A Prototype System for Kinematic Data Collection and Analysis of the AR-15 and M4's Firing Action

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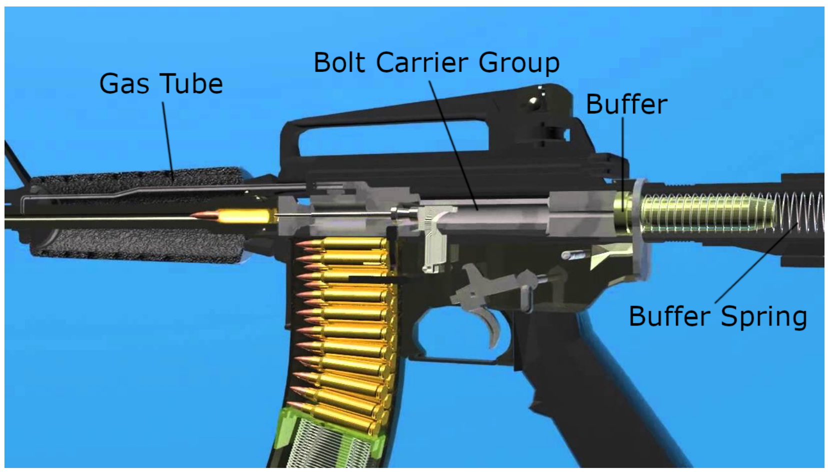
1 Introduction

The AR-15 is a ubiquitous example of a rifle used throughout the country in many sporting events. These range from long-range shooting competitions, to the Tucson-born 2-gun Action Challenge Match and the nationwide competitive 3-gun scene. Shooters in any of these events commonly use highly customized rifles built for competition, and each person has a unique set of requirements for their rifle that balances firing rate with recoil mitigation and reliability.



Above is an image depicting a cross-section of a sample AR-15. When the rifle is fired, a portion of the hot gas from the cartridge which pushes the bullet down the barrel of the gun exits through a gas port into the gas tube. This gas then charges the bolt carrier, which is pushed rearwards into the buffer. The buffer is a cylindrical tube containing a combination of aluminum and tungsten weights, and its weight usually ranges from 2.9 to 5.4 ounces. The buffer's rearward velocity is slowed by the buffer spring, and when the bolt carrier group has reached the maximum rearward extent of its travel, it is pushed forward by the buffer spring and chambers a new round.

Gas pressure and buffer weight are the two adjustable parameters which a user may change to suit their preferences. Non-standard springs are sometimes used as well, although this is seldom the case. Lighter buffer weights and/or higher gas pressure usually result in a higher rate of fire at the expense of increased recoil. Heavier buffer weights and lower gas pressure reduce felt recoil at the expense of fire rate. Too heavy of a buffer or too little gas pressure for the installed buffer's weight results in short stroking, a phenomenon that occurs when the bolt carrier does not complete its full range of motion. This reduces the reliability of the weapon, and may cause issues such as a failure to extract the spent casing or a failure of the bolt to lock in the rearward position when the last round in a magazine is fired. Failures such as these can ruin a competitor's time if they occur during competition, or can be life threatening in a military application.

Tuning the buffer weight and gas pressure is currently done simply by feeling the recoil of a rifle and eyeballing the ejection angle of spent casings from the rifle. Reliability is gauged by intuition and cannot be accurately measured without shooting hundreds to a thousand or more rounds and recording how many failures occur. Usually, competition rifles are tuned for lower recoil as reliability is somewhat less crucial in such a setting. This allows a shooter to get back on target quicker and reduces the time spent on one course of fire. Many competitors have experienced the disappointment of a failure to extract during competition for this reason. Rifles employed in military and law enforcement applications are usually slightly overgassed in order to ensure increased reliability, which increases recoil at the cost of some combat effectiveness.

Until now, there has been no way to scientifically and precisely measure the acceleration and velocity of the bolt carrier and buffer system. This is the problem which my device aims to solve. By solving this problem, a user may accurately and precisely balance gas pressure and buffer weight in a way that fulfills requirements for recoil mitigation, reliability, and fire rate. This ensures that the effectiveness of a weapon for its given task is maximized beyond that which is currently achievable from existing tuning practices.

Data gathered from this device can be not only used for simply balancing gas pressure and buffer weight, but also for projecting reliability percentages with differently pressured rounds, suggesting adjustments to gas pressure and buffer weight when shooting with a suppressor or other muzzle device which changes backpressure in the gun, and tuning firerate to a specific amount of rounds per minute.

2 Components

The device has five total components divided into two subsystems: the housing and the electronics.

