MACHINE-VISION-BASED DETERMINATION OF THE GENDER OF CHICKS

NUR SYAMIM BINTI AZLAN 1425772

MECHATRONICS DEPARTMENT

KULLIYYAH OF ENGINEERING

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

AUGUST 2020

APPROVAL

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as Final Year Project report as partial fulfilment for a degree of Bachelor of Engineering (Mechatronics)(Honors).

……………………………………..

Dr. Ali Sophian

Supervisor

ABSTRACT

Chick sexing in poultry industry needs to step up its game. Therefore, the introduction of image training alongside with the usage of UV lighting for system to see that chicks have UVIVF. Normal practice of chick sexing requires professional that needs ten or more years to be prominent in knowing which is male and female chicks. Knowing male and female chicks help a lot in the poultry industry as small farms needs smaller expenses in running the farm. Based on the literature review, there are a few patents that have patented ways of knowing chicks using UV lighting and image training. This method comprises of two parts which is UV lighting and image training. In this project, there is a need to have a mobile robot with a mounted camera and UV light as well as a microcontroller for image training. A preliminary image training system had been performed and it shows that image training needs to be done with a higher resolution image.

Keywords: Ultraviolet light (UV light); chick sexing; image training; final year project

ACKNOWLEDGEMENT

Alhamdulillah, all praises to Allah the Lord of Universe for giving me the strength and patience to complete Final Year Project 1 even if there are difficulties and hardships, especially with the current pandemic of COVID-19. I had managed to finish the project within this semester.

I would like to take this opportunity to express my highest gratitude and appreciation to my family for their support along my journey upon finishing my study. I would like to thank Mechatronics Department for giving me this precious opportunity to do my final year project.

Not to be forgotten, special thanks to my supervisor, Dr. Ali Sophian for approving my topic when I approached him during the start of the semester. I admit, I hadn't the courage to approach him much because I was concerned that he is busy, however he is open to any questions I had asked and answered it with outmost patience. He also guides me everything that he can, to provide me enough knowledge for me to write the report for the Final Year Project 1. He encourages me to keep doing my own study towards this project. Thank you, sir.

My further gratitude goes to my few closest friends for their unstoppable moral support and understanding and their discussion about this title had opened my eyes more than anything. Thank you everybody.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

FYP	Final Year Project
UV	Ultraviolet
UVIVF	Ultraviolet-Induced Visible Fluorescence
ML	Machine Learning
AI	Artificial Intelligence
BBC	British Broadcasting Corporation
MRI	Magnetic Resonance Imaging
VIS	Visible Spectrum
UV-LED	Ultraviolet Light Emitting Diode
MSP	Microspectrophotometers
RAW	Raw camera image file
IR	Infrared
ISO	International Organization for Standardization
CNN	Convoluted Neural Network
RGB	Red, green and blue

YOLO	You Only Live Once
IOU	Intersection Over Union
LiPo	Lithium polymer rechargeable battery
PWM	Pulse width modulation
USB	Universal serial bus
DIY	Do It Yourself
HD	High Definition
ROI	Region of Interest
OpenCV	Open Source Computer Vision Library

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

In the poultry industry, incubating male eggs and infertile eggs is a titanic waste of resources and finance. As of current market, all hatcheries have their eggs incubated until they are hatched (Hein, 2018). From there, the hatched chicks are sexed when it is possible to determine gender. This, in truth, occupies valuable resources, labour-extensive and there is also the concern of crucial animal welfare of slaughtering of male chicks. It is by no surprise that in the recent years of growth of technology, ideas are being developed to prevent this massacre.

The occupation of a chick sexer requires extensive period of training as well as high wage since they are a professional line of work. This is why implementation of AI is very helpful in this industry as it can help reduce finance.

In order to prevent the unethical practice of chick culling, a number of ideas as well as old patents are being brought forward to eliminate this problem. BBC News dated 13 June 2019, with title ‘German court rules mass-killing of male chicks legal’ is actually based on until cheap alternative can be found. Henceforth the impeding action for chick culling should be start right away to outright remove this unethical practice in poultry industry.

In Islam, doing good to animals are encouraged, as depicted in a hadith by Rasulullah SAW,

إنَّ اللَّهَ كَتَبَ الإحْسانَ على كُلِّ شيءٍ، فَإِذا قَتَلْتُمْ فأحْسِنُوا القِتْلَةَ، وإذا ذَبَحْتُمْ فأحْسِنُوا الذَّبْحَ، وَلْيُحِدَّ أَحَدُكُمْ شَفْرَتَهُ، فَلْيُرِحْ ذَبِيحَتَهُ

"Indeed, Allah is obligated to do good to everything. When you all want to kill (animals), kill it in the best way possible. When it comes to slaughter, sacrifice in the best way. You must sharpen the knife and rest its slaughter." Muslim History (1955)

1.2 PROBLEM STATEMENT

There are several techniques of chick sexing used in poultry industry nowadays. One of the problems arise is the extreme financial cost hatcheries are facing whenever they need to sex the chicks so that they are able to sell it to buyers. As mentioned, chick sexer profession is a highly paid wage, hence this leads to high financial usage by hatcheries to employ them. On the other hand, growing up the chicks into adults would take another toll on the finance as male chicks eat a lot and grows slower compared to female chicks. Grown males of the egg-laying breeds are of little value, and only a few roosters are required for reproduction. Henceforth, the usage of camera viewing together with deep learning would help save time as well as finance of the hatchery, which nicely coincides with Industrial Revolution 4.0.

1.3 OBJECTIVES

This project aims to integrate the relationship between camera and image processing together using Python. The objectives of this research as follows:

1) To identify a cost-effective and accurate way for determining gender of chick of day-old
2) To implement the method in a working prototype
3) To evaluate the performance of the proposed method by using the prototype

1.4 SCOPE OF THE WORK

The scopes of this project are as stated as below:

1) The system will use one camera.
2) The system will sex chicks one by one.
3) The system will use Python's Haar Cascade classifier for image learning and processing.
4) Male and female chicks are of the same family from one breed only.

1.5 METHODOLOGY

This project is divided into two phases, Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2). These two phases follow the timeline and steps in a few methodologies to ensure that the project is completed as scheduled.

The project starts with the collection of information and current technology related to the problem statement and objectives of the project. Then the project proceeds with the review of other researchers' works and findings. Together with the knowledge and details obtained, a conceptual design of the system is drafted as follows.

The project development is followed with the setup of two web cameras and a microcontroller.

The focus of the study is to learn to teach AI to know which one is a female chick and which one is a male chick after they are passed across the cameras that is setup to capture the image of the wings. The experiment is conducted and the data is collected from the microcontroller. The data are tabulated using MATLAB. The flow of the overall methodology for this project is shown in Figure. The summary of action is in **Table 1** and **Figure 1** respectively.

No.	Task name	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Title selection														
2.	Overall System Review														
3.	Literature Review														
4.	System Design														
5.	Experiment														
6.	Data Analysis														
7.	Report Writing														
8.	Submission & Presentation														

Table 1 Gantt Chart of Final Year Project 1

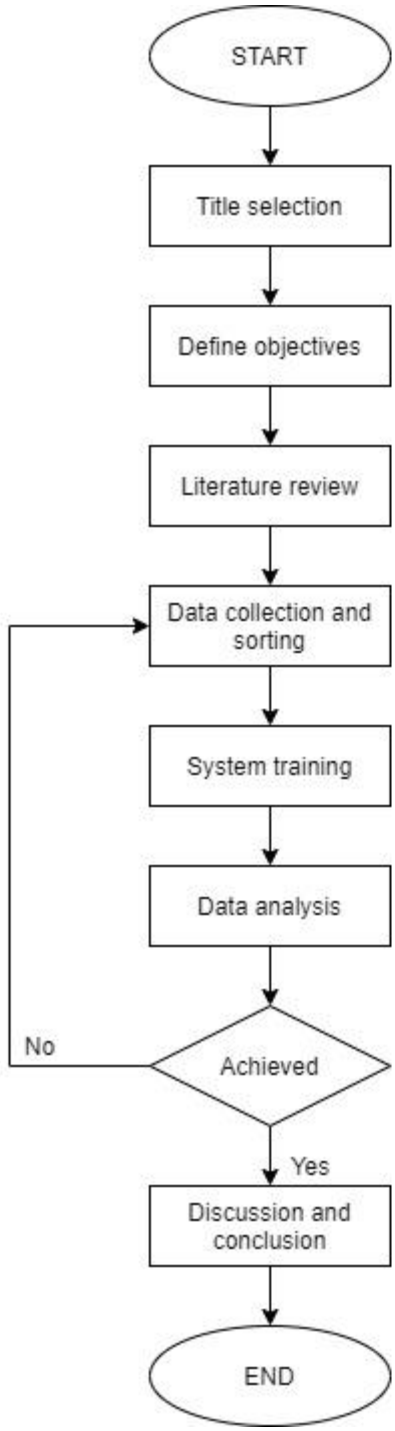


Figure 1 Flowchart of research methodology

1.6 CHAPTER OUTLINE

This project consists of five big chapters.

CHAPTER 1: Comprises the introduction of the project, problem statement, objectives, scope of work and methodology.

CHAPTER 2: Discusses the study of the previous research papers on Chick Sexing, which covers all pros and cons comparisons.

CHAPTER 3: Illustrates the system design, including the overall system design, circuit and algorithm development.

CHAPTER 4: Shows the results, tabulation of data and graph, analysing, and discussion of the outcomes.

CHAPTER 5: Explains the summary, its limitation, conclusion and recommendation that has been obtained.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Chapter 2 requires the study of what other researchers and/or engineers have used to solve the problem of chick sexing. The research studies, journal articles and patents that have been published in the past years are helping in achieving the objectives of this Final Year Project. It gives a better comprehension of the main idea of the project while understanding the concept behind the problem discussed. This chapter is divided into four subchapters.

The first subchapter will be discussing the methods available on determining sex of chicks. The following subchapter will review the use of UV-LED light and its properties. Continuing, the third subchapter will analyze the type of hardware available. To finish of Chapter 2, the fourth subchapter will go through software algorithm on image processing. Lastly, there will be a conclusion of what will be chosen as to achieve the objectives.

2.2 TECHNIQUES OF DETERMINING SEX OF CHICKS

There are a number of chick sexing system available in the market as well as the patents involved. These different technologies have since expanded and gave birth to new ideas and patents, as well as having their advantages together with its flaws.

2.2.1 VENT SEXING

It is little known fact that the world's best chick sexer hails exclusively from Japan (Horsey, 2002). Vent sexing is done by examining the cloaca of the chicks when it is first hatched. The first and foremost paper written and published on chick sexing was from Japan in 1933 by Professors Masui and Hashimoto, under the title "Sexing Baby Chicks" which was then roughly translated into English. The Japanese contribution in this regard was recognized in Britain as in other western countries due to the paper written by this Professors (show the reference supporting this statement). This system has effectively reduced the feeding cost for roughly 50 percent of the running expenses of an average farm, where unwanted males can be eliminated within a day-old by examining its cloaca. The only downside for this method is that it requires a professional chick sexer, and to employ a professional chick sexer, farms need to increase its expenses.

