Modelling a Remote-Controlled Weapon Station Through Additive Manufacturing

PETROS ANGELOPOULOS[1], CHRISTOS PAPAKITSOS[2],
EVANGELOS PAPAKITSOS[1*], NEKTARIOS NASIKAS[2], DIONYSIOS E. MOUZAKIS[2]
[1] Department of Industrial Design & Production Engineering
University of West Attica
Egaleo, Athens
GREECE

[2] Laboratory for Mechanics and Defence Applications (LAMDA)
Hellenic Army Academy
Vari, Attica
GREECE

Abstract: - This paper presents the modelling of a scaled-down unmanned weapon station (turret), constructed through additive manufacturing (3D printing). It is a design that will simulate the corresponding systems of an operational field and will demonstrate its operating principle. In order to achieve this, the definition of this system, its structure and equipment and the reasons why its development is considered necessary, in nowadays era of rapid development of unmanned systems, are firstly analyzed. The current level of its development technology is also listed. At the same time, their development trends and the next stage of their development are highlighted. Then specific models of remotely controlled weapons stations, developed by armed forces and security forces of various countries, which are characterized by the latest level of technology and dominate the operational space, are recorded. The benefits and problems arising from their exploitation in the operational field are emphasized. Afterwards, the development study of the improvised structure is analyzed. Extensive reference is made to the engineering design and the presentation of the construction. Finally, useful observations and conclusions from the entire process and development of such a station are highlighted, as well as their development potential.

Key-Words: - Unmanned Weapon Station, Turret, Additive Manufacturing, 3D Printing, Modelling, Remote-Controlled System.

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1 Introduction

In the context of the rapid technological developments taking place nowadays, and mainly in unmanned weapon systems, there is a tendency to replace human resources with robotic systems that will perform similar functions. Remote-Controlled Weapon Stations (RCWS) also belong to this sector. These are remote-controlled systems that are designed to control various types of guns from a protected position. They can be installed on a tank, armored vehicle, aircraft or naval high-speed vessel and can carry any weapon system, depending on operational requirements, either individually or in parallel [1]. These systems were firstly developed by USA and were utilized in the Iraq War, due to the need to avoid the exposure of turret gunners on top of armored vehicles during patrols in the difficult operational external conditions of the urban environment. They offered the ability to directly engage the enemy from a safe and protected location, comprehensive spatial awareness, and flexibility in combat conditions. In addition to the armed forces, they are widely used by security forces in the surveillance and protection of various areas and borders [2].

Depending on the desired size and function, the guns and the technological systems that an RCWS will carry, the design of such a station can vary greatly. However, it is a very detailed process, where many parameters must be considered. Nevertheless, its operating principle, in terms of its basic movements, displays a certain uniformity in the various models of its development around the world [3]. In this work, the design method and the construction process of a simulation of a similar system in mechanical terms and three-dimensional design are analyzed. However, in order to follow all of the above, it is necessary to make a reference to the structure of the mechanisms that make up an RCWS, the operation of each of them, their interaction and the principle of its operation as a single whole. At this point, the reasons why they are necessary systems are also clarified. Specific models of the modern operational field of various armed forces are mentioned and the benefits and problems of their utilization are highlighted.

2 Context

USA was the first country to develop remote-controlled weapon stations and to use them for the first time in an operation. Now, these stations are standard equipment of the US Army's armored vehicles, such as the M1A2 tanks, the MRAP vehicles, with which they operated in Iraq, and the Beckham Wei patrol vehicles. Among them, the most common are the XM101 and Protector turrets. Israel is developing such types of systems at a rapid pace and has also put these systems into active operational usage. It is worth noting that it adopted the idea of developing them for armored vehicles in the early 1970s. So far, it has manufactured the Heroes and Waves series with ten types of weapon stations. Sweden was late to enter the production of remote-controlled weapon stations, but it is famous for its high technology of targeting and target detection. It has developed the Trackfire weapon station, based on the EOS500 photoelectric control instrument, which is installed on various military vehicles and ships. Belgium has built the most high-tech weapon stations in the world, known as Arrow. They are manufactured by the FN company and are equipped with day and night optical systems (CCD). Germany is also in this field, at a very advanced technological level. The KMW company has been running a series of similar systems (FLW), in recent years [4].

