators would save on the time and money required to train and sustain the Army's marksmanship skills. This research will create a testbed for adaptive marksmanship wherein a variety of instructional strategies for adaptive instruction can be assessed and validated. The authors hope to transition this testbed to an EST platform, where the research is directly applicable to the EST program managed by the Program Executive Office for Simulation, Training and Instrumentation (PEO STRI). On an even larger scale, this project intends to answer the question of whether existing ITS and data mining techniques can be applied to expert performance within psychomotor domains of instruction for the purpose of augmenting existing training systems.

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