2.2.2 SEXING CHICKS BY COLOUR

Chick sexing can also be done by differentiating their color of their down as seen in **Figure 2**. However, it only works in certain breeds and in special sex-linked hybrids. It is quite easy to do chick sexing through this method and any newbies can proceed with this method.

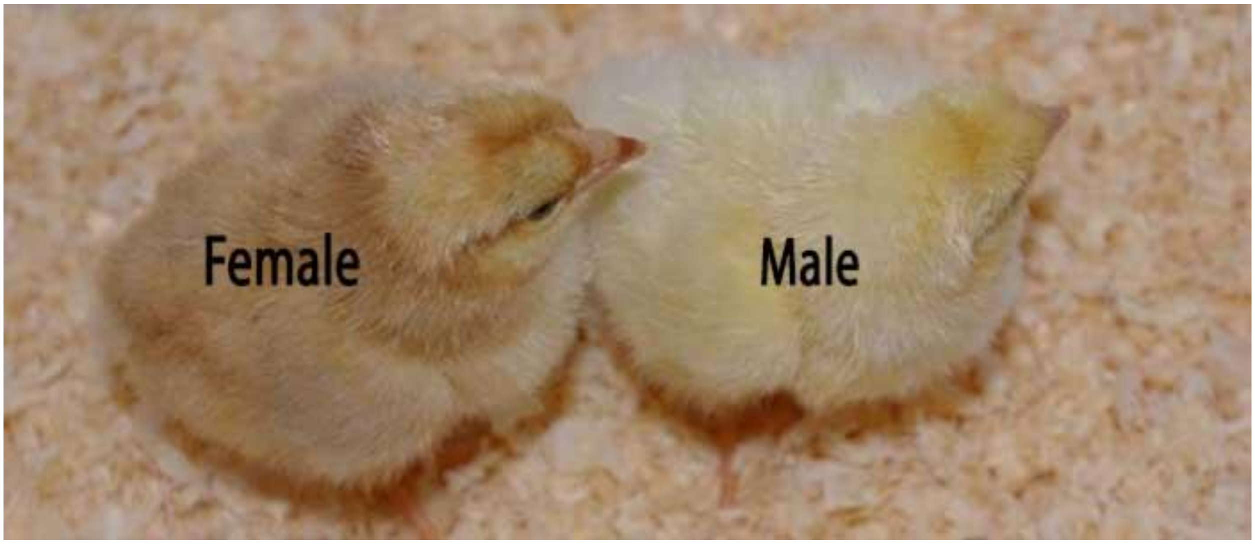


Figure 2 Female and Male chick (Daniels, 2015)

Small hatcheries use this kind of chick sexing. They use secondary sex characteristics to distinguish roosters from hens. The only downside is that the chicken owners need to wait until the chicken are several months old. This is only applicable for those that raises a certain breed and breeders are accustomed to their growth.

2.2.3 SEXING CHICKS BY FEATHERS

Feather sexing as seen in **Figure 3** is another simple technique, yet is able to be done to a chick when it is day-old. It is done through simple observation. One interesting thing to note is that this method is only applicable for only if the chick's father is of a breed that grows feathers rapidly and its mother is of a breed that grows feathers slowly. This trait is sex-linked.

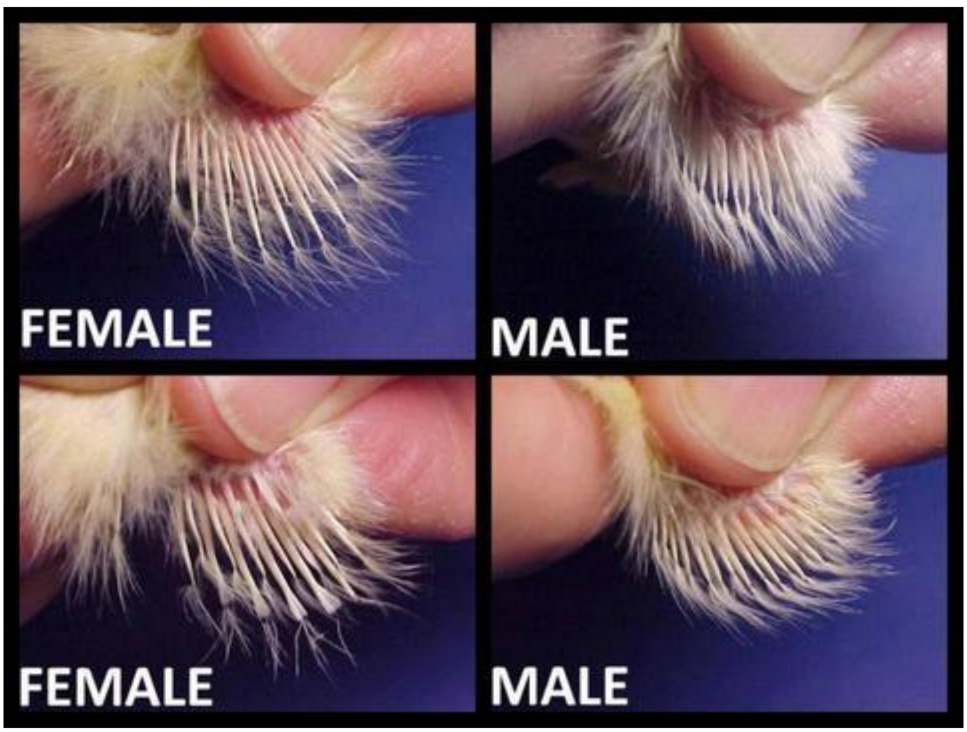


Figure 3 Feather sexing chick of day-old (Smith, 2020)

2.2.4 IN-OVO SEXING

Discovering whether a chick is a male or female while it is still in egg is how In-ovo sexing works (Epping, 2018). This is the definition of In-Ovo sexing, a shortened form of in-ovary sexing. This method can determine the sex of an egg within seconds on day nine after fertilization. It uses the presence of a specific biomarker to determine the sex of the chick by making a miniscule hole to the egg and retrieve a tiny sample of the embryo. In a way, this helps a lot in animal welfare as the unneeded male chicks can be repurposed without killing it. This company, 'Start-up in Ovo' was founded in 2013 by Leiden students, Wouter Bruins and Will Stutterheim.

2.2.5 ENDOSCOPE SEXING

Another discovery in determining the sex in hens' eggs was made in Munich, Germany, discovered by Prof. Dr Axel Haase, Prof. Dr Benjamin Schusser, Dr Maria Laparidou and Dr. Pedro Gomez (Krüger, 2018). The CEO of the company Bayerische Patentallianz GmbH (BayPAT), Dr Robert Phelps will continue to advice and monitor this new technology so that it is ready for the market. It is similar to how In-ovo method works, which is given the name ORBEM GENUS. Half of the eggs laid only have to be incubated for only a few days before ORBEM GENUS can identify the sex of the chicks by combining magnetic resonance imaging from the world of medicine with cutting edge AI.

Figure 4 BayPAT: ORBEM GENUS (Krüger, 2018)

Endoscope sexing as shown in **Figure 5** is an improved method of vent sexing by using an endoscope system. In this method, a probe of an endoscope is inserted from the cloaca into the intestine of a chick and the presence of testes or ovary can be observed through the wall of the intestine and clearly displayed on a computer monitor through S-video port.

A study done by a group of Japanese using this system determines that the percentage of success is over 95.0% for sexing male chicks compared to female chicks (86.0%). The overall accuracy of sexing is 90.2% and continuous usage and training will improve the handling of the endoscope system (Otsuka, Miyashita, Shibata, Sato, & Naito, 2016).

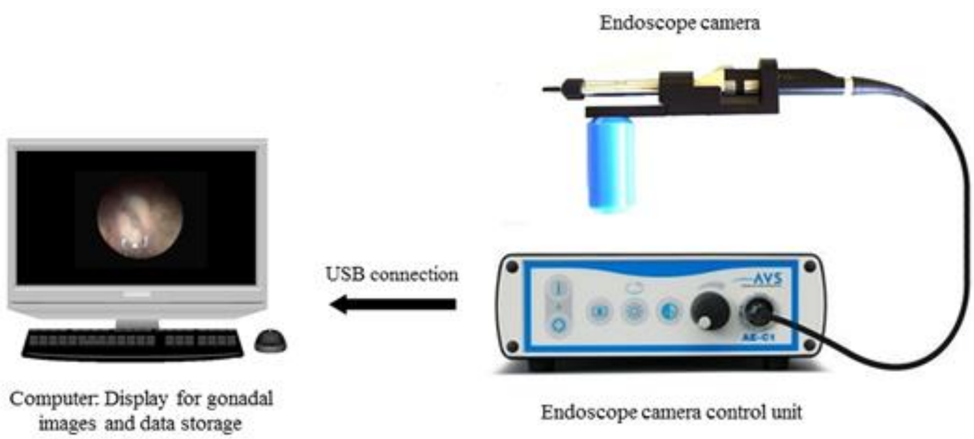


Figure 5 Devised Endoscope system (Otsuka, Miyashita, Shibata, Sato, & Naito, 2016)

2.2.6 IN-OVO SEXING BY FLUORESCENCE AND RAMAN SPECTROSCOPY THROUGH SHELL MEMBRANE

The method of In-ovo sexing in **Figure 6** below is by fluorescence and Raman spectroscopy through shell membrane is still under research by a team from Germany (Galli, et al., 2018). The presence of the inner shell membrane has a double effect on the excited fluorescence and Raman signals of blood cells which will be (i) scattered by the membrane leading to a reduced intensity and (ii) superimposed by Raman bands of the membrane. The excitation laser beam is also partly backscattered by the membrane which contributes to the decrease of Raman and fluorescence signal intensities of blood.

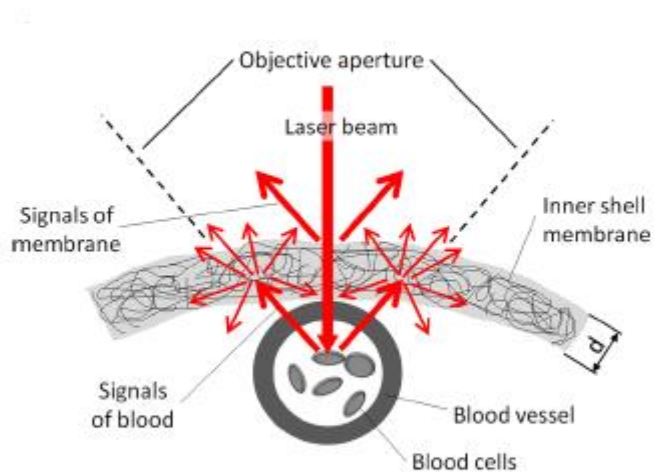


Figure 6: scattering of diode laser of the inner shell membrane (Galli, et al., 2018)

A number of patents have also been patented since 2001 for chick sexing method.