For the development of such a system, a detailed process with multiple designs and calculations is followed [5]. Specifically, some of the elements that are examined are the design of its structure, the assembly of all the components, the calculation of the dynamic characteristics, developed by the contact between each cannon, its anchoring frame and the vehicle, the optimization of its power supply and its distribution, the reliability and safety of its handling [6]. Considering the structure and characteristics of the carried cannon, the design of the structure must be such as to minimize the size of the station, as much as possible, while avoiding any contact between the components that would prevent any freedom of movement during its operation. The assembly of the system includes the design of each piece separately, in order to ensure its proper operation and its connection with the remaining parts of the structure. The aim of this design is to achieve the best capabilities and purposes of the station, in the smallest possible space. The cost of the stations depends on many factors, such as size, the weapons subsystems it carries, and the manufacturer. They can cost hundreds of dollars to millions. The total cost, in addition to operating costs, must also include maintenance, spare parts, and operator training.

The development of RCWS requires a wide range of technologies and mechanisms, covering various scientific fields, such as engineering, communications, optoelectronics, electronics, telecommunications, materials technology, etc. [7]. Therefore, the connection of these knowledge elements pre-requires the cooperation of various disciplines and demonstrates the high level of expertise required for the construction of such a system. Compared to manned weapon systems, the advantages of remotely controlled systems lie behind their development technology, which is subdivided into the sections of high-precision control and fast response, its stabilization technology and the capabilities of operational situation awareness, in all types of operational conditions.

3 Description

The RCWS is a weapon system that aims to increase the protection of vital personnel in the operational environment. In this chapter, the description of such a system is presented, with an explanation of the operation of each mechanism that constitutes it, its basic operating principles and the current technological level. In order, as mentioned above, the armed forces and security forces to keep up with the modern way of conducting war and to offer greater security, they have developed RCWS that directly protect the operator of a machine gun in a vehicle from snipers, explosive devices and many more.

A RCWS is a complex platform consisting of many mechanisms, which interact in the best possible way (Fig. 1). It is designed to be flexible, stable and withstand the harsh conditions of the external environment and the battlefield. It consists mainly of the fire system, the fire control system and the auxiliary equipment. The fire system consists of the weapon subsystem and its anchoring subsystem or its frame. The weapon subsystem concerns the set of machine guns of various calibers or whatever the station carries, rocket launchers, cannons, grenade launchers, etc. The selection of the aforementioned is made based on the desired range, targeting accuracy and firepower, which are based on the type of operation. At the same time, a station must have the ability to rapidly alternate its weapon subsystems and to reload them with ammunition or to replace them immediately when required. In an operation in the field outside the urban environment, large-caliber machine guns, armor-piercing missiles against armored targets can be utilized, while in urban environment or in peacekeeping missions, small-caliber machine guns, grenade launchers, etc. The system frame or the hooking mechanism is designed to hook the weapon subsystems and includes a support base, arms, rotation bearings (widely utilized in weapon stations as it is very effective for horizontal rotation), a shock absorption mechanism, etc.

Figure 1: RCWS [8].

The fire control system includes the mechanisms responsible for the effective control of the weapon subsystem, i.e., its stabilization, control of its movement or rotation and targeting (sensors). Its stabilization subsystem ensures that the platform is stable during firing, reduces and absorbs noise and vibrations. It is also characterized by design precision, since its position must be adjusted in real time during movement. In controlling its movement, the engines, the fire control computer with the control console and its screen (control station) act [9]. In targeting, day and night visual recognition subsystems, together with sensors, include CCD cameras, GPS, laser rangefinders, thermal cameras, sniper and mine detection systems, which have the capabilities of precise targeting and action in all weather conditions.

