THE EFFECTIVENESS OF USING GROUND AND UNMANNED AERIAL VEHICLES (UAV)-BASED BIRD DETERRENT METHODS IN INDUSTRIAL SETTING

IMRAN BIN MOHD HORNAIN

UNIVERSITI SAINS MALAYSIA

2025

THE EFFECTIVENESS OF USING GROUND AND UNMANNED AERIAL VEHICLES (UAV)-BASED BIRD DETERRENT METHODS IN INDUSTRIAL SETTING

by

IMRAN BIN MOHD HORNAIN

**Thesis submitted in fulfilment of the requirements
for the degree of
Master of Science**

April 2025

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful

Alhamdulillah, all praises to Allah S.W.T for showering His blessings and strength on me in completing this thesis. Throughout my master's journey, many hands were involved in assisting and supporting me to complete this study. First and foremost, I would like to express my deepest appreciation and gratitude to Professor Dr Nik Fadzly Bin N Rosely, my supervisor, for the time and guidance that he gave. I also would like to express our gratitude to Infineon Facility Management (FM) team members for their support during the fieldwork. Also, thanks to Universiti Sains Malaysia for financially supports this study through a grant entitled "The Feasibility of Using Autonomous Drones as Deterrence Against Swallows (*Hirundo tahitica*) at Infineon Factory, Kulim" with account no. 304.PBIOLOGI.6501144.I145. Finally, nobody has been more important in supporting me than my family members. I want to give my deepest gratitude to my beloved parents for their endless love, prayers, and encouragement. To those who indirectly contributed to this research, your contribution means a lot to me. Thank you very much.

TABLE OF CONTENTS

ACKNOWLEDGEMENT .... **ii**

TABLE OF CONTENTS .... **iii**

LIST OF FIGURES .... **vi**

LIST OF ABBREVIATIONS .... **ix**

LIST OF APPENDICES .... **x**

ABSTRAK…….. .... **xi**

ABSTRACT…… .... **xiii**

CHAPTER 1 INTRODUCTION **1**

1.1 Introduction to Pest Birds Problems & Overview of Bird Deterrents............. 1

1.2 Problem Statement & Aims of Study 3

1.3 Organization of Thesis 5

CHAPTER 2 LITERATURE REVIEW **7**

2.1 Ground-based Bird Deterrents 7

2.1.1 Visual Deterrents 7

2.1.1(a) Predator Model 7

2.1.1(b) Laser 8

2.1.1(c) Reflective Device 9

2.1.2 Auditory Deterrents 10

2.1.2(a) Alarm & Distress Calls 10

2.1.2(b) Ultrasonic 11

2.1.2(c) Pyrotechnics 12

2.1.3 Chemical Repellents 13

2.1.3(a) Methyl Anthranilate (MA) 13

2.1.3(b) Tactile Repellents 13

2.2 Unmanned Aerial Vehicles (UAV) 14

2.3 Pest Birds.. 15

2.3.1 Barn Swallow 15

2.3.2 Asian Glossy Starling.. 16

2.4 Summary 16

CHAPTER 3 GENERAL METHODOLOGY 18

3.1 Study Site 18

3.2 Pest Birds.. 21

3.3 General Methodology Flowchart 21

CHAPTER 4 THE TREND OF PEST BIRD POPULATION FOR 24 MONTHS……… 23

4.1 Introduction 23

4.2 Methodology 24

4.3 Result... 27

4.3.1 Population Trend 27

4.3.2 Population Trend by Building Structure 31

4.4 Discussion 33

CHAPTER 5 THE EFFECTIVENESS OF GROUND-BASED BIRD DETERRENTS.. 37

5.1 Introduction 37

5.2 Methodology 38

5.2.1 Ground-based Bird Deterrents 38

5.2.2 Study Spot 39

5.2.3 Setup of Ground-based Bird Deterrents 40

5.2.4 Experimental Design & Data Collection.. 50

5.2.5 Data Analysis 51

5.2.6 Methodology Flowchart 52

5.3 Result... 53

5.3.1 One Hour Trial Duration ... 53
5.3.2 Nine Hours Trial Duration ... 56
5.3.3 Four Days of Trial Duration ... 58
5.4 Discussion ... 59
CHAPTER 6 THE EFFECTIVENESS OF UNMANNED AERIAL VEHICLES (UAV) ... 64
6.1 Introduction ... 64
6.2 Methodology ... 66
6.2.1 Types of Drone Treatment ... 66
6.2.2 Study Spot ... 68
6.2.3 Experimental Design & Data Collection ... 69
6.2.4 Data Analysis ... 73
6.2.5 Methodology Flowchart ... 74
6.3 Result ... 74
6.4 Discussion ... 77
CHAPTER 7 CONCLUSION AND RECOMMENDATION ... 81
REFERENCES ... 85
APPENDICES
LIST OF PUBLICATIONS

LIST OF FIGURES

Page

Figure 3.1 Location of study site in Peninsular Malaysia. 19

Figure 3.2 Location of Office 1 & Office 2, FAB 1 & FAB 2, CUB 1 & CUB 2 buildings and water tank areas. Red rectangles indicate bird hotspot areas. 20

Figure 3.3 Overview of research methodology 22

Figure 4.1 Nikon coolpix P900 camera with 24-2000 mm lens that was used to take photo on number of pest birds. 25

Figure 4.2 Red lines represent perimeter where bird counts were made. 25

Figure 4.3 Methodology flowchart for objective 1. 27

Figure 4.4 Population trend of pest birds at study site across 24 months. 29

Figure 4.5 Comparison on number of pest birds population between year 2021 and 2022. 30

Figure 4.6 Total number of pest bird roosting in factory compound across 24 months sorted by building structures. 32

Figure 4.7 Pest bird roost (a) under zinc awning, (b) on zinc awning, (c) on cable tray, (d) along electrical conduit, (e) on angle support and along (f) pipelines. 36

Figure 5.1 14 types of ground-based bird deterrents that were used in this study: alarm & distress calls broadcasted from (a) commercial speaker and (b) industrial grade speaker – Bird X Peller Pro, sound frequencies ranged from (c) 24.5 kHz – 45.5 kHz & (d) 13.5 kHz – 45.5 kHz together with flashing lights emitted from sonic device, (e) electronic firecracker, (f) chemical bird repellent - Methyl Anthranilate (MA), (g) a type of tactile repellent - SaiRen, (h) moving and (i) static bird predator models, (j) Agrilaser handheld, (k) reflective compact discs, (l) high & (m) low visibility reflective tapes and (n) spiral rods. 38

Figure 5.2 (a) Study spot A and (b) study spot B which located at FAB 2 building. 39

Figure 5.3 Study spot C for Agrilaser handheld trial. 40

Figure 5.4 Setup method of commercial speaker on study spot. 41

Figure 5.5 Setup method of industrial speaker on study spot. 42

Figure 5.6 Setup method of electronic firecracker. 43

Figure 5.7 Setup method of sonic device. 44

Figure 5.8 MA was poured into portable mist machine and was put at the centre part of study spot. 45

