JIMESE
Journal of Innovation Materials, Energy, and Sustainable Engineering
JIMESE 2(2): 125–139
ISSN 3025-0307

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Electromagnetic launcher system prototype for non-lethal engagements: Innovation in materials and engineering for sustainable defense technologies

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Received Date: June 24, 2024 Revised Date: January 31, 2025 Accepted Date: January 31, 2025

ABSTRACT

Background: Electromagnetic launchers specifically coil guns have gained a considerable attention as one of the potential tools for non-lethal engagements. **Methods:** This research will explore the potential, working principles, and calculation that purpose. Coil guns utilize magnetic field in the form of coils are used to launch a projectile at high velocity without any chemical reaction, unlike conventional firearm. Development for coil gun on non-lethal engagements are still a challenge due to the precision of impact force, device's reliability, and more. This prototype was developed as a two-staged coil gun controlled by Arduino and using a ST41 steel projectile. The system also implements IR LED in the coil as a failsafe should the timing did not work as expected. **Findings:** The results that the predicted results from the testing shown that the device could be capable for non-lethal engagements because the prototype performed with a peak muzzle velocity of 15.9 m/s and did not exceed the maximum of 100 Joules of energy at impact. **Conclusion:** This clearly shows that with more research, this method of a launcher could be promising due to the fact that in future advancements of research, coil gun is capable of great things, especially in the segment of non-lethal engagements. **Novelty/Originality of this Study:** This study contributes to the field of non-lethal weapon technology by developing a two-staged coil gun prototype controlled by Arduino, demonstrating its feasibility for non-lethal engagements with a peak muzzle velocity of 15.9 m/s and impact energy below 100 Joules, while incorporating an IR LED failsafe system to enhance operational reliability.

KEYWORDS: arduino; coil gun; electromagnetic launcher; non-lethal; ST41 projectile.

1. Introduction

There are multiple variation and form of electromagnetic devices have appeared in novels, television, and video games, but such devices have never seen common use outside of entertainment purposes. Given the way this study understand electromagnetism today, it is vague why the exploitation of electromagnetic fields produced by coils has not found widespread application compared to their mechanical counterparts. Conceptually, the coil gun is an electromagnetic field produced by a current flowing through a coil acts on an object flowing through that coil and accelerates it along the route.

All applications of this concept involve launching projectiles of some kind that can be used in similar but differentiated ways. Some of them are used in multiple fields of application such as to move subway cars, building elevator systems, weapons, and many more. Information on coil gun design exists in many fragmentary documents and on the

Cite This Article:
Simatupang, J. W., & Simangunsong, E. H. P. (2025). Electromagnetic launcher system prototype for non-lethal engagements: Innovation in materials and engineering for sustainable defense technologies. *Journal of Innovation Materials, Energy, and Sustainable Engineering, 2*(2), 125-139. https://doi.org/10.61511/jimese.v2i2.2025.932

World Wide Web (WWW), there are multiple research papers regarding coil guns with multiple stages and varied processes, but this study as not yet found the usage for non-lethal capabilities of this launcher type be utilized that way.

The goal of this research work is to show that is electromagnetic launcher, especially coil gun is suitable for non-lethal use such that in the future could be implemented in civilian use and law enforcement use. Therefore, in order to understand the underlying physics behind electromagnetic launcher, this study proposed to build a prototype in a form of two-stage coil gun that will be able to only capacitate the person, not for killing them. With the developed prototype, this study hoped to construct a strong magnetic field in the coils, that shoots an armature through a series of coils. As part of the work, this study will investigate how much muzzle velocity that is produced by the prototype, the impact force and energy of the armature at impact, deciding is coil gun be able to use non-lethally, and the improvements for the device for future improvements.

Ultimately, for this research work, this study wanted to build an electromagnetic launcher with a compact size that could be used for non-lethal use. This device could be used for home defense, and even law enforcement and riot control use in the future. In the field of law enforcement and crowd control, the ethical and humanitarian aspects of minimizing potential harm to individuals during conflict have received substantial attention. Traditional less lethal tools such as rubber bullets and beanbags, while intended to minimize lethality, can still pose a risk of serious injury and unintended consequences. As a result, the search for more effective, precise and human less lethal technologies has led to the design and improvement of the Electromagnetic Launcher (EML).

