Testing the efficiency of laser technology to destroy the rogue drones

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Abstract

A large body of research shows the increasing numbers of drones attacks despite RF jammer systems and other technologies. This incredible increase in drone attacks means that the existing solutions are not enough to stop it. The objective of the article is to present a study on the combination of a laser beam with an optical focusing system to create a new cannon to crush rogue drones. The experimental method relies on an innovative design incorporating a laser module and groups of optical lenses to focus the power in one point to carbonize any target. Specifically, it is the laser with an adjustable lens position from 477mm to 617mm to focus the laser beam on the desired distant object. We measured the necessary time to burnt acrylic plastic, wood, and hard carton from a distance of 55 metres. It was noticed that the laser efficiency is proportional to the laser power and time the cannon is turned on. Tests on the laser cannon revealed that laser burner technology can destroy illegal drones. However, it was found that the laser is affected by adverse weather conditions, such as fog, rain, and clouds. Apart from that, the frailty of this technique is connected with the stabilizing system requirements, energy, overheating, and the time needed to destroy an object. Regardless of the drawbacks of the technique, the laser is the only solution with high efficiency that can ruin or intercept autonomously programmed drones, as this cannot be achieved by the RF jammer or any other solutions. The procedure can be repeated with new changeables to achieve a positve result, specifically, the use CO2 laser tube with a high-efficiency chiller to increase the laser power.

Keywords:

Introduction

Drones are obtainable by anybody who is interested in the aviation world. Apart from entertainment purposes, this technology offers a multitude of potential. Its accessibility has led to renewed attempts by malicious actors, including terrorist groups, drug dealers, and organised crime, to exploit drones for nefarious purposes (Dörtbudak, 2015; Zegart, 2020). It is possibly unsurprising that much of the current worry about the use of low-cost and modified drones is focused on their use as a supply system for explosive devices (Archambault and Veilleux-Lepage, 2020; Boyle, 2020). A drone can carry a 4K camera to fly over sensitive places for spying and collect secret and private data. Consequently, it can be applied to information collection, surveillance and reconnaissance, combat purposes, and mine detection. Drones can be used by terrorist groups, drug dealers, and organised crime, as shown in Fig. 1 (Englund, 2019).

Western military reports and investigations reveal extended use of rogue drones in Afghanistan, Iraq, and Syria. The increasing number of attacks with modified drones shows the limitation of the existing technology to stop and neutralise rogue drones (e.g. RF jammer, hand-held gun jammer, trained eagle). In this manuscript, we examine the danger of using rogue drones in our public lives and stress that this technology can be used by unauthorised groups to achieve their goals. We identify threats resulting from their misuse for air transportation and airports. Relying on an experimental approach, we designed an original method to carbonise any target with a laser beam and groups of optical lenses which focus the power in one point. Specifically, the idea was to use the laser with an adjustable lens position from 477mm to 617mm to focus the beam on a desired distant object. The fabrication phase of the laser cannon prototype is discussed. We aim to prove that high energy fixed laser cannons can burn holes in the errant drone and they can destroy the autonomously programmed drone. We consider laser systems as much cheaper and more effective than other technologies to knock out a drone.

Threats related to misuse of drones

Humanity has had a severe warning from the modified drone (assassinatians, destruction of the economy). The drone costs around $45; it can shut airports and spark global turmoil. In the future, it could push countries closer and closer to all-out war (Zhai et al.,2020). Far beyond being a nuisance and safety annoyance in restricted areas, including oil fields, airports, the liquidation of political figures is possible (Bhattacharjee, 2015; Ludvigsen, 2018). Drones are not simple toys; in the Middle East, a group of drones was used in the latest attack on an oil facility in Saudi Arabia, in the UAE, and Khmeimim airbase in Syria (*Drone strike deals a blow to Saudi energy ambitions*, 2019; Yan, 2020). On

May 14, a coordinated attack by ten modified drones caused fires at a major oil processing facility and nearby oil and gas field in the Abqaiq processing facility, suspending around 50% of the Saudi's daily petrol production. Saudi Arabia's oil production was halved after the irregular attack on its oil-field station. On Aug. 4, 2018, two modified drones detonated explosives in Caracas, where the President of Venezuela, Mr. Maduro, was speaking to the Bolivarian National Guard. The Venezuelan government says the event was a targeted attempt to assassinate President Maduro (*Venezuela Assassination Attempt,* 2018). Criminals used a drone to deliver drugs straight to a prisoner's cell windows in an individual smuggling bid in Manchester Apr. 22, 2016, and in Belgium in 2019. Drones attacks have not been limited to sensitive locations, as discussed in the next section.