2.2.7 PATENTS ON AUTOMATIC FEATHER SEXING OF POULTRY CHICKS USING UV IMAGING

Tao Y. and Walker J. explained in their patent named "Automatic feather sexing of poultry chicks using ultraviolet imaging" (Arkansas, Fayetteville Patent No. US6396938, 2002). [Figure 6]

Authors explained that by the usage of UV light, the optical system of a camera is significantly enhanced the feathers by suppressing the downs in images. From this, it will produce clear feather signals for subsequent identification and allocation of feathers in the image. It can be obtained through thresholding with any value from 200 to 230 on the 255 maximum intensity scale. The features that are important for this includes a video camera, special lighting, an image processing system and a computer for analysis. The digital video camera will capture a clear image of chick's wings using selected light wavelengths, including long UV wavelengths and particularly wavelengths from 250nm to 450nm; this is between the UV-C radiation range up until the VIS range of violet color.

The special lighting architecture should provide maximum illumination enhancement and feature extraction for the camera and the pattern recognition software. The digital image processing system processes signals from the camera and should make instantaneous image analysis. The computer is the main processing system for the image analysis. The selective imaging of chick feathers and particularly its feather shanks, according to the invention is achieved by detection of fluorescent radiation rather than reflected light. From **Figure 7**, fluorescent radiation is produced by ultraviolet lamp arrays using mercury vapor or a similar type with tubular envelopes permitting transmission of long UV rays of wavelengths from about 300 to 390nm. The illumination of the chicks by VIS is avoided by having the process be done across an enclosed conveyor and the video camera area and lamp arrays in an opaque enclosure.

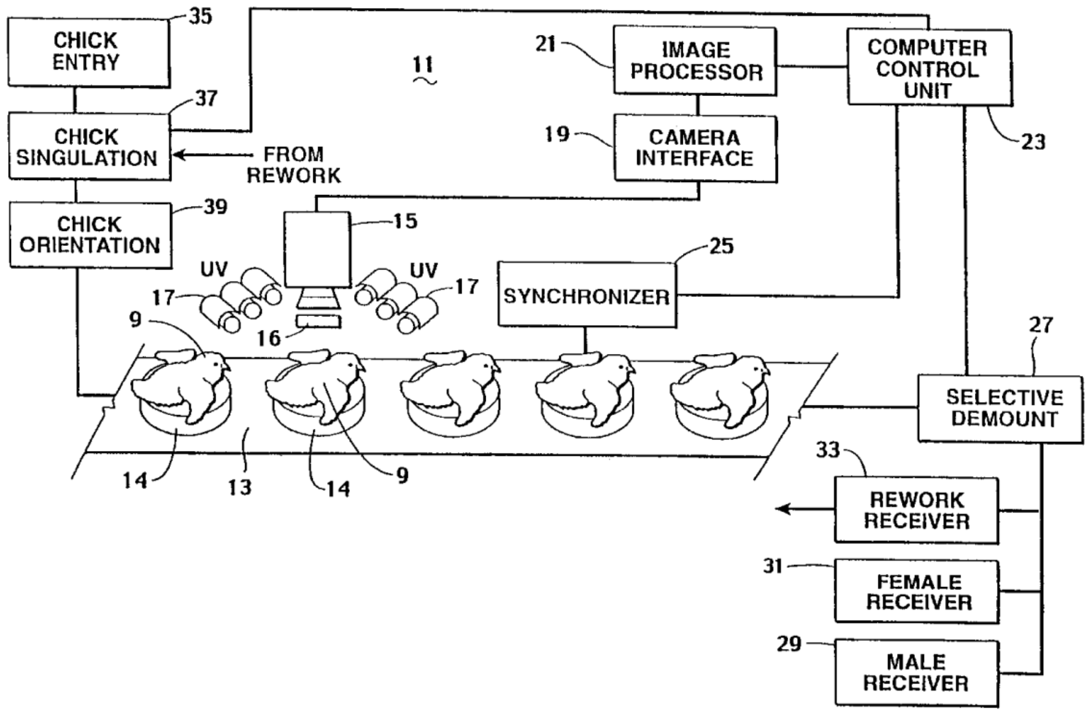


Figure 7 Automatic chicken sexing system using UV light induced visible fluorescence photography (Arkansas, Fayetteville Patent No. US6396938, 2002)

2.2.8 PATENT ON METHOD OF AUTOMATIC SEXING USING DIGITAL CAMERA AND BLUE LIGHT

Yavnai A. and Ehrlich S. explained in their patent named "Method of automatic sexing of chicks" (Virginia, Arlington Patent No. EP1092347A1, 2001).

It is a method of automatic sexing of day-old chick by causing the chick disequilibrium by using a cup with a rim, a funnel-removable seated on the rim and a free-rolling ball inside the cup; using apparatus such as conveyer belt, a mechanical vibrator attached to the surface of the conveyer belt and two poles for supporting the spread wings; using apparatus which includes a passageway enclosed on both sides whose bottom is attached to an oscillator. These methods are performed so that the wings of the chick to be spread so that chick sexing can be performed by photographing the chick, applying appropriate image processing to the photograph, identifying the sex of the chick from the processed photograph, weighing the chick and processing chicks based on sex and weight. It is advisable to perform the photography with the chick under blue light by using digital camera.

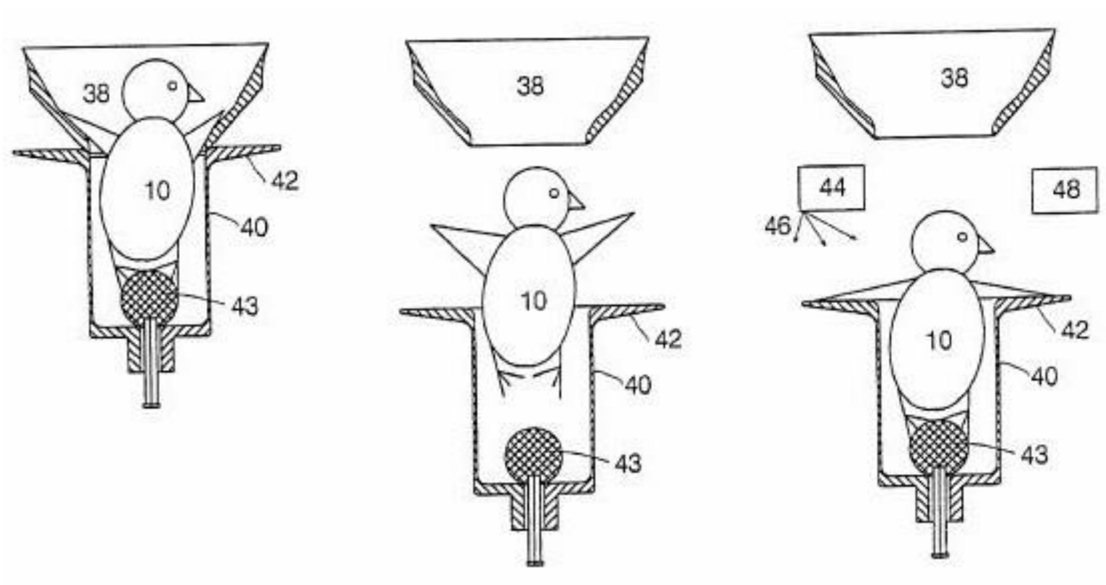


Figure 8: an illustration of causing chick disequilibrium by removing the chick's foot support (Virginia, Arlington Patent No. EP1092347A1, 2001)

This patent permits the means for full automation of chick sexing based on wing feather patterns by (i) having the chick in disequilibrium and (ii) the use of any light, however preferably the color blue to enhance the contrast between the white wing tips and yellow body of a chick.

This patent is explaining how to make the chick spread its wings for photographing the tip of the chick’s wings. There is usage of blue light to enhance the contrast of the wings tip for the camera to be able to capture an image for image processing.

2.2.9 PATENT ON ULTRASOUND SEX DETERMINATION FOR SORTING OF AVIAN HATCHLINGS

Toelken L.T. explained in their patent named "Ultrasound sex determination for sorting of avian hatchlings" (Missouri, Neosho Patent No. US7354401B1, 2002) [Figure 8]

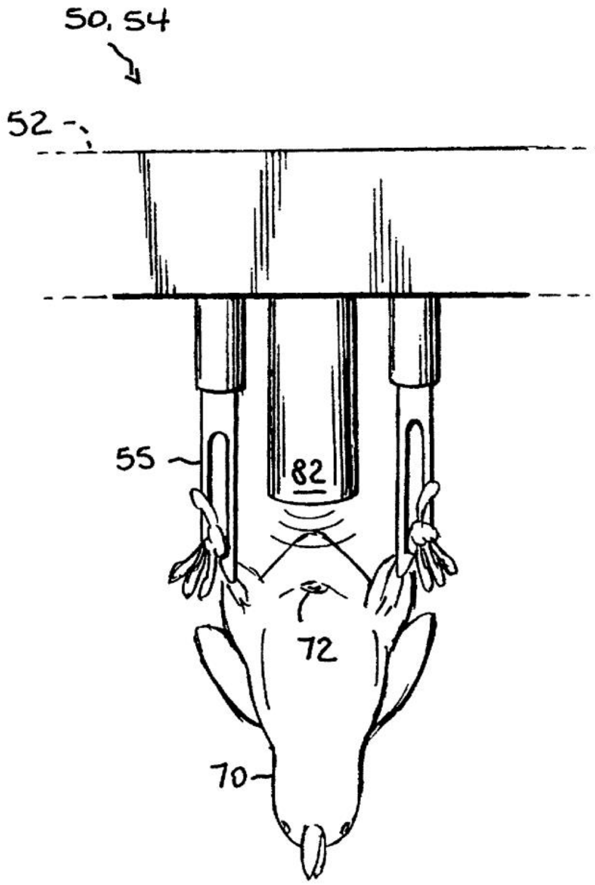


Figure 9 Ultrasound sex determination for sorting of chick of day-old (Missouri, Neosho Patent No. US7354401B1, 2002)

The detection is done by beaming ultrasonic energy to the vent or cloaca of each hatchling. Then, a detectable signal will be produced and the gender is determined from analysis of the signal by one or more processing units and sorting is accomplished. In an alternative method, the step of beaming ultrasonic energy comprises of aiming a non-contact probe at the vent. Also, preferably the probe is configured to provide both ultrasound source signal and detection of the reflected signal in one package. By these embodiments, the detectable signal is preferably analyzed for the presence or absence of a characteristic of male sex.

This patent recognizes the use of nuclear MRI of avian eggs to make a sex and possibly fertility determination. The usage of MRI equipment requires a very high capital investment and has unproven reliability. There are actually more disadvantages than advantages of using MRI equipment for sexing chicks.