Electromagnetic launchers operate on the principles of electromagnetic propulsion, a revolutionary approach that harnesses the power of electromagnetic fields to launch projectiles at controlled speeds (Kolm et al., 1980). Compared with conventional propellant-based systems, EML offers several advantages, including reduced risk of collateral damage, and elimination of chemical propellants that contribute to pollution. The prototype will use coilgun as the base for the EML. A coil gun generally consists of one or more coils arranged along the barrel such that the path of the accelerating projectile is along the central axis of the spool. The coil is turned on and off with precise timing, and the projectile is rapidly accelerated inside the barrel by magnetic forces (Chemin et al., 2017).

Based on the background above, two important problems arised: (a) How to develop another type of equipment that could be utilized as a non-lethal engagement by law enforcement? (b) What parameters are needed to design an electromagnetic launcher that can be utilized as one of equipment for non-lethal engagements? Therefore, the objectives of our research work is to design and implement a prototype of an electromagnetic launcher in the base of a coil gun type that will use two coils for operation, to measure the aspect of muzzle velocity, then the impact energy for deciding the non-lethal aspect by formula, and to implement sensors in the coil operation as a cutoff should the timing of the cutoff did not work as intended.

However, this research work has scope and limitations such as: (a) exploring the magnetic force to launch a projectile through six coils circumnavigating the barrel of the launcher, (b) using Arduino Integrated Development Environment (IDE) for the programming of the launcher and Arduino Nano as microcontroller that controls the launcher due to the flexibility and easy source, (c) exploring some aspects of the electromagnetic launcher that are compliance for law enforcement use, (d) due to the prototype dimension, this study will only use some small components with no capacitor will be utilized, and (e) for safety reasons, this prototype will be treated as a firearm, hence the firearm safety will be implied on the testing of this work and the testing ground will be at a firing range.

1.1 Electromagnetic launcher

Electromagnetic launcher (EML) is an electromagnetic device designed for energy conversion from electrical energy to kinetic energy. There are two types of electromagnetic launcher, they are railgun and coil gun. The first EML was introduced by André Louis Octave Fauchon-Villeplée in the form of a railgun. This railgun was tested with the model that was developed in 1917. But, then the project was abandoned because of World War 1 ended. So, ending the project on its entirety (Octave 1922; Suciu, 2024).

During World War 2, German Ordinance Office proposed a viable railgun. The theory muzzle velocity is around 2000 m/s with the payload mass of 0.5 kg. The rate of fire was theorized around 12 rounds per minute (rpm). The theory was conducted possible, yet the power required to operate each launcher would need to be enough to illuminate half of Chicago (Kolm et al., 1980).

The invention of the rail gun by Kristian Birkeland marked a significant milestone in the development of electromagnetic launchers. The first prototype, which he referred to as a "silent machine gun," utilized 17 electromagnets and an 81 cm barrel to accelerate a projectile weighing 500 grams to a speed of 50 m/s. Birkeland began working on this technology in 1945, and it is considered to be one of the earliest examples of a coil gun (Chemin et al., 2017).

Rail gun is defined as a linear motor device, typically designed as a weapon, that uses electromagnetic force to fire high-velocity projectiles. Projectiles typically do not contain explosives, instead relying on the projectile's high velocity, mass, and kinetic energy to do damage. A railgun system consists of a pair of parallel conductors (rails) along a frame that slides and accelerated by the magnetic effect of current flowing into the armature from one rail and returning along the other rail. It is based on the same principle as homopolar motors (Rashleigh & Marshall, 1978). An example prototype of a rail gun that will be utilized on warships as shown in Fig 1.

Fig. 1. Prototype of naval rail gun
(de Silva, 2017)

This project was tested with the model that was developed in 1917, and then the project was abandoned because World War 1 ended. During World War 2, German Ordinance Office proposed a viable railgun. The theory muzzle velocity is around 2000 m/s with the payload mass of 0.5 kg. The rate of fire was theorized around 12 rounds per minute (rpm). The theory was conducted possible, yet the power required to operate each launcher would need to be enough to illuminate half of Chicago (Hogg, 1969).

The invention of the coil gun by Kristian Birkeland marked a significant milestone in the development of electromagnetic launchers. The first prototype, which he referred to as a "silent machine gun," utilized 17 electromagnets and an 81 cm barrel to accelerate a projectile weighing 500 grams to a speed of 50 m/s. Birkeland began working on this technology in 1945, and it is considered to be one of the earliest examples of a coil gun (Birkeland, 1904).