Figure 5.9 Setup method of SaiRen. 46

Figure 5.10 Bird predator model was hanged at the middle of study spot. 47

Figure 5.11 Spiral rods were hung under upper-level awning. 48

Figure 5.12 Reflective compact discs were hung using metal hook and fishing lines. 49

Figure 5.13 Red lines indicate how reflective tapes were setup on top of study spot. 50

Figure 5.14 Mean percentage of birds after one hour of trial duration. 55

Figure 5.15 Mean percentage of birds after nine hours of trial duration. 57

Figure 5.16 Mean percentage of birds after four days of trial duration. 58

Figure 6.1 (a) white multirotor drone (DJI Phantom 4 Pro V2); (b) black multirotor drone (DJI Mavic Pro); (c) eagle plane; (d) standard fixed-wing drone (Skysurfer X8) and (e) DJI Phantom 4 Pro V2 with reflective tapes. 68

Figure 6.2 Location of FAB 1's chimney that was selected as drones' study plot. 69

Figure 6.3 Red arrow represents flight path for DJI P4 Pro V2, DJI Mavic pro and a treatment combination between DJI Phantom 4 Pro V2 and reflective tapes. 70

Figure 6.4 Yellow line represents Skysurfer X8 flight path. 71

Figure 6.5 Flight altitude of multirotor drone treatments (DJI Phantom 4 Pro V2, DJI Mavic Pro and a treatment combination between DJI Phantom 4 Pro V2 and reflective tapes) at 15m and fixed-wing drone treatment (Skysurfer X8) at 20m. 72

Figure 6.6 Research methodology for objective 3. 74

Figure 6.7 Average Number of Birds Activity / Minute. 75

LIST OF ABBREVIATIONS

AC	Alternating Current
ANOVA	Analysis of Variance
DJI	Da-Jiang Innovations
FAB	Fabrication
HSD	Honestly Significant Difference
Hz	Hertz
IBM	International Business Machines Corporation
KHTP	Kulim Hi-Tech Park
LED	Light-emitting Diode
MA	Methyl Anthranilate
SPSS	Statistical Package for the Social Sciences
UAV	Unmanned Aerial Vehicle
UiTM	Universiti Teknologi Mara
UK	United Kingdom
US	United States
USD	United States Dollar

LIST OF APPENDICES

Appendix A Example of datasheet on number of birds for ground-based bird deterrents trials.

Appendix B Example of bird count datasheet.

KEBERKESANAN PENGGUNAAN KAEDAH PENGHALAU BURUNG BERASASKAN DARAT DAN KENDERAAN UDARA TANPA PEMANDU (UAV) DALAM PERSEKITARAN INDUSTRI

ABSTRAK

Mengawal burung perosak di kawasan perindustrian besar merupakan cabaran yang lebih besar berbanding di kawasan kediaman yang lebih kecil disebabkan oleh skala, kerumitan, dan aktiviti burung yang berterusan. Kajian ini menilai keberkesanan 14 kaedah penghalau burung berasaskan darat serta pelbagai Kenderaan Udara Tanpa Pemandu (UAV) dalam menghalau spesies burung perosak biasa seperti burung layang-layang (Hirundo rustica) dan burung keruak (Aplonis panayensis) daripada bertenggek di sebuah kilang semikonduktor besar. Penghalau burung berasaskan darat umumnya dikategorikan kepada jenis bunyi (auditori), visual, dan kimia. Ujian pelbagai penghalau burung darat dan UAV adalah penting kerana perbezaan tindak balas mengikut spesies, kemungkinan kebiasaan burung terhadap satu jenis penghalau, serta kerumitan persekitaran kawasan industri, di mana burung mengeksploitasi pelbagai lokasi bertenggek. Zon perindustrian, seperti kilang semikonduktor, amat terdedah kerana infrastruktur yang besar dan terlindung yang menarik populasi burung yang berterusan, sekaligus menimbulkan risiko terhadap operasi, kesihatan, dan keselamatan. Keputusan menunjukkan bahawa tiada satu pun kaedah berasaskan darat yang berkesan dalam menghalau burung perosak dalam tempoh 4 hari. Namun, UAV jenis multirotor dan rekaan menyerupai pemangsa berkesan dalam menghalau kawanan burung keruak semasa waktu operasi aktif, walaupun burung-burung tersebut sering berpindah ke kawasan berdekatan. Penemuan ini mencadangkan bahawa keberkesanan penghalau mungkin bergantung kepada skala penggunaan, kedudukan,

dan kebolehan bergerak kaedah penghalau tersebut. Kajian ini menyerlahkan kekurangan strategi pengurusan burung perosak jangka panjang yang berkesan di kawasan perindustrian. Kelemahan kajian termasuk tempoh ujian yang singkat serta kecenderungan burung untuk membiasakan diri atau berpindah lokasi. Kajian mencadangkan bahawa kaedah penghalau hibrid atau gabungan, terutamanya yang melibatkan kedua-dua strategi dari udara dan darat, perlu diteroka dengan lebih lanjut bagi mengatasi kebiasaan burung dan meningkatkan keberkesanan jangka panjang. Kajian ini menyimpulkan bahawa cakera padat (CD) reflektif dan pita reflektif adalah kaedah yang paling praktikal dan menjimatkan kos untuk mengawal populasi burung perosak. Di Malaysia, pita reflektif berharga sekitar RM6 untuk 45 meter, manakala CD kosong biasanya berharga kurang daripada RM1 setiap satu apabila dibeli secara pukal. Menggunakan CD lama atau tidak digunakan merupakan penyelesaian yang sangat menjimatkan untuk penghalauan burung.

THE EFFECTIVENESS OF USING GROUND AND UNMANNED AERIAL VEHICLES (UAV)-BASED BIRD DETERRENT METHODS IN INDUSTRIAL SETTING

ABSTRACT

Controlling pest birds in large industrial areas presents greater challenges compared to smaller residential settings due to the scale, complexity, and persistent bird activity. This study evaluated the effectiveness of 14 ground-based bird deterrent methods and various Unmanned Aerial Vehicles (UAVs) in deterring common pest bird species such as barn swallow (*Hirundo rustica*) and Asian glossy starling (*Aplonis panayensis*) from perching at a large semiconductor factory. The ground-based deterrents were generally categorized as auditory, visual and chemical deterrents. Testing various ground-based bird deterrent and UAVs was necessary due to differences in species-specific responses, potential habituation to single deterrents, and the environmental complexity of industrial areas, where birds exploit numerous roosting sites. Industrial zones, like semiconductor factories, are particularly vulnerable due to large, sheltered infrastructure that attracts persistent bird populations, creating operational, health, and safety risks. Results showed that none of the ground-based methods were effective in deterring pest birds over a 4-day period. However, multirotor and predator-design UAVs were effective in dispersing Asian glossy starling flocks during active operation times, though birds often relocated to nearby areas. These findings suggest that deterrent effectiveness may depend on deployment scale, positioning, and the mobility of the deterrent. This research highlights a gap in effective, long-term pest bird management strategies in industrial settings. Limitations include short-term testing duration and the birds' tendency to

habituate or shift locations. The study suggests that hybrid or combined deterrent methods especially those involving both aerial and ground-based strategies should be explored further to overcome habituation and enhance long-term effectiveness. The study concludes that reflective compact discs (CDs) and reflective tapes are the most practical and cost-effective methods for controlling pest bird populations. In Malaysia, reflective tapes cost around RM6 for 45 meters, while blank CDs are typically less than RM1 each when bought in bulk. Using old or unused CDs offers a particularly economical solution for bird deterrence.

