Vision Networks for RoboCup

(THESIS REPORT)

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I, Nasrullah M Nafis, certify that this work does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

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ABSTRACT

To win against human soccer by 2050, RoboCup Federation has developed a platform for scientists to do research and develop intelligent multitask performing robots. This paper has been focused to develop a vision system for Robotis Op3 humanoid robots. The robot needs to be able to detect different field markings to participate in the RoboCup competition. The markings include straight lines, centre field circles and line intersections. This paper suggests a method to perform edge detection which eventually helps detect lines, circles and intersections. Two different methods of Hough Line transform have been tested on various data sets for detecting straight lines. This paper shows the use of Hough circle transforms to detect the field's centre circle. A simple simultaneous linear equation has been used as a method for detecting straight-line intersections. From the results we can see those real-time conditions like luminance of light, camera angle plays a big role in the detection process.

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TABLE OF CONTENTS

Table of Contents

LIST OF TABLES AND FIGURES

CHAPTER 1 - INTRODUCTION

As human civilization is advancing rapidly, various new complex problems arise regularly. Technologies are also advancing rapidly to solve these problems and make lives easier. Robotic technologies play a major role in this war against time. As a research and development platform for both wheeled and bipedal robots, the RoboCup national tournament since 1997 has encouraged the continuous development of artificial intelligence, locomotion and image processing for robotic systems by establishing a common objective of playing soccer (Niemueller et al., 2015). In the world of football, the ultimate goal of RoboCup is to have a team of fully autonomous humanoid robots play professional soccer matches against the world's best human players by 2050 (Kitano & Asada, 1998). The purpose of developing robots for playing soccer require multiple complex technologies to be implemented. They include dynamic movement, advanced vision system (to detect different objects in the soccer field), the network connection between robots and decision making using artificial intelligence. Due to the rapid development of robotic systems, the RoboCup has introduced various technical challenges and qualifications for participating robots (Gerndt et al., 2015). In terms of the RoboCup competition, perception is a major platform of research and development in the field of robotics. The goal of this thesis is to study the various aspects of the vision system for a robot, and how they can be utilized by the teams working on them.

Detection of different field markings is one of the most important tasks in the RoboCup competition. Field markings determined by the line detector is useful to locate the robot in the field. This method of robot localization is already being used in RoboCup competitions (Bestmann et al., 2019). For the goalkeeper to keep track of its distance from the goal, it needs to know the distance between the white lines in front of its goal and the boundaries established on the field. This method works by identifying the lines with respect to the distance (Jamzad et al., 2001).

A robot must pass relevant qualifications to participate in the RoboCup competition. This thesis will focus on the improvement of Robotis Op3's vision system, which includes the detection of different field markings. The methods developed in this paper will attempt to make the robot identify straight lines, the field's centre circle and different intersections of straight lines. This system will help the robot in self-localization and perform different tasks in future.

This thesis is categorised into following chapters:

- Chapter 1 gives introduction to the thesis and describes the main motivation behind the project.

- Chapter 2 provides in-depth analysis of the current methods and strategies being developed for detection of the field markings. This chapter provides greater understanding of current flaws in the developed methods.
- Chapter 3 provides details on methods in developing the strategies and techniques for each goal. Literature reviews have been used as guide to research necessary areas and develop the systems.
- Chapter 4 details the outcomes in the form of tables and graphical representations of the experiments that were constructed and conducted in this thesis.
- Chapter 5 discusses the results obtained in chapter 4. Critical evaluation of the outcome is done in this chapter.
- Chapter 6 This chapter describes the systems that were created and the validations that were performed. It also discusses the future work that is required in order to make these systems more efficient.

CHAPTER 2 – LITERATURE REVIEW

2.1 – Image Pre-processing

According to Wanmi et al., (2006) traditional processing algorithms of an image treat image as a motionless image with just geometric lines and forms. The verb processing operator complexity of the image is relative to sum of the height and width of the picture in the verb image processing. This will need far fewer CPU resources, making applications (real-time) more cost-effective. The image colour will be transformed to a grey image to conduct verb processing of an image. The key development in this article is that the created system decreases computing costs by employing column-wise & row-wise spatial verb compositions, resulting in a vision system with excellent accuracy and processing speed. In this article, they use computational verb theory in the image processing progression of the robot system to determine quickly and reliably the position & travelling way of the individual robots. The theory considers an image's grey values to be a dynamic process that occurs laterally spatial coordinates, i.e., spatial verbs and the use of the RoboCup domain spatial verbs because verb processing of an image is a potential technique to lower image processing computing costs (Zhu, et al., 2005). The trend in this article is that the distinctive characteristic of verb processing of the image is that the grey value change process is monitored, allowing the vision system to decrease detection mistakes and boost detection speed. The issue which they address in this article is mainly on AI robotics. RoboCup project is a worldwide collaborative initiative aimed at fostering intelligent robotics and AI research by offering a common issue for integrating and testing a diverse set of technologies. Because the RoboCup robot league (small size) is such a dynamic arrangement, it's critical that its system of vision performs in real-time & with great precision (Chen, et al., 2006).

2.1.1 – Blur Filtering

The article on the comparative analysis of the Gaussian filters, median filters and the denoise auto encoder presents the difference in the factors for the process of computer analysis and segmentation. The approach of the image in digital pictures can be further enhanced and denoised with the help of various filters. After reviewing the article, I learned, the use of a Gaussian filter, median filter and denoising autoencoder is used for the mitigation of noise. According to Kumar & Sodhi, (2020), the use of the Gaussian filter is done for the linear type function based on the Gaussian factors. The use of the median filter is further used for nonlinear functions. The use of the median filter is significant as it preserves the edge while mitigating the noise. The concept of a Deep Convolutional neural network (CNN) can be used for effective handling of the Gaussian denoising at various noise levels.

With the help of various evaluation methods, the approach of the noise removal method is explained in the present article with its effectiveness. With the use of the time performance and the peak signal to noise ratio(PSNR), structure similarity(SSIM) and the normalization of the mean square error(NMSE) the effectiveness of the factors for removing the noise is used effectively (Kumar & Sodhi, 2020). The approach of the Gaussian filter is further considered them, post-effective techniques for reducing the noise with effectiveness depending on the iteration of the filters. Furthermore, the approach of the denoise autoencoder can be used concerning the Gaussian and median filter for reducing the noise.