Auxiliary equipment includes power supply and communications subsystems. Power can be provided by batteries or generators or other energy sources. They must be capable of providing continuous and stable energy to the system, with the ability to quickly switch to backup power supplies in cases of emergency, as well as respond to extreme temperatures. Through communication equipment, interaction with unmanned aerial systems (UAVs) or ground ones (UGVs) or station and control centers is ensured. These means must be reliable and secure from possible enemy interference and provide data in real time.

RCWS support mainly medium and heavy machine guns, which cannot be carried individually by a fighter. When referring to a traditionally manned turret, it means that a fighter mans the turret and operates the weapon of the tactical vehicle. The turret rotates the weapon station that is exposed to the external environment. RCWS are weapon systems that are operated (aimed and fired) by the fighter remotely, through the safety offered by the armored vehicle, inside which he is located.

RCWS are mounted on the top and central or front part of the armored vehicle, at the point where its turret is located. It is operated from the control station, inside the vehicle. The control station is considered to be the seat or position where the control system is located. Through it, the operator can direct and rotate the weapon system (having a visual image of the target and the external environment through the sensors) to locate and hit it, firing against it. Without these systems, the weapon operator, who is in the turret and controls the weapon, is exposed to the external environment from the chest up. The system control station consists exclusively of its control panel. The control panel includes the screen, which displays what the weapon system is looking at, through the image transmission of the optical systems mounted on it. The control panel also includes the weapon control and rotation mechanism, as well as its firing button.

4 Operation

Initially, either the system automatically or the operator himself scans the battlefield, by observing the position and distance of the target, through the transmission of a live image to the fire control computer. During the day, visual recognition (targeting, search, target detection and distance estimation) is achieved through CCD white light optical instruments and laser rangefinders, while at night through infrared thermal cameras. At the same time, by receiving information about the height, azimuth and distance of the target from the visual recognition subsystems, the developed software helps the operator to aim correctly. Ultimately, the operator, utilizing all these elements, displayed on the control console screen, aims and engages the target. In the process of aiming and observation, the rotation of the weapon station horizontally and vertically, and stabilization is achieved by controlling these two subsystems from the motion control card.

In summary, the basic steps of an RCWS operation are:

- *Target detection*: Through the various sensors, detection and visual recognition systems, the target is identified and the threat is assessed.
- *Weapon subsystem selection*: Selection of an appropriate weapon, depending on the previous detection.
- *Target stabilization and tracking*: During engagement, the platform must be stabilized and maintain continuous and clear visual contact with the target, operating the station through the control systems.
- *Weapon subsystem firing*: The operator fires against the target.
- *Data collection*: The last stage is the collection of information about the environment, the assessment of the target's location and the evaluation of the engagement result, data that can be used for future events.

This process can be performed for multiple targets, either remotely via remote control or completely autonomously at a more sophisticated level from a secure location.

The crucial aspect of the RCWS's operation is the optical recognition and targeting. In Fig. 2, the larger upper circle corresponds to a distance of up to 100 metres, the middle circle corresponds to a distance of up to 200 metres, and the small lower circle corresponds to a distance of up to 400 metres.

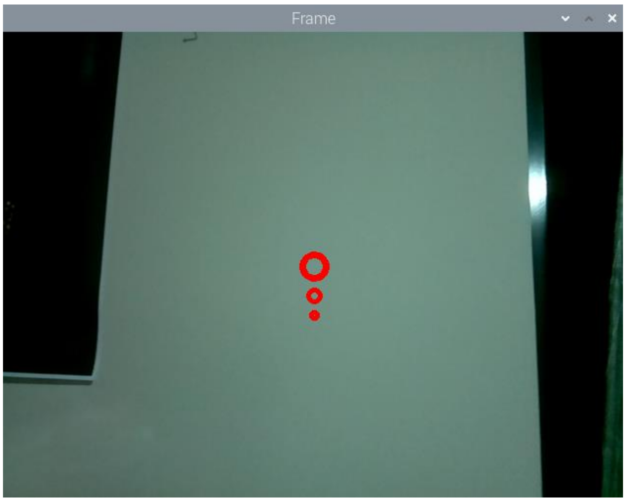

Figure 2: Optical recognition and targeting [10].