CHAPTER 1

INTRODUCTION

1.1 Introduction to Pest Birds Problems & Overview of Bird Deterrents

Birds are the most enchanting class in the animal kingdom. They are an important component of all-natural ecosystems, attracting the attention of many, including scientists, due to their biological characteristics and important role in nature. Due to the loss of natural habitats such as forests, grasslands and wetlands, many groups of birds have to rely on crops, aquaculture farms and man-made structures for their survival. Subsequently, these groups of birds are labelled as pest animals since they cause multiple problems for humans, such as crop depredation, noise, bird droppings, aesthetic and health issues (Anderson et al., 2013; Furlan et al., 2021). Human-wildlife conflicts can arise when human activity such as industrial or agricultural activity harms wildlife populations, when wildlife activity damages buildings or crops, or when humans or their domestic animals contract diseases or parasites from nearby wildlife (Pimentel et al., 2000).

The most common pest birds are feral pigeon (*Columba livia*), house sparrow (*Passer domesticus*), Asian glossy starling (*Aplonis panayensis*), common myna (*Acridotheres tristis*) and house crow (*Corvus splendens L.*) in Malaysia as well as in many countries around the world (Chong et al., 2012; Khan et al., 2015; Shieh et al., 2016; Sodhi et al., 2016; Díaz-Siefer et al., 2022).

A study conducted between 2000 and 2015 examined estimates of potential and actual losses resulting from different bird species (Montràs-Janer et al., 2019). Over this period, there were 2194 reports of crop damage, leading to an estimated overall loss of around 34,500 tons of various crops. Among the bird species considered, the common crane (*Grus grus*) accounted for the highest percentage of total losses (33.7%), followed closely by the barnacle goose (*Branta leucopsis*) (33.5%), the greylag goose (*Anser anser*) (26.6%), the bean goose (A*nser fabalis fabalis*) (2.6%), and the whooper swan (*Cygnus cygnus*) (2.2%). In United States, birds can cause crop damage up to 189 million USD and the benefits of managing bird damage were estimated to be at 737 million USD (Anderson et al., 2013).

Besides, aviation encounters significant challenges related to bird incidents, particularly bird strikes, which incur substantial costs exceeding 1.4 billion US dollars annually for the civil aviation industry (Dolbeer et al., 2014). Additionally, bird strikes have resulted in over 450 fatalities in military aviation alone throughout the past century (Thorpe, 2016; Pfeiffer et al., 2018). An incident occurred on September 26, 2017, where an Air Asia flight traveling from Medan, Indonesia to Penang had to return to Medan due to a bird being drawn into one of its engines (Mydinmeera, 2019).

In urban settings, bird flocks can cause damage to structures through nest-building, pose a potential disease transmission risk, and cause inconvenience by engaging in harassing behaviours towards individuals (Klug et al., 2023). Vehicles, buildings, walkways, yards, shrubs, and nearby plantings suffer from contamination and damage due to the presence of American crow (*Corvus brachyrhynchos*) fecal droppings and regurgitated pellets, which emanate from roosting sites (Johan et al., 2022). Furthermore, the morning departure of crows from their roosts is accompanied by vocalizations that contribute to noise disturbances for local residents, adding to the overall nuisance factor. In Malaysia, barn swallow (*Hirundo rustica*) and Pacific swallow (*Hirundo tahitica*) has significantly caused extensive damage to university structures, crops and machinery due to their droppings in UiTM Kuala Pilah, Negeri Sembilan (Zaimi et al., 2016).

In order to mitigate pest birds problems, human have developed various type of ground-based bird deterrents which generally can be categorized into; auditory deterrents, chemical deterrents, habitat modification, lethal techniques, natural predation, physical exclusion and visual deterrents (Bishop et al., 2003). Visual techniques use visual stimuli to activate a response in the birds, while auditory techniques employ auditory stimuli for the same purpose (Pruteanu et al., 2023). Chemical methods involve using chemical agents to either cause discomfort or eliminate the birds (McLean & Khan, 2013). Exclusion methods rely on physical barriers to prevent birds from accessing specific areas (Angkaew et al., 2022). Habitat modification entails altering environmental factors to make the area less appealing to birds, encouraging them to seek alternative locations (Pennell et al., 2017). Finally, removal methods encompass trapping or killing birds to remove them from a particular environment (Baxter & Allan, 2008).

1.2 Problem Statement & Aims of Study

Pest bird infestations present significant challenges in various human-modified environments, especially in large-scale industrial facilities. While extensive research has been conducted on bird deterrents in agricultural fields, aquaculture farms, and airport runways where damage to crops and risks of bird strikes are well-documented, there remains a noticeable research gap in understanding and managing pest birds in industrial and factory settings. Factories, particularly those with large sheltered structures such as semiconductor facilities, offer attractive roosting sites for pest birds, leading to persistent problems such as droppings on sensitive equipment, noise pollution, structural degradation, and potential health risks to workers. In Malaysia, species such as the barn swallow (*Hirundo rustica*) and Asian glossy starling (*Aplonis panayensis*) have been observed to frequently roost in such environments, yet effective management solutions tailored to these conditions are lacking.

Although a variety of bird deterrent techniques exist including auditory, visual, chemical, and physical exclusion methods, their effectiveness can vary significantly depending on species-specific responses, deployment methods, and site-specific environmental factors. Moreover, habituation to single deterrents over time further reduces long-term effectiveness. While Unmanned Aerial Vehicles (UAV) have shown promise in active bird dispersal in open fields and airports, their potential application in industrial areas remains underexplored. Given these limitations, there is a critical need for research that systematically investigates and compares the effectiveness of conventional ground-based deterrents and UAVs in industrial settings, while also providing insights into pest bird population trends over time. Addressing this gap is essential for developing integrated, effective, and species-specific bird management strategies in non-agricultural, man-made environments.

One of the semiconductor factories in Malaysia is facing a significant challenge with thousands of barn swallow and Asian glossy starling flocks. These pest birds would arrive in the semiconductor factory's airspace between 6.50 pm - 7.30 pm and subsequently roost on the factory structures, leading to health concerns and structural damage due to their droppings. The cost incurred by the company to address pest bird issues is estimated at RM400,000 annually. Thus, the general objective of this study is to examine the population trends of these pest birds and to assess and compare the effectiveness of various bird deterrent strategies including ground-based methods and

UAVs in mitigating pest bird presence at an industrial facility. The specific objectives are as follows:

(i) To examine the trend of pest bird population across a 24-month period within a factory setting.