2.3 ULTRAVIOLET-INDUCED VISIBLE FLUORESCENCE (UVIVF)

Ultraviolet (UV) light, is the radiation that makes up part of the electromagnetic spectrum of light. Human eye responds to light with wavelengths which are in the color portion of the spectrum, hence it is able to perceive colors from red to violet. Light with wavelengths shorter than the human eye can ‘see’ is called UV light, or beyond violet light. The sun is by far the strongest source of UV radiation in environment (Ultraviolet (UV) radiation, 2016). Solar emissions include visible light, heat and UV radiation. Just as visible light consists of different colors that is illuminated through the construction of a rainbow. The UV radiation spectrum is divided into three regions, namely UV-A, UV-B and UV-C. As sunlight passes through the atmosphere, all UV-C and most UV-B is absorbed by ozone, water vapor, oxygen and carbon dioxide. UV-A is not filtered as significantly by the atmosphere.

These three types of UV radiation are classified according to their wavelength. These three differs in their biological activity and the extent to which they can penetrate the skin. The shorter the wavelength, the more harmful the UV radiation, but they cannot penetrate the skin in higher success. Medium-wavelength UV-B is very biologically active but cannot penetrate beyond superficial skin layers. It is responsible for delayed tanning and burning. In addition to these shortterm effects, UV-B enhances skin ageing and significantly promotes the development of skin cancer. Most solar UV-B is filtered by the atmosphere. Whereas UV-A, the relatively long-wavelength of UV accounts for approximately 95% of UV radiation reaching the Earth's surface. This radiation can penetrate into deeper layers of the skin and is responsible for the immediate tanning effect as well as the ageing and wrinkling of a person over long-term exposure.

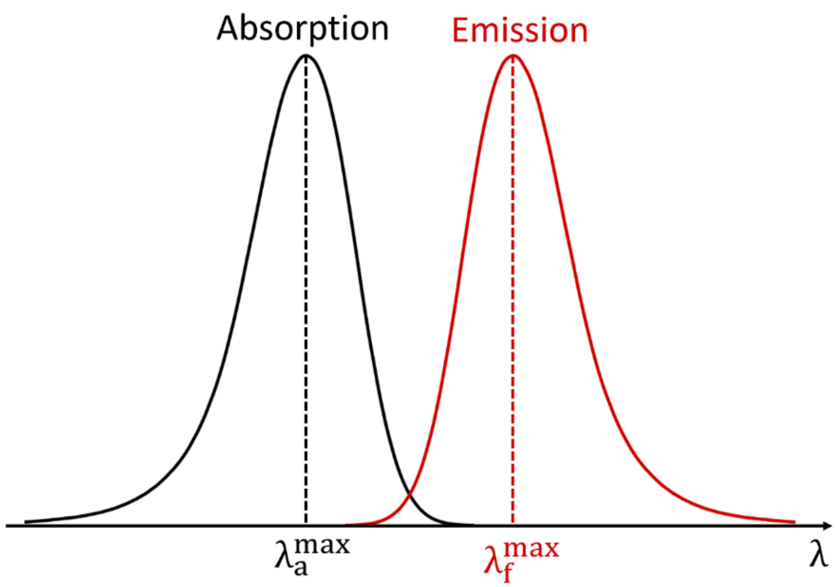
In general, human eyes cannot perceive UV light. Unlike humans and most other mammals however, many avian creatures can see UV light, although smaller avian eyes are able to perceive better in the UV spectrum (Hunt, Carvalho, Cowing, & Davies, 2009). This ability helps these creatures to attract mates, find food and detect predators. Take for instance, the kestrel (*Falco tinmunculus*) but also other birds of prey are able to perceive the presence of preys through UV reflectance of urine marks. This is useful for them to track preys during the night from the UV reflectance.

There are also instances where feathers of certain avian creatures give out visible UV excitation under certain degree of exposure towards UV-B and UV-C, but these light sources are difficult to obtain as well as it is harmful towards living being in long period of exposure and more niche and consequently sold at higher prices. UVIVF is the phenomenon that certain materials emit visible light when being exposed to UV light. The way that ultraviolet-induced visible fluorescence (UVIVF) works is that certain frequencies of UV 'excite' fluorescent materials which are called as fluorophores, which is perceived by humans as an extra bright color and/or light source in the visible spectrum. Different fluorophores are excited at different frequencies, and for avian creatures, it is a stable attribute for feather pigments and is very helpful for avian creatures to *see* in the night and to identify things.

2.3.1 STOKES SHIFT

Stokes Shift is a concept where the wavelength of UV light applied gives out different wavelength of visible light. Stokes Shift is the spectral shift to lower energy between incident light and emitted light after interaction with a sample.

Stokes' Law states that "…internal dispersion [fluorescence] which appears to be universal, that when the refrangibility [the extent of refraction is inversely proportional to wavelength] of light is changed by dispersion it is always lowered [shifted to longer wavelengths]" (What is the Stokes Shift?, 2019).



Stokes Shift (Wavelength) $\Delta\lambda = \lambda_f^{max} - \lambda_a^{max}$

Stokes Shift (Wavenumber) $\Delta\bar{\upsilon} = \bar{\upsilon}_a^{max} - \bar{\upsilon}_f^{max} = \frac{1}{\lambda_a^{max}} - \frac{1}{\lambda_f^{max}}$

Figure 10 Stokes Shift in Fluorescence Spectroscopy (What is the Stokes Shift?, 2019)

Fluorescence is a two-stage chemical process involving absorption of shorter-wavelength light (UV light) by a chemical fluorophore such as protein or carotenoid (excitation), followed by a release of some of the absorbed energy as longer-wavelength light (fluorescence) (Marshall & Johnsen, 2017).

The actual number of Stokes Shift wavelength and wavenumber could not be calculated due to lack of instruments. Fluorescence Spectrometer is needed to know the actual UV light induced and actual visible light emitted. Higher amount of Watts will give out stronger UV light. Higher Watts of UV light will be sufficient to create strong fluorescence effects over a certain amount of area.

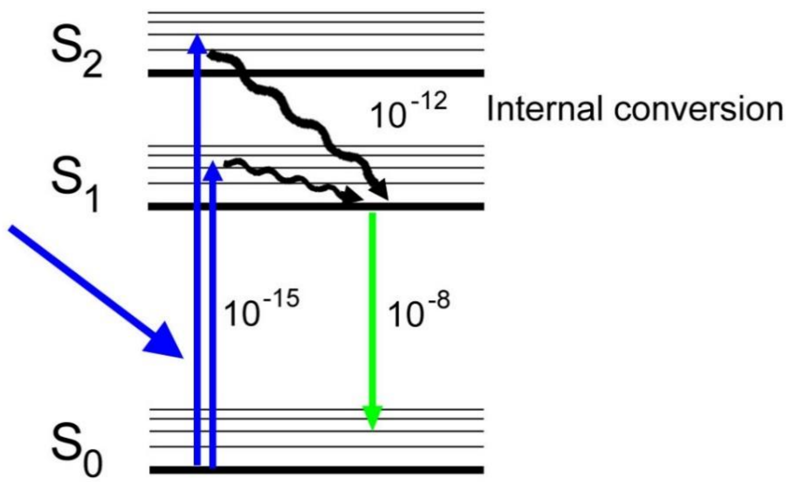


Figure 11 Simplified Jablonski Diagram (What is the Stokes Shift?, 2019)

Here is a simplified Jablonski Diagram, which is typically used to illustrate the physics of fluorescence. To begin, the fluorophores inside a subject's feather pigments are excited within a matter of milliseconds. Then it returns to ground state (S_0). The transition process is very fast, as indicated of the order of power written in **Figure 11**. This is how the glow that is seen through the naked eyes and through the photography of the chicks is explained.

Hence, the viewed UVIVF phenomenon on avian creatures and some other small predators (Lourenço, 2012) can be explained using this concept. The extent of Stokes Shift depends on the particular and its solvation (process of solvent molecules surrounds and interact with solute ions or molecules) environment.

The selection of UV wavelength to induce the strongest visible light may require a number of experiments, because the spectral sensitivities of animals are difficult to measure without machinery such as microspectrophotometers (MSP), electrophysiology recording gear, gene-sequencers or behavioral observation (Marshall & Johnsen, 2017). A strong UV light on a living subject might give out more disadvantages than advantages. It is also essential if absolute measures of fluorescent contribution to a signal are to be estimated.

2.4 HARDWARE FOR SOFTWARE IMAGING

UV photography is very confusing at first glance, as it has its own definitive styles and effects (Tuxworth, 2017). UV photography refers to techniques that use UV light to capture images. Essentially, light that has shorter wavelength than blue on the electromagnetic spectrum is invisible to the naked eyes, but with little tweaks here and there, and through a capable camera, UV phenomenon is able to be immortalized as a JPG file. There are two commonly used techniques for UV photography, namely UVIVF photography and Reflected-UV photography.

Reflected-UV photography is different than UVIVF photography where it requires bespoke UV-transmission optics, filters, lighting and ideally, a converted camera. Reflected-UV photography is the type of UV photography that produces monochrome results, so RGB color does not apply and it will show a bulls-eye pattern on yellow dandelions. UVIVF photography gives a result in the visible spectrum, mainly reds, blues and greens.

UVIVF photography requires 100% UV excitation source with no visible light spill together with a UV barrier filter. As explained in the previous subchapter, UVIVF occurs when certain materials that contain fluorophores are being excited by exposure to UV light, especially UV-B and UV-C, but UV-A will also excite the fluorophores although the result may or may not be satisfying.

2.4.1 UV-LED LIGHT SPECIFICATION

To 'see' what kind of glow is emitted through UVIVF photography, the subject must be experimented with a number of wavelengths to know which on it is sensitive for.

In the past, more Watts mean brighter light bulbs. However, today's light bulbs are energy efficient, therefore they only use fewer Watts to produce the same amount of light which is measured in Lumen. Lumen is the measure of the total quantity of visible light emitted by a source per unit of time. But this is only applicable for incandescent lights. UV light is invisible therefore this metric is useless. The most accurate metric is Watts of UV light output. Higher Watts of UV light output will be sufficient to create strong fluorescence effects over a certain area.

Unfortunately, most manufacturers do not list the UV light output, but instead simply indicates the electrical Watts input. Taking an example, there might be a product described as 40 Watts UV black light, but this only means that the black light consumes 40 Watts of electrical energy. It does not indicate how much efficient is the emission of UV.

There are a lot of UV lights in the market. Like a visible bulb, some UV sources have the capability to produce higher intensities than other UV sources (Top 4 Things to Consider Before Buying UV Blacklights, 2020). When more power is applied, UV sources generally behave the same way and produce more UV.

Doubling the power does not mean that the UV output will double. UV sources are categorized by the amount of applied electrical energy for each inch of the bulb. A 300 watt/inch system with 10-inch bulb would have 3000 watts of applied power and the same system with 20-inch bulb have 6000 watts of applied power. The applied power does not indicate the amount and type of UV arriving at the object and how much intensity it gives out. It is good to know that, the stronger the UV power is, gives out a stronger fluorescence. It will also give out an amount of visible light when used at high power.

For a novel UVIVF photography, 100% UV excitation is needed with no visible light spill using UV pass filter attached to UV light source and/or a UV cut off filter attached to camera lens to filter out UV reflection.