Drones threat to airports and airlines

Operations of the world's biggest international aviation hub have ground to a halt due to suspected drone sightings. Illegal modified commercial drones can be acutely confusing for international airports. In the UK, Gatwick Airport closed down for 33 hours due to an unlawful drone "attack," causing about 1,000 flights to be delayed or cancelled in 2018. Rogue drone activity forced Dubai International Airport to close three times in 2017, causing financial losses estimated at more than $16.6 million. On Sept. 22, 2019, Dubai airport was closed for 15 minutes after a suspected unidentified drone siting. On Aug. 8, 2019, the Houthi group attacked Abha international airport in Saudi Arabia, acutely confusing the airport's work. The fear in the future is of a collision between a commercial airplane and a drone. The problem now is that international airports are under pressure to fix and install an anti-drone technology system. In 2017, a rogue drone collided with a Boeing passenger plane, causing extensive damage to the aircraft at Mozambique Airport (Journal Wings, 2017). If you have multiple planes on fire and hundreds of dead on the runway, governments will be forced to install a counter-drone system overnight. Day by day, the number of suicide drone attacks is increasing, as shown in Fig. 2. Both incidents at airports and public facilities raise the need for new technology to protect from drone threats. Many radars systems *can't* easily or quickly detect and neutralise rogue drones. Even expensive patriot anti-missile batteries owned by influential countries are not explicitly designed for destroying and neutralising suicide drones. Experts say demand for anti-UAV systems is increasing rapidly on the market (Hartley and Belin, 2019; Brookes, 2019).

Figure 2. The map shows the increase in worldwide drone incidents and attacks (Dedrone, 2019).

The jamming system can cut off the radiofrequency communication links with drones, but it cannot stop autopilot programmed and autonomous code drones. The anti-drone trained eagle and catch class technology have drawbacks because of their limited range to catch a fast and agile drone. It is well-established that existing anti-drone technolo-

gies *can't* neutralise drones one hundred percent. The existing products and solutions proved useless to stop an illegal drone (Shi *et al.*, 2018; Csengeri, 2019; Mîndroiu and Mototolea, 2019). We found a laser technique that can kill drones with high accuracy, as will be discussed in the next section.

Existing technology limitations

Counter-drone technology, also known as counter-UAS, or counter-UAV technology, refers to systems that are used to detect and disable drones. All solutions used to disable rogue drones include:

- Anti-drone jammer system

- Counter-drone hand-held gun jammer

- Anti-drone trained eagle

- Anti-drone catch class

- Anti-drone airborne net-guns

The existing technology cannot control and neutralise autonomous pilot drones and have many drawbacks, as illustrated by the following examples:

- The jammer device can cut off the radiofrequency links with drones, but it absolutely cannot destroy autonomous pilot drones,

- Radar cannot detect low altitude drones,

- Cannot stop drones working with a frequency link communication higher than 6 GHz,

- Some criminals and terrorists have implanted anti-jammer systems inside the rogue drone, which means the radio frequency cannot be jammed.

We therefore concluded that there is no real system to counter illegal drones, whether radio-frequency jammer or any other solutions. We will study the concept of the laser beam to carbonise and destroy any types of drones, including the programmable drone in the next section. The purchase of technology to stop an illegal drone is expensive, but it may be not effective. Our research can be treated as an alternative solution for destroying illegal drones.

Study and realisation of a laser prototype solution to destroy an illegal drone

In this section, laser power energy will be examined as the best solution to kill a rogue drone, as illustrated in Fig.3. There is no research confirming the usefulness of this gun due to the confidentiality of the subject. So we will manufacture a prototype with 38W laser power to test and determine the feasibility of this technique to burn any drones (GPS communication, radio frequency communication links, or autopilot programmed). We studied and simulated all the mathematical equations and analysed the relationship between laser power and the wavelength. We will evaluate the influence of the atmosphere on the loss of energy to carbonise rogue drones. The laser cannon is a new protection system; it can so far neutralise any types of drones (Pu, 2019). The USA and China

have started using the expensive laser beam technology as a system to deter and destroy suicide drones.
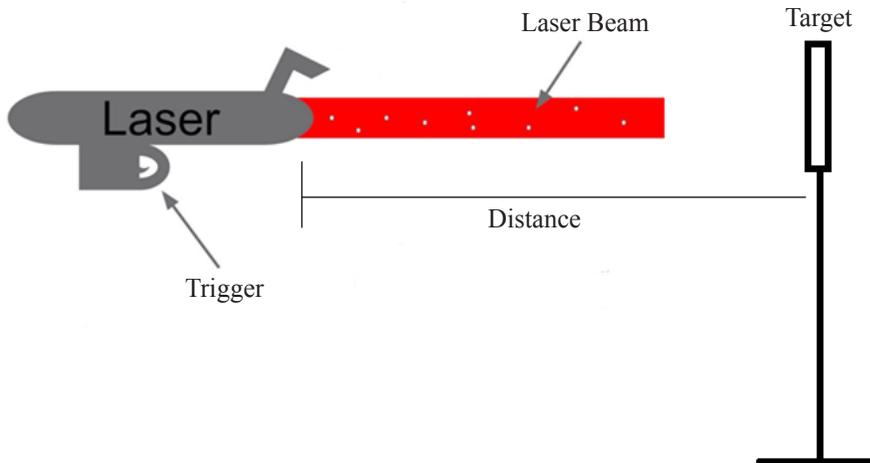
In 2018, China, created a laser gun ZKZM-500 that can carbonise humans at a range of 800 metres, yet weighs only 6.6 lbs (Yang, 2018). The US Naval Sea Systems Command created the Navy directed energy weapons program office. It aims to change the way the Navy fights in 2020 by transitioning directed energy and electric gun technology, providing the warfighter with additional tools to combat future battles (Lu *et al.*, 2020). This gun uses a laser beam that can be tuned to high output energy to crush the rogue drone or cripple the target's sensors (4K camera, GPS module). The weapon is low cost per shot, as each firing of the handheld laser weapon requires only minimal cost to produce the energetic pulse around it.

