NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

SAFE AND EFFECTIVE CLOSE AIR SUPPORT: LEVERAGING COTS PRODUCTS FOR MANEUVERABLE AERIAL IDENTIFICATION, FRIEND OR FOE

by

Ernest John C. Jadloc

June 2022

Thesis Advisor:	Leo J. Blanken
Second Reader:	Kevin D. Jones

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2022	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE SAFE AND EFFECTIVE CLOSE AIR SUPPORT: LEVERAGING COTS PRODUCTS FOR MANEUVERABLE AERIAL IDENTIFICATION, FRIEND OR FOE	**5. FUNDING NUMBERS** R4Q04
6. AUTHOR(S) Ernest John C. Jadloc	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) CRUSER (Consortium for Robotics and Unmanned Systems Education and Research)	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Although ground troops are equipped with identification, friend or foe (IFF) devices, many fratricide cases still occur during air-to-ground operations. When they are engaged in a firefight, ground troops seek cover and concealment, and consequently, their attached IFF devices are also covered and concealed. The situation is aggravated when firefights happen at night in vegetated areas, presenting additional challenges for air force pilots when conducting close air support (CAS) operations. Hence, ground troops need to be able to deploy a visual reference above the canopy of vegetation while they remain concealed physically. This research project explored how relatively inexpensive commercial off-the-shelf (COTS) technologies can be leveraged to construct a maneuverable aerial identification friend-or-foe (MAIFF) device. A systems engineering approach was employed to produce a prototype MAIFF using a sub-250 gram quadcopter drone mounted with infrared lights. In testing, its illumination lasted up to six hours. Although invisible to the naked eye, its illumination was visible up to one mile away with the use of a night vision device. A scenario-based test is recommended as a step toward MAIFF adoption by military organizations. Testing the MAIFF will determine whether it enhances situation awareness, reduces the occurrence of fratricide, and increases the lethality of CAS.

14. SUBJECT TERMS situation awareness, fratricide, identification friend or foe, IFF, close air support, CAS, visual reference, maneuverable aerial identification friend or foe, MAIFF, quadcopter drone, infrared, IR lights	**15. NUMBER OF PAGES** 73
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

SAFE AND EFFECTIVE CLOSE AIR SUPPORT: LEVERAGING COTS PRODUCTS FOR MANEUVERABLE AERIAL IDENTIFICATION, FRIEND OR FOE

Ernest John C. Jadloc
Colonel, Philippine Army
MATL, International Graduate School of Leadership, 2011

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN DEFENSE ANALYSIS
(IRREGULAR WARFARE)

from the

NAVAL POSTGRADUATE SCHOOL
June 2022

Approved by: Leo J. Blanken
Advisor

Kevin D. Jones
Second Reader

Carter Malkasian
Chair, Department of Defense Analysis

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Although ground troops are equipped with identification, friend or foe (IFF) devices, many fratricide cases still occur during air-to-ground operations. When they are engaged in a firefight, ground troops seek cover and concealment, and consequently, their attached IFF devices are also covered and concealed. The situation is aggravated when firefights happen at night in vegetated areas, presenting additional challenges for air force pilots when conducting close air support (CAS) operations. Hence, ground troops need to be able to deploy a visual reference above the canopy of vegetation while they remain concealed physically. This research project explored how relatively inexpensive commercial off-the-shelf (COTS) technologies can be leveraged to construct a maneuverable aerial identification friend-or-foe (MAIFF) device. A systems engineering approach was employed to produce a prototype MAIFF using a sub-250 gram quadcopter drone mounted with infrared lights. In testing, its illumination lasted up to six hours. Although invisible to the naked eye, its illumination was visible up to one mile away with the use of a night vision device. A scenario-based test is recommended as a step toward MAIFF adoption by military organizations. Testing the MAIFF will determine whether it enhances situation awareness, reduces the occurrence of fratricide, and increases the lethality of CAS.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

CAS	close air support
COTS	commercial off-the-shelf
FPV	first-person view
GPS	global positioning system
IFF	identification, friend or foe
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
LED	Light-emitting diode
MAIFF	maneuverable aerial identification, friend or foe
NVG	night vision goggles
p-OLED	Polymer-Organic Light Emitting Diode
SA	situation awareness
SWIR	shortwave infrared
VMIFF	vehicle mounted identification, friend or foe

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Ground troops are equipped with identification-friend-or-foe (IFF) devices. When they are engaged in a firefight, they seek cover and concealment, and consequently, their attached IFF are also covered and concealed. The situation is aggravated when firefights happen at night in vegetated areas, presenting additional challenges for air force pilots when conducting close air support (CAS) operations. Hence, ground troops need to be able to deploy a visual reference above the canopy of vegetation while they remain concealed physically. By contrast, the absence of visual reference may result in the delay of pilots positively identifying the friendly forces; provide additional time for enemy action; expose aircraft unnecessarily; and potentially cause fratricide.

This research project explored how relatively inexpensive commercial-off-the-shelf (COTS) technologies can be leveraged to construct a maneuverable aerial identification friend-or-foe (MAIFF) device. It would serve as a visual reference to enhance the situation awareness (SA) of pilots performing night CAS operations. This maneuverable device does not have a direct back azimuth to the soldier's specific location.

A systems engineering approach was employed to produce a prototype MAIFF using a sub-250 gram quadcopter drone mounted with infrared lights and other electronic and non-electronic parts—referred to in this project as the lamp. Hence, a MAIFF device is composed of a lamp mounted on a drone. The lamp weights 17 grams and has a diameter of 50.58 mm and a height of 25.59 mm. The lamp uses nine pieces of 3 mm infrared lights powered by two 3V coin batteries. The illumination provided by the lamp is invisible to the naked eye. It can only be seen using a night vision device. Its illumination can last six hours and visible up to one mile away. The lamp's mounting design is stable and versatile, enabling the lamp and the drone to fly as one unit.

This study designed a scenario-based test to measure whether the use of the MAIFF device improves the situation awareness of troops—particularly for pilots conducting night CAS operations. The conduct of the actual scenario-based test is not part of the study.

Nevertheless, the designed test may serve as a ready reference for regular training between major services, or during joint training exercises involving partner nations.

The research study recommends conducting a scenario-based test as a step towards MAIFF adoption by military organizations. Testing the MAIFF will determine whether it enhances situation awareness, reduces the occurrence of fratricide, and increases the lethality of close air support operations. The test can be done during regular training with the army and the air force, or during joint training exercises between the armed forces of the Philippines and the United States.

ACKNOWLEDGMENTS

To my Lord and Savior Jesus Christ, who said, "Neither do people light a lamp and put it under a bowl. Instead they put it on its stand, and it gives light to everyone in the house." (Matthew 5:15 NIV)

To my wife, Hazel, my sounding board, your support and encouragement helped me finish my studies and complete this project. Our visits to your craft stores provided me ideas and tools for building the prototype. You and our son, David, helped me in the wharf visibility test.

To my children, Harriet and David, thank you for the fun and memories. Both of you performed well in school and were courageous to ride those roller coasters in the various parks we visited. Harriet, you were brave and strong biking to school.

To my mother, Jovita; siblings, Joy, Sheila, and Jay; mother-in-law, Beighbee; friends and other relatives, thank you for the support and inspiration.

To the Pacania family, thank you for the companionship. You provided for our needs during our stay in Monterey. You are our family away from home.

To the Church of the Oaks congregation, thank you for the spiritual guidance and warm fellowship.

To the Filipino NPS students, thank you for the weekly socials and teamwork. May we continue the tradition of helping and supporting one another and particularly new students.

To Team NPS—classmates, professors, thesis advisory team, writing coaches, support personnel, and EMAW group, it was a meaningful journey with all of you.

To my comrades in arms who perished from fratricide, your service will not be in vain.

To those currently serving in the military, may the fruit of this study help us to come through every deployment victoriously and go home to our families.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Faulty situation awareness (SA) refers to situation in which a false target appears to be the correct one. If munitions are fired in such situation, the result can be disastrous. One night in a steep vegetated hill, I was leading Philippine Army troops to neutralize a terrorist group who were at the foot of the same hill. Attack helicopters were sent to support us. The pilots had a hazy view of a group on the ground that they believed were the enemies. In reality, the two opposing forces on the ground appeared to be one group from the top view. It took more radio conversation and the movement of troops before everything was clarified. This situation necessitated a capability for ground forces to deploy a visual reference above the canopy of vegetation to improve the situation awareness of the pilots. In this paper, I explore an innovation that may serve such purpose.

A. THE PRINCIPLE OF THE INNOVATIVE IDEA

In limited visibility situations, runway lights and approach lights significantly help pilots to connect the data from the cockpit to the physical runway on the ground. In approaching for a landing, the first runway light that becomes visible significantly influences the final decision of the pilots. Visual reference facilitates an accurate and safe landing. This principle is also present in conducting close air support (CAS) operations in limited visibility situations.

CAS is needed when friendly ground forces are engaged with hostile enemy in close proximity. It entails a well-coordinated delivery of air munitions in tandem with the fire and maneuver of the ground troops.[1] Before the pilots fire a weapon, they need ample information about the location of the friendly forces and the enemy. Pilots have initial data from the cockpit. A visual reference from the actual terrain will contribute to a safe and effective conduct of CAS. By contrast, the absence of visual reference may result in the delay of pilots positively identifying the ground forces; provide additional time for enemy action; expose aircraft unnecessarily; and potentially cause fratricide.

[1] *DOD Dictionary of Military and Associated Terms*, s.v. “close air support,” accessed April 1, 2022, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/dictionary.pdf.

B. LITERATURE REVIEW

This section discusses the problem of fratricide and the studies about identification devices intended for limited visibility situation.

1. Fratricide Is a Persistent Problem

Fratricide is defined as "the employment of friendly weapons and munitions with the intent to kill the enemy or destroy his equipment or facilities, which results in unforeseen and unintentional death or injury to friendly personnel."[2] In a journal published by the U.S. Army War College, Kenneth Steinweg claimed that the U.S. military fratricide rate is 10 to 15 percent, as opposed to the 2 percent that is commonly reported. Steinweg studied cases and methods in computing fratricide incurred by the U.S. forces during World War I, World War II, the Korean War, Vietnam, Operation Just Cause, and Desert Storm. According to him, if the fratricide rate was at 10 percent, the United States would have had 177,000 casualties inflicted by its own forces.[3] More recent wars have also been marred by fratricide. In a congressional report, Ronald O'Rourke claimed that the U.S.-Iraq war had about a 10 percent fratricide rate.[4] Examples of such disasters include an American F-16 in Afghanistan dropping a laser-guided bomb that killed four Canadian troops conducting a night exercise.[5] In the Philippines, during the 2017 Marawi crisis, ten ground troops were killed and several others wounded by an air strike from the Philippine Air Force.[6] These reports and studies suggest that despite advancements in war technology, the rate of fratricide is still high.

[2] Center for Army Lessons Learned, "Fratricide: Reducing Self-Inflicted Losses," 92–04 (April 1992): Chapter 1, https://rdl.train.army.mil/catalog-ws/view/100.ATSC/872FCEC6-C4C0-4B8F-960D-F5688059192A-1274416554821/92-4/a_call92-4.htm.