To adjust the target and place the circle in the correct spot, we follow a specific formula after testing. Minute of Angle (MOA) is an angular measurement of 1/60 of a degree and corresponds to approximately 1 millimeter per 100 yards (actually, exactly 1.047´´):

MOA = (Distance between target and impact in inches) / ((distance in yards) / 100).

So, 1 MOA corresponds to 1 inch at 100 yards. This means that 0.5 MOA corresponds to 0.5´´ at 100 yards and 0.25 MOA to 0.25´´ at 100 yards. As the distance decreases, the conversion from MOA to inches also decreases. At 25 yards, 1 MOA is 0.25´´, 0.5 MOA is also 0.25´´ and 0.25 MOA is 0.0625´´. For example, if the target distance is 25 yards away and the impact point is 5 millimeters below the red circle, then the following calculation is made:

MOA = 5 / (5 / 0.25) = 20 MOA down.

There, 1 MOA corresponds to approximately 1 millimeter, so we draw the circle 20 millimeters lower than its previous position.

5 Design

In this chapter, a brief report will be made on a design study and simulation of the construction of a RCWS (Fig. 3). The purpose of this design is to simulate the operation and structure of a real operational similar system, to have as small a size as possible in dimensions and with minor modifications to the anchoring section of the carrying armament to be able to carry any firearm. Also, it is important to present a flexibility for its installation on various mobile platforms and vehicles.

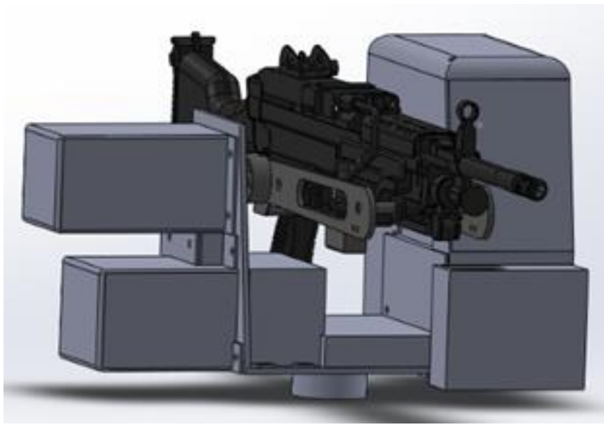

Figure 3: The completed design of the RCWS [10].

The design has been implemented through the Solidworks application. At the same time, the function of each component will be explained. In this work, a simulation of the above design will also be presented. It is noted that the components utilized are of lower capabilities than those required for a fully operationally efficient system in adverse conditions, as the cost for such a thing is very high. The parts can be made in 3D printers, with various materials. The structure of the RCWS is divided into the body that includes the electronics, the hooking mechanism that contains the firing mechanism, the hooking axis and the camera socket on the front axis, the horizontal rotation mechanism and the vertical tilt mechanism, with the rear axis that lifts the rear of the cannon (Fig. 4). The composition of the structure is presented in images.

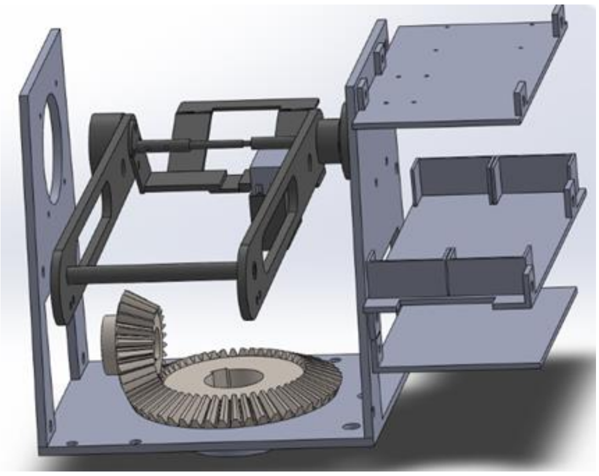

Figure 4: The skeleton of the RCWS [10].