2.4.2 CAMERA SPECIFICATION

Any cameras are viable to be used for UVIVF photography; cellphone, SLR, DSLR, GoPro, even webcam! Most of UVIVF photographers use DSLR because there are more custom options available – aperture, shutter speed, ISO, focus, White Balance, to name a few of the customization through the usage of Manual Mode (UV Blacklight Photography Tutorial (Ultraviolet-Induced Visible Fluorescence), 2016).

The shooting recommendation is through RAW format so that the images can be post-processed without degrading the images quality quickly, and to change the white balance to enhance the image. There is an argument that high ISO numbers are required to capture UVIVF since there are probability that the excitation of fluorophores by the certain materials are not very strong, so the fluorescence emitted are low.

There is also a requirement to install UV/IR filter so that the camera wouldn't accidentally capture Reflected-UV from the subject. However, most of the recent camera sensors has that pre-installed and seems to be doing a good job at blocking out most of the Reflected-UV.

2.4.3 UV-LED LIGHT COMPARISON

Part No.	Peak Wavelength (λ_p)	Radiant Flux (Φ_E)	Forward Voltage Max (V_F)	Directivity ($2\theta_{½}$)	I_F	Size
NVCUQ096A Nichia UV-LED	365	135	48.5	120	8	24.9x45.0x1.6 mm
UV3535 RF-UVXC35LN-UE REFOND	380	-	3.4	120	3.5	3.45x3.45x1.95 mm
Escolite UV Flashlight	395	-	4.5	-	-	7.6x1.5x3.1 in

Table 2 UV-LED light comparison

From the table of comparison, the Nichia UV-LED is the novel pick of UV-LED to be used since it has a low forward current. Its peak wavelength is near the range of visible light therefore it is very safe to be used for a period of time. However, this item is expensive so it is out of question. The second option is Escolite UV Flashlight which is easily obtainable from any online stores, therefore it is a good go-to alternative to obtain required data.

2.5 SOFTWARE ALGORITHM FOR IMAGE PROCESSING

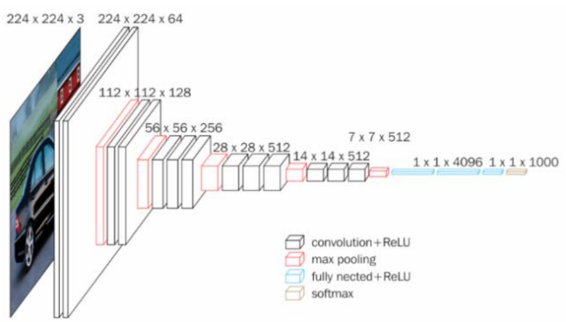
There are a number of methods to do image recognition and machine learning where that have existed even before computer is this powerful enough to be automated. What you see is what you get; for humans, yes, it is applicable but image recognition is harder in terms of training the computer to know which one is dog unless they are trained. These are a few methods mention that are linked in how image recognition is going to be implemented for this project.

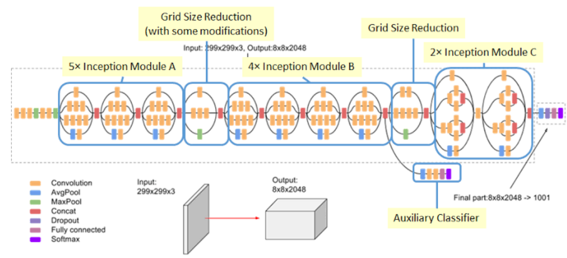
There is one famous machine learning object detection algorithm that is always used for image recognition, called as Haar Cascade (Deep Learning Haar Cascade Explained, 2018). It consists of training the machine by cascading the images between positive and negative images while providing what is the requirement of the true positive images. To do this, the machine needs to be trained using Convoluted Neural Network (CNN), a deep learning algorithm for it to be able to differentiate one from the other.

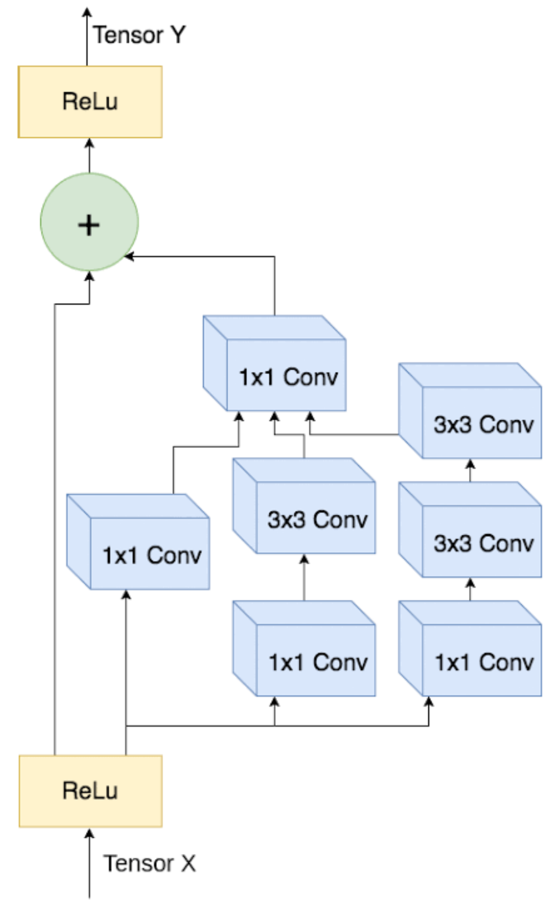
2.5.1 CONVOLUTED NEURAL NETWORK (CNN) ALGORITHM COMPARISON

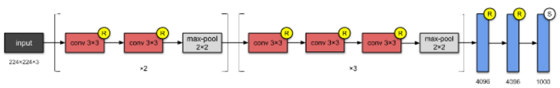
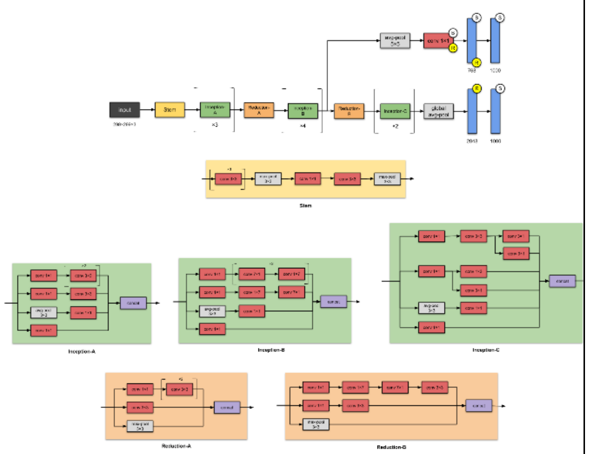
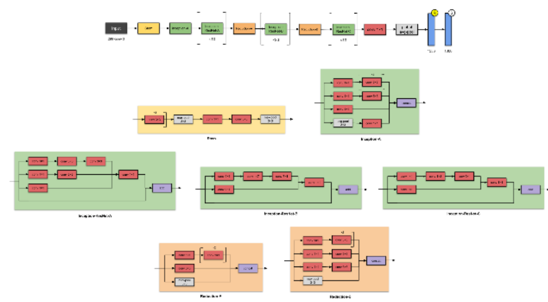
VGG16	INCEPTION V3	INCEPTION RESNET V2
This model and can be built both with 'channels_first' data format (channels, height, width) or 'channels_last' data format (height, width, channels).	This model and can be built both with 'channels_first' data format (channels, height, width) or 'channels_last' data format (height, width, channels).	This model and can be built both with 'channels_first' data format (channels, height, width) or 'channels_last' data format (height, width, channels).
Default input size is 224x224	Default input size is 299x299	Default input size is 299x299
weights: one of None (random initialization) or 'imagenet' (pre-training on ImageNet).	weights: one of None (random initialization) or 'imagenet' (pre-training on ImageNet).	weights: one of None (random initialization) or 'imagenet' (pre-training on ImageNet).
input_tensor: optional Keras tensor (i.e. output of layers.Input()) to use as image input for the model.	input_tensor: optional Keras tensor (i.e. output of layers.Input()) to use as image input for the model.	input_tensor: optional Keras tensor (i.e. output of layers.Input()) to use as image input for the model.
input_shape: optional shape tuple, only to be specified if include_top is False (otherwise the input shape has to be (224, 224, 3) (with 'channels_last' data format) or (3, 224, 224) (with 'channels_first' data format). It should have exactly 3 inputs channels, and width and height should be no	input_shape: optional shape tuple, only to be specified if include_top is False (otherwise the input shape has to be (299, 299, 3) (with 'channels_last' data format) or (3, 299, 299) (with 'channels_first' data format). It should have exactly 3 inputs channels, and width and height should be no	input_shape: optional shape tuple, only to be specified if include_top is False (otherwise the input shape has to be (299, 299, 3) (with 'channels_last' data format) or (3, 299, 299) (with 'channels_first' data format). It should have exactly 3 inputs channels,

<table>
<tr>
<td>smaller than 32. E.g. (200, 200, 3) would be one valid value.</td>
<td>smaller than 75. E.g. (150, 150, 3) would be one valid value.</td>
<td>and width and height should be no smaller than 75. E.g. (150, 150, 3) would be one valid value.</td>
</tr>
<tr>
<td>Returns a Keras Model instance.</td>
<td>Returns a Keras Model instance.</td>
<td>Returns a Keras Model instance.</td>
</tr>
<tr>
<td>Architecture


</td>
<td>Architecture


</td>
<td>Architecture


</td>
</tr>
</table>

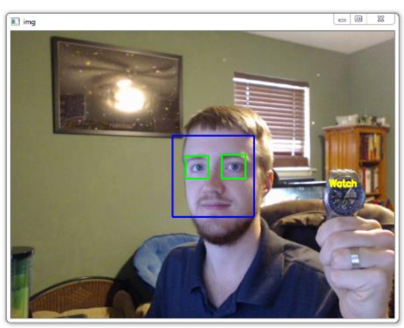
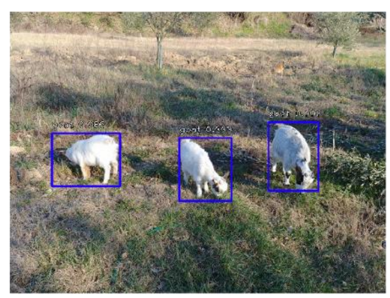
Drawbacks: • Painfully slow to train • The network architecture weights themselves are quite large		
		
What's novel of this model? • As mentioned in their abstract, the contribution from this paper is the designing of *deeper* networks (roughly twice as deep as AlexNet).	What's novel? • Among the first designers to use batch normalization (not reflected in the above diagram for simplicity).	

	What's improved from previous version, Inception-v1? 1. Factorizing *n*×*n* convolutions into asymmetric convolutions: 1×*n* and *n*×1 convolution 2. Factorize 5×5 convolution to two 3×3 convolution operations 3. Replace 7×7 to a series of 3×3 convolutions	**What's improved from the previous version, Inception-v3?** 1. Converting Inception modules to *Residual Inception blocks.* 2. Adding more Inception modules. 3. Adding a new type of Inception module (Inception-A) after the Stem module.
		Even though ResNet is *much* deeper than VGG16 and VGG19, the model size is actually *substantially smaller* due to the usage of global average pooling rather than fully-connected layers — this reduces the model size down to 102MB for ResNet50.

