Chapter 1

Introduction

Among the numerous challenges affecting global public health, parasitic infections pose a significant burden, affecting millions of individuals and livestock in developing as well as developed nations. Different groups of parasites, such as protozoa, helminths (worms), and ectoparasites [1, 4] can cause various types of diseases in humans and animals. Protozoan parasites, such as Plasmodium species, specifically P. falciparum and P. vivax, are responsible for the devastating disease malaria in humans, while Toxoplasma gondii leads to pain in the muscles in a variety of warm-blooded hosts, including humans [5]. Sleeping sickness in humans is caused by Trypanosoma brucei gambiense and T. brucei rhodesiense which are transmitted through the bite of infected tsetse flies [4]. Entamoeba histolytica causes amebic dysentery, which is transmitted through the ingestion of food or water [5]. Giardia lamblia is one of the major parasites in North America that is responsible for diarrhea in humans [4]. Leishmaniasis is a fatal infection caused by Leishmania protozoans, which is spread in humans through the bite of sandflies, leading to skin sores and organ damage [1]. Helminth nematode or roundworm such as Ascaris lumbricoides is a common intestinal roundworm that causes ascariasis, leading to symptoms such as abdominal pain, malnutrition, and intestinal blockages [1]. Hookworm is another widespread nematode disease caused by Necator americanus and Ancylostoma duodenale. Diarrhea, weight loss, abdominal pain, weariness, loss of appetite, and anemia are the symptoms of hookworm infection [6]. Toxocariasis. Trichinellosis or trichinosis, is caused by Trichinella spiralis and is transmitted by ingesting uncooked meat. Infection leads to muscle pain, fever, and digestive system problems [1]. Dirofilaria immitis is responsible for heartworm in animals, causing fatigue and cough, which can lead to death in the most severe cases [6]. Trichuriasis is a whipworm infection in humans caused by Trichuris trichiura that causes painful bowel movements with a mixture of mucus, water, and blood [1]. Schistosoma mansoni, S. haematobium, and S. japonicum are responsible for schistosomiasis, which is a serious parasitic disease. They attack various organs like the lungs, liver, etc., causing fever, anaemia, and stomach pain. Tapeworms enter humans through the consumption of undercooked meat. Beef tapeworm (Taenia saginata) causes allergic reactions and digestive issues, whereas pork tapeworm (T. solium) can cause severe problems if it infects other tissues [6].

Ectoparasites are organisms that attach themselves to the skin, fur, feathers, or scales of their host animals and humans. These parasites mostly cause skin irritations and allergic reactions [7]. There are two classes of ectoparasites: insects (including lice, flies, and bedbugs) and arachnids (including mites, ticks, and spiders) that cause human diseases [7]. Pediculus humanus capitis, Pediculus humanus corporis, and Pthirus pubis are three types of lice that primarily affect the scalp, body, and genital area, respectively [1, 7]. Tick-borne infections are mostly caused by viruses and bacteria. Encephalitis, Colorado tick fever, Crimean-Congo hemorrhagic fever, and Omsk hemorrhagic fever are some viral diseases spread by ticks. The deer tick is a type of arachnid that causes bacterial lyme disease [8].

The diagnosis of these infections in a timely and precise way is crucial for effective treatment, epidemiological understanding, and the implementation of appropriate public health measures. Traditional methods of diagnosis involve measures such as collecting samples, preparing microscopic slides, and analyzing these slides through a microscope [9, 10]. Figure 1-1 illustrates the typical process of identifying parasite eggs. Detecting and identifying many different kinds of parasite eggs and estimating their load using this approach demands the involvement of highly trained professionals. The approach is laborious and time-consuming as it requires preparing and examining more than one slide, and it is not always accurate [10]. In this context, the automatic detection and identification of parasite eggs in microscopic images has emerged as an efficient way, powered by the combination of image processing and machine learning approaches.

In recent years, image processing has become a backbone in medical diagnostics, aiding in the analysis and interpretation of various medical images, such as MRI, CT scans, X-rays, and microscopic images. These techniques enhance visual information, facilitating more accurate and efficient diagnostic procedures by helping clinicians identify patterns, anomalies, and pathologies that might be challenging to detect otherwise [11, 12].