4.1 Gaussian beam propagation calculator

We took the Rutherford-Bohr model of an atom and the position of its electrons in thermodynamic equilibrium as a basis, and more particles were found on lower electron paths. Lower energy levels were close to the atom core, and fewer electrons were situated on higher electron paths and higher energy levels. The number of particles (Nx) at any energy level (x) of an atom can then be determined based on the Boltzmann distribution (Lazer and Arul Teen, 2019), given by:

$$N_x = N_1 e^{-\frac{E_x}{K_B T}} \quad (1)$$

Here:

N_1: is the number of electrons in the ground state E1,
K_B: is the Boltzmann constant 1,
T: is the absolute temperature.

For the generation of light, this distribution has to be inverted. Electrons have to be excited from a lower laser energy level to a higher one by introducing external energy to the atom. In the case of artificial light generation, such an introduction of power is referred to as pumping. Pumping of electrons from a lower ground level to a higher state finally results in a population inversion. After a short lifetime at such a higher energy level, the electron spontaneously falls back to its initial (ground) state to compensate for the atom's excited state. In most laser uses, it is necessary to shape, focus, or modify the laser beam using optical elements and lenses. In a typical laser-beam, transmission

can be estimated by assuming that the laser radiation has an ideal Gaussian strength profile, which corresponds to the theoretical TEM$_{00}$ mode. One parameter useful in determining the effectiveness of a gaussian laser beam is the beam irradiance at the target. For a beam with output power P$_0$ and cross-sectional area, (A) at the goal, the peak irradiance IP at the destination is given by Eqn. 2:

$$I_P = \frac{P_0(\tau)}{A} \quad (2)$$

Where:

τ : The atmospheric transmittance,
A: Major system design goal is to maximise Ip by minimising the beam cross-sectional area (A) and optimising the product $P_0(\tau)$.
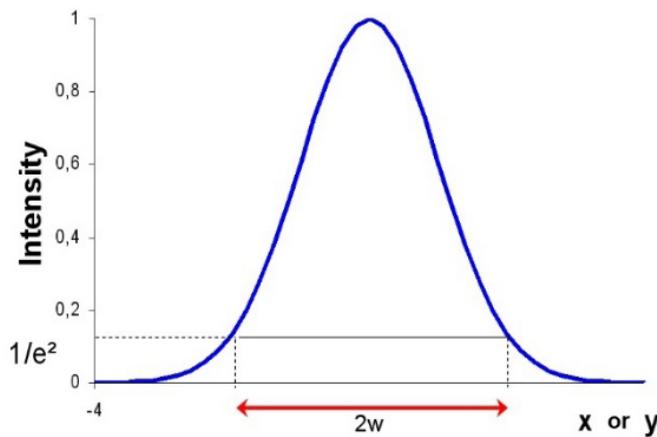
Figure 4. Intensity profile of Gaussian beam.

Most laser beams have a Gaussian intensity profile in the transverse dimension. The Gaussian beam is as regarded as a TEM wave with a spherical phase front. The beam radius (w) is defined as that transverse distance from the centre of the shaft, as shown in Fig. 4. The two parameters of most interest in describing the propagation characteristics of a gaussian beam are the beam radius $w_{(z)}$ at any distance (z) from the beam waist and the radius of the curve of the phase front $R_{(z)}$, as shown in Fig.5 (Mihoubi, Bencheikh and Manallah, 2018). These two parameters are specified in Eqn. 3 and 4, respectively:

$$W(Z) = w_0 \sqrt{1 + \left(\frac{\lambda_z}{\pi w_0^2}\right)^2} \quad (3)$$

and,

$$R(Z) = Z\left[1 + \left(\frac{\pi w_0^2}{\lambda_z}\right)^2\right] \quad (4)$$

Eqn. 5 gives the beam divergence angle.

$$\theta = \frac{W(z)}{z}, for\ Z'' \ Z_r = \frac{(\pi w_0^2)}{\lambda} \quad (5)$$

Where:

θ: in radians,
W_0: is the radius at the beam waist,
λ: is the wavelength.
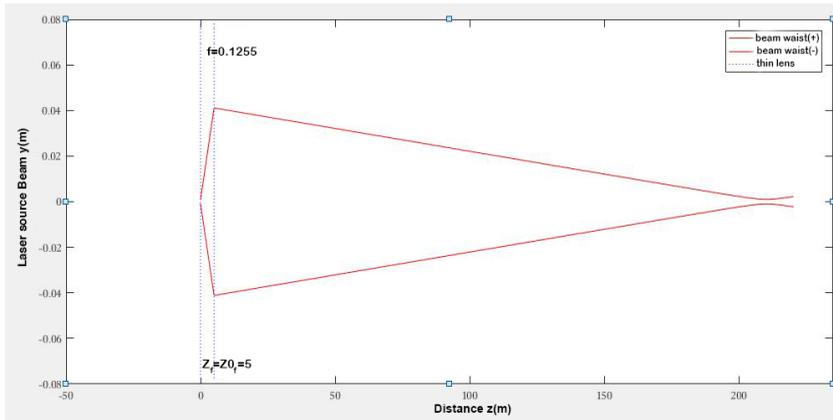
Figure 5. Gaussian beam propagation (Z=200 metres).

Attenuation of laser beam propagation in the atmosphere

During the laser diffusion in the atmosphere, the laser beam suffers reduction due to absorption and scattering by all the atmospheric species present in the propagation path, as illustrated in Fig. 6. In this section, we calculated a theoretical model for mitigation of the laser beam due to the dispersion by the atmospheric particle (mist, haze, fog, and dust) as a function of visual range (Frehlich, 2000). The laser beam's transmittance in the atmosphere is critical in many military and civilian applications with technique development using a laser beam (Zhang *et al.*, 2019). The atmospheric path is categorised horizontally (constant pressure) and the slant path (changed force). The absorption occurs via carbon dioxide, ozone, and water vapor. This is dependent on the weather and the path length. The general method by which radiant flux reduces in passing through the atmosphere is called extinction. The transmittance of a path through the atmosphere can be expressed by Lambert's law, as shown in Eqn. 6 and Eqn. 7, respectively:

$$T_L = e^{-\gamma L} \ (6)$$

Where T_L Transmittance through path length (L)

$$\gamma = S + a \ (7)$$

Where:

Total attenuation coefficient,

S: Scattering coefficient,
a: Absorption coefficient.

The size of the atmospheric particle determines the type of scattering concerning the laser wavelength. The size of the atmospheric particle is described by a dimensionless number labeled size parameter (k), as shown in Eqn. 8:

$$K = \frac{2 \, x \, PI \, x \, r}{\lambda} \ (8)$$

Where:

r: Radius of scattering particle and
λ: Laser wavelength.

The general relation between wavelength and scattering coefficient is shown in Eqn. 9:

$$S_\gamma = \frac{d}{\lambda^q} \quad (9)$$

Where:

d : Constant parameter,
q: A parameter whose value depends on the type of scattering.

The attenuation of laser radiation in the atmosphere is described by Beer's law, as shown in Eqn.10:

$$\tau = \frac{I_z}{I_o} = \exp(-\gamma Z) \quad (10)$$

Where:

τ : is the transmittance,
γ : is the attenuation coefficient,
z: is the length of the transmission path.

If the attenuation coefficient is a function of the path, then Eqn. 10 becomes, as shown in Eqn. 11:

$$\tau = exp \int_0^z \gamma(z)dz \quad (11)$$

Four individual processes determine the attenuation coefficient: molecular absorption, molecular scattering, aerosol absorption, and aerosol scattering. The atmospheric attenuation coefficient is 12 and becomes:

$$\gamma = \alpha_m + \beta_m + \alpha_a + \beta_a \quad (12)$$

Where:

γ : is the absorption coefficient,
β : is the scattering coefficient,
(m) and designate the molecular and aerosol processes, respectively.

Each factor in Eqn.12 depends on the wavelength of the laser radiation. We concluded that the efficiency of the laser beam depends on the extreme climate condition. Amospheric turbulence also disrupts the coherence of the laser radiation and optical wave. Wavefront distortions in the optical wave induced by climatic turmoil result in expanding the beam, and cause random variations of the status of the beam centroid, called rays, to wander. and the redistribution of the beam energy within a cross-section of the shaft leading to irradiance fluctuations. The climate condition significantly limits this laser technique to destroy and carbonise any types of rogue drones.
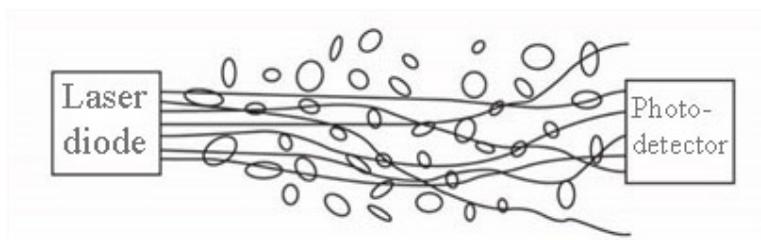
Figure 6. Turbulent cells through the whole optical path.