(ii) To evaluate the effectiveness of using multiple types of ground-based bird deterrents in preventing pest birds from roosting on targeted spots.

(iii) To evaluate the effectiveness of using multiple types of Unmanned Aerial Vehicles (UAV) in dispersing pest birds from perching on targeted plots during peak period.

1.3 Organization of Thesis

Chapter 1 provides the background and objectives of the study. It also presents an overview of pest bird problems and common deterrent methods. The problem statement and aims of the study are included in this chapter as well.

Chapter 2 consists of several sections. The first section discusses ground-based deterrents, divided into sub-sections, such as visual deterrents, auditory deterrents, and chemical repellents. The second section explains all types of UAV which consists of multirotor UAV and fixed-wing UAV. Summary of bird deterrents were also discussed in this chapter.

Chapter 3 focuses on general methodology such as study site. Specific methodology for each objective is discussed in their own chapter – Chapter 4, Chapter 5 and Chapter 6.

Chapter 4 presents the trend of pest bird population for 24 months of study duration. Data on pest bird population are collected from January 2021 until December

2022. A comparison of pest bird population was also compared between year 2021 and 2022.

Chapter 5 evaluates the effectiveness of ground-based bird deterrents in one hour, 9 hours and 4 days of trial duration. Any ground-based bird deterrent that produce significant positive result in one-hour trial would be further tested in nine hours and four days trial consecutively. This chapter has been published at Tropical Life Sciences Research Journal.

Chapter 6 evaluates the effectiveness of UAV in deterring pest birds. Five types of UAV treatments are used in this study, white and black multirotor drones, a standard fixed-wing model, predator design fixed-wing model and a treatment combination between white multirotor UAV and a ground-based bird deterrent, reflective tapes. This chapter has been published at Bulletin of Electrical Engineering and Informatics Journal.

Chapter 7 concludes the thesis by summarizing the whole findings of the study and emphasizing on several recommendations to mitigate pest bird problems in industrial setting.

Chapter 4 to **Chapter 6** are written as stand-alone. There are repetitions in the information that might appear in some chapters.

CHAPTER 2

LITERATURE REVIEW

2.1 Ground-based Bird Deterrents

In the context of pest bird management, a ground-based bird deterrent refers to a method or device used to discourage or deter birds from congregating or nesting on the ground. It is typically employed to prevent birds from causing damage or creating nuisances in areas such as gardens, agricultural fields, airports, rooftops, and outdoor dining areas. The general categories of ground-based bird deterrents commonly used in pest bird management are (i) bird scaring techniques which can be further divided into visual deterrents, auditory deterrents and falconry, (ii) population reduction such as poisoning and chemical fertility control, (iii) habitat management & decoy feeding, (iv) exclusion such as netting, (v) chemical repellents which can be divided into primary repellents, secondary repellents and tactile repellents (Tracey, 2012).

2.1.1 Visual Deterrents

Many visual deterrents use a perceived threat or a visual disturbance to scare the birds away. The example of visual deterrents are reflective tape, scarecrow, mirror and reflector, bird predator model, balloon with eye spots, kites and flags (Bishop et al., 2003). Birds may habituate towards these methods if they are exposed for a period of time.

2.1.1(a) Predator Model

Predator models, often resembling owls or hawks, are designed to mimic real predators and vary in their level of realism. An example of predator model is the "plastic owl" commonly used on buildings to deter pigeons, sparrows, and swallows. Predator decoys are utilized to disperse and discourage birds by emulating the physical attributes and behaviours of genuine predators. The act of evading predators holds significant survival value, creating a solid biological rationale for using predator models. However, it is crucial for the model to possess a high level of realism, as pest birds may become habituated if the model lacks authenticity. Predator models have primarily been employed to scare birds away from agricultural crops (Conover, 2001).

Predator models have limitations due to their lesser realism compared to live birds. Pest birds will eventually learn that the model poses no actual threat. However, if short-term deterrence is sufficient, predator models can be a cost-effective and easy-to-deploy option. Their effectiveness can be enhanced by regularly changing their location (Linz et al., 2017).

2.1.1(b) Laser

Lasers, which emit electromagnetic waves within the visible and infrared light frequencies. These waves, associated with the emitted light, can induce discomfort in birds, subsequently reducing their inclination to remain in such areas (Harries, 1998). In the 1990s, the commercial availability of semiconductor laser diodes, along with a rise in human-bird conflicts, triggered a surge in bird control research on utilizing handheld lasers as bird deterrents (Glahn & Dorr, 2000; Blackwell et al., 2002; Gorenzel et al., 2002). A study by Blackwell et al. (2002) showed geese with treated 650-nm laser treatment exhibited avoidance behaviour during the 20 minutes of study period. In another study, when lasers were employed to disperse crows, there was an initial scattering observed. However, the crows returned to their roosts on the same night that the lasers were utilized, and none of the roosts were ultimately abandoned (Gorenzel et al., 2002). While lasers have shown positive outcomes, it is crucial to note their potential danger to humans (Harries, 1998), making their usage not recommended.

2.1.1(c) Reflective Device

Reflective device such as tape, consisting of three layers, possesses an elastic nature. One side of the tape is coated with a silver metal layer while the other side is covered with a coloured synthetic resin, typically red (Linz et al., 2017). This particular tape exhibits flashing effects when sunlight is reflected upon it, and it generates a humming or crackling sound when stretched or moved by the wind. The combined reflective and auditory properties of this tape have made it effective in deterring birds within agricultural environments. Birds tend to initially avoid these products due to their inherent caution towards unfamiliar items. Additionally, they may display startled reactions in response to the sudden bursts of light and accompanying noise.

In a study by Al-Rajhi (2018), black-crowned night heron (*Nycticorax nycticorax*) individuals were successfully deterred by reflective tapes that were deployed at 2.5 meters height above waters and at 2.5 meters interval between reflective tapes streamers. The setup method offers several advantages, being cost-effective, readily accessible, highly portable and easy to deploy. The effectiveness of the tape may have been further enhanced by high winds, which increased the noise it produced.

Summers & Hillman (1990) conducted a study in the UK, where they tested the effectiveness of a 20 mm wide red fluorescent tape in winter wheat fields to deter brant geese (*Branta bernicla*). The experimental field, covering half of a 20.2 ha area, was compared to a control area of equal size. Another control field about 7.5 ha was established in a different location, equipped with a gas cannon and two scarecrows. Lines of tape were strung at intervals of 40-60m across the wheat rows in the experimental field. The study found that the tape was more effective than the cannon and scarecrows in repelling brant geese. While geese caused a 1% reduction in grain yield in the taped field, the un-taped field experienced a higher reduction of 6%. Interestingly, geese were observed grazing within 2 m of the taped field's edges.