According to D'Haeyer, (1989) In image processing multi-resolution, Gaussian filters commonly are utilised. Convolution of the picture with many Gaussian filters through increasing spread is common in multi-resolution methods. A limited impulse retort implementation including filter coefficients in large numbers and hence a large number of calculations for computing the convolution is required for large standards of spread. As stated by Wells, Gaussian filters may also be effectively built using the cascade of the uniform filters. In the sense that convolution of limited & continuous function with Gaussian creates a full function, Gaussian filter possesses strong regularisation or smoothing qualities. The key development is that convolution sense of a limited & continuous function with Gaussian creates a full function, Gaussian filter possesses strong regularisation or smoothing qualities. (The Taylor series' radius of the convergence is unlimited.) As a result, using a Gaussian filter assures that all the derivatives of the resulting picture exist (D'Haeyer, 1989). The theory which is used in this article is probability theory. Wells claimed that a uniform filters cascade may be used to efficiently implement Gaussian filters. This approach is based on probability theory's central limit theorem, which states that repeated convolution and modest non-negative purposes lead to Gaussian function under very generic conditions. The trend is that the study proposes a fast approximation Gaussian filter in this article that they use the same number of the calculations for altogether spread values, first one is computationally competent for spread values greater than 2, & the other one is that it possesses second instruction soothing qualities. The issue is in the variational and discrete problem. Reinsch and Schoenberg presented the resembling cubic spline as a solution to the variational issue and various solution is provided to solve this issue which is mentioned in this article (Terzopoulos, 1986).

According to Narendra, (1981) Tukey proposed MEDIAN filtering which is a superficial wave shape, which has now become popular for smoothing two-dimensional picture noise. Because the median rejects extremes (outliers), it has been discovered that the median filter is more successful than the linear filter and smoothing pictures with the prickly noise distributions. After the edge prominence filtering, the median filter, for example, has been used as a postfilter. The key development is that the techniques of edge enhancement which included unsharp masking and Laplacian. In which the images get sharp through the edges and the schemes of edge enhancement is done by amplifying the image noise. The noise resultant is quite spiky and annoying as well. The theory or method which have been used in this article is Simulation of Monte Carlo in which it is performed for verifying the asymptotic relations approximately in this fields of white noise pseudorandom there are mainly three Gaussian distributions, log normal and uniform and all of these are with the same variance and were filtered by two dimensional & median filters separable of the size three multiply three, five multiply five and seven multiply seven (Andrews, 1976). The trend in this article is that the median filter of two-dimensional as it is more effective and in the case of smoothing the noise it is efficient, with edges its behaviour is characterized. The issue which is highlighted in this article is the noise problem and its distribution which is quite spiky and annoying so this median filter is used for smoothing the edges of the images. Because of these characteristics and the ease with which it may be implemented in hardware, the median filter separable should be measured whenever real-time of the median filtering two-dimensional is required (Narendra, 1981).

2.1.2 – Edge Detection

According to Shrivakshan and Chandrasekar, (2012), Edge detection may be done in several ways. Laplacian & Gradient are two types of it. By observing for the highest and lowest in the image's first derivative, the gradient approach determines the edges. To locate edges, the Laplacian approach looks for zero crossings and also in the image's second derivative. Edges are assumed to be pixels with strong gradients in the edge detection algorithm. To determine the kind of shark fish, they use edge detection which is Laplacian-based on a sample of sharks. Discovering zero crossings, picture intensity second derivative may be used to determine the image's Laplacian depended edge detection sites. The *key development* in this article is recognising a shark fish category which is compared to edge detection methods and in this MATLAB was used to develop the programme (Shrivakshan & Chandrasekar, 2012). The main difficulty and *issue* which is highlighted in this article is to grasp the fundamental ideas of various filters & also apply them to the identification of shark fish kind, which is used as an example. The strategies for detecting edges are explored in this work which is the edge detection techniques. The *trend* is filters are utilised in the identification of the picture by positioning the sharp, discontinuous edges. These discontinuities result in variations in the intensities of the pixel, which outline the object's borders. The item is shark fish, & morphological traits are used to classify the shark type by using a novel approach. The *method or theory* which have been mainly focussed in this article is Laplacian Edge Detection as it wants to create morphing algorithm that uses automatically retrieved characteristics from target photos. Finding the target photos edges might be a useful starting point and they did it by using a Laplacian Edge Detector in this article (Huertas & Medioni, 1986).

According to Kaur & Garg, (2011) Edge detection method is a basic method for extracting information from pictures & frames that is extensively utilised in various processing applications of image. Picture interpretation requires the image separation into background and object. In the processing of image & computer vision, the edge detection method is a phrase used to describe the process of detecting and extracting features. Edge detection required to locate depth discontinuities, surface orientation discontinuities, material property changes, and lighting fluctuations in the scene. The key development in this article is mathematical morphology. The use of mathematical morphology for edge identification is more competent than other approaches. Based on the findings and comparisons in the article of the various edge detection approaches, it has been determined that edge detection mathematical morphological is superior to the conventional method. The edges of pictures were analyzed & contrasted utilizing mathematical morphology & classical approaches such as Sobel, Laplician of the Gaussian method. Canny, Prewitt on a subjective and objective foundation. The theory which is used in this article is Mathematical morphology as it is a novel approach for detecting edges. It is set theory-based theory and approach for geometrical structure analysis and processing (Mr. Salem, 2010). The trend or change is that the majority of remote sensing pictures are distorted by noise. Mathematical morphology can also help to reduce noise. As a result, the picture may be improved & edges can get discovered using mathematical morphology. The issue is that the remote image sensing is mainly get disturbed by the noise. And through the help of edge detected method and in that using mathematical morphology, quality of image can be increased and enhanced as well as the detection of edges can be done (Kaur & Garg, 2011).