The laser technique is affected by adverse weather conditions, such as fog, rain, and cloud. It's a challenge to keep the laser-focused on a fixed point on the body of a drone. High energy and high accuracy tracking mechanism are needed. The lasers can pose a hazard to the surrounding infrastructure and humanity.

Technical diagram of the laser prototype

The optimised technical block for the laser prototype, as illustrated in Fig.7.
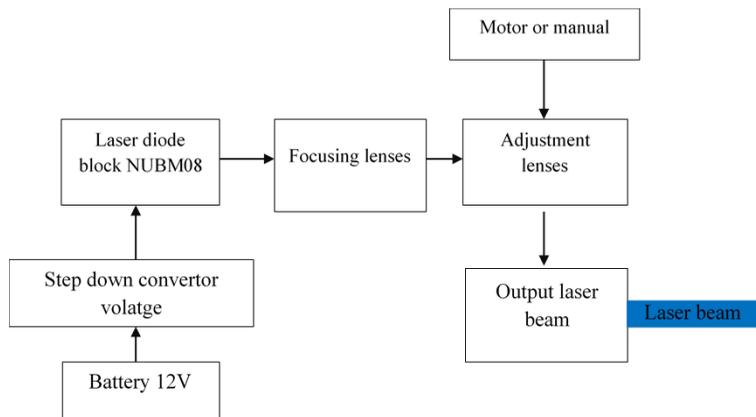
Figure 7. Block diagram of laser cannon.

The technical block diagram of the prototype is as organised as follows:

1. Laser source module 38W (448nm),

2. Overheating and water cooling system,

3. Focusing lenses,

4. Adjustable lenses (a concentrated laser strong enough to set fire to a small point),

5. DC-DC step down converter voltage regulator (12V/5V 30A).

The performance results of each block will be studied and analysed in the following subsection.

Laser source module 38W (NUBM08)

NUBM08 is a high-power laser diode block with optical output power of 38 W and wavelength 448 nm. This blue laser diode is the maximum power laser diode currently available for a laser with a single transmitter or in a standard package. This GaN laser operates at up to 45o without an effective cooling system. There are many applications for the Nichia NUBM08 laser diode due to its unique lasing wavelength of 448nm, as shown in Fig. 8.
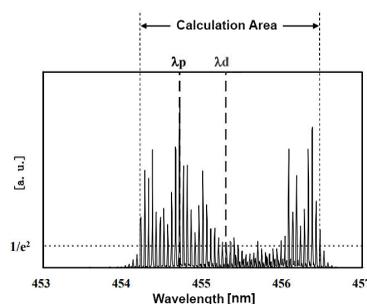
Figure 8. Definition of the dominant wavelength.

The blue laser beam is dim but more capable of getting targets burned. This helpful tool could bring lots of advantages beyond imagination. The laser beam with the focusing system is a high technology tool that can send a concentrated laser strong enough to set fire to an illegal drone. The overheating of the Nichia block of the laser LEDs is a disadvantage, and to make sure the block working with high efficiency, should keep the block under 25 degrees celsius. We put the Nichia NUBM08 laser module inside the aluminum water cooling, as shown in Fig. 9.
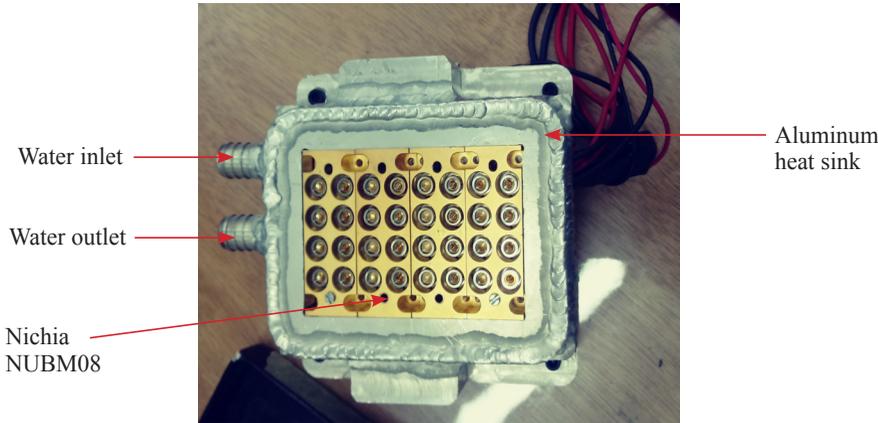
Figure 9. Fixing the Nichia NUBM08 laser module inside the aluminum water cooling.