2.1.2 Auditory Deterrents

Auditory deterrent encompasses frightening stimuli, including loud noises produced by pyrotechnics, or high-intensity sounds emitted from sonic devices such as recorded bird alarm and distress calls, ultrasonic, and predator sounds. The effectiveness of auditory techniques lies in their ability to generate loud noises that trigger a fear response from birds (Delwiche et al., 2005), capitalizing on the birds' natural instinct to evade potential threats. However just like visual deterrents, birds may habituate to them easily thus reducing their effectiveness over time. Plus, using auditory deterrents can raise noise issues, so it is impractical in using them near human residential areas.

2.1.2(a) Alarm & Distress Calls

Numerous bird species emit distress and alarm signals in situations where they are captured, restricted, harmed, or facing other forms of danger. These calls are unique to each species, indicating peril and alerting fellow members to disperse. There are commercially accessible systems that broadcast pre-recorded distress calls, with many of these units being portable and capable of being mounted at anywhere (Bird-X, 2023). Additionally, solar and wind-powered variations of these systems are now available. In recent times, there has been an emergence of high-quality digital recordings.

According to Ribot et al. (2011), certain growers utilize synthetic sounds that convey clear messages, such as distress calls, to evoke interspecific responses. They observed that crimson rosellas (*Platycercus elegans*) were successfully deterred at short to medium-range distances. Also, Delwiche et al. (2007) evaluated the effect of crow alarm and distress calls on damage levels in large commercial almond orchards. They found significant differences in damage distribution between treated and untreated sites in two out of three regions. The savings due to distress call treatment were estimated to be 12 USD and 25 USD per hectare in the regions with significant damage. Plus, they indicated that although alarm and distress calls do not exert lasting influence on animal distribution or feeding behaviours, it can yield temporary reductions in damage.

2.1.2(b) Ultrasonic

Ultrasound is commonly described as sound with frequencies beyond the range of human detection, typically exceeding the upper limit of 20,000 Hz, which only a few adults can effectively hear. If ultrasound were indeed effective, its clear benefit as a dispersal or deterrent method would lie in its inaudibility to humans. Unlike other noise-based deterrents such as propane cannons, ultrasound would avoid causing annoyance to humans in numerous scenarios.

An experiment was conducted by Nankinov et al. (2007) which evaluated a commercial ultrasonic device from Conrad Company designed to deter doves, starlings and sparrows at ornithological centre in Bulgarian. In their study, they noted that the ultrasonic sound emitted by the device did not seem to have a discernible impact on the behaviour of the targeted species of birds. However, they did observe a significant reduction in the number of birds visiting the centre after 10^{th} day. Bird species exhibit variations in their responsiveness to different sound frequencies thus suggesting that only certain species could potentially react to ultrasound (Beason, 2004; Siahaan et al., 2017; Fletcher et al., 2018).

Besides, a device was developed to operate within the ultrasonic frequency range of 15-25 kHz by Ogochukwu et al. (2012). The ultrasonic waves established an unfavourable setting for the targeted weaverbirds and blackbirds, eliciting a deterrent effect on them. Despite having a limited range, these waves effectively compelled the birds to depart from the targeted areas over time.

2.1.2(c) Pyrotechnics

Pyrotechnics encompass an extensive range of noise-producing projectiles launched from shotguns, starter pistols, and flare pistols. Among these are shellcrackers, flares, firecrackers, rockets, and mortars. Each of these pyrotechnics generates loud, explosive sounds, emits bursts of light thus possessing a visual deterrent aspect, or both. Pyrotechnics achieve their desired impact only for a limited duration, as birds tend to acclimate to the noise over time (Enos et al., 2021).

In urban parks, screamer shells were found to be 100% effective in dispersing Canada geese, even when broadcasts of alarm or distress calls were not (Aguilera et al., 1991). The utilization of screamer shells had lasting effects on goose distribution. Following five days of employing screamer shells, Aguilera et al. (1991) reported an 88% reduction in the number of geese frequenting a site during the subsequent five days.

A study by Glahn (2000) was conducted to differentiate the effectiveness of pyrotechnics and shooting in deterring double-crested cormorants (*Phalacrocorax auratus*). The study found no disparities between pyrotechnics and shooting in terms of duration before the roosts were reoccupied and the effort required to deter the roosts. Thus, it was concluded pyrotechnics and shooting were equally effective as methods for deterring cormorant roosts.

Baxter & Robinson (2007) found that the use of pyrotechnics did not cause habituation among gulls and corvids at landfills site although the frequency of pyrotechnic utilization increased over the trial period.

2.1.3 Chemical Repellents

Chemical repellents have found applications in various settings, including agricultural environments (Carlson et al., 2013), commercial (Clark & Avery, 2013) and residential areas (Marsh & Salmon, 2010). Notably, birds typically do not become habituated to chemical repellents.

2.1.3(a) Methyl Anthranilate (MA)

Methyl anthranilate (MA) consists of esters derived from anthranilic acid and is authorized by the U.S. Food and Drug Administration for use as a grape flavouring in human consumables, including candy, soft drinks, chewing gum, pharmaceuticals, and nicotine products (Linz et al., 2017). Additionally, it finds application in contemporary perfumes, being part of several essential oils and synthesized aromatic compounds.

Early in the 1960s, MA was recognised as a potential bird repellent (Kare, 1961). MA have been used in numerous field research to repel blackbird at Missouri rice fields and North Dakota sunflower fields (Werner et al., 2005) and dispersing large flocks of migrating swallows and killdeer that aggregate near Homestead Air Reserve Station during migration periods (Engeman et al., 2002).

2.1.3(b) Tactile Repellents

The majority of tactile repellents consist of adhesive substances such as aliphatic petroleum hydrocarbons, polybutenes, and polyisobutenes which are designed to discourage birds from perching on various surfaces, including building ledges, antennas, and airfield lights and signs (Clark, 1998). These sticky compounds can be conveniently applied using tools such as a caulking gun, putty knife, spray can, or small tube.

Similar to other animals, birds comprehend their surroundings through various stimuli, which encompass touch, specifically skin contact (Seamans et al., 2013). Exposure to pesticide other than dietary intake have revealed that birds can be affected by chemical absorption through the foot pads (Mineau, 2011).

Deliberto et al. (2020) found that different types of tactile repellents formulations reduced faecal accumulations by European starlings (*Sturnus vulgaris*) beneath treated aluminium perches compared to untreated control. An inherent drawback of using surface-applied repellents lies in their susceptibility to the buildup of dust or moisture on the treated surface, leading to a loss of effectiveness. Stock & Haag-Wackernagel (2013) also discuss how their testing involved the accumulation of insects, feathers, and faecal matter on both types of treatments.