Table 3 Convoluted Neural Network (CNN) Algorithm Comparison

2.5.2 OBJECT DETECTION ALGORITHM

There are a few object detection algorithms that has been around since 1990. Object detection plays a significant role especially in the making of an artificial intelligence where it can identify what it has been taught.

YOLO (You Only Live Once)	HAAR CASCADE CLASSIFIER	RETINANET
Its biggest advantage is that it is very fast, where it can process 45 frames/second (Sharma, 2018).	Its feature is of its calculation speed since it uses integral images.	RetinaNet features the usage of pyramid network to detect objects at multiple scales (Humbarwadi, 2020).
It uses grid system where it grids the image that it is fed to, where from there, it will predict from grid to grid whether there is an identifiable object or not in that specified grid. Then it will create bounding box where it will calculate the Intersection Over Union (IOU) between the boxes.	This algorithm uses an ML-based approach, where it forms a cascade of functions trained from numerous positive and negative images (Phuc, Jeon, Truong, & Hak, 2019) by creating weak learners called decision stumps. Then it will be trained using a technique called boosting.	Runs the same as YOLO algorithm except that it doesn’t grid the image. It has an additional anchor boxes which are fixed sized boxes that the model uses to predict the bounding box for an object.
		
It struggles with small objects that appear in groups.	The downside is that it requires a lot of time and a very big set of data to train since it has numerous pictures. It also requires a very powerful	RetinaNet cannot run real-time. (Nguyen, Do, Ngo, & Le, 2020)

	machine to run the machine learning.	

Table 4 Object Detection Algorithm Comparison

2.7 DISCUSSION

The method chosen to proceed with this project is to use the patents mentioned in the literature review, and use it together with Haar Cascade classifier. There reason why Haar Cascade classifier is used because Haar Cascade uses grayscale images, therefore it will not be needing complicated color images. Chicks' feathers respond to UV light, making it useful to use Haar Cascade classifier because the color will be enhanced in grayscale for training.

2.8 CHAPTER SUMMARY

According to these reviews from these researches, it is evident that through the usage of feather sexing on one-day old chicks is the most feasible technique to be implemented through the usage of image processing. It will also be done in the range of UV-A wavelength as that wavelength is enough for different fluorophores to be excited so that it will emit some visible light for the camera to capture the UVIVF photos for image processing to be eligible to be run.

CHAPTER 3: SYSTEM DESIGN

3.1 INTRODUCTION

In this chapter, the design of the project is introduced together with the block diagram, flowchart, simulation and camera system. The components that will be used will be discussed in this chapter. The conceptual design will be explained in details to give a clear picture on how the project will be conducted.

3.2 OVERALL SYSTEM DESIGN

Figure below simplifies the overall design of the system.

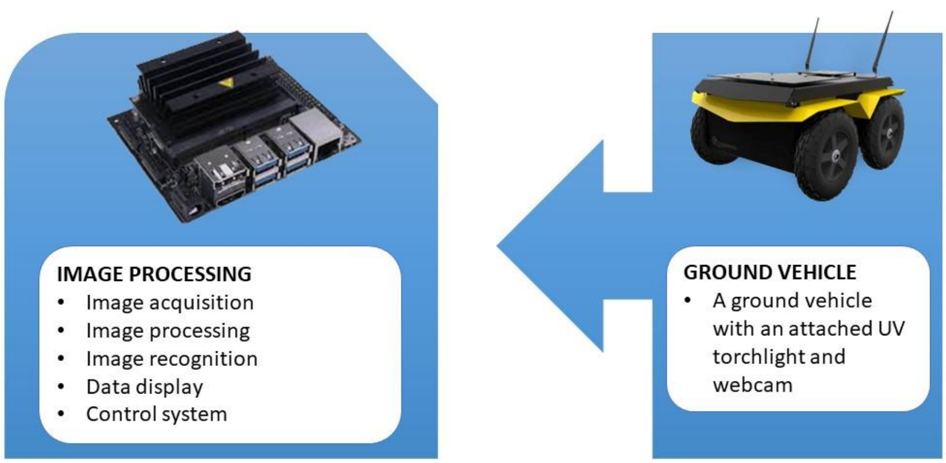


Figure 12 Overall system design

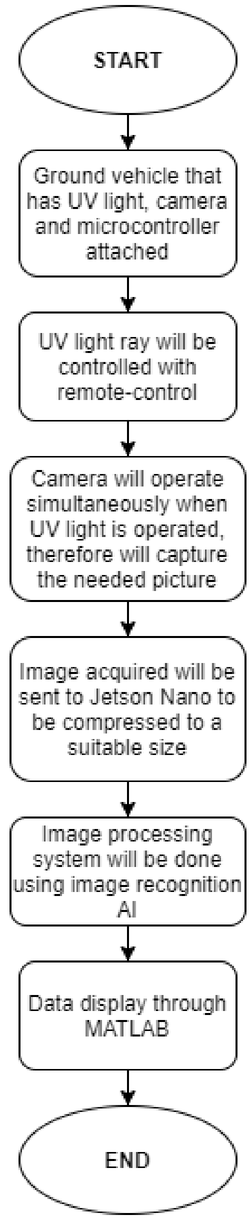


Figure 13 Flowchart of overall system

Firstly, there will be a remote-controlled UV torchlight mounted on a ground vehicle that will shine on the chick's feathers. Then there will be a camera connected to a microcontroller to shoot a picture of where the chick's feathers are located. The image acquired from the camera will be processed to be compressed to a size of 500x500 pixels. Within the microcontroller, there will first be a system that will control the image recognition of the acquired data. After that, the system will display data received using MATLAB.

3.3 GROUND VEHICLE DESIGN

The mapping robot will be controlled Jetson Nano microcontroller. It will be powered by lithium polymer rechargeable battery (LiPo). There will be attached a webcam and a UV torchlight as a way for data acquisition required. Bluetooth will also be added to the robot to synchronize with an Android controller.

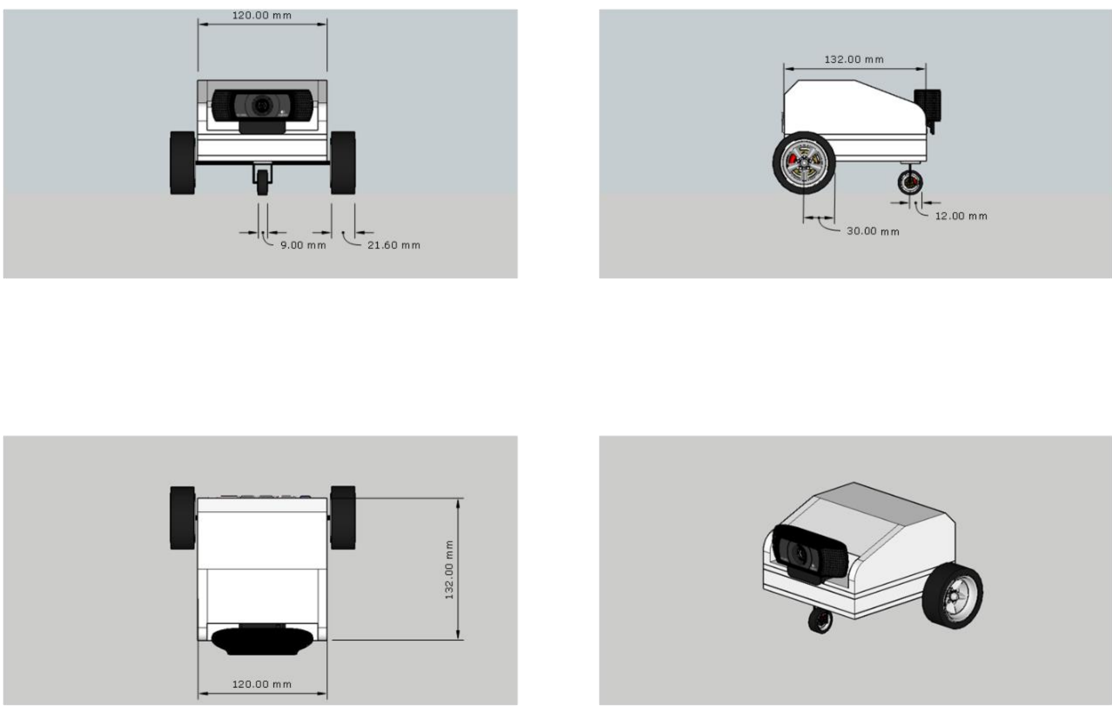


Figure 14 Exploded view of ground vehicle

3.4 MICROCONTROLLER CIRCUITRY DESIGN

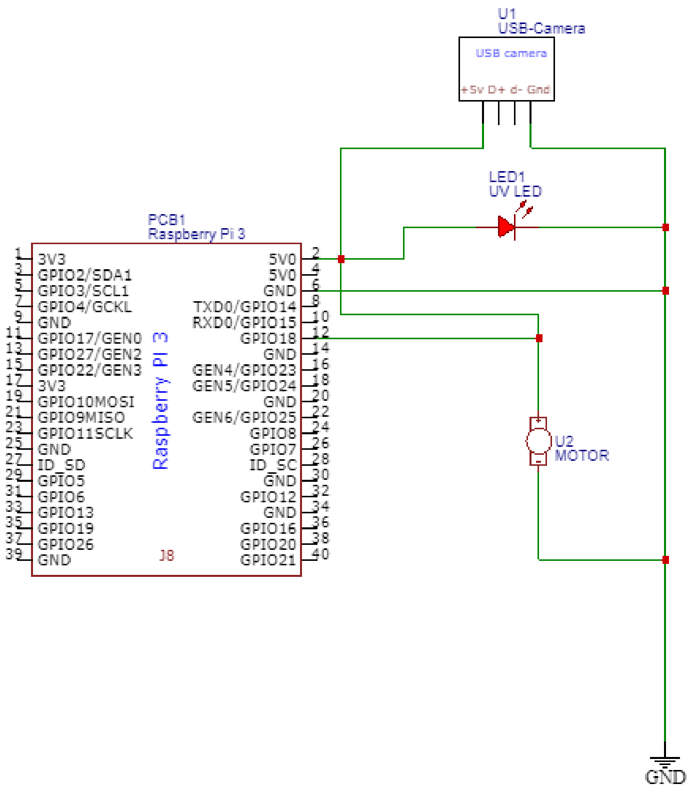


Figure 15 Circuit diagram

The USB web camera will be connected using USB of Jetson Nano microcontroller. The pins of Jetson Nano are more or less the same as Raspberry Pi 3, therefore the Figure above is using Raspberry Pi 3 to explain the connections. The UV torchlight will first be dissembled so that the push button for the torchlight can be connected to the microcontroller for easy control. The Jetson Nano requires a Bluetooth module therefore it is just a turn-on and customize through terminal through coding. The motor will be controlled using PWM control.