Water inlet

Water outlet

Nichia NUBM08

Aluminum heat sink

Overheating and water cooling system

According to the data-sheet, the laser beam P0 (W) decreases compellingly if the temperature of the modules is very high, as illustrated in Fig.10.
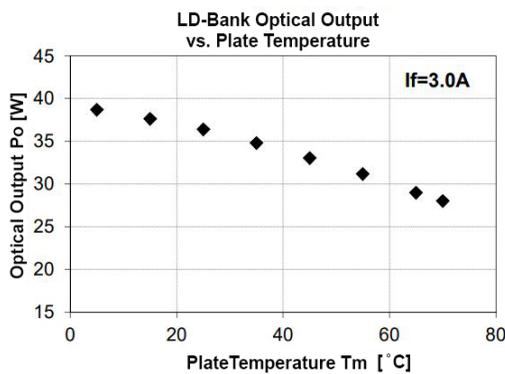
Figure 10. The efficiency of the output power related to the temperature of the module.

With the laser module, the cooling system usually consists of a small water pump placed with the reservoir. The ambient temperature, laser usage, and total water volume all affect the cooling system's performance. The cooling system consists of a DC fan and a heat sink aluminum radiator with a distilled water pump. The cooling system is necessary to keep the laser module's efficiency very high, as shown in Fig. 11.
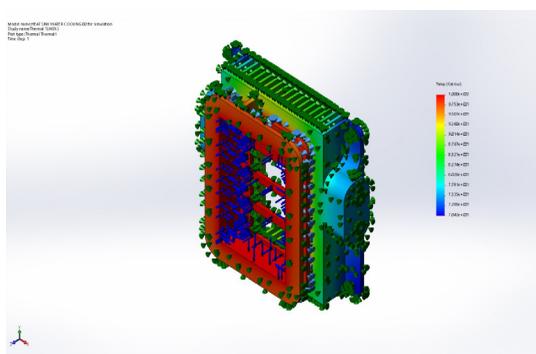
Figure 11. Heat sink thermal simulation with SolidWorks.

In the present section, the heat sink radiator simulated using the SolidWorks to show the temperature distribution in the aluminum radiator block. It also helped us find the pump a flow rate. Variations in the flow rate cause temperature changes in the laser block. To increase the efficiency of cooling, we used a heat sink and distillate water, as illustrated in Fig.12.
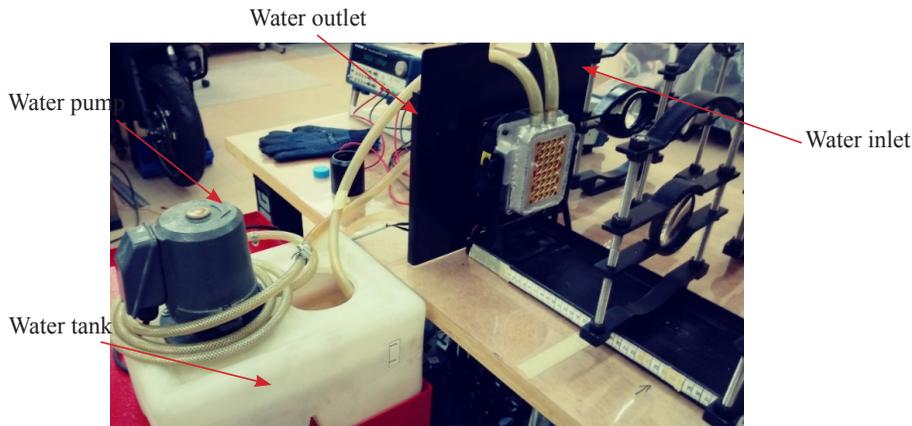
Figure 12. Laser water cooling system.

Focusing a laser beam

The optical system includes optical components designed to focus the laser energy beam, as shown in Fig. 13. Optical Lenses, which may consist of multiple parts, are used in a wide variety of applications from DSP to laser processing. Many industries use optical lenses in defence and industrial technology. As light passes across a lens, it is affected by the lens profile or substrate. Double-Convex (DCX) or A Plano-Convex (PCX) lens causes light to focus on a point, while a Double-Concave (DCV) or Plano-Concave (PCV) lens causes the light travelling through the lens to diverge.

Figure 13. Gaussian Beam propagation through multi lenses.

DC-DC step down converter voltage regulator

Each laser module consists of eight diodes, and each diode needs 4.8V until it shines. Every eight diodes of one block will connect parallel. So we need a power voltage of around 4.8V to 5V and we need Dc-DC converter steps down 12V to 5V/30A (150W). Prototype results and discussion