2.2 Unmanned Aerial Vehicles (UAV)

The emergence of autonomous technologies has opened possibilities for utilizing UAVs or mostly known as drones in various occasions (Barnas et al., 2018; Rebolo-Ifrán et al., 2019; Wandrie et al., 2019; Egan et al., 2020). Even though UAVs were initially developed primarily for military applications, it has witnessed a significant shift towards civilian usage due to technological advancements and the miniaturization of components. This shift has facilitated the emergence of a mass production industry, resulting in reduced prices and a subsequent proliferation of UAVs utilization across various civilian sectors. Ecological research has shown that UAVs can disrupt wildlife, including birds (Chabot et al., 2015; Vas et al., 2015; Brisson-Curadeau et al., 2017). Several commercially available UAVs claim to provide effective protection against bird damage, taking advantage of their proven ability to deter birds. These off-the-shelf bird deterring UAVs are generally compact which weighing less than 5 kg and come equipped with predator-like features, either visual or auditory, intended to frighten pest birds (Storms et al., 2022). There are various types of UAVs that are utilized for pest bird management. These UAVs are designed specifically to deter and control bird populations, preventing them from causing damage or nuisances in certain areas. UAVs can be generally categorised as multirotor UAV and fixed-wing UAV (Sandbrook, 2015). Fixed-wing UAVs possess a resemblance to airplanes in terms of their appearance, while rotary-style UAVs come in various configurations (such as quad or octo-copter) and generally feature a platform resembling a helicopter, enabling them to hover by means of rotating blades.

2.3 Pest Birds

2.3.1 Barn Swallow

Barn swallow (*Hirundo rustica*) is a widely observed and prevalent bird species found in human settlements, often nesting in barns or bridges near water and fields (Scordato & Safran, 2014). It belongs to the family Hirundinidae, which includes 83 species of swallows and martins (Turner, 2004). There are six subspecies of the barn swallow: *Hirundo rustica savignii*, which breeds in North Africa; *Hirundo rustica transitiva*, primarily breeding in the Middle East; *Hirundo rustica rustica*, breeding in Europe; *Hirundo rustica tytleri*, found in Siberia and Mongolia; *Hirundo rustica erythrogaster*, a breeder in North America (Del Hoyo et al., 2018); and *Hirundo rustica gutturalis*, whose breeding range extends from the eastern Himalayas to northeast Russia (Siberia), China, Korean Peninsula, and Japan (Dor et al., 2010), while spending its winters in Thailand and the Malay Peninsula (Mansor et al., 2020). The Thai-Malay peninsula serves as a significant migratory route and winter habitat for *Hirundo rustica gutturalis* (Wells, 2010).

Barn Swallows benefit from agriculture as the insects surrounding livestock provide an excellent food source for them. The population of barn swallows seems to frequently utilize service wires such as electricity and telephone wires for roosting in urban localities, including historic towns like Bentong, Pahang, Malaysia. This behavior mirrors their habits in both their temperate breeding and wintering habitats (Verma, 2010).

2.3.2 Asian Glossy Starling

Asian glossy starling (*Aplonis panayensis*) is a sociable bird species that congregates in sizable flocks to forage and shares communal roosts during the nighttime. This species is commonly encountered in human-inhabited areas such as cities, gardens, plantations, and parks (Sontag & Louette, 2007). It tends to be linked with places that offer tall trees and a plenty supply of fruit, often associating with buildings (Wells, 2010). Asian glossy starling is known to roost alongside flocks of invasive birds like the house crow (*Corvus splendens*), common myna (*Acridotheres tristis*), and Javan myna (*Acridotheres javanicus*) (Jeyarajasingam & Pearson, 2012). Urban roosting locations have the potential to generate noise pollution, and the resulting droppings can harm buildings and vehicles, contaminate pathways, and introduce pollutants into reservoirs (Yap et al., 2002).

2.4 Summary

Numerous ground-based bird deterrent methods such as visual and auditory deterrents, chemical repellents, and exclusion techniques have been explored and implemented in both agricultural and urban environments. Visual deterrents like predator models, reflective tapes, and lasers are common but often limited by habituation, realism, and safety concerns (Harris et al., 2016). Auditory deterrents, including distress calls and pyrotechnics, show varying levels of success but face constraints in urban or residential areas due to noise pollution and limited long-term effectiveness (Duttenhefner & Klug, 2024). Chemical repellents, though relatively effective and less prone to habituation, raise environmental and maintenance concerns.

More recently, UAVs have emerged as a promising tool in wildlife and pest management. UAVs, particularly those equipped with predator-mimicking features, have shown the potential to disturb or deter birds in open or ecological environments. However, most existing studies have been conducted in agricultural lands, coastal areas, airfields, and conservation zones (Egan et al., 2020). No prior literature specifically addresses the use of UAVs as a bird deterrent within industrial environments, especially high-sensitivity zones like semiconductor factories, where bird infestations can lead to serious contamination, structural damage, and costly clean-up efforts. Thus, this study served as the basis for evaluating UAVs in industrial settings.

Additionally, most bird deterrent strategies are tailored toward general agricultural or open landscapes, and there is limited data on species-specific deterrent effectiveness in Malaysia particularly against local pest birds such as the Asian Glossy Starling and Barn Swallow. While some studies have documented the damage caused by these species, quantitative assessments of economic losses in the Malaysian industrial context remain sparse.

CHAPTER 3

GENERAL METHODOLOGY

3.1 Study Site

The study was conducted at one of the semiconductor factories in Kulim Hi-Tech Park (KHTP) at the coordinate of 5.399357216, 100.5922385 (Figure 3.1). KHTP is an industrial park dedicated to high technology enterprises in Kulim district, Kedah, Peninsular Malaysia. The primary focus of KHTP is wafer fabrication, which holds significant strategic value in the country's push for industrialization, given its status as a fundamental technology within the semiconductor industry. The semiconductor factory is surrounded by forest and human residential areas. However, one of the forest areas has turned into empty land as the company expanded its production capacity. The total area for the semiconductor factory is about 0.25 km^2 which is mainly comprised of its car park, office buildings (Office 1 & Office 2), fabrication buildings (FAB 1 & FAB 2), centre utility buildings (CUB 1 & CUB 2) and water tank areas. Based on previous observations, there are two bird hotspot areas; the first is between the Office 1 & FAB 1 buildings, while the other is between the FAB 1 & FAB 2 buildings (Figure 3.2).