According to Gao et al, (2010) the main approach of the edge detection method is to look at the changes in a single picture pixel in grey region and detect edge by looking at variation of edge nearby first order and the second-order. The term "local operator of method edge detection " is used to describe this method. The fundamental goal of the edge detection method is to measure, identify, and locate changes in picture grey. The picture edge is one of the most fundamental aspects of image. The key development is that the Wavelet has been widely applied and developed in the signal processing, quantum theory, image processing & other technological disciplines. The wavelet alter may choose the transform radix freely, it can choose multi-band wavelets, translation invariant wavelets and wavelet packets, & so on based on signal characteristics & de-noising needs of the signal. The theory or model in this article is based on the Sobel operator. Sobel offers two distinct benefits over further edge operators: CD Since average factor was included, the image's random noise has been smoothed out a little. In this the advantages of this model are Because it’s two-row and two-column difference, the components of edge on mutually sides have been strengthened, giving the edge a thick & dazzling appearance. The trend in the article is that edge detection brought changes in the digital image. The fundamental goal of the edge detection method is to measure, identify, and locate changes in picture grey. The picture edge is one of the most fundamental aspects of image. The issue is that several edge detection algorithms have been presented in the recent years. The generally used approaches of combining Sobel operator & mean de-noising, or median filtering & the Sobel operator, are ineffective in removing salt & the pepper noise. In this study, they first reduce noise with wavelet of soft-threshold before performing edge detection method on the picture with the Sobel detection edge operator. This approach is mostly used on photos that contain White noise of Gaussian (Gao, et al. 2010).

According to Sun & Gao, (2013) Edge detection method is a crucial component of image processing since it serves as the foundation for further picture identification and comprehension. There is now an edge detection algorithms series based on the differential operators. The Canny operator presents an enhancement to the standard single threshold approach, in which the high & the low thresholds are chosen based on the picture histogram's gradient. Canny operator will be able for producing a decent edge detection outcome for single background and little alteration in the backdrop and goals of image. The key development is that Canny algorithm in its original form do filtering & smoothing of the images Because presented optimization detector's form of Canny is comparable to first order imitative of Gauss function, it may be used to create Gauss function. The theory or method which is used in this article is Otsu method. The Otsu technique is used to extract the matching sub-block threshold worth for respectively sub-block, & then interpolates the value matrix of threshold to get image edge. The trend is that with the help of the Canny edge detection algorithm Not only does the algorithm perform well against noise, but it also has a higher detection accuracy. The issue is that when there are big variations in the backdrop of the picture & the target grey, the Canny traditional edge detection technique employs global threshold selection approach, which may lose some limited edge information. As a result, this work provides adaptive active threshold enhanced Canny edge detection technique to solve this problem (Sun & Gao, 2013).

2.2 – Line Detection

The author in this article explains the line detection with the help of the regularised Hough transform approach. The issues arising in the analysis and identification of the location with the appropriate orientation of the straight lines thus differ in the processing of the image and the process of computer vision. With the distinctive combination of the linear features, the factors of straight lines can be further identified in various natural and artificial objects (Aggarwal & Karl, 2006). The application of the line detectors is observed in the tracking of the aerial images of roads and tracks. With the help of various interventions, the problem in line detection can be further achieved. Moreover, the intervention of Regularised Hough transforms the identification of straight lines can be made simpler along with the systematic identification of various formulations of the strategies.

According to Aggarwal & Karl (2006), the approach to mitigate the problems of the Random transform operator can be used for transforming the data which significantly incorporates the image. The significance of the problem formulation according to the author helps to analyse the systematic way for the conversion through the specification of the approach of the regularizer. With the use of various regularizers, the significance of the transformation process to regularization can be further evaluated with the mitigation of the same problems in the detection of line with the help of the respective approach. Moreover, the use of various iterative techniques for solving the problems and optimizing the process of line detection is thus considered an effective and convergent technique.

The article on "Extended Hough transforms for linear feature detection" evaluates the necessary approaches required for the enhancement of the accuracy of the line segments. The linear feature detectors aim to reduce the complexity of various high-level interventions in cartographic processes detection. The coordination involving both horizontal and vertical coordinate points of the image further provides incremental information focusing on the length of the linear feature. The author further presents the concept of the Bayesian probabilistic approach to execute the process of the hough space for maintaining and enhancing the accuracy of the transformation of Hough.

The study of line detection refers to the fundamental constituents of various man-made approaches to provide information related to the high cartographic interest. Following the considerable high-level processing, the extraction of the cartographic features refers to the building of short line segments by further using the Hough transform. Moreover, the low-level processing of the short line segments with the help of the Hough transform help to evaluate the low-level processing used by the considerable high-level processing. The author explains the ability of the prior elimination of various information to provide a unique functional advantage for the detection of the line segments. After carefully analysing the articles various irrelevant information regarding the feature of the project can be made which incorporates the distinctive and precise knowledge and idea explaining the line feature. According to Cha, et al., (2008) the resulting system can thus achieve a higher rate of line detection.

In their article, Duan et al., (2010) focuses on the enhancement of the Hough transform for the enhancement of the line detection with the help of the robust method for the identification and detection of the lines in digital imaging. The fundamental challenges mentioned in the study incorporates various computational complexity and the storage requirements of the standard Hough transform which is further applied to real-time detection of the lines. The variation in the approach of hough transform has been proposed to implement an effective strategy of computational and storage burden. According to Duan et al., (2010), the enhanced hough transform aims to detect the line with effective sharing of the characteristics and modification of the Hough transform (MHT) and random Hough transform (RHT). After the careful analysis of the article, the proposed method further helps to implement the concept of "many to one" mapping along with the techniques for the alleviation of the computational load along with storage issues.

The experimental analysis of the article further reveals the information that the extensive experiments must be enhanced and with better techniques the performance of the previous variation of the transform approach of Hough can be mentioned. The study further incorporates the approach of the proposed algorithm for evaluating the process of gathering the evidence for arbitrating the data point in the image sourcing. Furthermore, with the help of changing function the vote of the parameters can be further achieved. The vote can further incorporate the possibility to pass through the data points according to the marketing on the parameter space.

The transformation of the probabilistic Hough transform is used for the detection of utilizing the suppression of images. The approach of line detection is the fundamental and significant challenge in the process of image processing and the vision of computer approaches. Various categories of the problems arising in the process of line detection deal with the effective method to analyse the shapes of the image fundamentally incorporating the analytical curves with an appropriate description of the parameters. According to Guo et al., (2008) the approach of probabilistic Hough transform is required to effectively maintain the standard scheme of the Hough voting by further utilizing the approach of random sampling with a small portion of the pixels obtained from various images. These factors further aim to reduce the computation load of the computing process significantly. The article further presents the approach of the probabilistic Hough transform for the detection of line and utilising the same for surrounding the suppression.