3.5 SYSTEM TOOLS AND HARDWARE

3.5.1 2WD SMART ROBOT CAR CHASSIS DIY

Figure 16 2WD Smart Robot Car Chassis DIY

Figure above shows the base of ground vehicle that can be controlled using Bluetooth function of Jetson Nano microcontroller. The web camera as well as UV torchlight will be attached here.

3.5.2 LOGITECH C920E HD WEBCAM 1080P HD CAMERA

Figure 17 Logitech C920E HD Webcam 1080p HD Camera

This webcam will be connected to Jetson Nano through USB. This camera is the way for data to be acquired. It will recognize the chick feather's location and will snap a picture.

3.5.3 UV TORCHLIGHT

Figure 18 UV Torchlight

Any UV torchlight of 395mm wavelength will do as the UV light that is needed to capture UVIVF so that microcontroller can do image recognition.

3.5.6 360° ROTATION SERVO

Figure 19 Servo motor

Figure shows a servo motor that will be the drive force for the tyres of the chassis.

3.6 BILL OF MATERIALS

Table shows the expenditure of the project with the price list of materials and components. There are few components that will be borrowed.

No	COMPONENTS	QTY	PRICE PER UNIT (RM)	PRICE (RM)
1.	2WD Smart Robot Car Chassis DIY	1	25.90	25.90
2.	Logitech C920E HD Webcam 1080p HD Camera	1	-	-
3.	UV torchlight	1	15.00	15.00
4.	360° Rotation Servo	1	16.00	16.00
5.	Jetson Nano	1	-	-
6.	Lithium Polymer Rechargeable Battery (LiPo)	1	-	-
Total				**56.90**

CHAPTER 4: SIMULATION STUDY AND ANALYSIS

4.1 INTRODUCTION

Due to the current situation of COVID-19, there is hardship in obtaining parts and assembling the prototype. This chapter shall discuss what the data needed to train the system in the future for Final Year Project 2.

Together with it, it will also include the training that have been done with the data available.

4.2 DATA REQUIREMENT

First, the system will require a lot of negative images, as well as a set of positive images that have been trained through the negative images. Let’s say that at the start of the training, there is 2000 negative images for one positive image. With that,

$$2000 \; negative \; images \; x \; 1 \; positive \; image = 2000 \; positive \; images$$

The training using Haar Cascade requires a lot of positive images to let the computer knows which one it needs to search for when a data set is passed through the completed training.

Below are a few tables of data that will be needed for the image training using Haar Cascade.

Chick A	Chick B	Chick C	Chick D	Chick E
				

Table 5 Female chicks of a day-old

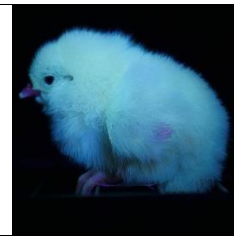
Chick F	Chick G	Chick H	Chick I	Chick J
				

Table 6 Male chicks of a day-old

These images are pre-acquired during the internship period. From these images, the images will first be enhanced to let the region of interest, the wing part of chick, and then that region will be cropped to be trained by the cascade classifier.

Images used are from Table 2's Chick D and Table 3's Chick F to create the difference in wing's length between the sex of the chicks, where it can be seen that the Chick D's wing length is longer than Chick F. This obvious characteristic will be the main focus for the image training using Haar Cascade.

Figure 20 Wing length difference. Left: Female Chick D. Right: Male Chick F

4.3 PREFERRED SYSTEM OUTPUT

After being trained, the system will output as the following Table below.

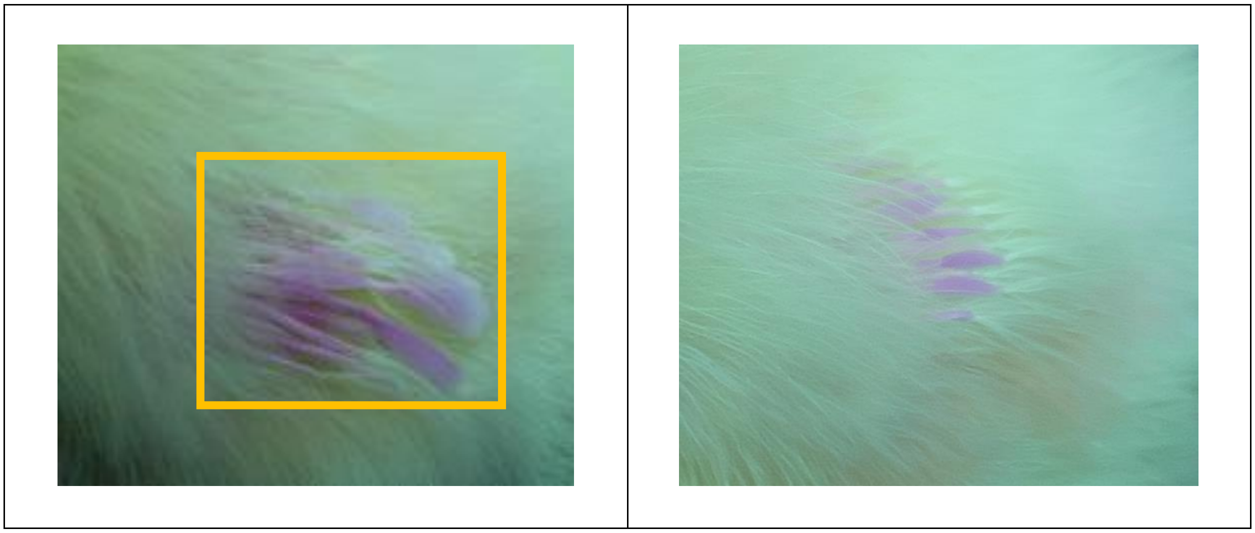


Figure 21 System output with bounded box that shows the region of interest

4.4 ACTUAL SYSTEM OUTPUT

4.4.1 ANALYSIS STUDY

However there seems to be some problems regarding the training with the available data. It is probably due to the background image and the actual image that needed to be recognised have similar values of hexadecimal colour codes to each other. Let’s take a look at the first training output using the required Region of Interest (ROI) which is a female chick’s wing.

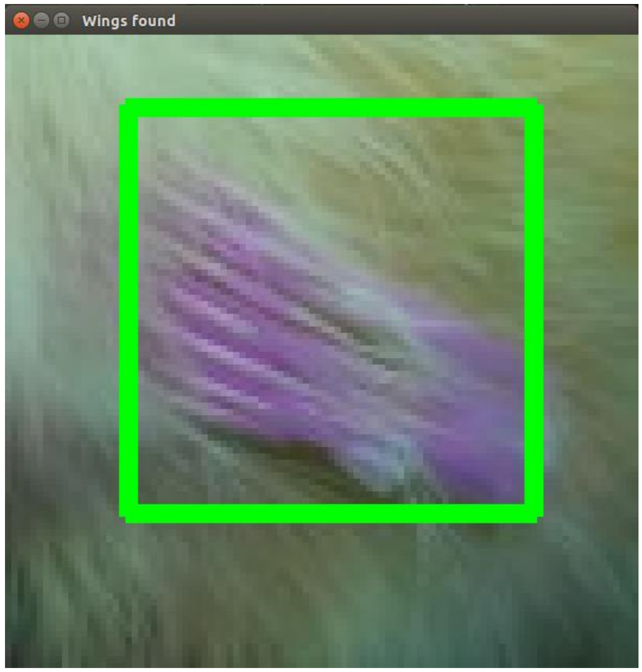


Figure 22: Desired output

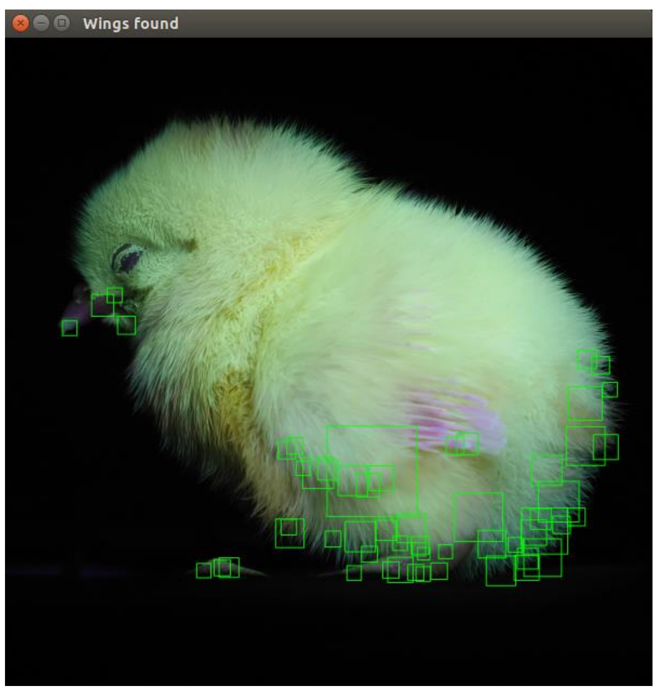


Figure 23: Actual output

As it turns out, when the system is run with a full image of a chick, it gives out false negatives, making the training system obsolete. This is because the system is confused due to it being trained with a very small image size, which is 100 x 100 pixels. The reason why it is trained with a very small image size is so that the hardware is not burdened by the training.

Below is the summary of the output the system has given. The data are gathered in an Excel file and is tabulated accordingly.