The outer housing consists of two parts, the buffer body and the buffer bumper. The buffer body is 3D printed using a process known as selective laser sintering (SLS), in which very small beads of a target material are melted together with a laser. SLS printing is known for its ability to enable a part to be printed with extremely tough materials which are not able to be utilized in traditional fused deposition modeling (FDM) 3D printing, and for this reason, SLS is a popular additive manufacturing option for creating functional prototypes that must withstand high loads and repetitive shock. The material chosen for the buffer body is 3201PA-F nylon. 3201PA-F nylon is significantly stronger and more durable than traditional FDM filaments such as ABS and is less prone to shattering, although it is somewhat less rigid. It is also RF-transparent, an important feature that was sought out in order to enable downloading collected data over Bluetooth from the device in the future. Machining the housing out of steel or using a 3D printing process such as selective laser melting to construct the buffer housing out of metal would not have allowed wireless data downloading to be ever be effectively implemented.

The buffer bumper is 3D printed using an FDM printer out of thermoplastic polyurethane, or TPU. This material was chosen because the Colt M4A1 data package from which certain specifications for this housing were drawn specified the use of polyurethane as the bumper material. TPU is extruded instead of cast and has subtle differences in its material properties, but for this application it makes very little difference to the functionality of this part. A production version of this device would have either a cast polyurethane bumper, or data on the spring coefficient of the TPU bumper would be measured and accounted for.

The electronics housing is a cylindrical insert which fits perfectly into the buffer housing and provides a rigid mounting platform for the electronics. It was also printed using an FDM 3D printer, except in PETG plastic.

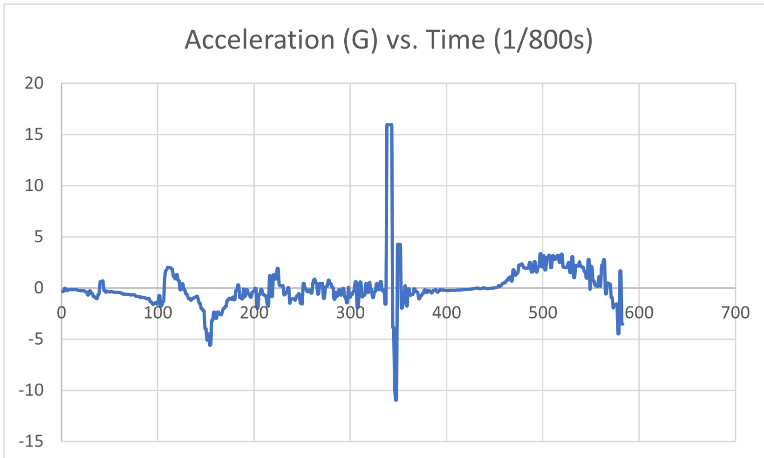
The electronics consist of a 3.7 volt, 100mAh lithium ion battery and a Seeed Studio Xiao NRF52840. The Seeed Xiao provides a relatively powerful processor for its size, but more importantly it has 256kB of RAM and 2MB of QSPI flash memory for storing captured data. It also has an integrated Bluetooth 5.0 low energy chipset and an LSM6DS3TR 3-axis accelerometer all inside of a 21x17.5mm footprint. It also has a battery charger onboard, which enables convenient charging of the lithium ion battery via a USB connection.

3 Programming

The Seeed Xiao runs code written in a variant of C that constantly records the previous 0.25 seconds of X-axis acceleration data. When an acceleration over 2G is detected, the board records the following 0.5 seconds of X-axis acceleration data, appends it to the 0.25 seconds of data recorded immediately prior to the acceleration event, and saves it in an array that stores up to 10 shots of recordings.

Data is currently downloaded via USB from the Seeed Xiao using a program written in Python. Bluetooth downloading is still a work in progress. The Python program handles serial communication with the Seeed Xiao, as well as the conversion of bytes written to the host computer's serial port by the Seeed Xiao into a human-readable form and the saving of the received data as a CSV file.

4 Results



Above is a graph of buffer acceleration versus time created using data recorded with the device. This test was conducted using an AR-15 with a 10.3 inch long barrel, a carbine-length gas system, and a mil-spec buffer spring. This was one of several shots recorded.

There are two major takeaways from this graph: one, that the LSM6DS3TR accelerometer's +/-16G measuring range is insufficient for the accelerations experienced by the buffer, and two, that the 800Hz polling rate implemented in the program running on the Seeed Xiao is insufficient. These problems can be remedied simply. My plan going forward is to design and produce my own microcontroller board using an ATMEGA microcontroller and an ADXL-series accelerometer, which have measuring ranges going up to +/-500G. However, this does demonstrate that the device is working as intended. The current state of this project can be described as a completed prototype and proof-of-concept.