Fundamental image processing techniques, such as image segmentation, feature extraction, and pattern recognition, play crucial roles in analyzing complex medical images. Segmentation allows for isolating regions of interest, such as tissues or cells, and is pivotal in identifying and classifying different biological structures. Feature extraction and pattern recognition enable the identification of specific attributes and abnormalities, thereby assisting in automated diagnosis and quantitative assessment.

Furthermore, advances in machine learning and deep learning have amplified the capabilities of traditional image processing, enabling the development of automated systems that offer enhanced diagnostic accuracy and significantly reduce analysis time. These methods have shown promising results in several diagnostic applications, including cancer detection, ophthalmology, and infectious disease diagnosis, underscoring the growing importance of image processing techniques in modern medical workflows [13].

Automated systems have proven invaluable for detecting a wide range of biological elements, including blood cells, tumours, and other microscopic structures, providing a strong foundation for diagnostic advancements across various medical fields. For example, automated image analysis enables precise identification and quantification of red and white blood cells, aiding in the diagnosis of conditions such as anemia and infections [14]. In oncology, automated tumour detection leverages segmentation and deep learning algorithms to distinguish tumour boundaries in radiology scans, improving accuracy in early diagnosis and facilitating targeted treatment planning [13]. Such systems not only enhance diagnostic accuracy but also reduce the workload for medical professionals, enabling more efficient workflows. By integrating parasite detection within this broader scope of automated biological analysis, its potential to simplify routine diagnostic processes and improve the reliability of medical outcomes is recognized.

This thesis presents a comprehensive approach to the automatic detection and identification of parasite eggs in microscopic images of fecal samples. A unique dataset is developed, containing images of three types of parasite eggs of varying shapes, sizes, and levels of noise and debris, to closely represent real-world diagnostic conditions. Various features are extracted from these images and analyzed using multiple classification methods, including traditional machine learning techniques and CNN-based approaches. Comprehensive analyses of the results are carried out to evaluate the effectiveness of these methods. This work not only addresses key challenges in parasite detection but also provides a robust framework for improving diagnostic accuracy and automation in parasitology.

In this chapter, the significance of an automated system for parasite egg identification, typical approaches for building such a system, and various challenges related to it are discussed.

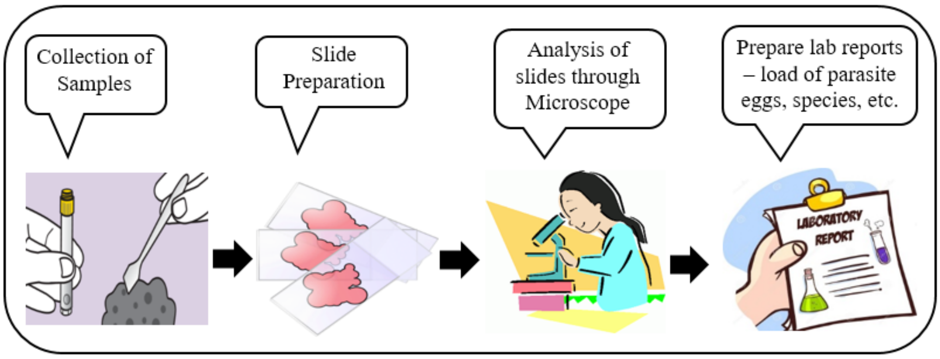


Figure 1-1: Various steps involved in a manual identification process of parasite eggs.

1.1 Automatic Detection and Identification of Parasite Eggs

In recent years, image processing and machine-learning techniques have revolutionized the healthcare sector. These techniques are essential in the automation of many medical diagnosis systems, such as brain tumour detection, cancer cell identification, etc., which become an important part of our present computer-assisted world. These automatic systems use various data sources, including images, videos, or numerical data, to extract meaningful information by applying different computer vision techniques. By leveraging advances in image processing, pattern recognition, and artificial intelligence, these techniques hold the potential to automate and standardize the process of identifying parasitic eggs, leading to more efficient and accurate diagnoses. Figure 1-2 demonstrates the integration of an automatic system for parasite diagnosis with the manual process. It should be noted that the automatic system still requires manually preparing microscopic slides and capturing images from them. The system analyzes the images, detects the presence of parasite eggs, and identifies their species.