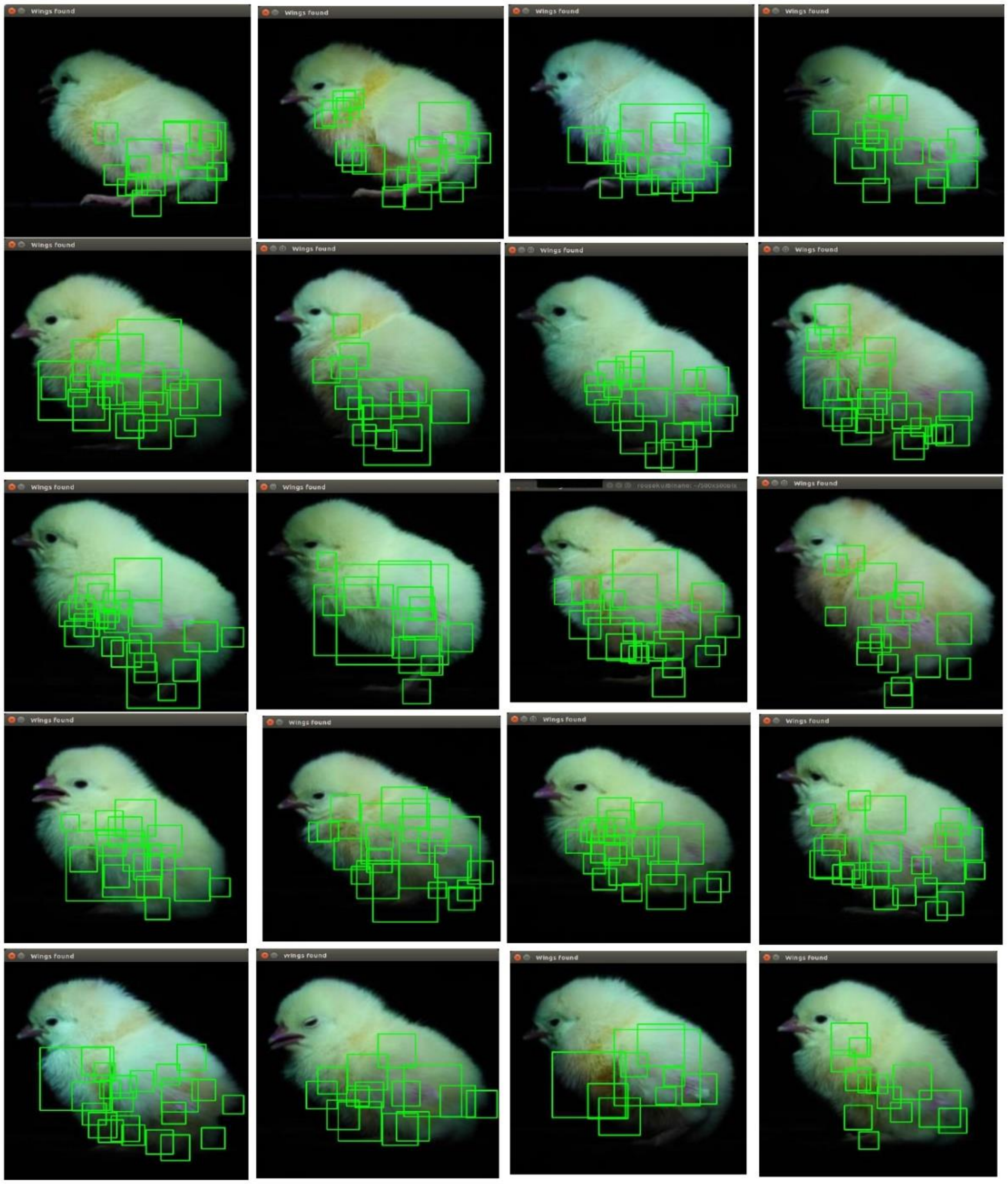


Figure 24: Actual data recorded and lined

4.4 SUMMARY

The system uses Haar Cascade algorithm as discussed in Chapter 2. It is done using Nvidia Jetson Nano microcomputer, with OpenCV library from Python. There are other cloud computing websites such as Digital Ocean which requires the user to pay per hour.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

The objectives of this project are to identify a cost-effective and accurate way for determining gender of chick of day-old, to implement this method in a working system and to evaluate it for further improvements. Python is chosen for the coding because it is an interpreted, high-level, general purpose programming language that is easy to use.

5.2 CONCLUSION

To conclude, the general layout on how to proceed with this project has been discussed with the supervisor to proceed with the best option to achieve the objectives. It requires a lot of training images so that the network can learn what it needs to recognize the region of interest.

5.3 RECOMMENDATION

Some recommendations are given, especially on the thought of the library. YOLO algorithm is another real-time object detection system which applies a single neural network to the full image, where it will divide the image into regions and predicts bounding boxes and probabilities.

REFERENCES

Cireşan, D., Meier, U., & Schmidhuber, J. (2012). Multi-column Deep Neural Networks for Image Classification. *Proceedings / CVPR, IEEE Computer Society Conference on Computer Vision and Pattern Recognition. IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 3642-3649. doi:10.1109/cvpr.2012.6248110

Damerow, G. (2017, September 22). *What is Feather Sexing? Separating Fact from Myth*. Retrieved March 13, 2020, from Cackle Hatchery: https://blog.cacklehatchery.com/what-is-feather-sexing-separating-fact-from-myth

Daniels, T. (2015, July 3). *Gold and Silver Sex-Linkage*. Retrieved December 24, 2019, from Poultry Keeper: https://poultrykeeper.com/poultry-breeding/gold-and-silver-sex-linkage/

Deep Learning Haar Cascade Explained. (2018). Retrieved March 24, 2020, from Will Berger: http://www.willberger.org/cascade-haar-explained/

Ehrlich, S., & Yavnai, A. (2001). *Virginia, Arlington Patent No. EP1092347A1.*

El-Ghali, N., Rabadi, M., Ezin, A. M., & Bellard, M. E. (2010). New methods for chicken embryo manipulations. *Microsc. Res. Tech., 73*, 58-66. doi:10.1002/jemt.20753

Epping, M. (2018, March 30). *In Ovo method of determining chicks' sex before hatching*. Retrieved March 13, 2020, from Zootecnica International: https://zootecnicainternational.com/news/ovo-method-determining-chicks-sex-hatching/

Galli, R., Preusse, G., Schnabel, C., Bartels, T., Cramer, K., Krautwald-Junghanns, M.-E., . . . Steiner, G. (2018). Sexing of chicken eggs by fluorescence and Raman spectroscopy through the shell membrane. *PLOS ONE 13(2): e0192554*. doi:10.1371/journal.pone.0192554

Gibbs, C. S. (2016). *A Guide to Sexing Chicks.* Amherst: Read Books Ltd.

Hein, T. (2018, June 27). *Egg sexing close to market*. Retrieved March 13, 2020, from Poultry World: https://www.poultryworld.net/Eggs/Articles/2018/6/Egg-sexing-close-to-market-301797E/

Horsey, R. (2002). The art of chicken sexing*. *Psychology*, 107-117.

Humbarwadi, S. (2020, May 17). *Object Detection with RetinaNet*. Retrieved July 23, 2020, from Keras: https://keras.io/examples/vision/retinanet/

Hunt, D. M., Carvalho, L. S., Cowing, J. A., & Davies, W. L. (2009). Evolution and spectral tuning of visual pigments in birds and mammals. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 364(1531)*, 1941-2955. doi:10.1098/rstb.2009.0044

Hussain, S. a., & Balushi, A. S. (2020). A real time face emotion classification and recognition using deep learning model. *Journal of Physics: Conference Series 1432 013087*, 1-13. doi:10.1088/1742-6596/1432/1/012087

Krüger, S. (2018, July 24). *A Technological Breakthrough for Sex Determination in Hens' Eggs*. Retrieved December 24, 2019, from BayPAT: https://www.baypat.de/news/a-technological-breakthrough-for-sex-determination-in-hens-eggs

Li, J., Zhang, Z., Liu, F., Liu, Q., Gan, W., Chen, J., . . . Li, D. (2008). UVB-based mate-choice cues used by females of the jumping spider Phintella vittata. *Current Biology, Volume 18, Issue 9*, 699-703. doi:10.1016/j.cub.2008.04.020

Lind, O., Henze, M., Kelber, A., & Osorio, D. (2017). Coevolution of coloration and colour vision? *Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 372(1724), 2016033*, 1-8. doi:10.1098/rstb.2016.0338

Lourenço, W. R. (2012, December). Fluorescence in scorpions under UV light; can chaerilids be a possible exception? *Comptes Rendus Biologies, Volume 335, Issue 12*, 731-734. doi:10.1016/j.crvi.2012.11.001

Marshall, J., & Johnsen, S. (2017). Fluorescence as a means of colour signal enhancement. *Phil. Trans. R. Soc. B37220160335*, 1-9. doi:10.1098/rstb.2016.0335

Nguyen, N.-D., Do, T., Ngo, T. D., & Le, D.-D. (2020). An Evaluation of Deep Learning Methods for Small Object Detection. *Journal of Electrical and Computer Engineering Volume 2020*, 1-18. doi:10.1155/2020/3189691

Otsuka, M., Miyashita, O., Shibata, M., Sato, F., & Naito, M. (2016). A novel method for sexing day-old chicks using endoscope system. *Poultry science 95(11)*, 2685-2689. doi:10.3382/ps/pew211

Pearlstein, E., Hughs, M., Mazurek, J., McGraw, K., Pesme, C., Riedler, R., & Gleeson, M. (2015). ULTRAVIOLET-INDUCED VISIBLE FLUORESCENCE AND CHEMICAL ANALYSIS AS TOOLS FOR EXAMINING FEATHERWORK. *Journal of the American Institute for Conservation, Vol. 54, No. 3*, 149-167. doi:10.1179/1945233015Y.0000000010

Phuc, L. T., Jeon, H., Truong, N. T., & Hak, J. J. (2019). Applying the Haar-cascade Algorithm for Detecting Safety Equipment in Safety Management Systems for Multiple Working Environments. *Electronics, 8, 1079*, 1-14. doi:10.3390/electronics8101079

Rajchard, J. (2009). Ultraviolet (UV) light perception by birds: a review. *Veterinarni Medicina 54*, 351-359. doi:10.17221/110/2009-VETMED

Sharma, P. (2018, December 6). *A Practical Guide to Object Detection using the Popular YOLO Framework – Part III (with Python codes)*. Retrieved July 20, 2020, from Analytics Vidhya: https://www.analyticsvidhya.com/blog/2018/12/practical-guide-object-detection-yolo-framewor-python/

Smith, K. (2020, June 26). *Chicken Sexing - How to Determine the Gender of your Chickenss*. Retrieved March 13, 2020, from Backyard Chicken Coops: https://www.backyardchickencoops.com.au/blogs/learning-centre/chicken-sexing-in-an-eggshell

Tao, Y., & Walker, J. (2002, May 28). *Arkansas, Fayetteville Patent No. US6396938.*

Toelken, L. T. (2002). *Missouri, Neosho Patent No. US7354401B1.*

Top 4 Things to Consider Before Buying UV Blacklights. (2020). Retrieved March 19, 2020, from Waveform Lighting: https://www.waveformlighting.com/tech/top-4-things-to-consider-before-buying-uv-blacklights

Tuxworth, B. (2017, December 13). *Getting started with UV Fluorescence Photography*. Retrieved December 19, 2019, from Adaptalux: https://adaptalux.com/getting-started-uv-fluorescence-photography/

Ultraviolet (UV) radiation. (2016, March 9). Retrieved March 15, 2020, from World Health Organization: https://www.who.int/health-topics/ultraviolet-radiation

UV Blacklight Photography Tutorial (Ultraviolet-Induced Visible Fluorescence). (2016, February 21). Retrieved December 19, 2019, from Photo Extremist: https://photoextremist.com/ultravioletinduced-visible-fluorescence-photography-tutorial

Viennet, E., Garros, C., Lancelot, R., Allène, X., Gardès, L., Rakotoarivony, I., . . . Balenghien, T. (2011). Assessment of vector/host contact: comparison of animal-baited traps and UV-light/suction trap for collecting Culicoides biting midges (Diptera: Ceratopogonidae), vectors of Orbiviruses. *Parasites Vectors 4, 119*, 1-12. doi:10.1186/1756-3305-4-119

What is the Stokes Shift? (2019). Retrieved March 24, 2020, from Edinburgh Instruments: https://www.edinst.com/blog/what-is-the-stokes-shift/