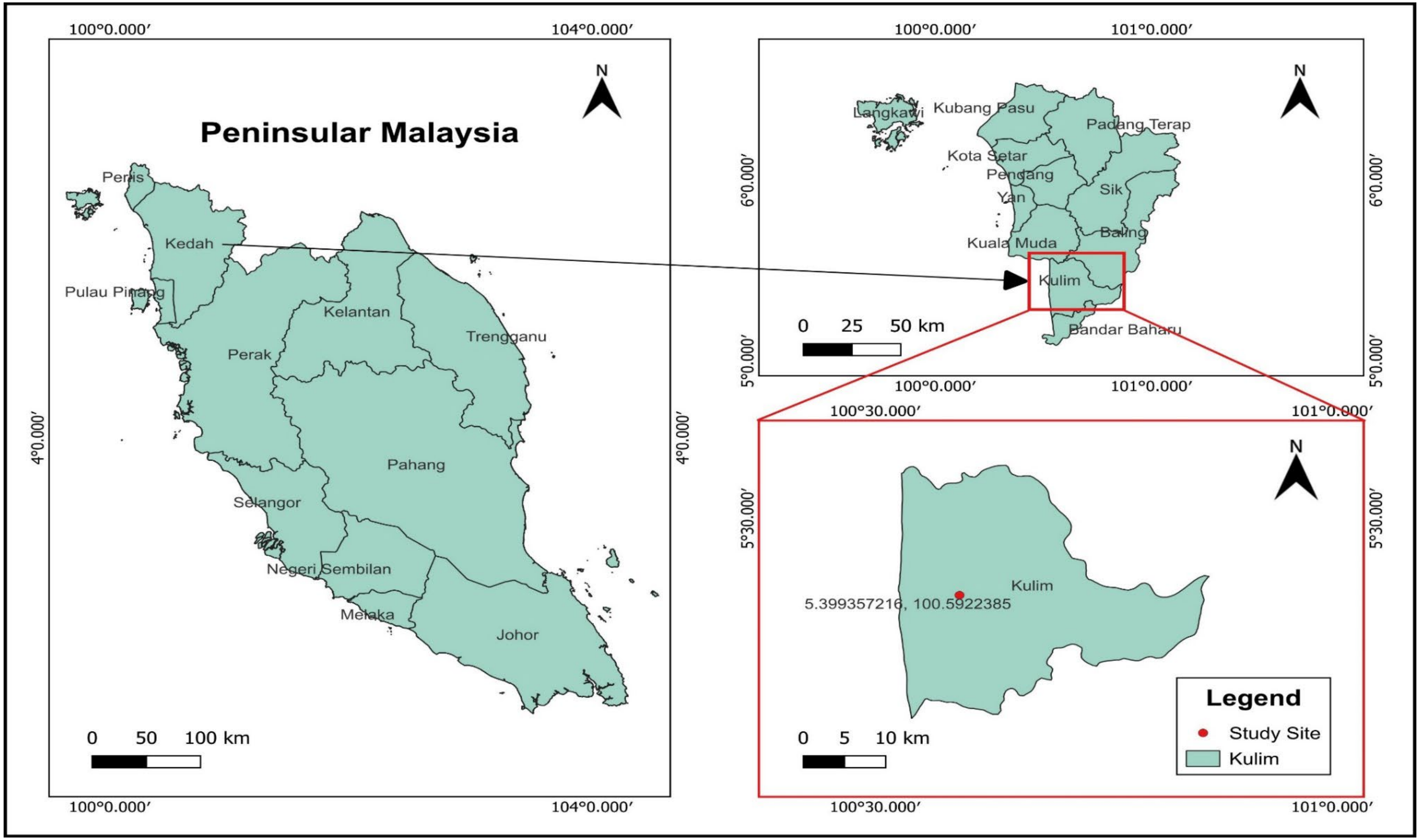

Figure 3.1: Location of study site in Peninsular Malaysia.

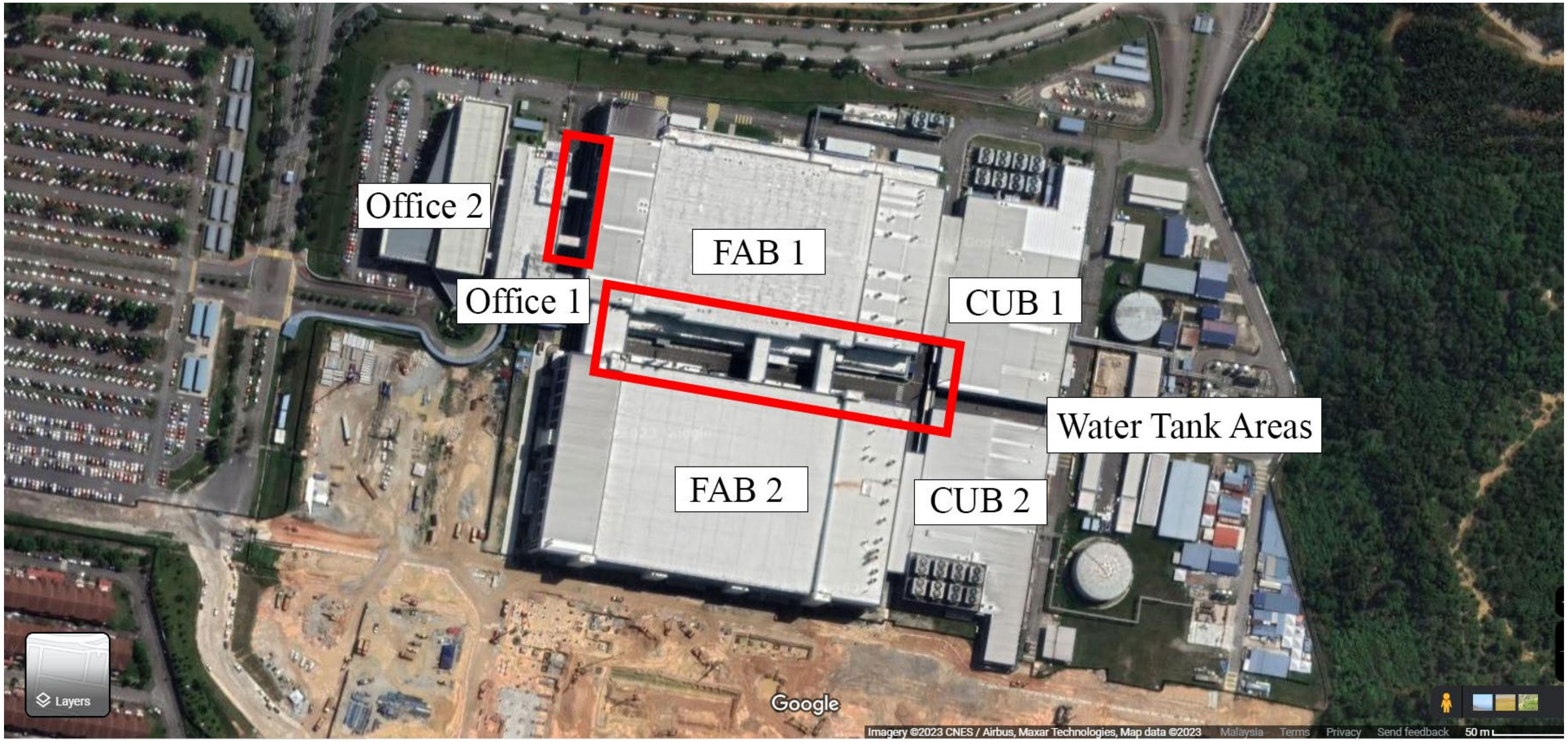

Figure 3.2: Location of Office 1 & Office 2, FAB 1 & FAB 2, CUB 1 & CUB 2 buildings and water tank areas. Red rectangles indicate bird hotspot areas.

3.2 Pest Birds

Preliminary observation on the presence of pest birds at study site was conducted for four weeks. A few main bird species were identified onsite: barn swallow (*Hirundo rustica*) and Asian glossy starling (*Aplonis panayensis*). There were also other species of pest birds: house crow (*Corvus splendens*), rock pigeon (*Columba livia*), common myna (*Acridotheres tristis*), Eurasian tree sparrow (*Passer montanus*) and zebra dove (*Geopelia striata*).