1.2 Coil gun

On the other hand, coil gun, also known as a Gauss gun, is a type of mass driver consisting of one or more coils used as electromagnets in a linear motor configuration to accelerate a ferromagnetic or conductive projectile to high speeds A coil gun generally consists of one or more coils arranged along the barrel such that the path of the accelerating projectile is along the central axis of the spool. The coil is turned on and off with precise timing, and the projectile is rapidly accelerated inside the barrel by magnetic forces (Gopinathan et al., 2024; Khandekar, 2016; Ombe et al., 2019; Shubov, 2020; Skala & Kindi, 2013). An example of a prototype coil gun is shown in Fig. 2.

Fig. 2. Prototype of a coil gun
(Go et al., 2018)

A coil gun differs from a railgun because the direction of railgun acceleration is perpendicular to the central axis of the current loop formed by the power rail. Additionally, railguns typically require the use of wipers to pass high currents through projectiles or sabots, whereas coil guns do not necessarily require wipers.

1.3 Non-lethal weapons (NLW)

Non-lethal weapons (NLW) are mentioned as “weapons, devices, and munitions that are explicitly designed and primarily employed to incapacitate targeted personnel or materiel immediately, while minimizing fatalities, permanent injury to personnel, and undesired damage to property in the target area or environment. Non-lethal weapons are intended to have reversible effects on personnel and materiel” by the United States Department of Defense (DOD) (Department of Defense (DoD), 2011; National Security Research, Inc, 2002; US Department of Defense, 2020).

Non-lethal weapons are designed with the primary objective of minimizing injury or loss of life. However, incidents resulting in fatalities may still occur as a result of several factors, including misdirected shots, pre-existing medical conditions, inadequate training of the user, repeated applications, and deliberate misuse of the weapon. It is pertinent to note that any armament with the ability to neutralize a target is intrinsically capable of causing fatality in particular situations. The term "non-lethal force" denotes the lack of the intent to take life.

As of now, non-lethal launchers are launching non-lethal rounds that are designated to incapacitate a target without causing death. Mostly, these rounds rely on kinetic energy and blunt force trauma to achieve this effect. Examples such as rubber bullets, beanbag rounds, and sponge grenades are some examples of non-lethal rounds used by law enforcement agencies for crowd control and other similar purposes (Kapeles & Bir, 2019; Lyon, 1997; Sandia National Labora; United Nations, 2015).

There's room for improvement in non-lethal weapons and their methods for utilize, and claims for their relative security are more often than not subordinate on their appropriate use. For case, elastic bullets were expecting to be terminated at the ground and hit the target as it were after ricochet, and other non-lethal bullets are outlined to be let go at the lower body as they can be deadly on the off chance that terminated specifically at the head (United Nations, 2020).

Hence there are limits of applied force on a certain launcher that if exceeded or placed wrongly (headshot, vital organ shots), will fatally wound or even incapacitate the target. One of the leading examples of this less-lethal launchers that currently in use are FN 303, 12 Gauge munitions for shotguns, and 40mm launcher that is launched by grenade launcher. For this project this study will be comparing how the prototype compares to the FN 303 in terms of performance on deciding if the prototype is a non-lethal or not.

To effectively incapacitate a person with a beanbag 12-gauge shotgun shell, the force of impact that is affected by the perpetrator is "Standard" MK Ballistic Systems Flexible Baton-12 (also known as MK12S) fires at around 70-90 meters per second or 230-300 feet per second.

Given the characteristics of coil-guns and the aforementioned factors above, to predict the muzzle exit velocity, impact force, impact energy, and time, this study must use Eq. 1 to Eq. 4 (Gong et al., 2012; Holzgrafe et al., 2012; Zweifel et al., 2017).

$$v_{exit} = \sqrt{\frac{2}{m} V \ \mu o \chi_m n^2 I^2} \quad \text{(Eq. 1)}$$

$$F_p = \left(\frac{1}{2d} * \ m * \ {v_x}^2\right) * 2 \quad \text{(Eq. 2)}$$

$$E = \frac{1}{2} * m * {v_{exit}}^2 \quad \text{(Eq. 3)}$$

$$t = \frac{d}{v_{exit}} \quad \text{(Eq. 4)}$$

The parameters in this study are defined as follows: m represents the mass of the armature, measured in kilograms (kg), while V denotes its volume in cubic meters (m^3). The symbol μ_0 refers to the vacuum permeability, a physical constant defined in SI units as $4\pi \times 10^{-7}$ V·s/(A·m). The magnetic susceptibility of the projectile is denoted by χ_m, a dimensionless proportionality constant that indicates the degree of magnetization a material undergoes in response to an applied magnetic field, expressed in henries per meter (H/m). The variable n represents the number of coil turns per unit length, calculated by dividing the total number of turns by the total length of the coil in meters. The electric current flowing through the coil is symbolized by I and is measured in amperes (A). The exit velocity of the projectile is indicated by v_x in meters per second (m/s), and the impact energy is represented by E, measured in joules (J). The peak impact force is denoted by F_p and expressed in newtons (N). The distance from the muzzle tip to the target is indicated by d in meters, while t represents the time taken to reach the target, measured in seconds (s).