[3] Kenneth Steinweg, "Dealing Realistically with Fratricide," *The U.S. Army War College Quarterly: Parameters* 25, no. 1 (July 4, 1995): 4–29, https://press.armywarcollege.edu/parameters/vol25/iss1/36.

[4] Ronald O'Rourke, *Iraq War: Defense Program Implications for Congress*, CRS Report No. RL31946 (Washington, DC: Congressional Research Service, 2003), https://apps.dtic.mil/sti/citations/ADA476239.

[5] Howard LaFranchi, "'Friendly Fire' Deaths in Afghanistan: Relatively Rare, They Draw Attention.," *Christian Science Monitor*, June 10, 2014, https://www.csmonitor.com/USA/Military/2014/0610/Friendly-fire-deaths-in-Afghanistan-Relatively-rare-they-draw-attention.

[6] DW, "Friendly Fire Hits Philippine Troops Fighting Islamists in Marawi," accessed August 9, 2021, https://www.dw.com/en/friendly-fire-hits-philippine-troops-fighting-islamists-in-marawi/a-39074280.

2. Air-to-Ground Operations Are Conducive to Fratricide

Air-to-ground operations are the leading contributor to fratricide. In his master's thesis, James Towe found that from World War II to the Persian Gulf War, self-inflicted casualties in air-to-ground operations were consistently high.[7] *The Journal of Net-Centric Warfare* published an article by Tom Potendyk in which he reported that 58 percent of all incidents of fratricide in Operation Iraqi Freedom and Operation Enduring Freedom occurred from air-to-ground fires. Most of the victims were dismounted troops.[8] As a preventive measure, a study conducted by RAND recommended that the U.S. Army and the U.S. Air Force should continuously work on new concepts and technology and integrate them through training and education.[9] RAND focused more on discussing the respective roles of the land force and the air force. But another study, by Laura Rafferty, recommended that all forces involved in CAS operations should be intentional in providing necessary information to the pilots who are designated to fire weapons.[10]

3. Situation Awareness Is Foundational

Laura Rafferty et al. claimed that errors by pilots in the cockpit are linked to faulty situation awareness.[11] The authors made this assertion using the Five Factors Teamwork model to study fratricide. According to Rafferty et al., this model, which is a combination of error models and teamwork models, is well suited for this purpose because fratricide is a process of errors in the military system with many participants. The new model is composed of five core conceptual categories: communication, cooperation, coordination,

[7] James A. Towe, "Eliminating Fratricide from Attack Helicopter Fires: An Army Aviator's Perspective" (master's thesis, Army Command and General Staff College, 1994), 50, https://apps.dtic.mil/sti/citations/ADA284508.

[8] Tom Potendyk, "Fund Combat ID and Keith Kellogg," *C4ISR — The Journal of Net-Centric Warfare*, January 1, 2011, https://infoweb.newsbank.com/resources/doc/nb/news/134EB62246CC8250?p=AFNB.

[9] Bruce R. Pirnie et al., *Beyond Close Air Support. Forging a New Air-Ground Partnership*, MG-301 (Santa Monica, CA: RAND, 2005), https://apps.dtic.mil/sti/citations/ADA433042.

[10] Laura A. Rafferty, Neville A. Stanton, and Guy H. Walker, "The Famous Five Factors in Teamwork: A Case Study of Fratricide," *Ergonomics* 53, no. 10 (October 2010): 1187–1204, https://doi.org/10.1080/00140139.2010.513450.

[11] Rafferty, Stanton, and Walker, 1196.

schemata, and situation awareness. Communication is the transfer of information. Cooperation is the attitude aspect of teamwork. Coordination is the synchronization of actions. Schemata refers to expectations and assumptions. These four concepts point to the fifth concept—situation awareness. SA requires specific information and knowledge about the current situation.[12] This model implies that during CAS operations, there should be a deliberate effort by all troops involved—air force and ground forces—to help enhance the SA of the pilots designated to fire weapons.

4. Identification, Friend or Foe—a Tool to Prevent Fratricide

The use of night identification, friend or foe (IFF) is a major tool to address fratricide. IFF has been studied in various master's theses. In one Naval Postgraduate School (NPS) thesis, Scott Gardner worked on an IFF patch that emits a signal in the shortwave infrared (SWIR) spectrum.[13] Hence, it is not visible to ordinary night vision devices that are most likely used by the enemies. In another NPS thesis, Eric Rose worked on a vehicle-mounted identification, friend or foe (VMIFF) that provides instantaneous feedback when verified by a friendly target laser designator,[14] While James Elmore's research focused on an individual identification, friend or foe (IIFF) patch using a Polymer-Organic Light Emitting Diode (p-OLED).[15] It can be observed from these various studies that IFF devices are attached to the soldier or to the vehicle. When soldiers seek cover and concealment, the attached IFF will also be covered and concealed. Thus, there is a need to provide the ground troops with an option to visually expose their identity while they remain concealed physically.

[12] Rafferty, Stanton, and Walker, 1197.

[13] Scott R. Gardner, "Visible-to-SWIR Downconversion and Its Application to Individual Identification Friend or Foe (IIFF)" (master's thesis, Naval Postgraduate School, 2009), 39, https://calhoun.nps.edu/handle/10945/4715.

[14] Eric Q. Rose, "Generation of Mid-Wave Infrared Signature Using Microradiating Devices for Vehicle Mounted Identification Friend or Foe Applications" (master's thesis, Naval Postgraduate School, 2009), 60, https://calhoun.nps.edu/bitstream/handle/10945/4739/09Jun_Rose.pdf?sequence=1&isAllowed=y.

[15] James M. Elmore, "Transient Effects of Polymer-Organic Light Emitting Diodes and Their Impact on Individual Identification Friend/Foe" (master's thesis, Naval Postgraduate School, 2008), 47, https://calhoun.nps.edu/bitstream/handle/10945/3854/08Dec_Elmore.pdf?sequence=1&isAllowed=y.

5. Night Vision Devices and Vegetated Terrain

War capabilities are reduced during limited visibility situations. The Center for Army Lessons Learned has emphasized that "during limited visibility or in restricted terrain, units in proximity can mistake each other for the enemy due to short engagement windows and decision time."[16] Jungle warfare is a typical restricted terrain situation. Triple canopy forest, swamps, and mountains reduce the effectiveness of tanks, aircrafts, and even artillery.[17] Similarly, night operations present a typical limited-visibility situation. To deal with the dark environment, government forces rely heavily on night vision goggles (NVG). According to Del Beilstein's NPS master's thesis, however, a pilot's night vision device presents constraints in terms of field of view, visual resolution, and other visual noise.[18] It is therefore very challenging for pilots to positively identify ground forces in vegetated areas particularly during nighttime.

Laser aiming devices, on the other hand, are used by ground troops as a visual reference to locate and identify friendly forces. However, if the enemy is equipped with a night vision device, the beacon of light from a laser provides a back azimuth that betrays a soldier's position.[19] In this regard, the ground forces need to have an option to detach an IFF from their body, maneuver it between trees, and hover it above the jungle's canopy. This could give the pilot a relative location of the ground troops and a demarcation reference between friendly forces and the enemy. This concept could reduce the possibility of fratricide among friendly forces and increase lethality towards enemy forces.

---

[16] Center for Army Lessons Learned, "Fratricide: Reducing Self-Inflicted Losses," Chapter 2.

[17] *The Oxford Companion to American Military History*, s.v. "Jungle Warfare," accessed August 10, 2021, https://www.encyclopedia.com/history/encyclopedias-almanacs-transcripts-and-maps/jungle-warfare.

[18] Del L. Beilstein, "Visual Simulation of Night Vision Goggles in a Chromakeyed Augmented Virtual Environment" (master's thesis, Naval Postgraduate School, 2003), 12–16, https://calhoun.nps.edu/bitstream/handle/10945/1025/03Jun_Beilstein.pdf?sequence=1&isAllowed=y.

[19] Jon Tishman and Dan Schoen, "We Don't Own the Night Anymore," Modern War Institute, January 22, 2021, 8, https://mwi.usma.edu/we-dont-own-the-night-anymore/.

6. IFF Adoption by the Military Organization

An innovation in IFF passes through a rigorous process before it can be officially used by ground troops. In a journal of net-centric warfare, Nick Adde wrote about the Coalition Combat Identification Capability Demonstration, also known as Bold Quest, which has provided a recurring venue for the combat identification community to assess potential solutions to fratricide. In the area of IFF for dismounted troops, Adde said that some industries are hesitant to push their technology further because they are not sure if the U.S. Defense Department intends to buy it. On the government side, the selection committee considers weight, cost, and compatibility of proposed IFFs.[20] In the Philippines, the Department of National Defense and the Armed Forces of the Philippines are heavily reliant on a limited defense budget and a very legalistic procurement process in buying defense capabilities.[21] IFF is less of a priority. These bureaucratic processes and budgetary constraints make commercial-off-the-shelf (COTS) technologies a better option, particularly for developing countries that do not have their own defense industry.

7. COTS Technology in the Military

COTS technologies can be utilized to meet military requirements. In his NPS master's thesis, Romulo Dimayuga designed a low-cost COTS drone specifically for the operational needs of Force Recon Companies of the Philippine Marines.[22] This project would be beneficial if adopted by the Armed Forces of the Philippines. In their journal article, Timothy Hawkins and Michael Gravier came up with a knowledge-based framework for COTS integration and adoption into the defense sector.[23] The framework

[20] Nick Adde, "Target: Fratricide," *C4ISR — The Journal of Net-Centric Warfare*, July 1, 2011, https://infoweb.newsbank.com/resources/doc/nb/news/13DB6E670D1F4C78?p=AFNB.

[21] Renato Cruz De Castro, "The Twenty-First Century Armed Forces of the Philippines: Orphan of Counter-Insurgency or Military Geared for the Long War of the Century?," *Contemporary Politics* 16, no. 2 (June 1, 2010): 153–71, https://doi.org/10.1080/13569771003783885.

[22] Romulo G. Dimayuga II, "COTS Drone Design: A Rapid Equipage Alternative for Force Recon Companies" (master's thesis, Naval Postgraduate School, 2020), 81, https://calhoun.nps.edu/handle/10945/66626.

[23] Timothy G. Hawkins and Michael J. Gravier, "Integrating COTS Technology in Defense Systems: A Knowledge-Based Framework for Improved Performance," *European Journal of Innovation Management* 22, no. 3 (January 1, 2019): 493–523, https://doi.org/10.1108/EJIM-08-2018-0177.

identified the barriers and facilitators that determine the appropriateness of a certain technology for adoption by the military. Hawkins emphasized that in order to facilitate the decision to adopt COTS technology, decision makers need to see an actual demonstration of the proposed innovation. Such a demonstration can confirm whether an innovative concept does address a specific problem.[24] In the same manner, military COTS innovations should undergo capability demonstrations.

8. The Need for Innovation

The previously mentioned literature suggests that there is a need to come up with a maneuverable aerial identification, friend or foe (MAIFF) device that can be deployed by ground forces. The developed MAIFF would provide ground forces a capability to hover a visual reference above the vegetation canopy while they remain concealed physically underneath the foliage. Such a device would also serve as a visual reference to enhance the situation awareness of pilots performing night CAS operations. Moreover, this maneuverable visual reference should not have a direct back azimuth to the soldier's specific location. In light of this need, COTS technologies offer a wide range of options.