The demonstration of the algorithm is used for the moderate execution of various experiments for the promotion of the rate of detection and accuracy of the process of line detection. To present the more stable detection performance the careful analysis of the line detection process must be made. The algorithm is further achieved with the help of the applications meeting the requirements for determining the rate of detection along with the accuracy of the interventions along with fixed execution time.

With the help of the survey on the process of transformation of the Hough approaches with effective theory and techniques is explained with a clear application of the uses of the intervention of Hough transform. The concept of spatially extended patterns is further explained with the help of a transformed process to produce compact characteristics in the parameter space. According to Hassanein et al., (2015), the concept of Hough transform is further used for the conversion of the global problem analysis and detection with specific image space for easier peak detection in the parameter space. The authors in the respective article further presents the Hough transform algorithm with slope-intercept from the parameterization with an effective voting scheme. The concepts included in the study focus on the detection of the shapes along with the line detection and the detection of various analytical shapes and objects. Moreover, the approach to detect the shapes include the identification of irregular objects.

With the help of the survey, the author further presents various approaches such as analysis of the tone and colour required for the detection and analysis of the objects is explained clearly. The author explains the approach of Hough transform further attracts huge research and the significant motive behind the success of the Hough transforms (Hassanein et al., (2015). It further develops effective interpretation in the approach of noise immunity with the ability to deal with various challenges such as occlusion and the process of expandability.

Hart (2009) commented that the approach to study the process of Hough transformation, which can be explained with the help of the history and various enhancements in the present hough transformation approach. The present Hough transform is used for the detection of various geometric features in the digital imaging process and is the most widely used procedure in computer vision. The concept of the Hough transform patent is the marvel used for analysing the brevity with no significant algebraic equations used for defining the transformation of Hough. The intervention used for the analysis of the disclosure of the Hough transform incorporates the description of the components used such as the amplifiers and the sawtooth generators (Hart, 2009). The author further utilized the key idea behind the transformation of the Hough approach that underlines the transformation with the help of various factors such as collinear points used in the plane of the image where the identification of the geometric shapes is essential.

The intersection of the collinear points in the transform space by further mapping the geometric shapes. The identification of the geometric shapes is hardly recognised due to the use by the computer vision community and thus to provide an effective approach for the mitigation of the problems in the hough approach the implementation of various changes and transformation is essential. The application of the Hough transformation is further related to the safety of the automotive with the use of the respective transformation in the vision-based systems used for the identification and detection of various vehicles departing from a lane.

Reviewing the article by Mukhopadhyay & Chaudhuri (2015) reveals that one of the major challenges regarding the automated analysis of digital image and that challenge is shape detection being a significant part of recognizing the object. Thus, reviewing the works of literature used in this article, it is found that the authors have applied mathematical equations for focusing on the Hough transformation. The authors have utilized concepts such as GHT (generalized Hough Transform), PHT (probabilistic Hough Transform) and many others. Going through these concepts reflects that it seems intuitively obvious that for a longer line, a few and smaller size fractions regarding the supporting points need to vote before any corresponding accumulator bin reaching the count. The count is non-accidental, however, for some shorter lines; higher proportions regarding supporting points need to vote. Another concept that gets encountered during carrying out the literature review of this article is the evaluation of implementation. In addition, the authors have discussed the issues getting encountered during implementation, for example, the implementation of any method needs to satisfy the constraints regarding the applications. Furthermore, these constraints are related to memory and time needs, for example, while discussing the software solutions, the authors discussed the NN or Neural Networks, data structures and many others. Apart from hardware solutions, the authors further focused on software solutions, thus, the author continued with the implementation issues such as when it comes to parallel implementation among the processing elements. For example, there seem various configurations for parallel implementing the Hough Transform, thus getting varied within the ways that they transform spaces and image gets distributed among the PEs.

According to Patrick, et al., (2013) in the line detection process, three steps are followed which are RGB image original, scanner generate the point and lines are detected in the subsequent step in feature procedure of extraction, it is required to identify and then extract the information reacted to the line which intersected the other line and every crossing indicates confidence measure which is depended on the intersection geometrical properties. Method of line chaining was used for projective variant detection of middle circle (De Kok, et al., 2013). The Key developments in this article is Nao simulation which makes it simpler to learn new motions by hand or through guided learning. Previously established keyframe motions, such as varied stand-up motions, kicks and, keeper movements, will be translated to framework of NaoTH. The open loop movements will be enhanced to make them more resistant to external perturbations. The theory is Monocular visual odometry in which the robot's trajectory is calculated using step-to-step approach, which finds translation vector and rotation matrix indicating camera displacement based on feature movement between two following frames (Kooijman, et al., 2013). This article theory provides the foundation for a robot trajectory estimation system. Although the performance of the presented system cannot be evaluated, it may be utilized as a foundation for application (real-time) that can do quite well on trajectory estimation & 3D reconstruction. The *Trend* is a successful landmark detection mechanism which is critical for attaining the self-localization, that can be thought of as the first step toward creating a working robot soccer squad. The ***issue*** which the article highlights is the problem in autonomy and robotics which the team of Dutch Nao try to solve it by using combination of robotics and artificial intelligence. By providing a more robust low-level base, it is possible to concentrate on the programming (high-level). With the help of NaoTH Framework, can concentrate on incorporating the most cutting-edge AI approaches into the code.

2.3 – Circle Detection

In this article the authors refers to the detection of the circular Hough transformation with the help of various proposed systems and interventions further leads to the enhancement of the respective approach. To determine the image from a noisy and cluttered approach in computer vision the approach of circular Hough transformation is widely used. Rizon et al., (2005) reflected that with the help of the separability filter and the circular Hough transformation the identification of the objects can be further made easier and simpler. The article incorporates the approach to analyse the circular patterns within a digital image. The transform of the circular Hough transformation is used for the change in the feature points of the image. The approach of the proposed system uses images within 320*240 pixels and with the use of a portable grey map the input of the proposed recognition process can be further identified. Reviewing the articles, the concept of separability filter provides a template to analyse the separability between two significant regions

The experimental results further present the success rate of the proposed system for the detection of the object which was 96% by moving the circle template in every 20 pixels towards the right and with 20 pixels towards the down further presents the success rate to be 80% (Rizon et al., 2005). The author in this article states the approach of the CHT is a type of Hough transform for extracting circular objects from digital imaging.

