CHAPTER I
INTRODUCTION

1.1. Study Background

Visual impairment is a general term referring to individuals who experience difficulties in sight, encompassing barriers to vision that can significantly affect their social interactions and communication skills [1]. Based on of visual limitation degree, visual impairment classified into several distinct types. Broadly, there are two main categories of visual impairment. First visual impairment is total blindness, which refers to a complete and permanent loss of visual function [2]. Second category is low vision which referred as partial blindness. Low vision described as condition in which individual retains some degree of residual visual capacity but with substantially reduced functional sight [3].

For individuals with visual impairment, access to information and independence of daily life represent fundamental challenges in world predominantly by visual communication [4]. Visually impaired individuals face difficulties accessing and exchanging information or knowledge when such content presented or required to conveyed in visual text formats [5]. Limitations access to printed text, public signage, and other forms of visual information can restrict individuals with visual impairments participation in education, employment, and social activities [6]. Therefore, technology innovation expected to play a crucial role bridging this gap enabling visually impaired individuals to learn, communicate, and interact more effectively, both with their surrounding environment and with others individuals, regardless of whether those individuals share same disability or not.

Braille is fundamental tactile writing system that underpins literacy, education, and communication of visually impaired individuals worldwide [7]. Physical Braille documents rely embossed dots raised on paper to enable reading through tactile finger contact. However, this physical medium is susceptible to various limitations over time, including material degradation such as dot flattening caused by repeated pressure, surface staining, and paper perforation renders duplication difficult and digitally impractical to store and retrieve using common consumer devices such as smartphones [8].

This problem compounded further by inherent physical nature of Braille documents as a tactile medium. Braille documents are particularly vulnerable to deterioration from repeated use, which gradually causes embossed dots flatten and become difficult to read over time. Therefore, urgent need to digitize and preserve existing Braille documents in order to prevent irreversible loss of valuable information. Technological solution for this challenge is Optical Braille Recognition or OBR. OBR aimed to converting Braille documents images into text that machine-readable and accessible to all individuals [9]. OBR isn’t straightforward task unlike conventional Optical Character Recognition or OCR which designed to recognize characters defined by continuous strokes. OBR system must be capable of identifying patterns formed by discrete collections of dots [10]. This distinctive characteristic renders standard OCR methods ineffective for Braille recognition.

Digitization of Braille documents captured using non-professional devices such as smartphone cameras introduces technical challenges such as image acquisition process. Captured documents frequently suffer from various forms of degradation including worn paper texture that led to unwanted surface noise, uneven illumination resulting from dots shadows, and from stains or smudges contamination. These issues collectively render resulting images difficult to process reliably. Such obstacles make preprocessing steps critical among which binarization holds foremost importance. Binarization is responsible for separating the pixels corresponding to Braille dots as foreground from underlying paper as background.

Global binarization approaches such as Otsu's method have been demonstrated to fail on images exhibiting uneven illumination as this approach frequently misclassifies shadowed regions as foreground, resulting in significant data loss [11]. To address this limitation, local adaptive thresholding methods are considerably more suitable. Niblack method offers local adaptability however; it is tended to produce excessive noise as output [12] As a refinement of this approach, Sauvola method was specifically designed to handle images characterized by nonuniform illumination intensity and high levels of background noise [12]. Braille document images share many characteristics with degraded documents including surface texture irregularities and staining. Sauvola binarization method was selected as preprocessing approach with theoretical robust foundation for this research.

Once Braille image has been cleaned through binarization and noise has been successfully eliminated, subsequent stage is dot detection. Given that Braille dots are physically circular in shape, application of *Circle Hough Transform* or CHT represents most efficient and accurate approach for isolating these features and achieved detection accuracy of 99.8% as demonstrated in study by Khanam et al. [13].

Prior research reported by Khanam et al achieved remarkably high detection accuracy reaching up to 99.8%. However, that study was conducted using a private dataset that is not publicly available or freely accessible. Furthermore, study exhibits notable limitations in terms of parameter transparency as it does not provide any analysis of interrelationships among parameters across pipeline neither in image preprocessing stage nor in dot detection stage using CHT. Parameters involved in both preprocessing and CHT-based detection have a substantial influence on the final output. Detection performance of CHT is heavily dependent on quality of input image produced by preceding preprocessing stages. Improper parameter configuration during preprocessing can lead to erosion of Braille dots or emergence of false noise with both of which may directly and or adversely impact CHT detection accuracy [13].