The development of an automatic system for the detection, identification, and quantification of parasite eggs holds significant importance across various domains, offering advancements in medical diagnostics, public health, and research. It addresses various challenges associated with traditional manual methods, providing several noticeable benefits that include:

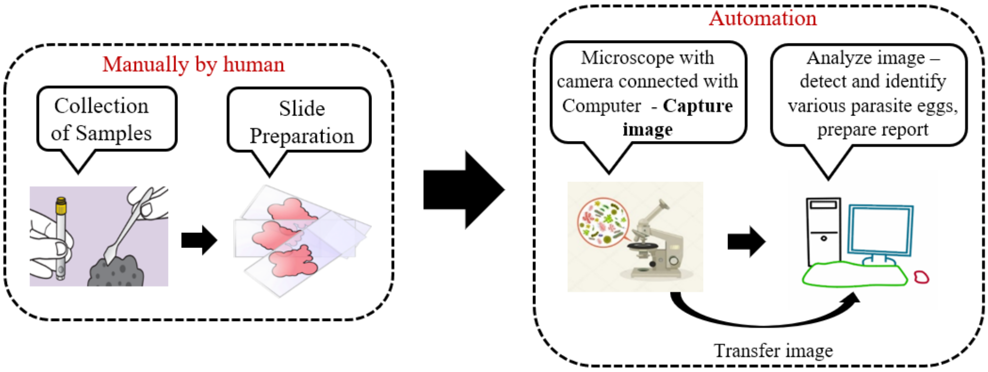


Figure 1-2: Integration of automated parasite egg identification process.

- Efficiency and Speed: It accelerates the diagnostic process, enabling the rapid detection and analysis of parasite eggs. This speed is particularly crucial in clinical settings, where timely results are essential for effective patient treatment and management.
- Accuracy and Consistency: Automatic systems reduce the risk of human error inherent in manual techniques. This leads to higher accuracy and consistency in the identification and quantification of parasite eggs, enhancing the reliability of diagnostic results.
- Resource Optimization: The automation optimizes the use of resources in diagnostic laboratories. It reduces the manual workload on laboratory personnel, freeing up time for more complex tasks and improving overall laboratory efficiency.
- Quantitative Analysis: Automatic systems provide precise quantification of parasite eggs in samples, offering valuable information about the severity of infections. This quantitative data aids in tailoring treatment plans and assessing the effectiveness of interventions.
- Scalability: Automatic systems can be developed to identify numerous types of parasite eggs and microscopic structures. These systems can also be trained to identify new species of parasite eggs as they emerge in the future.
- Veterinary Applications: In veterinary, automated systems contribute to the diagnosis of parasitic infections in animals. This is crucial for maintaining animal health, preventing the spread of diseases, and ensuring the safety of animal-derived products.

1.2 Typical Approach for the Automated System

An automated system for parasite egg detection and identification primarily utilizes microscopic images. The system applies various computer vision methods on these images to detect the presence of eggs within them. Typically, such a system performs multiple operations, which can be categorized into stages. These stages include pre-processing of input images, separating objects of interest from the background, detecting parasite eggs, and identifying their types. Figure 1-3 illustrates the various stages involved in such a system, and the subsequent sections describe each stage in detail.