C. RESEARCH QUESTION

How can relatively inexpensive COTS technologies be leveraged as a MAIFF device that can be deployed by ground forces during night air-to-ground operations in vegetated areas?

D. RESEARCH APPROACH

This study mainly took a systems engineering approach through prototype building. Most of the concepts came from the following: first, S*ystems Engineering* by Dahai Liu.[25] Second was the knowledge-based framework by Timothy Hawkins and Michael Gravier.[26]

---

[24] Hawkins and Gravier, 511.

[25] Dahai Liu, *Systems Engineering: Design Principles and Models* (Boca Raton, FL: CRC Press, 2017), https://doi.org/10.1201/9781315273860.

[26] Hawkins and Gravier, "Integrating COTS Technology in Defense Systems."

Third was the practice followed by the U.S. government in considering a new product—as applied to IFF for dismounted troops.[27]

The research project was conducted in three phases. Phase one was the building of the prototype. Phase two was the testing of the prototype. Phase three was designing cases for the MAIFF for possible adoption into the military organization.

Phase one—building the prototype: According to Liu, "a prototype is a simulated representation of the system that enables designers and users to visualize, conceptualize, touch and feel, and interact with it to validate the design effectively and efficiently."[28] He further said that building a system starts with the users' requirements. For this research project, all requirements were confined to the specifications of readily available COTS technologies. Such an approach may not be ideal, but as Liu suggests, they can be mitigated by making necessary modifications to fit the system.[29] Other factors emphasized in this project were compatibility, weight, and cost. These were the major considerations in coming up with a new IFF for dismounted troops.[30]

Phase two—testing the prototype's capabilities: According to Hawkins and Gravier, "COTS appropriateness is the extent to which a COTS product adopted for use as-is or integrated into another product or system that can meet program objectives."[31] The MAIFF prototype developed in the present research was tested for battery endurance, visibility of the light, and flight stability and maneuverability.

Phase three—designing the MAIFF's application or its possible adoption into the military organization. The study designed a scenario-based test to measure whether the use of the MAIFF device improves the SA of pilots. Scenario-based tests facilitate the decision making of concerned leaders when determining whether to adopt a particular capability

---

[27] Adde, "Target."

[28] Liu, *Systems Engineering*, 63.

[29] Liu, 65.

[30] Adde, "Target."

[31] Hawkins and Gravier, "Integrating COTS Technology in Defense Systems," 499.

into the armed forces.[32] The conduct of the actual scenario-based test is not part of this study. Nevertheless, the designed scenarios may serve as a ready reference for regular training amongst the army and the air force, or between partner nations—the Philippines and the United States.

32 Hawkins and Gravier, 502.

THIS PAGE INTENTIONALLY LEFT BLANK

II. BUILDING THE PROTOTYPE

The prototype of a MAIFF device is a visual reference for night operations. It has two main components—a drone and a light. The drone is a quadcopter that serves as a maneuver vehicle while the light mounted on the drone serves as the identifiable visual reference. The illumination provided by the light is invisible to the naked eye. It can only be seen using a night vision device. The light is composed of infrared light-emitting diode (LED) lights and other electronic and non-electronic parts. These components are taken as one—referred to in this project as the lamp. Hence, a MAIFF device is composed of a lamp mounted on a drone. The study used trial and error of inexpensive COTS components to build the lamp.

A. THE DRONE

The drone used for the MAIFF project is a sub-250 gram custom-built quadcopter with a low-light nano camera.[33] It is currently part of a continuing effort for the assembly of hobby-grade intelligence, surveillance, and reconnaissance (ISR) platforms with practical military application. This quadcopter was built based on a previous work on COTS drone design of a small helicopter for Force Recon Companies.[34]

Small drones were ideal for the MAIFF project because they produce less noise, are widely available commercially, and are commonly used in various organizations. The MAIFF project works well using small drones and is expected to work with bigger drones that can accommodate more payload.

B. BUILDING THE LAMP

This section discusses the steps in building the lamp and the materials used in the project.

[33] The quadcopter and its literature were provided by Professor Kevin Jones from the Mechanical and Aerospace Engineering Department, Naval Postgraduate School.

[34] Dimayuga, "COTS Drone Design."

1. Available Workspace

The first step was to determine the available workspace on the drone. Figure 1 shows a flat surface at the center of the quadcopter where the lamp can be mounted. It has a five-centimeter (5 cm) workspace, which is equivalent to 50 millimeters (50 mm). The space for the width and length were optimized to provide the widest surface possible for the LED lights while the workspace for the height was minimized to keep the lamp compact. The next step was to come up with the lens that can fit the workspace. The lens is expected to magnify the illumination of the light and physically protect the bulbs.

Figure 1. 50 mm workspace on a sub-250 gram quadcopter

2. Lens Selection

Shown in Figure 2 are circular lenses purchased online—one glass and the other plastic. Because there were limited data about these products, the best way to know their actual features was to purchase them. Table 1 shows their respective characteristics.

Table 1. Characteristics of possible lenses for the prototype.

Lens	Diameter	Weight	Remarks
Glass	80 mm	55.97 grams (g)	Wider lens, wider visibility Needs to be elevated to be clear from the propellers Heavy
Plastic	50 mm	5.25 g	Within the 50 mm workspace Lighter weight

Figure 2. Lens options

Both lenses provide a 360-degree field of view. The glass lens appears to have more magnifying effect, but it is too heavy and requires a taller frame in order to elevate it above the propeller area. The plastic lens was the better choice because it is lighter and perfectly fits the 50 mm workspace.

3. Infrared Light Selection

Infrared (IR) was the preferred light for this project because it is invisible to the naked eye. Its illumination can only be seen by using a night vision device. The wavelengths of infrared lights range from 1,000 micrometers to 760 nanometers.[35] Figure 3 shows the spectrum of light, including the wavelengths of visible and invisible light.

[35] Possibility Editorial, "How Deep Is Your Light? Imaging Across the Spectrum," Teledyne Imaging, October 22, 2020, https://possibility.teledyneimaging.com/how-deep-is-your-light-imaging-across-the-spectrum/.

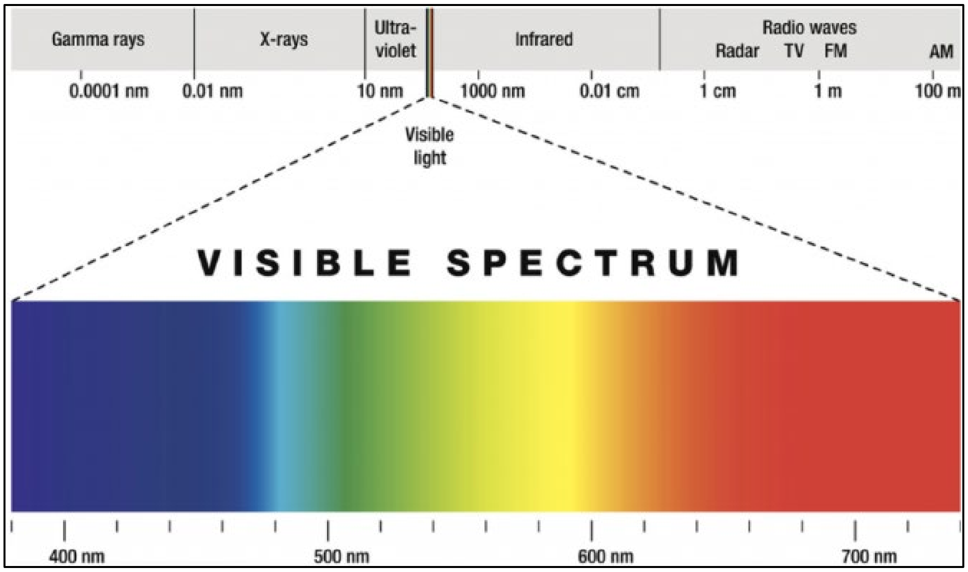

Figure 3. Light visibility spectrum[36]

Some lightbulbs are advertised online as infrared, but they are actually in the 700 nm category. These lightbulbs are therefore still in the visible spectrum. The challenge in buying online is that published information sometimes does not correspond to the actual product or the data sheets are not available at all. Various kinds of infrared lights were purchased in order to physically test them. Figure 4 shows six kinds of LED infrared lights, which are semiconductor devices that produce light when forward voltage is applied. Table 2 shows some of the characteristics of the purchased lights.

[36] Adapted from Possibility Editorial, https://possibility.teledyneimaging.com/how-deep-is-your-light-imaging-across-the-spectrum/.

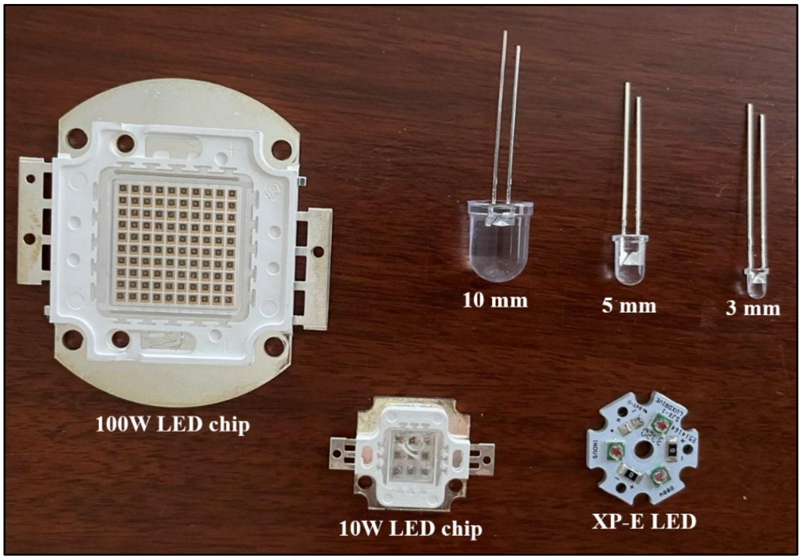

Figure 4. Infrared light options.

Table 2. Characteristics of possible IR lights for the prototype.

Light option	Weight	Remarks
100W LED chip	27.71 g	Light is attached to a metal frame Heavy
10W LED chip	5.23 g	Light is attached to a metal frame
XP-E LED	1.32 g	Advertised online as infrared, but it emits a strong visible red light
10 mm LED	1.21 g	Forward Voltage V(F): 1.45–1.65V Current 20 mA
5 mm LED	0.29 g	Forward Voltage V(F): 1.45–1.65V Current 20 mA
3 mm LED	0.14 g	Forward Voltage V(F): 1.45–1.65V Current 20 mA

Table 2 shows that the 100W and 10W LED chips are heavy because of their metal frames. Separating the metal part and the light, however, will damage the product. The XP-E LED is labeled infrared in the online store. It has a promising design—three bulbs are already in place and the illumination of each bulb covers a wide angle. However, XP-E LED emits a visible light. Hence, it cannot be part of the project.