1.4 HT-X3005 chronometer

A ballistic chronograph (in this case the Chronometer type is HT-X3005) is a device used to measure the initial velocity of a small arms projectile. Using this device will allow the author to know the armature's muzzle velocity, in order to calculate the bullet's energy and vertical correction when shooting from a distance. This device will accurately measure the muzzle velocity of the armature; hence it will be used by then in this research work (Carlucci, 2007; Hanks & Ayers, 1993).

The mechanism of this device is determined by two sets of photodiodes and photodetectors, one on each end of the tube. As soon as the bullet dives into the tube, the ray is blocked at the beginning and end of the ray. A microcontroller detects these events and then calculate the velocity based on the time difference between the two events and the known distance difference between the two detectors (Gilson et al., 2021; Ma et al., 2021;

Milutinovic et al., 2019; Syam & Mochtar, 2019). The physical photo as an example of the Chronometer with its specification can be seen in Figure 3 and Table 1.

Fig. 3. HT-X3005 type chronometer

Table 1. HT-X3005 chronometer specifications

Item/Parameter	Description
Manufacturer	HANTE
Firerate	0-3600 shoot/minute
Velocity	2-1500 m/s (10-5000 fps)
Energy	0-999 J
Range	0-999 m
Accuracy	Error ≤ 0.5%
Bullet weight	0.01 gr - 99.99 gr
Caliber	0.01 mm - 99.99 mm
Dimension	44 x 73 x 33 mm
Working temperature	-10 ℃ ~ + 50 ℃

(Holzgrafe et al., 2012)

1.5 Related works

Bohumil Skala and Vladimir Kindl proposed a single stage, sensor less coil gun that demonstrate the basics of an operating coil gun especially with simple system where it is sensor less and only use a single coil for operation. This prototype shown that high capacitor charge needed to run this prototype because the stress on the components will be great should be no capacitor used on this prototype. This prototype also respected the time constraint in the coil placement because it affected the muzzle velocity of the prototype (Skala & Kindi, 2013).

Raffiudin Syam proposed a design of an EML in a form of a coil gun that utilizes DC current source. The design operated by seven stage system and the operation voltage used by the coils are in between 25.1 V and 70.6 V. This research shown that the change in the voltage at the coils played a huge part because the magnetic force increases in the coils, increasing the performance on the prototype. The distance between coils also affected the velocity inside the barrel and the exit velocity in the armature itself (Syam & Mochtar, 2019).

Byeong-Soo Go; Dinh-Vuong Le; Myung-Geun So proposed a prototype, fabrication process, and the analysis from the coil gun system with a pulsed power module. The mechanical design of the coil gun itself has been simulated with the voltage and velocity of the armature itself. This resulted at the muzzle velocity at 107 m/s achieved at peak performance using 10 KV capacitor and 21.68 Kg armature weight (Go et al., 2018).

Arcflash has developed a working commercial coil gun to be used in the broad market. This device is called EMG-01 Alpha 8. This device is 8 stage coil gun with IGBT switch and low voltage that can be fired on fully automatic fashion. This device is also used as a benchmark as a comparison for this prototype. This device is capable of velocity up to 45 m/s. The device also used a 6s battery with voltage of 25.2 V. This prototype is magazine fed with a projectile weight of 4.6 gr with carbon steel composite material (Archflash Labs, 2018). The whole related works comparison is summarized in Table 2.