Therefore, this research is specifically directed toward addressing that analytical gap, utilizing publicly available *Semantic Segmentation Dataset* provided by *project-f7z2k* and accessible through Roboflow platform [14]. This study focuses Braille dot detection preprocessing by conducting a parameter sensitivity analysis on a single selected pipeline, consisting of Sauvola adaptive binarization thresholding as binarization stage followed by Circle Hough Transform for Braille dot detection. Primary objective of this research is to examine causal relationships between parameter variations and detection accuracy, aimed to identifying optimal parameter configuration that is tested and quantitatively validated on selected dataset. Outcomes of this research are presented in the form of two-dimensional heatmaps and individual sensitivity curves that visually characterize both optimal parameter regions and performance boundaries of each parameter, alongside quantitative evaluation using mean Precision, mean Recall, and mean F1-Score computed across all images in selected dataset.

1.2. Problem Statement and Formulation

Based on foregoing discussion, this research problem addressed are as follow:

1. How does combined influence of Sauvola binarization parameters namely *window_size* and *k* affect structural integrity of Braille dots in images that remain identifiable by CHT on Braille dataset project-f7z2k [14] as measured by Precision, Recall, and mean F1-Score across the entire dataset?
2. How does parameter *Param2* of Circular Hough Transform (CHT) influence dot detection performance after image has been processed through Sauvola thresholding binarization on selected dataset, as measured by Precision, Recall, and mean F1-Score across all images in dataset?
3. What is combined performance of Sauvola thresholding binarization and Circle Hough Transform for Braille dot detection on selected dataset, when evaluated using Precision, Recall, and mean F1-Score across all images in dataset?

1.3. Research Objectives

In accordance with problem formulation elaborated in previous section, primary objective of conducting this research as follows:

1. To analyze sensitivity of *window_size* and *k* parameters in Sauvola thresholding method, as measured by Precision, Recall, and mean F1-Score across all images in dataset.
2. To analyze *param1* parameter and sensitivity of *param2* parameter in CHT applied for Braille dot detection on binarized images using optimal

Sauvola thresholding configuration, measured by Precision, Recall, and mean F1-Score across all images in dataset, with *param1* fixed as a constant value determined from preliminary testing results.

3. To evaluate combined performance of Sauvola thresholding and Circle Hough Transform, measured by Precision, Recall, and mean F1-Score as primary evaluation metrics on selected dataset.

1.4. Significance of the Study

Competition of this research expected to yield various theoretical benefits including:

1. Provide an understanding of parameter sensitivity in Sauvola and CHT pipeline.

   This research expected to deliver clear quantitative data regarding the causal relationships between variations in Sauvola preprocessing parameters and CHT detection parameters with respect to accuracy outcomes. By understanding the behavior of these parameters, readers can identify which configurations are the most sensitive and critical in the Braille dot detection process an analysis that has not been thoroughly addressed in previous studies
2. Serve as a technical guide and parameter configuration reference for future researchers.

   Sensitivity analysis findings of this research can function as a reference for other developers or researchers working with Braille dataset project-f7z2k or datasets with similar characteristics. This is particularly valuable in enabling future researchers to bypass time-consuming trial-and-error processes from scratch, thereby reducing development time in construction of more complex Optical Braille Recognition (OBR) systems.
3. Support development of improved Braille document digitization systems.

   This research is intended to serve as a foundation effort to build accurate OBR systems. By ensuring that the fundamental stage of dot detection can operate optimally through the parameters examined in this study, it is expected to facilitate the development of character recognition systems in subsequent stages with a higher likelihood of success in translating Braille documents into digital text

4. To contribute to the provision of information accessibility for visually impaired individuals.

   This research findings can be indirectly leveraged development of more precise assistive reading tools or Braille scanner applications. An optimal parameter model can serve as basis for technologies that help bridge communication and information gap for visually impaired community in digital era.

1.5. Scope and Limitations

To maintain focus targets and objective of this research as explained previously, scope limitation has been established following:

1. Focus on single-sided Braille document images sourced from a public dataset.

   This research focused exclusively on processing of Braille document images printed on a single side Braille paper. It does not encompass handling of double-sided Braille documents, in which dots from reverse page may be visible through the paper, nor does it address real-time detection through video input. Primary focus is solely on still images drawn from public Braille Semantic Segmentation Dataset provided by project-f7z2k[14].

2. Scope limited to Dot Detection stage.

   This research is confined system's capability to identify presence and location of Braille dots within an image. It does not extend to Clustering or Classification stages. The system is developed solely to distinguish between Braille dots and background.