The viable options were the 10 mm, 5 mm, and 3 mm LED bulbs. According to the information on these LED bulbs, they have the same Forward Voltage V(F) of 1.45–

1.65V.[37] Among the three, the 3 mm LED was chosen for the project. It was the lightest in weight and most compact in size. The next step was to determine how many 3 mm LED lights can be accommodated within the 50 mm lens.

4. Board and Reflector Construction

A perforated Phenolic prototype board was used as a frame for the light bulbs. It was shaped like the plastic lens. Figure 5 shows that the perforations in the board provided several options on how to arrange the lightbulbs and other possible electronic parts.

Figure 5. Perforated prototype board

Nine pieces of 3 mm LED lights can be inserted into the board. Each light requires at least two (positive and negative) soldering points. More lights can be accommodated, but nine was the number the author found comfortable soldering together in the tight workspace.

[37] “3mm IR LED,” Digi-Key Electronics, January 22, 2022, https://www.digikey.com/en/products/detail/everlight-electronics-co-ltd/HIR204C-H0/2675515?s=N4IgTCBcDaIBIEkBKYAMAWAwgejqgBAIyoAcqAtMWOuQHIAi%2BAogLIIAq7TS%2By%2BJAVlS0WRVKhYBBfEkn0EkkAF0AvkA.

A 3 mm LED light is hard to detect in the open field, particularly in vegetated areas. In order to improve its visibility, an adhesive foil was used to serve as reflector. It does not conduct electricity. Figure 6 shows the reflector attached to the board and the nine LED lights inserted through it.

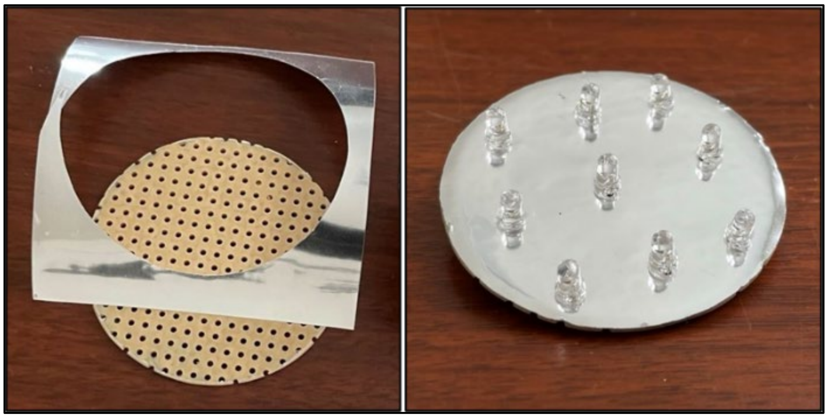

Figure 6. Adhesive foil reflector

5. Power Source

The lamp can be powered in two ways. It can share the battery of the drone, or it can have its own independent power source. The latter is preferred for the following reasons: First, the electronic circuit of the lamp can only cater to a maximum of a 6-volt (V) battery. The circuit will be overloaded and burn, if the lamp shares a drone's battery that is more than 6 V. Second, the drone would need a special port for the lamp's plug. This would reduce the compatibility of the lamp with commonly used drones. Third, an independent power source would make the lamp a stand-alone IFF device. On the other hand, the disadvantage of having an independent power source for the lamp is that the batteries are additional payload to the drone. In this situation, compatibility is a higher priority than weight.

A coin-type battery is preferred for the project because it is small, lightweight, and widely available. The nine infrared bulbs need at least two 3V coin-batteries to ensure that the lamp will obtain its maximum illumination and have more endurance. Figure 7 shows two types of batteries—CR2032 and CR2016, which are labeled according to a standard format.[38] The C in CR means lithium chemistry and the R stands for round shape. The first two numbers represent the diameter of the battery and the last two numbers identify the height. Thus, the battery labeled CR2032 consists of (C) lithium chemistry, (R) round shape, a diameter of (20) 20 mm and a height of (32) 3.2 mm. Two CR2032 batteries weigh 5.88 g while two CR2016 batteries weigh 3.37 g. Consequently, the CR2016 was chosen for the project.

Figure 7. Coin batteries

Figure 8 shows a battery case with an ON/OFF switch. It is designed to hold two CR2032 coin batteries. However, CR2016 batteries also fit in the case well.

Figure 8. Battery case with ON/OFF switch

[38] Microbattery, "CR2025 vs. CR2032," accessed April 11, 2022, https://www.microbattery.com/blog/post/cr2025-vs-cr2032:-the-important-difference-between-cr2025-and-cr2032/.

As per design of the battery case, the two 3V coin batteries are stacked one on top of the other. Thus, the two batteries are connected in series, and their respective voltages should add up to a total of 6 V. Figure 9 shows that the total voltage coming from the battery case is 5.98 V, which is approximately 6 V.

Figure 9. Total battery power

The 5.98 V from the battery case increased the available power for the nine infrared LED lights. However, the batteries and the lights cannot be connected directly because the maximum forward voltage of the LED bulbs is only 1.65 V. Therefore, the 5.98 V from the batteries needed to be regulated to avoid damaging the LED lights. Such a situation requires a specific electronic circuit.

6. Electronic Circuit

According to Ohm's law, named after German Physicist Georg Ohm, a resistor is needed to regulate the flow of current from a voltage source.[39] This process is calculated by using Ohm's law formula E = I x R. The voltage (E) is equal to the product of the current (I) and resistance (R). Table 3 shows the units of measurement and their role in the circuit.

[39] Fluke, "What Is Ohm's Law?," accessed February 19, 2022, https://www.fluke.com/en-us/learn/blog/electrical/what-is-ohms-law.

Table 3. Ohm's law.[40]

Symbol	Quantity	Unit of measurement	Role in circuit
E	Voltage	Volt (v)	Pressure that triggers electron flow
I	Current	Ampere, amp (A)	Rate of electron flow
R	Resistance	Ohm (Ω)	Flow inhibitor

According to the data sheet for the 3 mm infrared LED light, a 20 mA current (20 mA is equal to 0.02 A) is needed for the LED lights to perform normally. Therefore:

E = I x R
5.98 Volts = 0.020 Amperes x R
R = 5.98 / 0.020
R = 299 Ohm (a 300 Ohm resistor is needed in the circuit)

Another electronic requirement for the project is a flasher that will initiate a blinking pattern for the LED lights. This will make the lamp more noticeable in the dark. A LED flasher will need resistors, an optocoupler, and a capacitor.[41] These additional electronic components would be challenging to solder into the board that has nine LED lights. However, there was another option from a hobbyist website for remote controlled airplanes. They sell a ready-made electronic circuit that may address the electronic needs of the project.[42] Figure 10 shows two options for the electronic requirements. The total weight of the separate components (resistors, optocoupler, and capacitor) is 1.19 g while the ready-made circuit is 1.15 g. The latter is thinner and requires less soldering, making the ready-made electronic circuit a better option.

---

40 Adapted from Fluke, https://www.fluke.com/en-us/learn/blog/electrical/what-is-ohms-law.

41 "LED Flasher Circuit with Optocoupler," October 05, 2019, D-LEC, video, 5:02, https://www.youtube.com/watch?v=_R9U0JiZGyY.

42 Joyplanes, "LED Strobe Lights Circuit Kit," accessed February 21, 2022, https://joyplanes.com/en/product/led-strobe-lights-circuit-kit/.

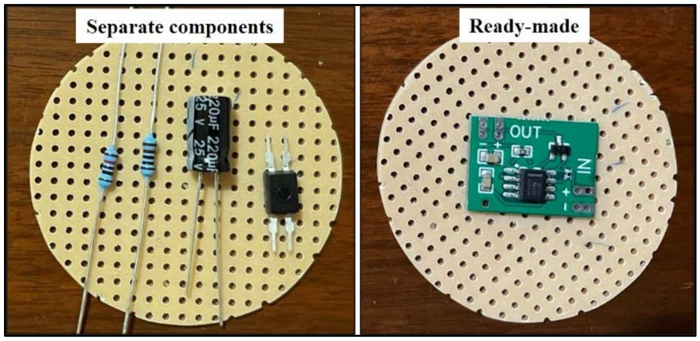

Figure 10. Options for additional electronic needs

The capabilities and installation instructions for the ready-made circuit are shown in Figure 11. This circuit can regulate the voltage from the battery and at the same time act as a flasher to provide a blinking pattern for the LED lights. Specifically, it can regulate a maximum 5.5 V battery to power eight LED lights, but the lamp project uses 5.98 V batteries. Hence, there is a voltage difference of 0.48 that may burn the circuit. The author bought extra pieces for testing, and the ready-made electronic chips performed well during the tests.

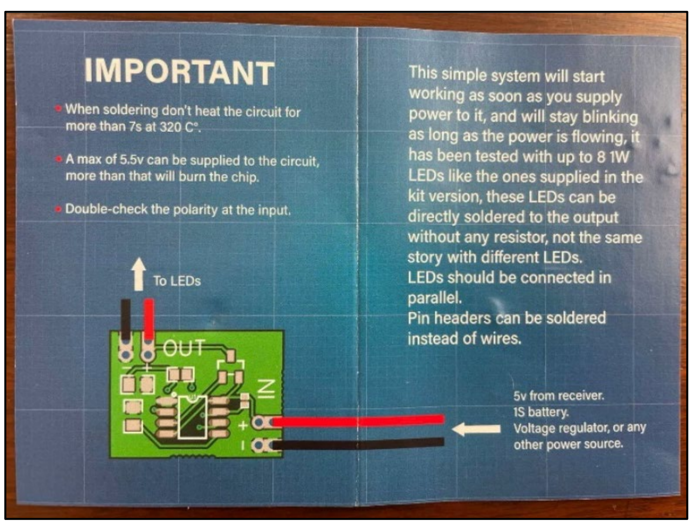

Figure 11. Ready-made electronic circuit installation manual[43]

[43] Adapted from Joyplanes product manual.

After all the electronic requirements were tested individually, the next step was to test them as a whole system. Figure 12 shows a breadboard test of all the electronic parts of the lamp. Two coin batteries are inside the battery case. It is connected to the ready-made electronic circuit that regulates the voltage and provides a flashing signal to the infrared LED bulbs. Once connected the LED lights turned red in a flashing manner, but its illumination cannot be perceived by the naked eye. Everything worked well.