Table 2. Related Works Comparison

No.	Related Research	Coil stages	Variable voltage	Voltage	Power Source by	Capacitor Used	Dimension
1	Skala & Kindl (2013)	1	X	28 V	MatLab Simulation	Y	Not Specified
2	Syam & Mochtar (2019)	7	Y	25.1-70.6 V	MatLab Simulation	Y	Not Specified
3	Go et al. (2018)	1	X	4 kV	Pulse Power Source	Y	Not Specified
4	Arcflash Labs (2018)	8	X	Max 25 V	LiPO Battery	Y	10.0" (Barrel length)
5	This Work	2	X	24 V	LiPO Battery	X	5.0" (Barrel length)

2. Methods

2.1 Full prototype implementation

This research work follows the conventional life cycle method, which consists of 5 stages: planning phase, analysis phase, design phase, implementation phase and testing phase. After conducting an in-depth literature review, this research work then continues with the design, implementation and testing of the prototype. Aim of developing a launcher that is capable of less-lethal purposes in the future. Now, this study will be focusing on the design and implementation. Fig. 4 shows a block diagram of operation of the launcher in a single cycle.

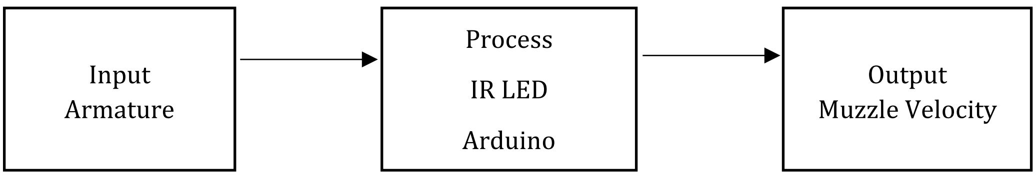

Fig. 4. Block diagram for a single cycle operation

The design of the prototype is to cycle and launch a projectile properly. This system consists of 2 firing coils and will use Arduino as the system managing the whole firing system because the IR LED phototransistor and receiver to act as a cutoff for the firing system.

The system used two stage coil operation for launching the armature. This is shown that there are two coils in the system. This is for increasing the velocity of the armature that once passed the first coil, there are another coil for accelerant purpose so that the muzzle velocity is faster.

If the coils did not cut off properly, the armature will be stuck on the first coil, and did not launch into the second, hence making the armature stuck into the system. The same principle goes into the second coil as well; the launch sequence did not run successfully should the armature stuck at the second coil. Top view of the prototype is shown in Fig. 5.

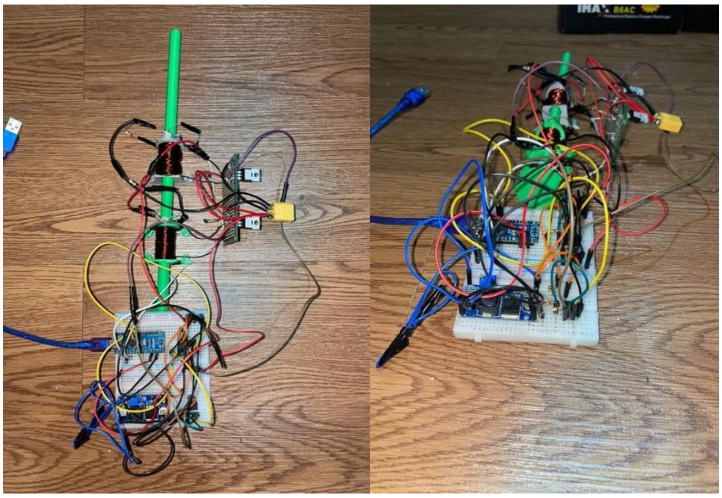

Fig. 5. (*Left*) Top-down view of the prototype and (*Right*) Back view of the prototype.

2.2 System flow chart

The system flowchart can be described as a single cycle of an armature that went from the magazine and the launching sequence, until the armature left the barrel and the launcher entirely. The launcher's flowchart is shown in Fig. 6.

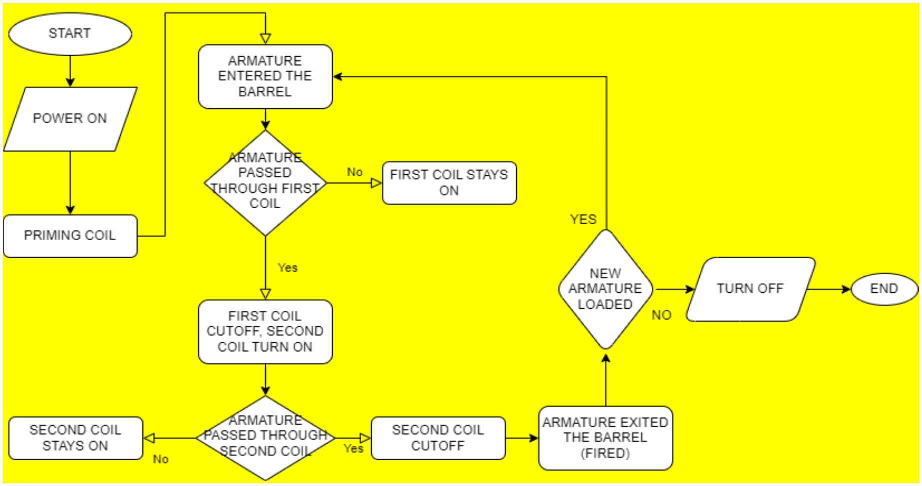

Fig. 6. Flowchart of the two-stage coil gun.