Smreka & Duleba (2008) discussed the detection of the circular objects using the technology of Hough presents an in-depth analysis of the practical modification and implementation of the technology of Hough. Reviewing the entire article reveals that the work of literature is based on the technology of Hough, which aims to enhance the identification of the low contrast circular objects. To improve the efficiency and to provide an appropriate explanation of the complexities of the algorithm, the respective approach is used as a form of literature review. To determine and identify the low contrast circular objects along with a clear understanding of the algorithm is applied to localize the nuclei of a specific cell significantly of the cytological smears to be visualized under the phase-contrast microscope. Two specific methods for detecting the circular and elliptical shapes from a low contrast phase are selected which incorporate the approach to the detection of the single circular images. The most significant methods selected for the respective study incorporates Circular Hough Transform(CHT) and Elliptical Hough Transform (EHT).

Definition of CHT concept

The concept of Circle Hough Transform is defined as the basic feature for the detection of circles in imperfect images significantly in the process of the digital image. The high parameter is further used for voting the circle candidates with an effective selection of the local maxima incorporated in the accumulator mix (Smereka & Dulęba, 2008). The approach of the Elliptical Hough Transform is used for the process of image extraction in digital images specifically identifying the elliptical shapes. The process of EHT further requires five parameters by using the algorithm determined for identifying the elliptical spaces. Thus the identification of the single cells facilitated the formulation of various approaches with the help of CHT and EHT.

While reviewing the given article, Beltrametti, Massone & Piana (2013) commented that the Hough Transformation got introduced in the processing of the image for automatic detecting the straight lines encountered within the images. The author further described the idea behind the computational tool, which reflects that the computational tool within the typical parametric representation that gets represented as a straight line. Beltrametti, Massone & Piana (2013) continued defining the concept of special classes of the curve, which is needed in Hough transformation, for example, the histogram can be one of those curve classes, wherein Hough Transform can effectively be applied for automatically recognizing the specific classes based on curves. Furthermore, curves are having algebraic forms, which are also known, however importantly more are complicated as compared to conics or lines. As a result, the authors reflected on the complex curves as well, for example, conics or lines, which seem more complex as compared to the histogram. Hence, the overall assignment utilizes concepts, contexts and theoretical perspectives on the respective curves such as lines, cones or histograms. In addition, the authors have utilized a mathematical foundation that is based on the algebraic-geometry arguments for Hough transformation, thus, it is found that for particular classes of curves, the Hough transforms regarding the pointed curves, for example, every curve gets met in at least one point within the space of parameter that uniquely identifies the curve. The authors have attempted to cover the conceptual perspective of Hough transformation, for example, the above result naturally inspires the extensions regarding a classic pattern recognition method for detecting the complex curves.

The analysis of the new methods for the detection of the curve implies the interventions which can be used for the detection of the straight lines along with detection of the curves in computer vision. The analysis of articles is explained with the help of three basic steps which is explained as the pixel of the image which is further converted into the parameterized curve, the process of accumulating the cell array on the parameter space with various scores of the cell lying on the coordinates to evaluate the segment of the curve in the image and transform space (Xu et al., 1990). Thus these factors further enhance the feasibility of the method to mitigate the issues of detection of line segments. The author further explains the significance of the detection of the pixel coordinates in the image space through random hough transform which is further significant to mitigate various challenges and difficulties in the approach of digital imaging.

According to Xu et al., (1990), the process of randomized hough transform is associated with the analysis of the curves in the computer vision process. Thus with the help of the steps mentioned in the earlier section of the study the analysis of the computer vision to enhance the factors and the interventions with the use of various approaches aims to provide an effective outcome of the detection of lines including curves, straight lines and many others. The author further explains the significance of the RHT as supplying infinite parameter space for the identification of the lines and to mitigate the problems associated with the same.

2.4 – Intersection Detection

The study on straight line intersection of the point analyses the detection on the curve fitting of the Hough parameter in the transform space. The concept of straight line intersection point refers to the fundamental point used for the machine vision and to execute the basic processing of the machine. Various methods are used for the detection of the straight line intersection of the image points. After reviewing the article two fundamental points have been analysed which explains the process of intersection. The two methods mentioned in the study are:

1. Calculating the specific equation of the intersecting straight line and further calculating the intersection point about the different equations.
2. The implementation of the vertex with appropriate examination on the link provided around the point of intersection.

According to Chen, Wang & Xiong, (2010), the analysis of the complexity and the result on the stimulation of the methods to analyse the potential challenges explains various factors of complexity such as the function of the space parameter of Hough causing accumulation of the complexity, the function for selecting the candidates in the Hough space complexity, the function of the sine curve along with the approach of the detection of the fitting complexity based on the factor of the least square method. The careful analysis of the paper presents the scope to analyse the significant challenge of the straight-line intersection along with the point detection in the process of machine vision and the analysis of the video for further analysing the method of Hough transformation for the analysis and identification of the straight lines.

According to Tommy & Mohan, (2011), because the images collected by camera are standpoint in the nature, they must be transformed to parallel view earlier being utilised in any applications in order to get photorealistic output. Image-based version & view metrology benefits greatly from standpoint image correction. Line intersections, Plane Homography and Hough Transform are used in the procedure. The key development is that by using edge detection, the Hough transform, perspective transformation and plane homography, this work proposes method for correcting perspective photographs. The approach may be used on photos & videos from various angles and with various lens lengths & image sizes. The proposed strategy is also applicable to horizontal. The theory or method used in this article are perspective transformation and plan homography. When view volume is replaced with a rectangle-shaped one, the Perspective Transformation method is utilised. View volume becomes axis-aligned which is rectangle following transformation. The perspective picture's view volume is turned into an alternative view volume containing transformed (rectified) pictures by using plane homography (Maurizio Pilu, 2001). The *trend* is Lens distortion which is corrected with Hough Transform and Least Square Error, whereas perspective distortion is corrected with plane homography. The approach assumed the picture included rectangular items such as photo frames. The *issue* is that perspective image is quite but the images are not turning out to be effective so to solve this they offer a method which are line intersections, plane homography and Hough transform for automatically correcting standpoint images based on intensity fluctuations of the objects in picture that is both efficient and easy. The perspective alteration for photos and videos is automated using this method (both online and recorded). For perspective correction, it doesn't employ any calibration data or any kind of explicit information of any mental imagery hardware (Tommy & Mohan, 2011).