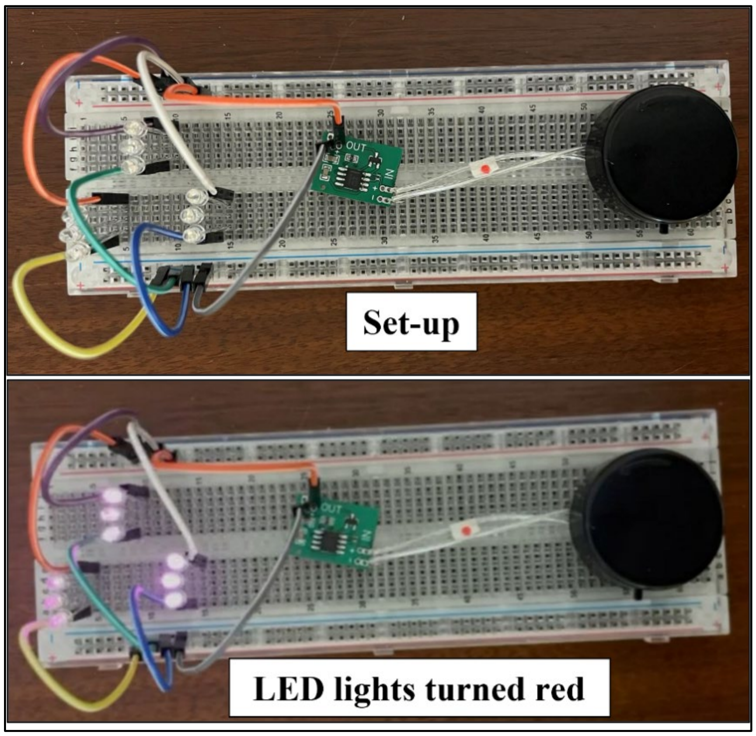

Figure 12. Complete breadboard set-up

7. Main Frame Composition

The main frame for the lamp is a 3D printed plastic that houses all electronic and non-electronic components. Figure 13 is a computer representation of the design. The small holes at every corner of the base are anchor points for rubber bands. These are used for mounting the lamp on the drone.

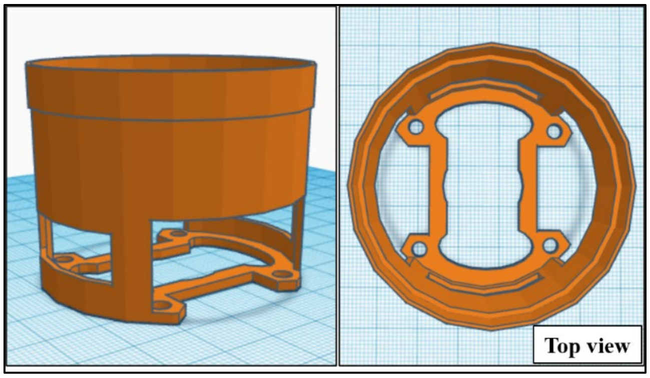

Figure 13. Main frame sketch

Figure 14 depicts the first version of the lamp (Lamp-v1). It weighs 26 grams. The open space at the sides provide access to the ON/OFF switch and to the battery case for changing batteries. Lamp-v1 was evaluated at night using a night vision device. It revealed an unwanted light under the board. If the lamp was hovering in the air, the unwanted light could possibly be noticed by adversaries from the ground if they were using night vision device.

Figure 14. First iteration of the lamp

The effect of the lens was also evaluated. The Lamp-v1 was placed four feet away from a flat surface. A night vision device recorded the behavior of the illumination from the LED lights when the lamp had a lens cover and without a lens cover. Figure 15 shows that the lens cover spreads the illumination evenly, subduing the intensity of the light to a certain degree. When the lens cover was removed, the illumination of the light became more intense, particularly at the center area. It appeared that it would be better for the lamp to have no lens cover.

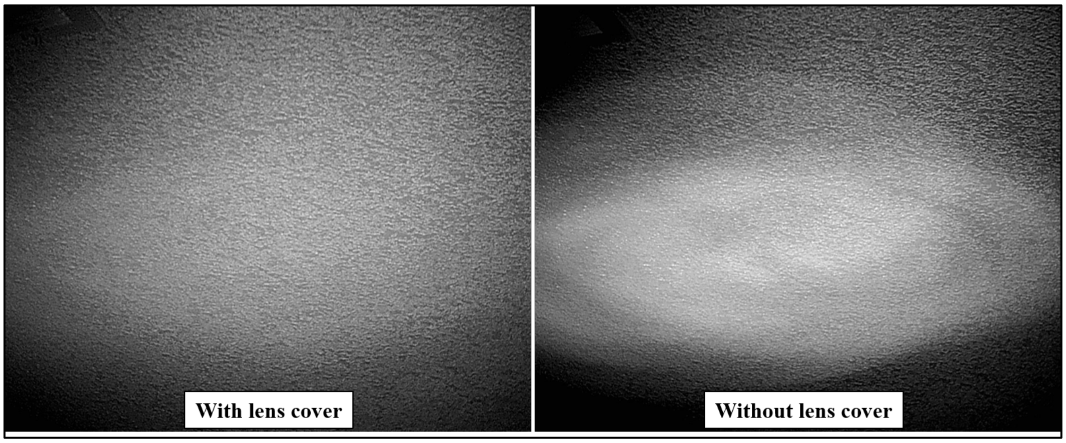

Figure 15. Lens cover evaluation

According to Michael Bourget, “LEDs are very rugged devices. There is no fragile glass envelope to break.”[44] Figure 16 shows that LED lights are covered with an epoxy lens.[45] These characteristics of LEDs contributed to the final decision to remove the lens from the lamp.

---

44 Michael Bourget, “An Introduction to Light-Emitting Diodes,” *Horticultural Science* 43, no. 7 (December 1, 2008): 1944, https://doi.org/10.21273/HORTSCI.43.7.1944.

45 Inderpreet Singh, “Know Thy LED,” Hackaday, August 8, 2017, https://hackaday.com/2017/08/08/know-thy-led/.

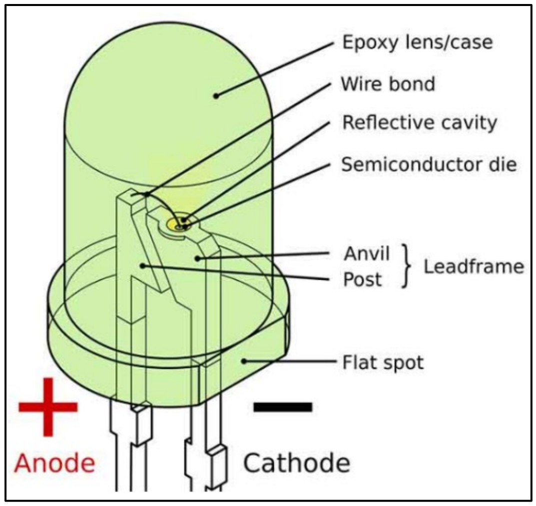

Figure 16. Parts of an LED light[46]

A new main frame was designed to address the evaluation of Lamp-v1. Figure 17 shows that a floor was made on which to rest the board. This ensures that no light will be visible under the lamp. The hole at the center of the floor is for the wires from the battery, and the battery case will cover it. All modifications were also intended to reduce weight. The author used sandpaper to smooth surfaces and further reduce the weight.

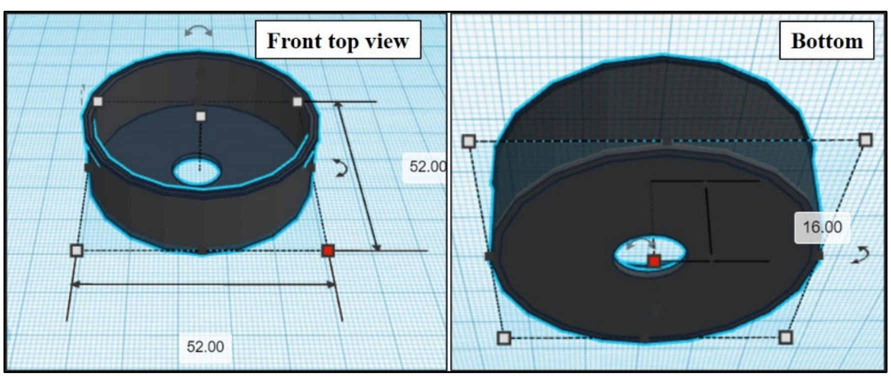

Figure 17. New frame design

Figure 18 shows how the complete breadboard set-up in Figure 12 was put into the new frame to address the issues of Lamp-v1. The IR LED lights are soldered together in

46 Adapted from Singh, https://hackaday.com/2017/08/08/know-thy-led/.

the reflectorized board. It is connected to the batteries through the electronic chip. Figure 18 also shows that the screws inside the battery case were removed to be used in two ways. First, they will serve as anchor posts for the rubber band that will secure the lamp to a drone. Second, they will attach the battery case and the main frame together. There were five screws available because the battery case was sold online in packs, each of which contained five pieces.

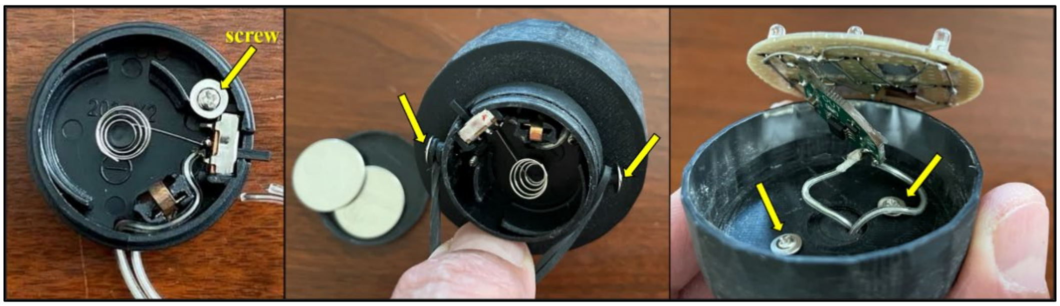

Figure 18. Assembling the new lamp design

Figure 19 shows the final version of the lamp. Its total weight is 17 grams, including batteries and mounting mechanism. The diameter of the lights area is 50.58 mm. The overall height is 25.59 mm. The diameter of the battery case is 31.54 mm. The battery case serves as the base of the lamp that has contact with the drone. The lamp can be mounted on commonly used drones starting with sub-250 gram quadcopters and up.

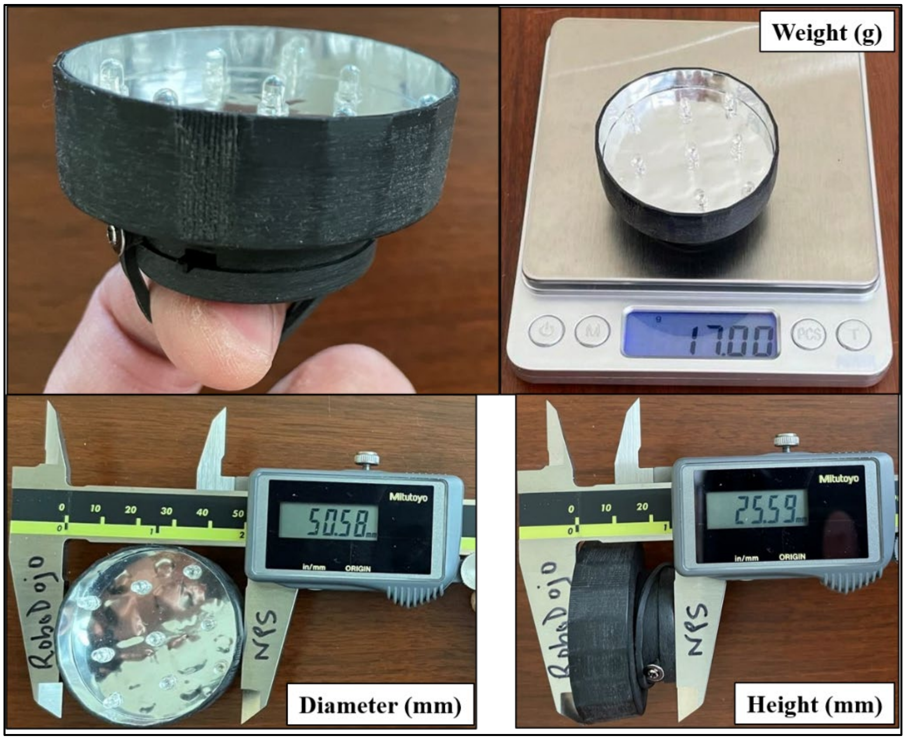

Figure 19. The lamp

C. THE MAIFF PROTOTYPE

Figure 20 shows the prototype of a maneuverable aerial identification, friend or foe (MAIFF) device with its two main components—a drone and a lamp. It is fully functional in hover position.