As seen from the flowchart above, the process of coil priming is mandatory and highly necessary because it takes time to form the magnetic field around the coils so that the armature is able to be fired from the barrel. Simple mechanism of the firing system is when that the timing is off, the IR LED will conduct as a second parameter should the coils are deactivated to launch the projectile into the second coil or to launch it properly exiting the barrel to the target. This study decided to use breadboard for the main board for the op amp, converter, and the Arduino because during the solder process, the LM358 did not attach properly onto the PCB board.

2.3 Testing procedures

The testing procedures of this coil gun is conducted by using a device called chronometer. Chronometer works as a measurement device for exit velocity of the launcher. This device is placed at the tip of the launcher and the armature will pass through two light gates so that the exit velocity can be measured (Hartawan et al., 2023).

The proceedings will be conducted ten times, with a delay of 60 seconds so that the system can be fully restarted for safety reason and the chronometer is reset and ready for measurement. The placement of the chronometer in the coil gun shown at Fig. 7.

Fig. 7. Chronometer placement for muzzle velocity testing

The research work/performance is measured by using a uniform armature in terms of material, length, and weight for consistency of the muzzle velocity and in a uniform distance of 5 meters to hit a steel. This test is conducted in a safe area to negate the risks of stray bullet hitting other property, animals, even humans. This test is conducted by firing the prototype in a stable position to the target within a uniform distance and voltage for 10 samples for the data acquiring, each firing attempts will be recorded to count the muzzle velocity, then using the formula mentioned above at chapter 2 will determine the impact force of each trial.

Then, once the muzzle velocity is obtained, this study will calculate the impact force and impact energy to measure the lethality of the device. The parameter used is at the impact energy at least 100 Joules, the minimum energy to harm a person (Hartawan et al., 2023). The testing will be conducted at a firing range at a safe location to ensure the safety of the launcher, tester, and the surroundings. This is done so that should be there are accidental mischarge, mechanism jam, mechanical and electrical faulty, etc. Steel ST41 composite with a density of 7.85 g/cm^3, diameter of 7 mm with a length of 2 cm, and the volume of 3.08 cm^3 and weight of 6.04 g will be used for the armature on this project. This ensure that the armature is using ferromagnetic material and will slide out of the barrel easily in case a jam occurred in the system.

3. Results and Discussion

The testing procedures of this coil gun is conducted by using a device called chronometer. Chronometer works as a measurement device for exit velocity of the launcher. This device is placed at the tip of the launcher and the armature will pass through two light gates so that the exit velocity can be measured (Skala & Kindl, 2013). The proceedings will be conducted ten times, with a delay of 60 seconds so that the system can be fully restarted for safety reason and the chronometer is reset and ready for measurement. This project is measured by using a uniform armature in terms of material, length, and weight for consistency of the muzzle velocity and in a uniform distance of 5 meters to hit a steel. This test is conducted in a safe area to negate the risks of stray bullet hitting other property, animals, even humans.

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Steel ST41 composites with a density of 7.85 g/cm^3, diameter of 7 mm with a length of 2 cm, and the volume of 3.08 cm3 and weight of 6.04 g will be used for the armature on this project. This ensure that the armature is using ferromagnetic material and will slide out of the barrel easily in case a jam occurred in the system. The result of electromagnetic launcher prototype in the form of coil gun for non-lethal engagements are: (1) two quantity of the coil for the launcher; (2) arduino as the main board with the Metal Oxide Semiconductor Field Effect Transistors (MOSFETs).