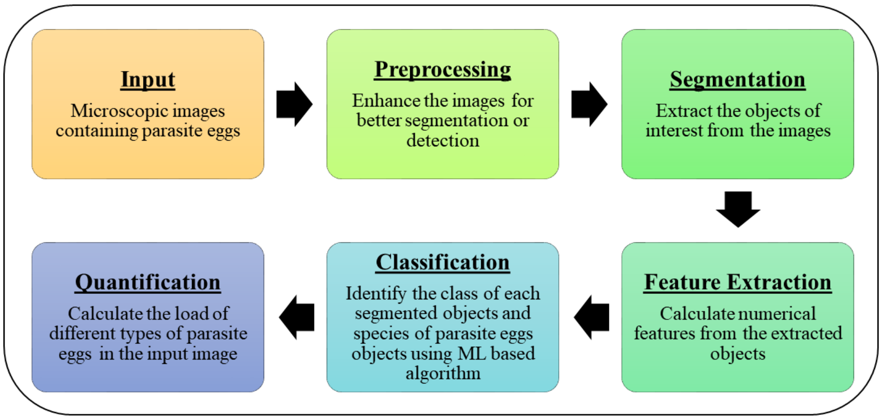


Figure 1-3: Various stages involved in an automatic identification process of parasite eggs.

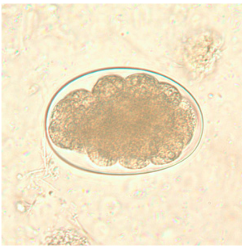
1.2.1 Parasite Egg Images

Different types of parasite eggs can be found in various samples, as previously discussed. The majority of intestinal parasite eggs are found in fecal samples and are frequently utilized in laboratory examinations. [15]. Eggs of Ascaris lumbricoides (Roundworm), Trichuris trichiura (Whipworm), Necator americanus (Hookworm), Enterobius vermicularis (Pinworm), and Taenia saginata (tapeworm) are the most commonly found in fecal samples [16, 17]. Images of the parasite eggs can be captured using a microscope camera. A few images of different types of parasite eggs are shown in Figure 1-4. Parasites that infect the bloodstream, such as the malarial parasite Plasmodium, do not produce eggs in the same way that intestinal worms do. Blood parasites that are commonly observed are Haemoproteus spp., Leucocytozoon spp., Plasmodium spp. (malaria), Trypanosoma spp. and microfilaria [18]. Trypanosoma and Plasmodium are the two most common parasites that infect humans among them. In animals and birds, Haemoproteus, Leucocytozoon, and Plasmodium are prominent. Figure 1-5 shows some common types of blood parasites. Trichomonas vaginalis and Schistosoma haematobium are the common parasites that can be found in urine samples [19]. Eggs of these types of parasites can be seen in Figure 1-6. The presence of parasite eggs in human tissues is relatively uncommon. However, one of the most well-known parasites associated with tissue involvement is the larval stage of the pork tapeworm named Taenia solium [20].

(a) Fertilized *Ascaris lumbricoides* (Roundworm) egg

(b) Unfertilized *Ascaris lumbricoides* (Roundworm) egg

(c) *Trichuris trichiura* (Whipworm) egg



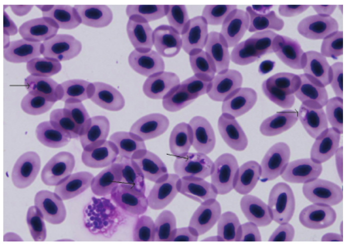
(d) *Necator americanus* (Hookworm) egg

(e) *Enterobius vermicularis* (Pinworm) egg

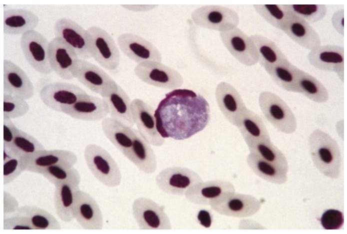
(f) *Taenia* spp. (Tapeworm) egg

Figure 1-4: Some common species of parasite eggs found in fecal or stool samples [1].