The prototype shown in Fig.14 consists of a mechanically-casing, aluminum heat sink, water tank, battery 12V, DC-DC converter step-down, water pump, and the laser module (NUB08). The system is also supported by a high ratio motor to move the concave lens to get the focusing of energy at one point on the body of the target.
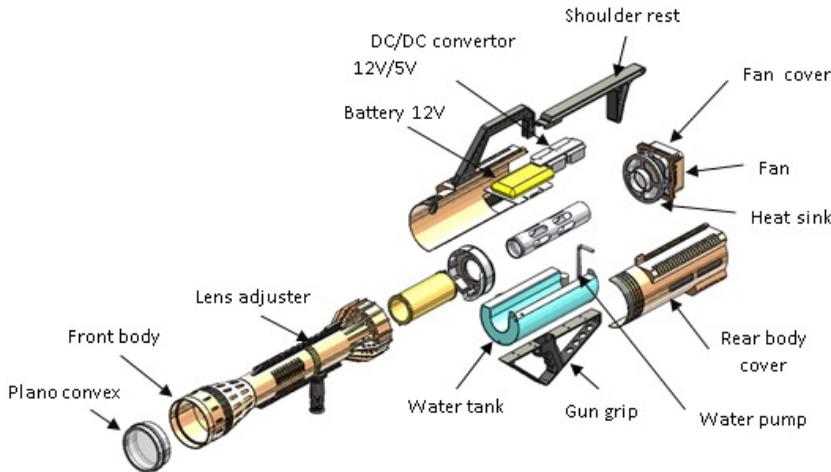
Figure 14. The different parts of the cannon prototype.

There are many approaches to the result analysis. But the only method that we have used to represent the effect of parameters on the laser burn appeared to be significant. We have used two laser modules of 38W, and we have installed them inside the cooling system to keep the temperature of the module very stable to maintain a high output beam. We experimented with the prototype for burn of both the canvas fabric, acrylic plastic, wood, and hard cartons. The prototype represents an innovative design combining a laser module and groups of optical lenses to focus the power in one point to carbonise any target. The idea is to use the laser with an adjustable lens position from 477mm to 617mm to focus the laser beam on the focus's desire distance, as shown in Fig. 15, and Fig. 16 are respectively. The tests we ran with this laser cannon will help us to manufacture the alpha prototype in the future.

Figure 15. Cutaway view of the lens position inside the cannon.
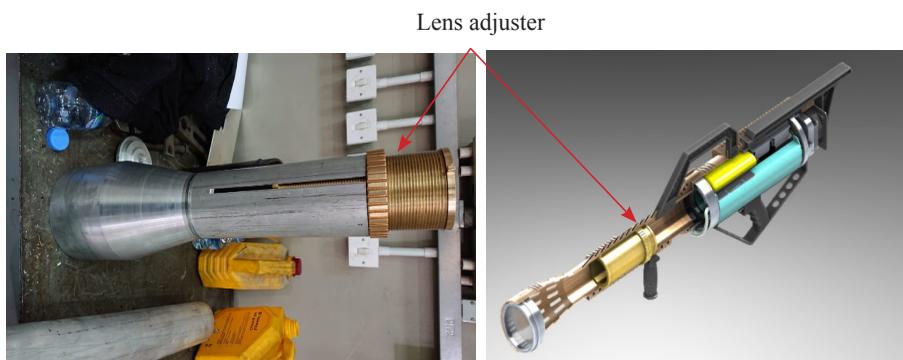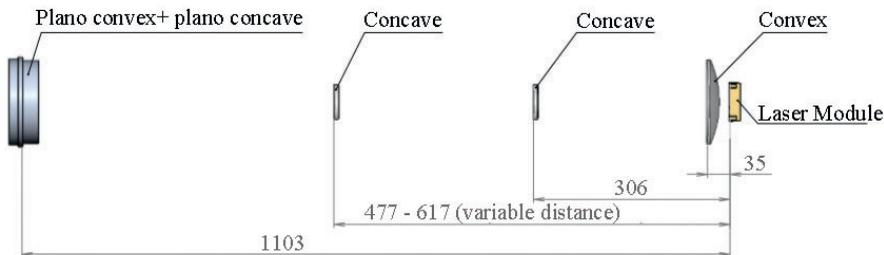
Figure 16. The mechanism to adjust the laser beam.

To adjust the focus of the laser, just rotate the lens adjuster according to the desired distance of focus. In this test, we are keeping the same materials to burn holes with a laser. But we change only the distance between the laser source and the target, as shown in Fig.17 and Fig.18.

Figure 17. Experimental laser cannon.

Figure 18. The experiment shows it burns holes through clothes in a few seconds.

Table 1 shows the results of the experiment and the time needed to burn holes in the leather. According to the experiment, the time needed to burn holes in the errant drone related to the laser beam's output power and the firing duration.

Table 1. Laser attenuation is proportional to the distance.

The gap distance between the laser block and the target to burn	Thickness of leather	The time-taken for burning holes in the leather
10 metres	2 mm	4.55 minutes
15 metres	2 mm	5.58 minutes
20 meteres	2 mm	6.23 minutes
25 metres	2 mm	6.01 minutes
50 metres	2 mm	9.76 minutes

The experiment shows the low power needs a long time to carbonise leather, so to destroy drones in a few seconds should be the cannon of a higher power laser. Potential burns caused by the laser module (wavelength 448nm) were evaluated. Table 2 below shows the time needed to burn differents materials, and we were keeping the same distance of 55m. We experimented with the effect of the laser fire duration and laser power, both to destroy and carbonise drones using this technology.

Table 2. The necessary time to burn holes in the materials.