Table 3. Testing results

No.	Muzzle Velocity (m/s)	Maximum Force (N)	Impact Energy (J)	Time Travelled (s)
The first measurement				
1	13.7	0.225	0.563	0.365 s
2	13.3	0.212	0.531	0.375 s
3	12.9	0.199	0.499	0.387 s
4	12.3	0.181	0.454	0.406 s
5	11.7	0.164	0.411	0.427 s
6	11.6	0.162	0.404	0.431 s
7	11.4	0.156	0.39	0.439 s
8	10.8	0.14	0.35	0.463 s
9	10.1	0.122	0.306	0.495 s
10	9.9	0.118	0.294	0.505 s
The second measurement				
1	15.7	0.296	0.74	0.318 s
2	15.3	0.281	0.702	0.327 s
3	14.8	0.263	0.657	0.338 s
4	13.5	0.219	0.547	0.370 s
5	12.6	0.190	0.476	0.397 s
6	12.1	0.176	0.439	0.413 s
7	11.9	0.17	0.425	0.420 s
8	11.1	0.148	0.3696	0.450 s
9	10.8	0.14	0.35	0.463 s
10	9.7	0.113	0.282	0.515 s
The third measurement				
1	15.9	0.303	0.758	0.314
2	15.5	0.288	0.721	0.323
3	14.9	0.266	0.666	0.336
4	14	0.235	0.588	0.357
5	13.7	0.225	0.563	0.365
6	12.3	0.182	0.454	0.407
7	11.9	0.17	0.425	0.420
8	10.5	0.132	0.331	0.476
9	9.2	0.102	0.254	0.543
10	8.3	0.083	0.207	0.602

At the time of testing, the source voltage at 24V for each testing. The velocity of the armature will be recorded using a chronometer and will be calculated individually for the impact force in each run as mentioned in sub-chapter 3.3. This prototype will run 3 tests in total that consists of 10 trials for each testing. Each testing will use both coils for uniformity of the data. The interval of each trial will be at 5 seconds. Testing results are recorded in Table 3.

About the measurement of maximum force and impact energy, the calculation below will be used. For example, if this study use the first measurement of speed as 13.7 m/s, then this study can indicate the maximum force and impact energy as mentioned:

$$E = \frac{1}{2}\ x\ 0.006\ kg\ x\ 13.7^2 = 0.563\ J \quad \text{(Eq. 5)}$$

$$F = \frac{1}{2x5}\ x\ 0.006\ kg\ x\ 13.7^2 = 0.112164\ x\ 2 = 0.225\ N \quad \text{(Eq. 6)}$$

$$s = 5/13.7 = 0.365\ s \quad \text{(Eq. 7)}$$

As seen from the measurement results in Fig. 8, there is a drop in the performance of the muzzle velocity. This is due to performance drop of the battery in the coil operations. This is expected due to the charge that is contained from the battery is discharged for the operation of the coils. In the aspect of performance of the prototype can be seen from the table above shown that the drop off in the performance is deemed acceptable due to the fact that impact energy and the impact force shown at the table above dropped off slightly. The drop-off can be mitigated by the usage of capacitor at the coil driving system, so that the device can show more stable performance during the run of the testing. The drop-off also varied on the distance that the armature took to impact to the target.