2.5 – Robot Localization

The article mentions the process of self-localization to determine multi-robot coordination such as the Robocup Middle size league. Messias et al., (2008) states the approach of Monte Carlo localization is the most popular algorithm used for the process of self-conceptualization. The approaches mentioned in the articles for specific sensor data incorporates the Monte Carlo approach which is used to extract the data and information in any given location with the help of a gyroscope for resolving the ambiguous issues regarding localization. The respective approach further incorporates the concept of "points-on-lines" detection of the algorithms providing reliable information on the sensor data for resolving the ambiguous postures with the effective use of the gyroscope. With the use of various interventions, the problem can be further solved with the help of the Bayes Filter algorithm and Kalman filter (Messias et al., 2008). The probability distribution of the posture of various robots can be further propagated with the help of the Bayes filter algorithm and Kalman filter.

The author further explains the use of gyrodometry which helps the robots to evaluate and correct the orientation angle in a large discrepancy between the measured angles but further analyses the odometry with the help of a gyroscope. The results of the article refer to the various approaches of the MCL algorithm with positive, consistent results and many others. The results further present the particle adaptation with the approach of self-localization which further ranges between 5-10 particles. Iteration is also defined in the articles where the data is reflected at the end of 10 points.

CHAPTER 3 – METHODOLOGIES

3.1 – Field Setup

I set up the field inside Flinders University's Advanced Control Systems Laboratory. According to the rules for field size of RoboCup (Virtual RoboCup Soccer Humanoid League Laws of the Game 2020/ 2021, 2021), the length of the touchline must be greater than the length of the goal line. For KidSize matches, length of the touch line (field length) should be approximately 9m and length of the goal line (field width) should be approximately 6m. Following are the rules for the field setup:

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Figure 1: Kid size humanoid robot soccer field (Virtual RoboCup Soccer Humanoid League Laws of the Game 2020/ 2021, 2021).

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Table 1: Table for approximate dimensions of the field (Virtual RoboCup Soccer Humanoid League Laws of the Game 2020/ 2021, 2021).

The width of the green turf in the lab has 9 meter field length but 4 meter field width. Therefore, the above mentioned dimensions could not be applied to the lab's turf. To overcome this limitation, the given measurements have been scaled down to match the field width. The new approximate measurements are :

A	Field length	6 m
B	Field width	4 m
C	Goal depth	0.4 m
D	Goal width	1.7 m
E	Goal area length	0.5
F	Goal area width	2 m
H	Centre circle diameter	1 m
J	Penalty area length	1 m
K	Penalty area width	3.3 m

Table 2: Approximate dimensions of the actual field.

All lines have the same width of approximately 5 cm.

3.2 – Dataset

For image data collection to use in my thesis, initially, I used the dataset from TORSO-21 Dataset: Typical Objects in RoboCup Soccer 2021 (Betmann, et. al., 2021). The goal of this paper is to provide a comprehensive and annotated set of images that are taken in real-world locations and simulated images in order to compare the various vision systems in use in RoboCup. The repository can be used to evaluate the various approaches and methods used in the game. It also enables users to evaluate vision training data in a realistic environment.

Secondly, I used the Robotis OP3 humanoid robot's vision system to collect image data. The robot has got a Logitech webcam installed to capture image. It has got a webcam of 720p resolution installed.

3.3 – Image pre-processing

Before the images were fed into field marking detection algorithms, they were pre-processed with the following techniques.

3.3.1 – Converting image from RGB to Greyscale

Image processing is an important research area. Scientists are working on different research areas such as image restoration, image compression etc. They are enhancing the current image processing techniques and are inventing new methods to solve ever-changing image processing problems. Different image processing methods are used in the latest image processing applications such as satellite image processing and medical image processing. Another advantage of image processing includes the increment of ability in using a wider range of algorithm to be applied to the input data so that problems such as the build-up of noise and signal distortion during processing can be avoided (Baker & Nayar, 1996). Image processing needs to use colour. The main two reasons behind the use of colour are first, colours help human eyes to extract and identify objects from a scene, secondly, they are more distinguishable than all the different grey shades (Kumar & Verma 2010).

The system that is used to represent the colours to be used on a computer display is called RGB (red, green, and blue). Any colour in the visible spectrum can be achieved by using different proportionate of the combination of these three colours. The intensity of the colours ranges from 0 to 100% which is represented in decimal numbers ranging from 0 to 255. In hexadecimal, this is equivalent to 00 to ff. We can find the total available number of 256 * 256 * 256 = 16,777,216 possible colours. An RGB image is also known as true colour image. According to Kumar and Verma (2010), a true colour image is an image in which each pixel is specified by three values one each for the red, blue, and green components of the pixel scalar. Values range from [0, 1] for single or double arrays. Values ranges from [0,255] for uint8. Usually, 8 bits is used to store the intensity of each colour channel. Therefore, 256 is the quantization level.

The range of monochromic shades which ranges from pure white on the lightest end and pure black on the darkest end is called greyscale. We can find only luminance information on greyscale rather than any colour information. Hence, we can see the zero luminance as black and maximum luminance as white. Everything else between the range is different shades of grey. Both greyscale information or luminance and colour information can be found in digital images. Removal of the colour information will provide us with a greyscale image. Removing the greyscale information from an image will leave a total dark image. To convert a colourful image to a greyscale image, we need to remove the colour information from the image by removing colour information from each RGB channel. Bala and Braun (2003) proposed a method where colours are first sorted according to their original lightness values. Then they are equally spaced in grey or according to the difference in their 3D colour from colours adjacent to them along the lightness dimension.

3.3.1.1 – Conversion process

One of the steps in image processing is the conversion of RGB image to Greyscale image. There are several reasons behind this, first off, colour information does not assist us in identifying critical edges or other characteristics in many image processing applications. Exceptions do exist. If there is a hue edge (a step change in pixel value) that is difficult to detect in a grayscale image, or if we need to distinguish items of known hue (orange fruit in front of green foliage), colour information may be beneficial. If we do not need colour, we may classify it as noise. Greyscale images require less time in doing complex operations because of their 2D information. On the other hand, RGB images require more time because they contain more data.