Test	Material	The gap distance between laser and target (metre)	Time for burning holes (seconds)
1	Canvas fabric	55	720
2	Canvas fabric	35	43
3	Canvas fabric	33	26
4	Canvas fabric	30	120

5	Canvas fabric	22	131
6	Canvas fabric	20	130
7	Canvas fabric	15	51
8	Canvas fabric	10	36
9	Canvas fabric	5	30
10	Hard Carton (Thick: 3mm)	55	120
11	Hard Carton (Thick: 3mm)	30	100
12	Hard Carton (Thick: 3mm)	20	77
13	Hard Carton (Thick: 3mm)	10	23
14	Acrylic (Thick: 2mm)	10	134
15	Acrylic (Thick: 2mm)	20	300
16	Wood	20	780

The experiment shows that laser efficiency is proportional to the output power and time needed to switch on the laser beam. We tested the system and we measured the time needed to burn acrylic plastic and hard cartons from a distance of 55 metres, as illustrated in Figs. 19, 20, and 21.
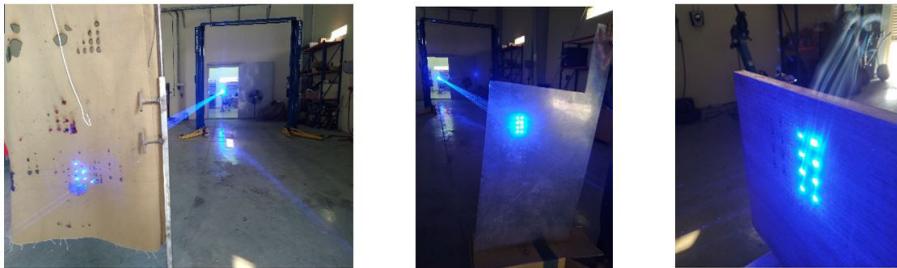
Figure. 19. We are burning holes in different materials such as canvas fabric, plastic, and wood using the laser to check the efficiency of this prototype.

Figure 20. The Canvas fabric burned by the laser beam from a distance of 55 metres in a few minutes.
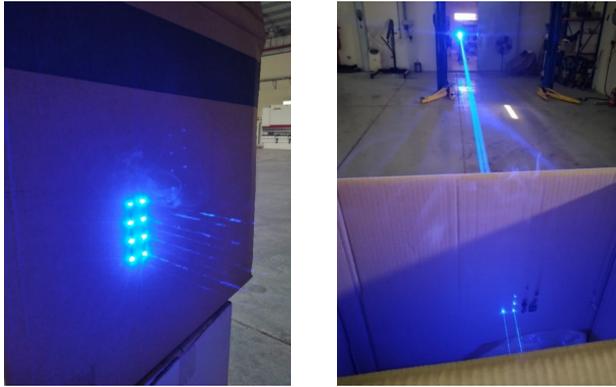
Figure 21. The laser beam burns holes in the hard carton in 20 seconds.

We concluded that the laser using high energy to burn holes in the rogue drone and especially programmed drones needed to be a HEW laser to knock out a drone over a very long distance. The cannon requires a high power beam and a high-efficiency cooling system. That's why these requirements result in the low mobility of the prototype.

Conclusion

In this phase, we could not use drones to test because this requires authorisation, but we used many materials similar to the drone body such as plastic, wood, and carton. In this paper, we analysed and studied the danger of drones in public life and how they can be used by terrorists. Buying civilian drones requires at least $400, and to neutralise or destroy them, governments must pay more than $200,000. We discussed the relationship between the weapon makers (terrorist and drug traffickers) and illegal drone users. With the present technology, the laser can destroy any unlicensed drone pilot by RF, GPS, and auto programmed drone. The concept suggests reducing radio interference and safer civilian and military airports and eliminating modified and programmed drones. We tested and proved the laser cannon prototype, and we evaluated that laser burner technology can carbonise illegal drones.

The experiments showed that laser is the better solution with high efficiency for destroying or intercepting an autonomously programmed drone.

After testing this prototype, we concluded that the technology has a lot of drawbacks including:

1. A highly competent stabilising system for long-range aimis required;

2. Very high energy is affected by the ease of movement of the system;

3. Overheating of a laser, which requires cooling water with a high-efficiency exchanger system;

4. This technology is susceptible to the weather and the atmosphere;

5. Drones are usually fast and agile, so destroying them should require a short time and high energy.

We recommend using the laser as the best technology counter-drone. Humanity should know the drone is good, but many groups misuse it, potentially affecting our lives. Laser technology is considered the best solution to reduce the risk of unauthorised drones. After the experiments, we discovered that the laser has a lot of limitations and weaknesses.

In this research, we concluded that the technology is not enough to reduce this danger. Should enforcement regulation standards and roles reduce the threat of rogue drones?. We advise governments to apply strict laws on the use of drones.

We will use the CO_2 laser tube with a high-efficiency chiller to increase the laser power in the future. We will try to get more distance and high efficiency to carbonise any drone after obtaining approval for the test.

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