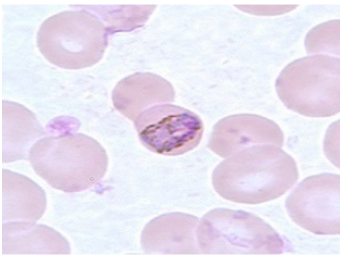
Microscopic images of fecal samples having one or more parasite eggs along with other sample impurities or debris tend to be used in an automated system. Examples of these types of images are shown in Figure 1-7. The size, shape, colour, and texture of various parasite eggs vary based on the staining process, quality of slide samples, and zooming effects of the camera during the image acquisition process. Lighting is also an important factor that causes different brightness and contrast effects in the images. Apart from the parasite eggs, different types of impurities or non-egg objects, such as air bubbles, food particles, etc., are widely present in these microscopic images. Some of these objects may have properties similar to the parasite eggs. In many cases, it is often seen that some of the eggs are fully or partially covered with sample impurities, touched, and overlapped with



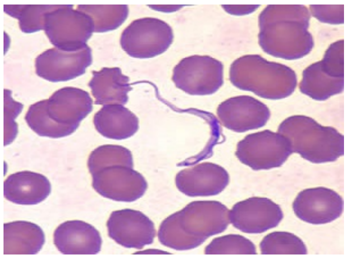
(a) Eggs of *Haemoproteus* spp. [21]



(b) Eggs of *Leucocytozoon neavei* macrogametocyte (round morph) [22]



(c) Eggs of *Plasmodium malariae* [1]



(d) Eggs of *Trypanosoma brucei* spp. [1]

Figure 1-5: A few commonly found parasite eggs in blood samples of animals and humans.

other eggs or non-egg objects.

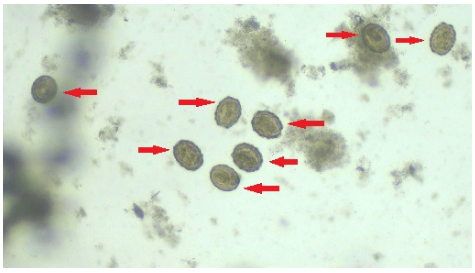
1.2.2 Pre-Processing of Input Image

The pre-processing stage plays a crucial role in improving the quality of images and preparing them for subsequent analysis, such as segmentation. In biological or medical images of parasite eggs, the pre-processing steps are even more essential as they can significantly impact the detection accuracy. Some pre-processing operations that can be applied before the segmentation of parasite eggs include

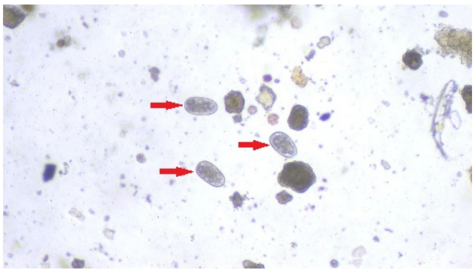
(a) Trophozoites of *Trichomonas vaginalis*

(b) Egg of *Enterobius vermicularis*

Figure 1-6: A few commonly found parasite eggs in urine samples of animals and humans [1].

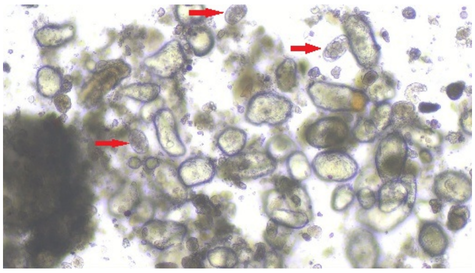


(a) Microscopic images of fecal samples containing Roundworm (*Ascaris*) eggs.



(b) Image containing Hookworm (*Necator americanus*) eggs with a moderate amount of debris.

(c) Image of Whipworm (*Trichuris trichiura*) egg surrounded by little sample impurities.



(d) Image containing Hookworm eggs with a heavy load of sample and fecal debris.

Figure 1-7: Microscopic images of fecal samples containing different species of parasite eggs. Image credit - ”E-Varaha Information System for Safe Pork Production in North-East India” - ITRA, Digital India Corporation-sponsored project and R.S Hadi [2].

adjusting the brightness, contrast, and sharpness of the image. This helps in bringing out important features like contour information and texture, making it easier for the automated system to identify and segment the objects accurately.