First, the frame system should be mentioned, which is the main structure of the construction, to which all the other mechanisms and all the aforementioned electronic components are attached and has a U-shape (Fig. 5).

Figure 5: The frame system [10].

These are the horizontal and vertical tilt mechanism and the hooking mechanism. The latter can be modified to stabilize any firearm. In this specific case, it will be presented for a random imaginary firearm, designed in three dimensions. The frame has designed mounting points for the stepper motors and the placement of the electronic equipment, as well as a special camera socket.

The horizontal rotation mechanism rotates the station on the horizontal axis. It includes the Nema 23 stepper motor, mounted on the body of the structure. The motor rotates a bevel gear, which in turn rotates a horizontal bevel gear, located in the center of the base of the body (Fig. 6). The movement is transmitted to the inside of a “lazy susan” type rotation bearing, which, in addition to being attached to the gear, is also connected to the body, and its outside is fixed to an external base or lid, depending on the platform or turret on which we want to place the station.

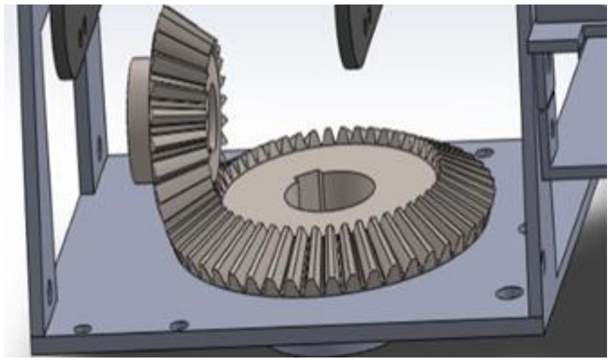

Figure 6: The rotation mechanism [10].

In the vertical tilt mechanism, the Nema 17 stepper motor is fixed to the end of the barrel, and through a coupling, it is connected to the rear shaft, which penetrates the pistol grip of the cannon and ends at the opposite end in a UCF type bearing. Its basic function is to rotate the station on the vertical axis. The anchoring mechanism consists of two rollers, which connect the shaft that supports the firing mechanism with the front shaft (Fig. 7).

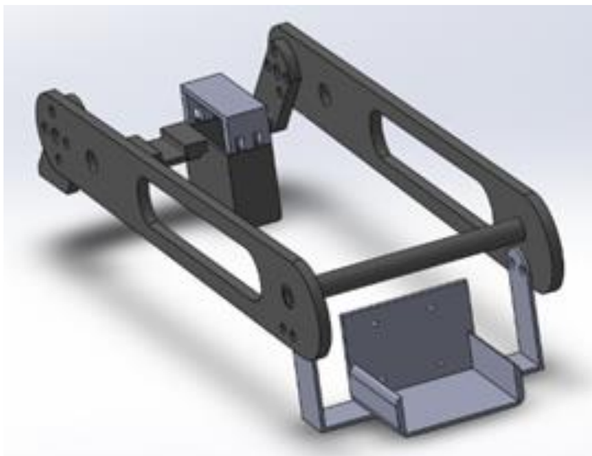

Figure 7: The anchoring mechanism [10].

At the same time, its role is to stabilize the cannon. It can be modified depending on the cannon it will support. On the rear shaft, in the middle of it, a special servomotor socket has been designed, which, with a movement of a lever placed on its top, presses the trigger, in order to fire the weapon. The front shaft passes through a hole in the cannon and stabilizes its front part. In the center of this is the camera mounting mechanism, aligned with the barrel of the weapon to achieve the best possible aiming. A deformation of the horizontal rotation has been chosen, where the gears do not come into direct contact, but the movement between them is transmitted via a V-belt and from there to a small bearing, capable of rotating a load of the order of 50 kg.

Another crucial design issue includes the power supply (Fig. 8). For the stepper motors, two battery cases of 4 positions in series are used and 4 rechargeable 18650 batteries of 3.7 V and 2200 mAh each are placed, so that a total of 14.8 V is provided from each power source to each controller.