Professor Kevin Jones piloted the MAIFF. The author took the picture.

Figure 20. The MAIFF prototype

D. MATERIALS USED

The prototype was built from various tools and materials. Some of them were available at the RoboDojo NPS laboratory while others were bought commercially. The author made all necessary purchases for the research project. Table 4 shows the cost of materials used in the final version of the lamp.

Table 4. Materials used

Item	Amount	Remarks
Infrared bulbs (3 mm)	$30.22	100 pieces cost $23.09 plus tax and shipping. Purchased online from digikey.com USA
Perforated prototype board	$6.49	Available at NPS RoboDojo lab—no need to buy. Price is from Amazon.com
Electronic circuit	$5.67	€5.0 ($5.67) per piece. Purchased online from joyplanes.com Dublin, Ireland

Item	Amount	Remarks
Coin battery	$1.19	1 pack of 2 3V batteries from Ord Community Commissary, Monterey, CA
Coin battery holder	$7.49	1 pack (5 pieces with lead wire). Bought two packs online from Amazon.com
Adhesive foil (reflector)	$11.99	1 roll (12 inches by 48 inches), which can make more than 50 prototype lamps. Purchased from Michaels craft store, Monterey, CA
Rubber band	$1.0	1 pack rubber bands weighing 75 grams (about 100 pieces). Purchased from National Bookstore, Philippines.
Main frame	3D printed	Available at NPS RoboDojo lab

E. CONCLUSION

The prototype of a MAIFF device is a quadcopter drone mounted with a lamp. The drone weighs less than 250 grams while the lamp weights 17 grams and has a diameter of 50.58 mm and a height of 25.59 mm. The illumination of the lamp is invisible to the naked eye and can only be seen by using a night vision device. The lamp uses nine pieces of 3 mm infrared LED lights powered by two 3V coin batteries. The maker spaces—RoboDojo lab—played a significant role in the making of the innovative concept into a tangible device.

The MAIFF is maneuverable to a desired location without a potential back azimuth—a light that directly traces back to its controller. Thus, the MAIFF can provide ground troops an option to remain in their covered fighting positions and deploy a visual reference for incoming friendly aircrafts.

THIS PAGE INTENTIONALLY LEFT BLANK

III. TESTING THE PROTOTYPE

This chapter is in two parts. The first part describes testing the capabilities of the MAIFF prototype. The second part presents a suggested scenario-based test. It aims to serve as a reference on how to use the MAIFF device in an actual field test or through regular military training among different branches of the service or between partner nations.

A. CAPABILITIES OF THE PROTOTYPE

The MAIFF prototype was tested for battery endurance, the visibility of its illumination, and flight stability and maneuverability. The battery endurance test was focused on the lamp. Using a night vision device, the visibility test measured how far the lamp could be seen. The drone's battery was not part of the test. The flight stability and maneuverability tests were conducted to determine whether the mounted lamp has an adverse effect on the efficiency of the drone. It also tested the mounting design of the lamp

1. Lamp's Battery Endurance

The objective of the test was to determine how many minutes the lamp can provide illumination. A new set of batteries was installed for this test. Two units of night vision devices were utilized to document the entire experiment. The set-up of the experiment is shown in Figure 21. It was done in the backyard of the author's residence in the La Mesa housing facility near NPS. The lamp was turned on at 1850H in the evening. Its illumination was consistent for six hours. Thereafter, its illumination started to deteriorate. The lamp still worked but its brightness continued to decrease. The lamp no longer emitted light after seven hours.

Thus, the lamp can be used for a prolonged period. It can stand alone as an IFF or be mounted on a drone. Commercial drones fly an average of 30 minutes.[47] The lamp's battery can work with drones that have spare batteries. It is highly encouraged to track the

[47] Max Wales, "Top 10 Drones with Longest Flight Time [2021]," Wondershare, January 14, 2022, https://filmora.wondershare.com/drones/drones-with-longest-flight-time.html.

number of hours the lamp has been used to make sure it can provide sufficient illumination throughout the flight when mounted on a drone.

Figure 21. Lamp battery endurance test

2. Lamp's Visibility

The lamp's visibility was tested in two sites—inside NPS campus and Monterey Municipal Wharf 2.

a. Inside NPS Campus

The objective of the test was to determine how far the lamp remains visible. The longest line of sight inside the NPS campus is between Spanagel Hall and Ingersoll Hall. Shown in Figure 22 is the 889.66-foot (890 feet) distance between the two buildings. The lamp was mounted on a tree beside Ingersoll Hall. A commercial-grade night vision device was mounted at the entrance of Spanagel Hall. A military-grade night vision device would have been ideal for the experiment, but it was not available.

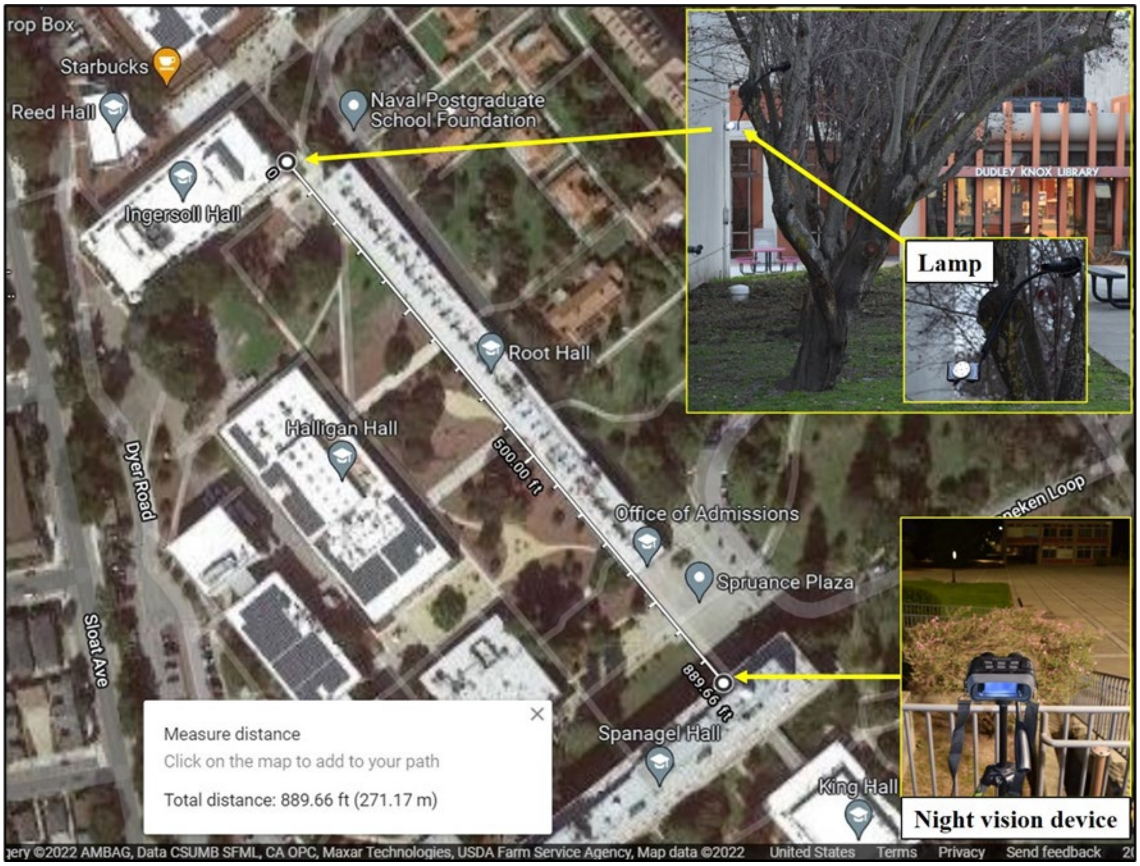

Figure 22. Lamp's visibility inside NPS campus[48]

The author recorded in night vision mode and in natural night mode. Figure 23 shows the lamp was visible in night vision mode, but invisible in natural night mode—naked eye view. The lamp was highly visible at 890 feet. A longer distance was needed to conduct the visibility test. The author was advised to look at the roof deck of Herrmann Hall. It is an elevated spot inside the NPS campus that has a direct line of sight to prominent landmarks of Monterey.

48 Adapted from Naval Postgraduate School map, Google Maps, accessed January 28, 2022, https://www.google.com/maps/@36.5958176,-121.8752945,314m/data=!3m1!1e3.

Figure 23. Observations from Spanagel Hall

b. Monterey Municipal Wharf 2 and Herrmann Hall NPS

Monterey Municipal Wharf 2 was a good site to conduct the visibility test. After a map assessment, the author conducted an area inspection of the site on March 2, 2022. Shown in Figure 24 is a hydrant in the wharf that was ideal to mount the lamp. From that spot, it had a view of Herrmann Hall. Likewise, from Herrmann Hall, the wharf is visible. Herrmann Hall was therefore a good spot to mount the night vision device. The distance between the two locations is exactly one mile (5,280 feet).

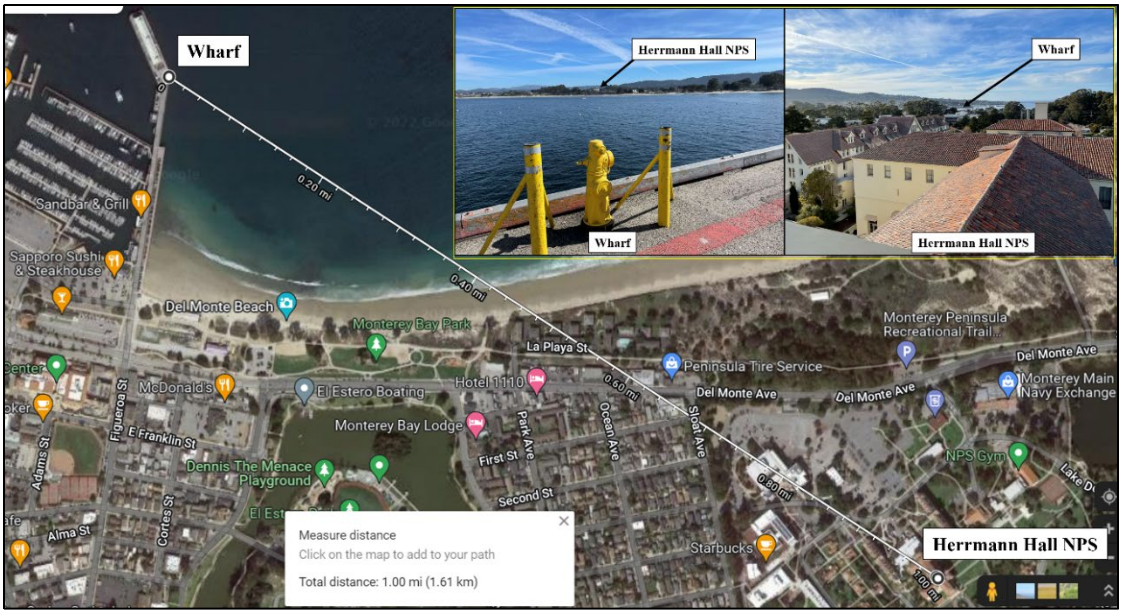

Figure 24. Line of sight between Municipal Wharf 2 and Herrmann Hall[49]

The visibility test was conducted on March 11, 2022. Shown in Figure 25 is a night vision device mounted at Herrmann Hall. First, the author took a photo of the wharf at dusk using natural night mode.