Microscopic images of parasite eggs are often prone to noise caused by various sources, such as image acquisition devices or environmental factors [10]. Noise reduction techniques, such as Gaussian smoothing or median filtering, can be applied to minimize the impact of irrelevant details and enhance the clarity of the images. Microscopic images may also suffer from colour variations due to factors like uneven staining. Colour correction methods are applied to standardize colour representations, ensuring that the colour information in the images is consistent and reliable for analysis. Conversion of images into different colour spaces, such as grayscale or a specific colour model, can also simplify image processing, reduce data dimensionality, and enhance the visibility of parasite eggs against the background. In some cases, resizing or scaling the images may be necessary to standardize the input for downstream processing. This step can also improve computational efficiency during subsequent stages of analysis.

1.2.3 Segmentation

Image segmentation is the crucial stage for detecting the presence of parasite eggs in microscopic images [23, 24]. The segmentation process separates different objects and parasite eggs from the image background based on their pixel intensity or some similarity measures [25]. There are several image segmentation techniques, including binary thresholding, edge detection, clustering-based methods, and watershed-based methods, that can be employed in images of parasite eggs. Depending on the image content, the performance of these segmentation techniques varies. The application or task that is being solved and the images used are the prime factors in the adaptation of any segmentation method [25, 26]. It should be noted that similar methods are utilized in a variety of ways to obtain a range of outputs in the parasite egg detection process.

Morphological operations may be applied to smoothen the segmented images to detect the objects accurately. Some commonly used morphological operations are dilation, erosion, opening, closing, and filling holes. Apart from the traditional image-based methods, machine learning algorithms such as ANN, kNN, Random Forest, K-means, etc., and deep learning techniques such as Convolutional Neural Networks (CNN) can also be used for image segmentation.

1.2.4 Feature Extraction

After the image segmentation stage, different types of features are extracted from the segmented objects. These features are then used for the identification of different species of parasite eggs. Parasite eggs exhibit a wide range of characteristics, including shape, size, shell structure, and texture. A summary of characteristics of different types of parasite eggs is mentioned below:

- **Nematode (roundworm) eggs**:
  - Appear oval or elongated under a microscope [27].
  - Mature eggs have a protective shell that varies in thickness and texture; usually thick with a smooth or sculptured surface [28]. Unfertilized eggs are larger and longer than fertilized eggs [1].
  - Internal structures of fertilized eggs may include developing embryos, larval stages, and yolk materials, varying among species [1].
- **Trematode (fluke) eggs**:

  - Typically ovoid or elliptical with an operculum (lid-like structure) at one end.
  - The eggshell is thin and transparent, with a smooth surface.
  - Some may contain miracidia, which hatch when the operculum is dislodged [1].

- **Tapeworm eggs**:
  - Generally spherical or ovoid with a thick, radially striated shell.
  - Smaller than nematode eggs [1].
  - Internal structures may include oncospheres or hexacanth embryos (infective larval forms).

- **Hookworm eggs**:
  - Typically oval-shaped with a very thin, almost transparent shell [1,28].
  - Shell may have a delicate, colourless outer layer.
  - Internal structure may show a developing embryo.

- **Whipworm eggs**:
  - Characterized by a thick shell and a distinctive polar "plug" at one end [1].
  - Generally contain embryonated larvae that are coiled with a distinctive spiral structure.

- **Leishmania (Leishmaniasis)**:
  - Appears as small, oval-shaped structures within host cells [1].

Based on the characteristics, a variety of features can be extracted. Some of the key features for parasite egg identification include:

1. **Shape and Size:** Parasite eggs often have distinctive shapes. Hence, measuring the length-to-width aspect ratio of the egg can be a useful feature. Measuring the egg's circularity or roundness also plays an important role since certain parasites have a shape close to a circle or oval. Morphological features like eccentricity and convexity may also be used to distinguish between different egg types. The area of the parasite eggs is used to differentiate them from larger objects in the images.

2. **Texture features:** It is one of the most effective features employed by many researchers for image analysis. Various texture features, such as contrast, energy, homogeneity, and correlation, to capture textural patterns in the egg can be calculated using the Gray-Level Co-occurrence Matrix (GLCM) [29].