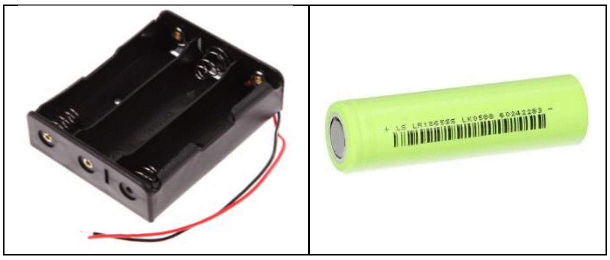

Figure 8: The power supply [10].

The purpose of this construction is to demonstrate primarily the operating principle of the entire system and each component, but also the correctness of the design and the possibility of parameterization and change, according to the user's preferences and desires for use. We assume that the electronics are placed in an application box, adjacent to the station.

6 Manufacturing

Since the present paper refers to the construction of a RCWS and the mechanisms it consists of, it is important to consider the manufacturing process during the design phase. The selection of the manufacturing process such as subtractive manufacturing (CNC machining), sheetmetal manufacturing, metal casting, injection molding and additive manufacturing not only influence the geometry design but also the final cost and logistics of the assembly [11].

Choosing the part to be manufactured solely on conventional and well-established subtractive technologies, the designer "locks" on a small to medium range production. The production can be scaled from medium to large by utilizing the global network of machine shops, however, if we consider the nature of the researched design, it would be wiser to think of local production capabilities. Technologies such as sheetmetal manufacturing and metal casting can provide quantities of medium to large scale, however, the complexity and the area needed for such infrastructure is reserved to limited entities nationwide.

Additive manufacturing offers a decentralized and more flexible way of manufacturing. These machines tend to be smaller and easier to install. In terms of handling the manufacturing, additive manufacturing machines demands less expertise from their operators, since software handles everything that needs to be done for the operation. There are no tool changes, specific tool handles or constant demand for monitoring that usually goes along with the subtractive manufacturing. Although the conditions seem perfect, parts that are manufactured through additive manufacturing are not on par with parts from subtractive manufacturing. If there is a need for tight tolerances, further handling is mandatory in order to get the part to the desired specifications.

Since additive manufacturing is a cutting-edge technology, a quick presentation will be made to the basic categories and the associated materials. Furthermore, the basic difference regarding the produced part will be briefly discussed.

Additive Manufacturing or 3D printing to the general public consists of three main technologies named as Fused Deposition Modeling (FDM), Stereolithography (SLA) and Selective Laser Sintering (SLS).

FDM is based on the heating of a polymer – thermoplastic material through a heating element and then the extrusion of it through a nozzle on the heating build plate of the machine. The heating build plate of the machine provides the base from where the manufacturing of the part starts. A specific software is generating the tool path that the tool head (heating element and nozzle) follows in order to build the part. Most common materials that are associated with FDM are Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polyethylene Terephthalate Glycol (PETG), Polyamide (PA6 / PA66), Polyether Ether Ketone (PEEK) etc. [12]. Specifically, for PEEK, which is considered a high performing engineering polymer, its use cases involve corrosion resistance, heat resistance and strong mechanical properties. These properties, along with the exotic nature and the high price of the material, proposes that the part designed should be optimized, not only for mechanical stress and weight, but also for minimum wasted material. The FDM technology is suitable for manufacturing such parts, since the waste material is minimum and, depending on the design, the parts could have similar or same properties with the ones from CNC machining.

Stereolithography (SLA) is used when the part that needs to be manufactured has to be precise. The materials used in this procedure is usually various photo-polymer resins and photo-cured ceramic resins. Most common industries that use SLA are Dentistry [13], hoppy/toy making and the Semi-Conductors Industry for the production of 3D geometry on silicon wafers.