In order to convert RGB images to Greyscale images, I will be using the *cv2.cvtColor()* method also known as the colour space conversion method (Pisarevsky, 2010). This method is inherited from the OpenCV library of Python, which helps to convert an image from one colour space to another. According to the OpenCV (2021) documentation, transformation within RGB space such as the conversion of RGB to Greyscale happens using :

$$\text{RGB[A] to Gray:} \quad Y \leftarrow 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$$

3.3.2 – Blurring Image

Based on the finding in the literature review, no single filter perfectly work on every type of image. To get the optimal solution, I used the most popular and reliable filters called Gaussian filter and Median filter.

Gaussian filter:

Gaussian blur is an image processing technique that blurs an image. It works by using a Gaussian function. This effect is commonly used in image processing to reduce image noise and detail. It is a smooth blur that resembles the look of a translucent screen. Gaussian smoothing is a pre-processor stage used in computer vision algorithms to improve the representation of image structures at different scales.

In one dimension, the Gaussian function is:

$$G(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2}{2\sigma^2}}$$

Here the standard deviation of the distribution is σ.

For two dimension , the Gaussian function is (Haddad and Akansu, 1991):

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Median filter:

The median filter is a non-linear digital filtering technique that removes noise from an image or a signal. It is very widely used in digital image processing. The median filter is an algorithm used to replace the entries in each signal with the median entries of nearby neighbors. The pattern of neighbors that appears over the entire signal is referred to as the window. Basically, it works by placing the median values in the input window and then filtering the output image. Like Gaussian filtering, median filtering is a type of smoothing technique that removes noise from a signal without affecting its edges. It is commonly used for estimating the grey-level value under long-tailed noise (Ohki et.al. 1995). This technique is best used when performing low-level noise filtering and preserving the edges. It is generally considered to be the most effective method for minimizing noise in each image.

3.3.3 – Edge Detection

The Canny edge detector is extensively used in computer vision to identify abrupt changes in intensity and to denote the borders of objects in an image. A pixel is classified as an edge by the Canny edge detector if its gradient magnitude is greater than the gradient magnitude of pixels on both of its sides in the direction of greatest intensity change (Ding & Goshtasby et.al, 2001). John F. Canny developed it in 1986. Canny edge detection is a technique for extracting structural information from separate visual objects while significantly reducing the amount of data that must be analysed. It uses a Gaussian filter to determine the intensity of the gradients. It does so by reducing the noise in the image and removing non-maximum pixel sizes. The Canny algorithm can be adapted to various environments. Its flexible parameters allow it to be adapted to recognize edges of varying characteristics.

3.3.4 – Region of Interest

Sometimes, it is necessary to process a subregion of an image while leaving other regions unchanged. This is often referred to as ROI processing. Regions of an image may easily be represented using Mathematica Graphics primitives such as Point, Line, Circle, or Polygon, or by simply listing the vertex positions (Digital Image Processing: Region-of-Interest Processing -- from Wolfram Library Archive, 2021).

A region of interest (ROI) is a portion of an image that is desired to filter or manipulate. A ROI is created by creating a binary mask, which is a binary image the same size as the image being analysed but with all pixels in the ROI set to 1 and all other pixels set to 0.

In an image, many ROIs may be defined. The regions may be defined geographically, for example, by polygons that span successive pixels, or by a range of intensities. The pixels in the latter situation are not necessarily contiguous. ROIs are applied to every image before they are fed to field marking detection algorithms. In this project, ROIs helped to ignore the un-necessary noises outside the soccer pitch.

3.4 – Field Marking Detection

3.4.1 – Hough Transform

In computer vision, image analysis and digital image processing, the Hough transform is used to extract features from images (Shapiro and Stockman, 2001). Rosenfeld introduced the Hough transform (HT) into popular image analysis literature in 1969, although it was invented in 1962 by Paul Hough to locate straight particle tracks in high-energy nuclear physics. The approach was further improved by Duda and Hart in 1972 and used for the detection of lines and curves in digital images (Davies, 2005).

Detecting basic forms like straight lines is a common difficulty in automated picture analysis. Therefore, images have been pre-processed by using edge detector to locate the image pixels on a line. However, there may be missing pixels on the expected line due to flaws in the image data or the edge detector, as well as spatial variations between the ideal line and the edge detector's noisy edge points. As a result, grouping the retrieved edge characteristics into suitable sets of lines, circles, or ellipses is typically not easy. Hough Transform solves this problem by performing an explicit voting mechanism over a collection of parameterized image objects to execute groups of edge points into object candidates (Nixon and Aguado, 2020).

3.4.2 – Standard Hough Line Transform

Based on the literature review, standard Hough line transform is a commonly used method to detect straight lines in digital images. Standard Hough Line Transform algorithm is implemented to determine the straight lines in the images captured from Robotis OP3 vision system.

To detect lines in an image, standard Hough line transform uses the normal form of equation of the given line (Duda and Hart, 1972):

$$r = x\cos\theta + y\sin\theta$$

Here, r is the distance of the straight line from the origin, and theta (θ) is the angle between the line connecting straight line with the origin and x axis.

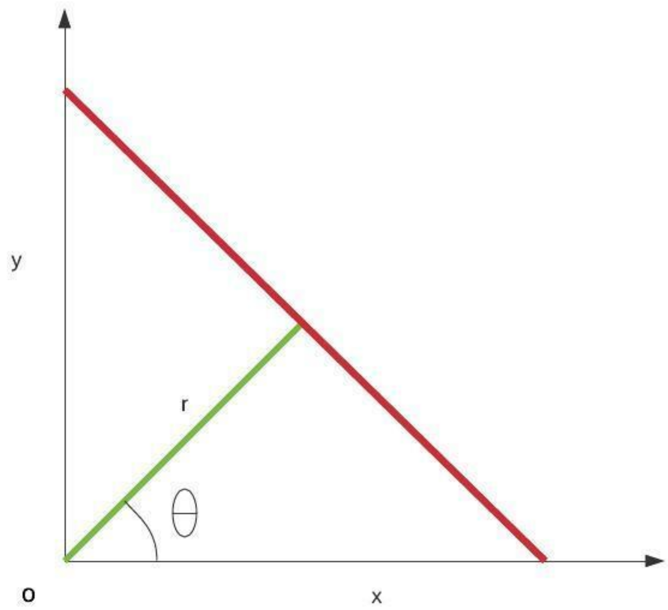

Figure 2: Straight line in Hough Transform

Initially the parameter values of r and θ are given to find the desired line. Then to store the values of the given parameter, the algorithm first generates a 2D array or accumulator (which is initially set to 0). Then it detects whether a pixel is an edge pixel for each pixel on the edge detected image. When the edge pixel detected, to find the theta and rho index pairs in the accumulator, the algorithm finds all possible theta values, calculates the relevant rho, and then increases the accumulator based on those index pairs (Herout et.al., 2013). This process is continued for every edge pixel of the line.