Figure 25. Observation from Herrmann Hall NPS

[49] Adapted from Monterey Municipal Wharf 2 map, Google Maps, accessed February 15, 2022, https://www.google.com/maps/@36.6014373,-121.8840344,1177m/data=!3m1!1e3.

Figure 26 shows the blinking light of the lamp. It was recorded using night vision mode. The photo on the left shows when the lamp illuminates, while the photo on the right shows when the light rests during intervals. The lamp was highly visible one mile away. It was bright like the other lights on the wharf that are big, high wattage, and powered by electricity. The lamp could be distinguished among other lights in its vicinity. In actual military application, the MAIFF device is designed for night fighting in vegetated areas. Therefore, the lamp is expected to stand out in areas without electricity. A military grade night vision device can possibly detect the illumination of the lamp beyond one mile away.

Figure 26. Lamp blinking at the wharf recorded in night vision mode

3. MAIFF Maneuverability

The objective of the maneuverability test was to determine whether the mounted lamp would have an adverse effect on the flight of the drone. The experiment was conducted on February 25, 2022, from 1000H to 1100H at the AirSpace Integration facility, 450 McQuaide Dr, La Selva Beach, CA. The weather was fine—clear skies and calm winds. The drone was piloted by Professor Kevin Jones. It was the same drone used throughout the research project.

Figure 27 shows the MAIFF device—a lamp mounted on a drone. The lamp's rubber band was tied through the belly of the drone, then looped around to the other mounting post of the lamp. The drone has no global positioning system (GPS), and thus, it cannot be deployed to programmed locations. A trained operator needs to fly it continually. The MAIFF device took off from a grassy portion of the field and made many kinds of maneuvers. It climbed to a higher altitude, made all types of turns, descended to a lower altitude, and landed. The experiment showed that the MAIFF prototype can fly normally and can be maneuvered effectively. The mounting design of the lamp is stable. The lamp and the drone work successfully together as one unit.

Professor Kevin Jones piloted the MAIFF in first-person view (FPV). The author observed and recorded the experiment in FPV and natural view.

Figure 27. MAIFF prototype flight stability and maneuverability

B. EQUIPMENT USED

The building and testing of the MAIFF prototype needed specific materials and equipment. Some were available from the NPS RoboDojo lab while others were purchased by the author from commercial establishments and online stores (see Table 5).

Table 5. Equipment used

Item	Amount	Remarks
Night vision device with video and photo recording capability	$209.99	Purchased online from Unishh
Night vision goggles with head mount	$218.49	Purchased online from Amazon
Tripod	$38.23	Purchased online from Amazon
Gooseneck mount	$17.99	Purchased online from Amazon
Nikon D3300 camera	From RoboDojo NPS lab	Used to take photos
Mobile phone (iPhone 12 pro)	Personal phone	Used to take photos and videos

Figure 28 shows a night vision device with video and photo recording capability. It can be mounted on a camera tripod, and its lens can be adjusted manually to enhance focus. It is powered by six AA batteries. The ideal equipment for the research project would be a military grade night vision device used by combat pilots, which would likely to pick up the illumination of the lamp beyond one mile. However, a military-grade night vision device was not available for this research project.

Figure 28. Night vision device with video and photo recording capability

Figure 29 shows night vision goggles (NVG) that can be mounted on the head of the person operating the drone while the operator's hands are on the remote control of the drone. The NVG's primary purpose in testing was for flying drones at night. It does not need dry cell batteries; it is rechargeable. This NVG cannot record a video or take a photo, but it was very useful in viewing the various iterations of the lamp during the design phase.

Figure 29. Night vision goggles with head mount

Figure 30 is a camera tripod that can extend from 18 inches to 66 inches. Several gadgets can be mounted on it like night vision devices, DSLR cameras, and mobile phones. The tripod helped provide steady videos and photos.

Figure 30. Tripod

Figure 31 shows a flexible bracket clamp also called a gooseneck mount. It is a versatile device that can be mounted on irregular surfaces. Its head can rotate 360 degrees.

This gadget held the lamp in place during the prototype testing phase. It was also used to hold the MAIFF device in the air during the design phase, so that the author could engage the various iterations of the innovative concept that led to the final design.

Figure 31. Gooseneck mount

C. SCENARIO-BASED TESTS

A scenario-based test is suggested to determine whether the use of MAIFF improves the SA of troops—particularly for pilots conducting CAS operations. The test can be conducted during regular training exercises between the army and the air force. It can also be conducted during joint training exercises involving the Armed Forces of the Philippines and the United States forces.

Scenario-based tests facilitate decisions by concerned leaders on whether to adopt MAIFF into the armed forces. Testing the MAIFF device can determine whether it will help reduce the occurrence of fratricide and increase the lethality of CAS operations.

1. Scenarios

The scenarios happen at night in vegetated terrain. Attack helicopter pilots conduct an air mission to support ground troops engaging with hostile enemies. The friendly forces occupy a ground area 300 feet in length and 100 feet in width. The enemy forces occupy a ground area 500 feet long and 200 feet wide. The area of the friendly forces is filled with 18 mock soldiers wearing IFF. They are in concealed and covered positions. A radio operator acts as the team leader. He is in a safe area coordinating with the pilots. He is well versed in the scenarios and the terrain.

a. Scenario One

One night in a vegetated terrain, a reconnaissance team is compromised behind the enemy line. They are engaged in a firefight and in danger of being surrounded. Heavy enemy fire is coming from 45 degrees northeast, approximately 300 feet away (see Figure 32). Enemy fire is preventing the troops from disengaging the encounter site. Attack helicopters are on the way to provide CAS. The pilots inform the ground team leader that they are 10 minutes away from the encounter site. The team leader notices an opening in the canopy of vegetation where a MAIFF device can hover above the foliage. The team leader informs the pilots that he has deployed a MAIFF, and the troops are underneath it. It has a maximum hover time of 25 minutes.

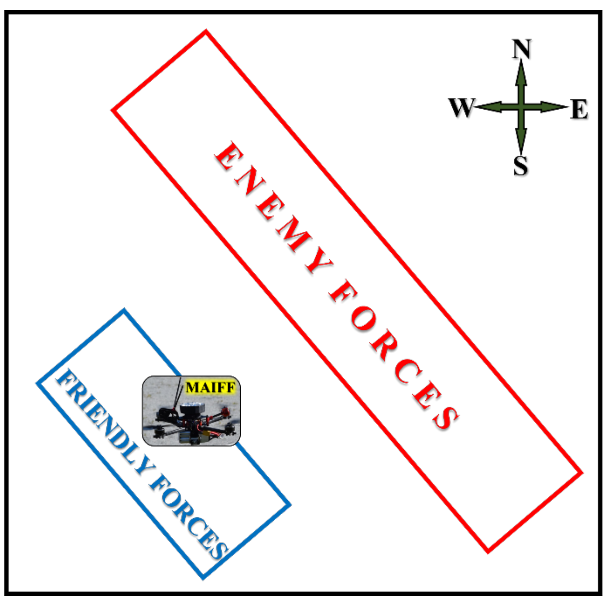

Figure 32. Scenario one

b. Scenario Two

Scenario two has the same factors as scenario one except that it happens in a different location and the enemy is in a different orientation. The enemy is directly south of the reconnaissance team (see Figure 33). The same set of pilots provides CAS.

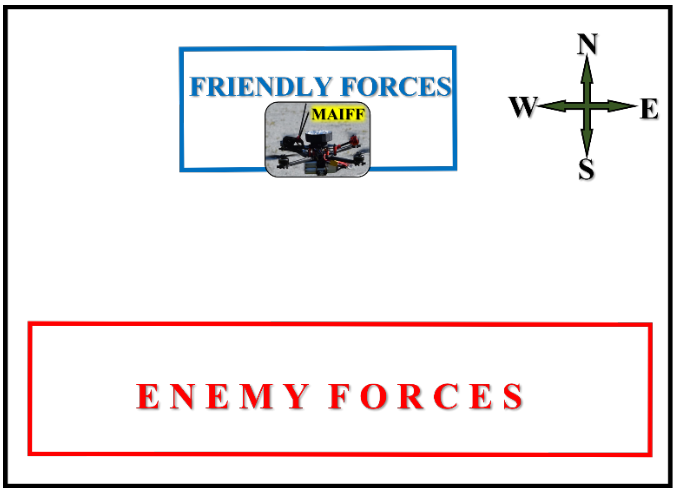

Figure 33. Scenario two

2. Close Air Support Operations

Two sets of attack helicopter pilots (set A and set B) perform four missions each. They engage in each scenario twice—with a MAIFF and without a MAIFF device. Shown in Table 6 are the flight missions.

Table 6. Close air support flight missions.

	Scenario 1		Scenario 2	
	First mission	Second mission	Third mission	Fourth mission
Pilots Alpha	With MAIFF Flight number 1A	Without MAIFF Flight number 1B	Without MAIFF Flight number 2A	With MAIFF Flight number 2B
Pilots Bravo	Without MAIFF Flight number 1C	With MAIFF Flight number 1D	With MAIFF Flight number 2C	Without MAIFF Flight number 2D

3. Evaluation Metrics

The evaluation metrics are based on two factors. First, the reaction time of the pilots from takeoff to first munition fired is assessed. The total time of all flight missions with the help of the MAIFF device should be 10% faster than the total time of missions without the MAIFF device. The 10% passing time is a suggestion. Test organizers may opt to have their own elapsed time metrics. The second evaluation metric is the effectiveness of munitions fired. Munitions that land inside the box of enemy forces are considered lethal—that is, effective. Munitions outside the box of the enemy are less lethal. The munitions that land inside the box of friendly forces will make the flight mission a failure. If the two evaluation metrices are met, the MAIFF prototype can be considered an innovation that improves SA for a safe and effective night CAS.

D. CONCLUSION

The MAIFF prototype functions as designed. It is maneuverable and flies normally like any other quadcopter drones. The lamp can provide six hours of illumination. It is invisible to the naked eye but visible up to one mile away by someone using a night vision device. The lamp's mounting design is stable and versatile, enabling the lamp and the drone to fly as one unit.