SLS is a technology that uses a fine layer of powder material and a laser beam, in order to melt and fuse the powder for the purpose of creating the desired part. The laser technology can be, but not only, CO_2 and nitrogen lasers. The part is created inside a chamber that increases in depth after each layer pass. After the production of the part is complete, the operator removes the part for the powder chamber for further handling. The design freedom that this technology provides is unparalleled with any subtractive technologies or other additive manufacturing processes, especially when the production involves metal powder and mixture of metal powders. Bi-metal printing, meaning the combination of two or more metal powders in a part, unlocks the potential of highly optimized parts that can only be manufactured from this technology [14]. The aerospace industry is actively researching the SLS technology, since the need for highly optimized geometries and parts are crucial for the operation vehicles and engines [15].

The biggest barrier of the previous mentioned additive manufacturing processes is the anisotropic nature of the produced parts. This characteristic exists and is produced from the manufacturing process, since the part is not injected or casted into a mold but rather built layer-by-layer. This anisotropic nature produces parts that are strong on one dimension but weak in another. For example, when we consider compressive forces, a part is most capable of handling them when the direction is vertical to the “layer lines” but least capable when parallel to them. As of the previous, the manufactured orientation of the part is very important, in order for it to be able to handle the forces applied. Furthermore, material’s Tensile Strength and Tensile Modulus are not always representative, when simulating the part’s performance, since standard simulation software considers the part as isotropic in nature.

7 Conclusion

In this work, a construction was presented that supports the basic functions of a RCWS. Beyond that, there are many ways to perform these functions, especially horizontal rotation and stabilization. This depends solely on the wishes and requirements of the manufacturer. The possibility of implementing such a project and the simplicity of its basic actions are therefore demonstrated, where for the further evolution and development of its technological level, a greater cost and the ability to combine the know-how of various mechanisms are required. There are also many modifications that it can accept at the software and targeting level. With a laser rangefinder in our construction, it would be possible to calculate the distance of the target precisely and therefore to make targeting more accurate. A possible development would be to predict the future position of the target - object through the Kalman Filter and target it at exactly that point or completely autonomous targeting, where the target will be recognized and the weapon will be directed towards specific coordinates (x, y) and the operator will only perform the firing action (decision-making). It is therefore a field with great scope for development, limited only by the imagination of the manufacturer.

The events of nowadays and the current developments in the field of conducting military operations and security actions demonstrate the continuous trend of upgrading the technological level of the equipment of these bodies worldwide. RCWSs are also moving in this direction. At this time, similar systems have not only been developed at a high level, but have also been utilized by armed forces and security bodies around the world on the battlefield. There is also the possibility of interaction with mobile platforms and unmanned systems in the context of their interoperability and joint control, which directly integrates them into the flow of development of any technological means.

In conclusion, RCWS play an important role in modern operations as, in addition to their effectiveness, they reduce the risk of danger to vital resources. Together with a multitude of other communication systems, sensors, and multi-machine gun control capabilities, they become systems with many functions and capabilities. At the same time that robot soldiers are being developed on the world stage and the world stage is slowly joining the autonomous level of operation of technological means, the next stage of RCWS development is the removal of the operator from the vehicle and his/her placement in a control station inside the base, where he/she will only monitor and intervene, without being exposed to the outside environment, putting him/herself in direct threat. From this operations center, he/she will be able to control not only one remote-controlled weapon station but many as well as other systems, whether they are airborne, sea-based or ground-based. This is the future not only for technological branches related to military operations and security operations but for the entire robotics space.

Finally, in terms of manufacturing, future works could include the analysis of the structure in terms of forces and the selection of the appropriate materials. The parts could also be examined for their suitability, depending on the manufacturing process (subtractive or additive) and the design intent. A theoretical scenario could also provide useful constraints, regarding geometry and material selection.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Petros Angelopoulos conducted the study, the modelling and wrote part of the text.
Christos Papakitsos wrote part of the text and assessed the design aspects.
Evangelos Papakitsos assessed the modelling aspects and structured the research process.
Nektarios Nasikas assessed the material aspects.
Dionysios E. Mouzakis assessed the research methodology and supervises the project.

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