3.3 General Methodology Flowchart

All three objectives were carried out concurrently due to time constraints in accessing the study site areas. For objective 1, pest bird species and building structures within the bird counting perimeter were identified, followed by bird counts and statistical analysis (Figure 3.3). Objective 2 involved identifying ground deterrent study spots, deploying ground-based deterrents, quantifying bird activity, converting observations into percentages, and performing statistical tests. Similarly, objective 3 focused on identifying UAV deterrent study spots, deploying UAVs, recording bird counts, converting data into percentages, and conducting statistical analyses. Detailed methodology and parameters for objectives 1, 2 & 3 were discussed separately in Chapter 4, Chapter 5 and Chapter 6.

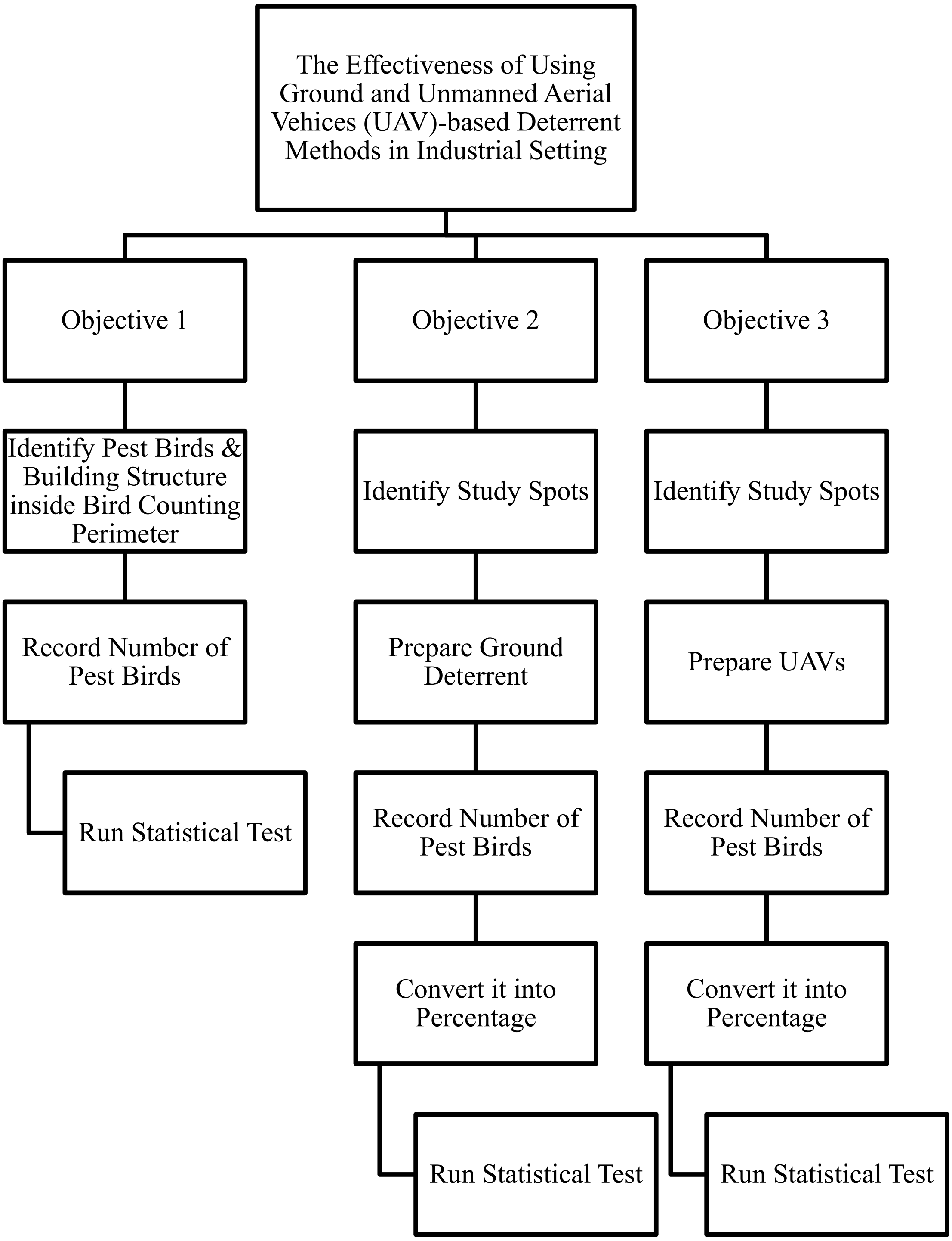

Figure 3.3: Overview of research methodology.

CHAPTER 4

THE TREND OF PEST BIRD POPULATION FOR 24 MONTHS

4.1 Introduction

In recent years, the presence of pest bird populations has become a growing concern in various urban and industrial settings (Sodhi et al., 2016). Industrial settings, characterized by their large structures, open spaces, and abundant resources, often provide favorable habitats for pest bird species (Haag-Wackernagel & Geigenfeind, 2008). These birds exploit the available food sources, nesting sites, and shelter, resulting in population growth and potential damage to infrastructure, products, and overall operations. The presence of pest birds in industrial environments can lead to health and safety concerns, contamination of goods, disruption of production processes, compromised employee well-being, and increased maintenance costs (Wiesner et al., 2012; Fu et al., 2016). The impacts of these pest birds on public health, workplace productivity, and infrastructure integrity cannot be understated. Numerous species of birds have developed strong connections with humans and their actions, relying on them to some degree. At its most basic level, this connection can involve using man-made structures for activities like perching, roosting, or even building nests. Consequently, the assessment and management of pest bird populations have become crucial considerations for industries striving to maintain operational efficiency and regulatory compliance.

Recognizing the urgency of addressing this issue, the aim of this study is to evaluate the trend of pest bird populations in an industrial setting for 24 months. Through this research, the output of this study is to provide a foundation for the development of targeted and effective strategies to manage and mitigate the challenges posed by pest bird populations.

4.2 Methodology

Number of pest birds were counted by taking photo using Nikon Coolpix P900 camera with 24-2000 mm lens (Figure 4.1). Bird counts were made about three hours in duration, usually from 2100 – 0000 hours depending on the weather condition and were conducted on the fourth or fifth week except for the last month (Dec 2022) where it was conducted on the third week of the month. The counts were made in monthly interval starting from January 2021 until Dec 2022. Bird counts were made at every section of the factory's main buildings (Office 1 & Office 2, FAB 1 & FAB 2, CUB 1 & CUB 2) and the areas between CUB's buildings and water tank areas (Figure 4.2). Bird counts across 24 months were also categorised according to building structures; Office 1, Office 2, FAB 1, FAB 2, CUB 1, CUB 2, bridges that connecting FAB buildings and Office buildings (bridge areas), water tank areas and chiller plant room. No ground-based bird deterrent installed at chiller plant room during study period.