3. **Colour feature:** Calculating histograms of colour channels (RGB, HSV, or LAB) to capture colour information can be useful since some eggs may have distinct colour characteristics. Statistical moments like mean, standard deviation, and skewness for each colour channel may also be calculated for better performance [30].

4. **Histogram of Orientated Gradients (HOG):** In many image classification applications, HOG proved to be effective for capturing shape and contour information, which can also be used for parasite egg identification.

5. **Convolutional Neural Networks (CNN) features:** Features extracted using pre-trained CNN models or a custom CNN can be useful and prominent feature sets for the recognition of parasite eggs. CNN can automatically calculate effective features to represent the shape, size, and texture of an object by training them with a sufficient number of samples.

1.2.5 Classification

The classification stage is crucial for identifying parasite eggs and differentiating between various types of parasite eggs in microscopic images. Various machine learning algorithms, such as Naive Bayes, Artificial Neural Networks, Support Vector Machines, K-nearest neighbours, etc., can be used for classification, leveraging features extracted from the detected objects. The classifier is trained on a labelled dataset containing images of different parasite eggs and other objects, allowing it to learn the distinguishing characteristics of each type. During the classification stage, the classifier takes the extracted features from segmented or detected eggs and assigns them to specific categories, corresponding to different parasite species.

1.3 Issues and Challenges

The automatic detection and identification of parasite eggs in microscopic images represent a significant advancement in medical diagnostics. It offers the potential to reduce the labour-intensive and time-consuming processes of manual identification. However, this effort is accompanied by several challenges that require thorough analysis and creative solutions. The key issues and challenges are listed below:

1. **Limited Datasets and Image Quality:** The development and evaluation of accurate systems rely on the availability of large and diverse image datasets. Constructing such datasets for parasite egg identification is challenging due to the need for expert annotation, variability in species, and ethical considerations. As a result, researchers often struggle with limited training data, hindering the generalization capabilities of their algorithms. Moreover, the quality of microscopic images depends on several factors, including sample preparation techniques, staining methods, and imaging conditions. Research should address the development and sharing of such datasets as well as pre-processing standards to enhance the quality of the images, remove noise, and normalize illumination.

2. **Complex Backgrounds and Artifacts:** Microscopic images often contain complex backgrounds, sample debris, and artifacts that can cover parasite eggs. The presence of cellular structures, particulates, and other non-parasitic objects adds noise to the images and hampers accurate segmentation and identification. Additionally, multiple parasite eggs may overlap or be densely packed, making it more challenging to separate and detect individual eggs.

3. **Variability in Morphological Characteristics:** Parasite eggs exhibit a wide range of morphological characteristics depending on the species, life cycle stages, and environmental factors. The vast diversity of egg shapes, sizes, colours, and textures complicates the development of a universal detection and classification model. Variability in staining techniques, sample preparation, and imaging conditions further complicates this challenge, necessitating robust algorithms that can adapt to diverse and heterogeneous datasets.

4. **Inter- and Intra-Species Variability:** Different species of parasites can exhibit overlapping morphological features, making their differentiation a complex task. Parasite eggs from the same species can vary significantly in size, shape, and texture, while some non-parasitic structures or debris may share visual similarities with parasite eggs. These factors challenge the capability of algorithms to accurately identify eggs, necessitating the extraction of discriminative features that capture subtle differences.

5. **Class Imbalance:** In many cases, the presence of certain parasite species may be significantly lower than others, resulting in a class imbalance within datasets. Moreover, the number of parasite eggs in a fecal sample is often much smaller than the number of non-parasitic structures. Machine learning models trained on imbalanced data can become biased toward the majority class, leading to poor performance in identifying minority classes. Addressing class imbalance is crucial to ensure comprehensive coverage of parasite types.

6. **Different development stages of parasite eggs:** There are several stages of development of a parasite egg - from the early stages through the larva's growth inside the egg. To carry out a proper diagnosis, it may be necessary to consider these stages. However, the identical characteristics of the eggs at different stages make it difficult to distinguish between the various growth stages.