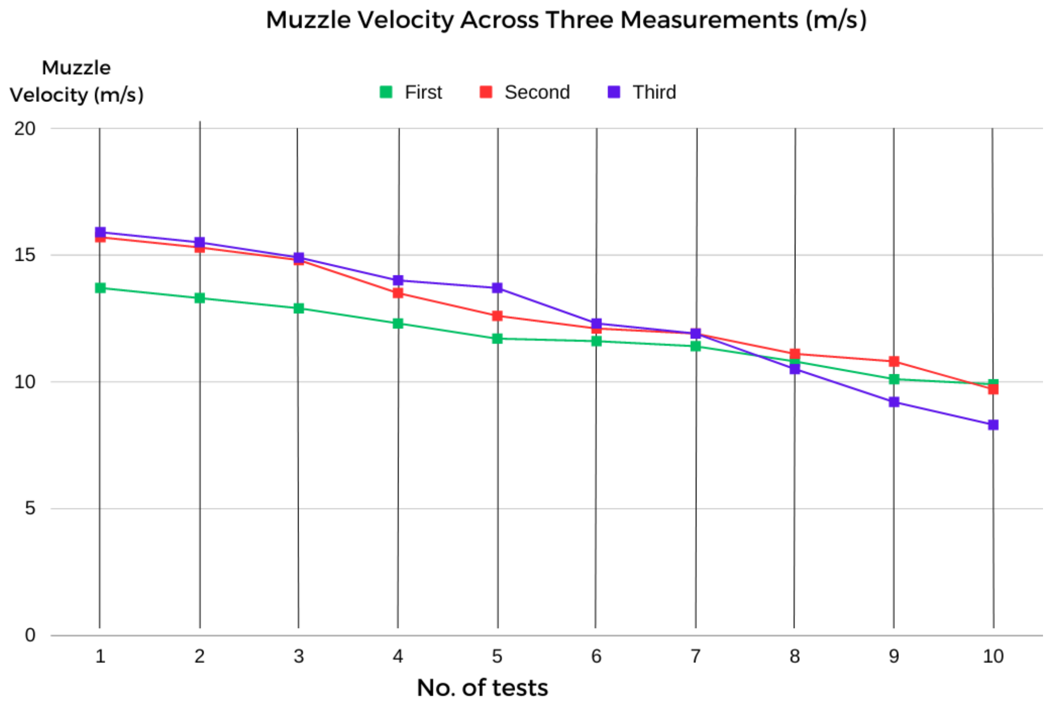

Fig. 8. Graph of muzzle velocity across three measurement

The performance also showed that because of that during the priming phase, the battery consumed a lot of charge in the battery. Hence, the impact energy will be decreased due to this factor. More coil stages should be implied further to the prototype to increase the performance. Shown at the parameters above, the prototype in terms of impact energy started quite impactful and dropped some in a consistent manner in test 1, and dropped quite surprisingly but with a tradeoff with a higher first muzzle velocity that occurred in the test 2 and 3. The impact energy is deemed non-lethal, but more energy is needed due to the fact that the comparison device, is capable of 4 Joules in terms of maximum impact energy. This is still on the non-lethal range, yet could be improved for more impact energy. More

 https://doi.org/10.61511/jimese.v2i2.2025.932

coil stages with more turns on the prototype could boost the energy resulted that could match the comparison device.

The velocity also decreased in a acceptable drop-off due to the fact that this prototype uses two coils as a launcher for the prototype. Should the system increased to use six coils, the velocity will increase greatly, at an expense of more use of battery charge to prime the coil and to operate the coil. Coil placement also play a huge factor at this prototype. This is because should the coil be placed at the end of the muzzle; the exit velocity will be increased greatly. This comes with a tradeoff that the velocity of the first coil and the second coil will be decreased significantly rather than the coils placed close to each other. From the testing above, the velocity is highly dependent for the impact force and energy derived from the calculation mentioned above. This is due to the fact that should one of the nominals at the formula is changed, this is highly affecting the final product that the armature will change in terms of velocity. For example, larger armature weight, current, coil turns, etc. Should be changed, the velocity will change greatly, and then the results will differ every time.

After conducting a series of tests, it was concluded that the two-stage coil gun prototype utilizing an Arduino Nano presented several strengths and weaknesses. Among its strengths, the use of an infrared (IR) LED as a sensor proved to be successful, as it allowed the system to detect when the armature passed through the coil, enabling the coil to disengage automatically—integrating the coil effectively into the weapon system. Furthermore, the prototype achieved the primary objective of the research, as the calculated impact force demonstrated the potential to incapacitate a person efficiently and with relatively simple mechanisms. The use of two-stage coils was also found to be effective in delivering sufficient impact energy to neutralize a target, confirming the design's functional viability.

However, the prototype also exhibited notable weaknesses. A major concern was the lack of safety mechanisms and failsafe features, which could lead to a high risk of accidents in future applications. Additionally, the system lacked the ability to control individual coil operations and adjust voltage levels, resulting in inefficient energy usage and potentially rapid battery depletion during extended use. Another critical drawback was the direct power supply from the battery without the inclusion of capacitors, leading to high power consumption and a significantly shortened battery life. These limitations highlight the need for further refinement before the prototype can be considered for practical deployment.

4. Conclusions

To recapitulate the result and the discussion of design and implementation of two stage coil gun using Arduino and without capacitors, this study can conclude that the prototype can incapacitate a person non-lethally should the situation is necessary. The reason behind it because the energy calculated from the obtained maximum muzzle velocity is 15.9 m/s with 0.758 N of force. The impact energy did not exceed the maximum energy of 100 Joules that is the minimum energy that it could incapacitate a person lethally.

Acknowledgement
The authors deeply acknowledged The Research Institute and Community Service (RICS) of President University for supporting this work through the incentive schemes for journal publications.

Author Contribution
The authors have equally contributed to the conception, writing, and revision of this article, ensuring its accuracy and integrity.

Funding
This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest
The authors declare no conflict of interest.

Open Access

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