A scenario-based test can be formulated to further evaluate the MAIFF prototype. The test in this research used two scenarios and two sets of pilots. The total time for flight missions and the placement of munitions, respectively, are the criteria to determine whether the use of the MAIFF device improves the situation awareness of troops conducting CAS. This test can be used during regular military training with the army and the air force, or during joint exercises with partner nations—especially the Philippines and the United States.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. CONCLUSION, CHALLENGES, AND RECOMMENDATIONS

A. CONCLUSION

COTS technologies can be leveraged as a maneuverable aerial identification, friend or foe (or MAIFF) device. A systems engineering approach was used in this research to produce a MAIFF prototype utilizing a sub-250 gram quadcopter drone equipped with a 17 grams lamp. The lamp is composed of nine 3 mm infrared LED lights powered by two 3V coin batteries. The batteries can support up to six hours of light illumination. The illumination of the lamp is invisible to the naked eye but visible up to one mile away by someone using a night vision device. The lamp is expected to be more prominent in an undeveloped environment—particularly in dark vegetated areas without electricity. A military-grade night vision device can possibly observe the lamp even beyond one mile away.

The lamp's mounting design is stable and versatile. It can handle all types of maneuvers of the drone. The MAIFF prototype can take off, climb, turn, descend, and land in a stable manner. The drone and the lamp can work together as one unit.

The MAIFF device can provide ground troops with an option to remain in their covered fighting positions while deploying a visual reference into the air to guide friendly aircraft. A scenario-based test can be designed to validate the use of the MAIFF. This innovation is expected to improve situation awareness that will contribute to safe and effective CAS operations in limited visibility situations.

B. CHALLENGES

The weight factor of the lamp was the most challenging aspect of the prototype developed. Sub-250 gram drones can only accommodate a small amount of additional payload without affecting their overall efficiency. The concept and technology involved to produce the lamp were straightforward, but to make the physical output of the design as light as possible required a lot of innovation and iterations.

Commercial drones usually have LED lights that are visible to the naked eye. Some of them are quite bright could therefore risk revealing the position of the drone to the enemies. These lights need to be concealed.

Another challenging aspect of this research was the COVID-19 pandemic, which slowed down the timeline of the project. Offices and the lab were sometimes closed or only partially manned. Receiving materials and equipment purchased online was unpredictable as the delivery time was sometimes delayed. In some cases, products needed to be returned.

C. RECOMMENDATIONS

This section highly promotes the testing of the MAIFF prototype to determine if it improves situation awareness. This section also suggests various ways to improve the current prototype.

1. Future Work

In follow-on work, several enhancements could be made to the prototype developed in this research. The lamp can be improved by making it more rugged by using more durable material and making it more waterproof. That would make the lamp more usable as a separate IFF as well as ready to be mounted on a drone when a situation needing a MAIFF device arises.

The intensity of the infrared lights can also be improved. The bulbs, reflector, and the frame can be adjusted to attain a more intense illumination that would be visible to a line of sight with a steeper angle.

Another enhancement to the prototype could be the incorporation of an additional blinking mode into the electronic circuit. A user could then have the option to make the lights blink faster, slower, or steadily. If the drone technology allows, turning the lamp on/off in flight would also be desirable. This capability can also be used in selecting a blinking mode.

Under all these possible improvements, the MAIFF device should maintain two of its basic design elements: First, improvements should not increase the overall weight of the lamp, which should remain a maximum of 17 grams. Second, the illumination of the lights must remain directed upward when mounted on a drone. It must not be visible to adversaries from the ground.

It would also be useful to test the lamp using drones that have a global positioning system (GPS) and compass. Such a test would determine whether the mounted lamp disrupts the GPS signal. Additionally, it could determine whether the coin batteries disrupt the compass reading.

2. A Step Toward Adoption

The conduct of a scenario-based test using a MAIFF device will facilitate the decision making of concerned leaders on whether to adopt this innovation into the military organization. Testing the MAIFF will determine whether it enhances situation awareness, reduces the occurrence of fratricide, and increases the lethality of close air support operations. In future, the usefulness of the MAIFF device should be tested during regular military training with the army and the air force, or during joint exercises involving partner nations—especially the Philippines and the United States.

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Adde, Nick. "Target: Fratricide." *C4ISR — The Journal of Net-Centric Warfare*, July 1, 2011. https://infoweb.newsbank.com/resources/doc/nb/news/13DB6E670D1F4C78?p=AFNB.

Beilstein, Del L. "Visual Simulation of Night Vision Goggles in a Chromakeyed Augmented Virtual Environment." Master's thesis, Naval Postgraduate School, 2003. https://calhoun.nps.edu/bitstream/handle/10945/1025/03Jun_Beilstein.pdf?sequence=1&isAllowed=y.

Bourget, Michael. "An Introduction to Light-Emitting Diodes." *Horticultural Science* 43, no. 7 (December 1, 2008): 1944–46. https://doi.org/10.21273/HORTSCI.43.7.1944.

Center for Army Lessons Learned. "Fratricide: Reducing Self-Inflicted Losses," 92–04 (April 1992). https://rdl.train.army.mil/catalog-ws/view/100.ATSC/872FCEC6-C4C0-4B8F-960D-F5688059192A-1274416554821/92-4/a_call92-4.htm.

De Castro, Renato Cruz. "The Twenty-First Century Armed Forces of the Philippines: Orphan of Counter-Insurgency or Military Geared for the Long War of the Century?" *Contemporary Politics* 16, no. 2 (June 1, 2010): 153–71. https://doi.org/10.1080/13569771003783885.

D-ELEC. *LED Flasher Circuit with Optocoupler*. Video, 5:02, 2019. https://www.youtube.com/watch?v=_R9U0JiZGyY.

Digi-Key Electronics. "3mm IR LED." January 22, 2022. https://www.digikey.com/en/products/detail/everlight-electronics-co-ltd/HIR204C-H0/2675515?s=N4IgTCBcDaIBIEkBKYAMAWAwgejqgBAIyoAcqAtMWOuQHIAi%2BAogLIIAq7TS%2By%2BJAVlS0WRVKhYBBfEkn0EkkAF0AvkA.

Dimayuga, Romulo G. "COTS Drone Design: A Rapid Equipage Alternative for Force Recon Companies." Master's thesis, Naval Postgraduate School, 2020. https://calhoun.nps.edu/handle/10945/66626.

DW. "Friendly Fire Hits Philippine Troops Fighting Islamists in Marawi." Accessed August 9, 2021. https://www.dw.com/en/friendly-fire-hits-philippine-troops-fighting-islamists-in-marawi/a-39074280.

Elmore, James M. "Transient Effects of Polymer-Organic Light Emitting Diodes and Their Impact on Individual Identification Friend/Foe." Master's thesis, Naval Postgraduate School, 2008. https://calhoun.nps.edu/bitstream/handle/10945/3854/08Dec_Elmore.pdf?sequence=1&isAllowed=y.

Fluke. "What Is Ohm's Law?" Accessed February 19, 2022. https://www.fluke.com/en-us/learn/blog/electrical/what-is-ohms-law.

Gardner, Scott R. "Visible-to-SWIR Downconversion and Its Application to Individual Identification Friend or Foe (IIFF)." Master's thesis, Naval Postgraduate School, 2009. https://calhoun.nps.edu/handle/10945/4715.

Hawkins, Timothy G., and Michael J. Gravier. "Integrating COTS Technology in Defense Systems: A Knowledge-Based Framework for Improved Performance." *European Journal of Innovation Management* 22, no. 3 (January 1, 2019): 493–523. https://doi.org/10.1108/EJIM-08-2018-0177.

Joyplanes. "LED Strobe Lights Circuit Kit." Accessed February 21, 2022. https://joyplanes.com/en/product/led-strobe-lights-circuit-kit/.

LaFranchi, Howard. "'Friendly Fire' Deaths in Afghanistan: Relatively Rare, They Draw Attention." *Christian Science Monitor*, June 10, 2014. https://www.csmonitor.com/USA/Military/2014/0610/Friendly-fire-deaths-in-Afghanistan-Relatively-rare-they-draw-attention.

Liu, Dahai. *Systems Engineering: Design Principles and Models*. Boca Raton, FL: CRC Press, 2017. https://doi.org/10.1201/9781315273860.

Microbattery. "CR2025 vs. CR2032." Accessed April 11, 2022. https://www.microbattery.com/blog/post/cr2025-vs-cr2032:-the-important-difference-between-cr2025-and-cr2032/.

O'Rourke, Ronald. *Iraq War: Defense Program Implications for Congress*. CRS Report No. RL31946. Washington, DC: Congressional Research Service, 2003. https://apps.dtic.mil/sti/citations/ADA476239.

Pirnie, Bruce R., Alan Vick, Adam Grissom, Karl P. Mueller, and David T. Orletsky. *Beyond Close Air Support. Forging a New Air-Ground Partnership*. MG-301. Santa Monica, CA: RAND, 2005. https://apps.dtic.mil/sti/citations/ADA433042.

Possibility. "How Deep Is Your Light? Imaging Across the Spectrum." Teledyne Imaging, October 22, 2020. https://possibility.teledyneimaging.com/how-deep-is-your-light-imaging-across-the-spectrum/.

Potendyk, Tom. "Fund Combat ID and Keith Kellogg." *C4ISR — The Journal of Net-Centric Warfare*, January 1, 2011. https://infoweb.newsbank.com/resources/doc/nb/news/134EB62246CC8250?p=AFNB.

Rafferty, Laura A., Neville A. Stanton, and Guy H. Walker. "The Famous Five Factors in Teamwork: A Case Study of Fratricide." *Ergonomics* 53, no. 10 (October 2010): 1187–1204. https://doi.org/10.1080/00140139.2010.513450.

Rose, Eric Q. “Generation of Mid-Wave Infrared Signature Using Microradiating Devices for Vehicle Mounted Identification Friend or Foe Applications.” Master’s thesis, Naval Postgraduate School, 2009. https://calhoun.nps.edu/bitstream/handle/10945/4739/09Jun_Rose.pdf?sequence=1&isAllowed=y.

Singh, Inderpreet. “Know Thy LED.” Hackaday, August 8, 2017. https://hackaday.com/2017/08/08/know-thy-led/.

Steinweg, Kenneth. “Dealing Realistically with Fratricide.” *The U.S. Army War College Quarterly: Parameters* 25, no. 1 (July 4, 1995): 4–29. https://press.armywarcollege.edu/parameters/vol25/iss1/36.

Tishman, Jon, and Dan Schoen. “We Don’t Own the Night Anymore.” Modern War Institute, January 22, 2021. https://mwi.usma.edu/we-dont-own-the-night-anymore/.

Towe, James A. “Eliminating Fratricide from Attack Helicopter Fires: An Army Aviator’s Perspective.” Master’s thesis, Army Command and General Staff College, 1994. https://apps.dtic.mil/sti/citations/ADA284508.

Wales, Max. “Top 10 Drones with Longest Flight Time [2021].” Wondershare, January 14, 2022. https://filmora.wondershare.com/drones/drones-with-longest-flight-time.html.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California