1.4 Objective of the Thesis

This research aims to develop efficient approaches for the automatic detection and identification of parasite eggs in microscopic images of fecal samples using image processing and machine learning techniques. Based on the challenges mentioned above, we propose to achieve the following objectives:

1. ***Creating a Dataset of Microscopic Images of Different Types of Parasite Eggs and Ground Truths*** - A dataset with a sufficient number of images is necessary for the training and validation of computer vision models. In this study, a dataset of microscopic images of fecal samples containing three types of parasite eggs is created. Future scholars in this discipline may find the dataset useful since there aren't many publicly accessible datasets containing microscopic images of parasite eggs.

2. ***Explore the Available Image Segmentation Techniques and Develop an Effective Approach for Segmentation of the Parasite Egg Images*** - Examining the existing image segmentation techniques and evaluating their effectiveness on our dataset of parasite egg images is vital before developing an efficient approach for the automatic detection and identification of parasite eggs in microscopic images. Based on the effectiveness of various methods, an efficient strategy is developed for the segmentation

of parasite eggs irrespective of their size, shape, texture, appearance, and image quality.

3. ***Extraction of Robust Feature Sets for Identification of Various Parasite Eggs*** -The feature sets have a major impact on how well a classifier performs. It is possible that the features that work best for one type of parasite egg may not work in a similar way for the others. The addition of more features increases the dimension of the feature vector, which may result in decreasing the performance of the classification algorithms. It is important to extract only those features that are relevant and non-redundant for the classification task. Six different feature sets are extracted and examined for their effectiveness in identifying various types of parasite eggs.

4. ***Explore Different Machine Learning Algorithms for Classification of Parasite Eggs***- The segmented parasite eggs are classified into their respective classes using machine learning-based classification algorithms. Several well-known classification algorithms, including ANN, SVM, KNN, Decision-Tree, Naive-Bayes, and ensemble techniques, can be utilized. The number of training samples, feature vectors, and their dimensions are some of the most important factors that affect the performance of a classification algorithm. It is important to experiment with several classifiers with different feature sets, analyze the results, and select the ones that work best for our objective. The study explores various classifiers and analyze their effectiveness in classifying various parasite eggs and non-egg objects from the microscopic images.

5. ***Detection and Identification of Parasitic Eggs Using Deep Learning Techniques***- Modern methods for solving many computer vision problems include deep learning (DL) approaches. Image segmentation, object detection, and classification can all be done using DL-based techniques. The use of DL-based approaches may improve the accuracy of the automatic identification process of parasite eggs in microscopic images. Several techniques are explored and used in this research work to develop a robust system for automatic detection and identification of parasite eggs.

1.5 Thesis Organization

The rest of the thesis is organized as follows.

- In Chapter 2, a detailed literature review on various segmentation approaches for parasite egg images, different types of features, machine learning-based classification methods, and deep learning-based approaches for automatic detection and identification of parasite eggs is presented. The chapter provides adequate background for the thesis contributions.

- Details about the microscopic image dataset and different species of parasite eggs used in this study are presented in Chapter 3. The chapter summarizes the steps involved in preparing the images for different tasks.

- Chapter 4 presents the details of the development of a segmentation approach using various image processing methods. The chapter describes the system architecture, the proposed approach, and provides the segmentation results.

- In Chapter 5, the step-by-step process of extracting different types of features from the segmented images of parasite eggs and other non-egg objects is discussed in detail.

- Chapter 6 provides details on the classification of various segmented objects. The effectiveness of different classifiers and features in distinguishing between various types of parasite eggs and non-egg objects is discussed in detail. Various analyses are presented to identify the most effective feature sets and classifiers for the accurate identification of parasite eggs.

- In Chapter 7, applications of Convolutional Neural Network-based techniques for segmentation, classification, and Object Detection of parasite eggs are presented. Different approaches are evaluated and presented as solutions to effectively apply these approaches for developing an effective automatic detection and identification system.

- Finally, Chapter 8 summarizes the overall contributions of the thesis and identifies some future research directions in this domain of research.