The images have been pre-processed by converting from RGB to Greyscale images. This is done to reduce the colour noise. As mentioned earlier, grayscale images are more effective in detecting edges. The next step is to detect the edges in the images. This pre-processing was done using Canny edge detector. Finally, Standard Hough Line Transform was implemented to detect straight lines in the images. The parameters have been set to certain values to avoid false detection of multiple lines.

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Figure 3: Canny Edge Detection and Standard Hough Line Transform detecting line on images ((Bestmann et al., 2021)

The method was tested on several images to tests its validity. As depicted in the above figure, multiple false line was detected. To avoid the false detection, more noise reduction needs to be done. Applying blurring filter to an image reduces noise significantly, which increases effectiveness of image processing (Kumar & Sodhi, 2020). Based on the literature review, Gaussian Filter is a very effective blurring filter. It is commonly used for edge detection. After applying Gaussian filter to the image before edge detection, the results have improved. However, it seems the algorithm is not providing accurate measurement of the detected lines. In some images it is still detecting false lines as shown in the figure above.

3.4.3 – Probabilistic Hough Line Transform

Probabilistic Hough Line Transform is the optimization of the Hough Line Transform described above. Instead of taking all the points into consideration, it takes random subset of points which are enough for line detection. This algorithm, instead of using all M edge points, it works using only a subset m. This reduces the voting complexity from O(M.Nθ) to O(m.Nθ) as m<M (Kiryati et.al., 1991).

This method has been tested on the same image data tested on Standard Hough Line Transform algorithm. The images have been pre-processed in similar method with initially converting from RGB to greyscale, then blurring out with Gaussian filter and then detecting edge with Canny edge detector.

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Figure 4: Probabilistic Hough Line Transform detecting line on image (Bestmann et al., 2021)

After setting up the parameters in the algorithm, the result seems to be better than the Standard Hough Line Transform algorithm. However, since the probabilistic Hough transform uses the random subsets of edges, the performance may sometimes be slightly impaired.

3.4.4 – Hough Circle Transform

Another major component of this thesis is detection of centre circle of the soccer field. This detection algorithm should detect only the centre circle and should not detect and confuse the ball as the field marking. There are several methods to detect circles in an image but in this thesis, the Hough Circle Transform method has been used. According to the literature review, this method is common and reliable to detect circles in an image.

Hough Circle Transform algorithm is another application of Hough Transform it is designed to detect circles. It can detect circular objects in an image even if the circles are not complete. The transform is also very selective for circles and will ignore elongated ellipses. It can also determine the radius and centroid of each object in an image (Yuen et.al., 1990). The parametric equation of a circle where the radis R and centre (a,b) is known:

$$x_c = a + R\cos(\theta)$$
$$y_c = b + Rsin(\theta)$$

After the angle is implemented across the 360-degree range, the points (x,y) nearly trace the circumference of the identified circle. However, since it needs 3D accumulator, it is computationally expensive. The accumulator can be reduced to 2D if the radius R is known (Su et.al., 2020).

Images with centre circle marking of soccer field from Robotis OP3's vision system has been tested with this algorithm. Before implementing the algorithm, the images have been converted from RGB to Greyscale. Then the median filter was used to denoise the images. The median filter was used here because it works better with images for circle detection (Nosrati et.al., 2012). The Canny edge detector was used to detect the edges of the circle.

Figure 5: Circle detection

3.4.5 – Intersection Detection

Since the field has a number of intersections, it is important that the line detection algorithm can also effectively recognise and process intersections. This is done through a combination of linear mathematics and the output of the probabilistic Hough line transform algorithm.

When the algorithm detects two lines in the same picture, it generates four sets of coordinates as part of a numbered array. The coordinates can then be retrieved from the array using simple index. In the probabilistic Hough Line Transform, the coordinates of the first line are given through elements 0,1,2,3 and the coordinates of the second lines through 5,6,7,8. These are (x_1,y_1) and (x_2,y_2) for the first line in the picture and a secondary (x_3,y_3) and (x_4,y_4) for the second detected line in the picture. This means that there is four data points within the same picture (There could be more than two in this algorithm but the football field never has more than two lines intersecting at a point so this scalability of the algorithm is avoided). Once the intersection detection algorithm receives the four sets of coordinates, it does the following calculation.

The slopes of both lines are calculated from the ratio of differences of the x and y coordinates of the lines. The slope is represented by m_1 for line 1 and m_2 for line 2

$$M_1 = y_2 – y_1 / x_2 – x_1$$

$$M_2 = y_4 – y_3 / x_4 – x_3$$

Once the two slopes are calculated, the algorithm can then set up two separate linear equations to represent the lines.

Equation 1 ⟶ $Y=M_1 x + c$
Equation 1 ⟶ $Y=M_2 x + c$

These two linear equations are then rearranged to standard linear equation form of

$$Y - M_1 x = c$$
&
$$Y – M_2 x = c$$

These two equations are then fed into a linear system of equations solving algorithm like the one designed by Richard Peng and Santosh Vempala of University of Georgia, or any linear system solving algorithm for that matter (Peng and Vempala, 2021). The solving of the systems reveals two variables, x and y coordinates of the point of intersection. The algorithm then checks whether this point exists within the photo. If the point is detected within the photo, this point is then attributed as a point of intersection within the photo. Similar pre-processing methods as pre-processing methods for line detection have been applied to the images for intersection detection.

CHAPTER 4 – TESTING/RESULTS

This chapter is focused on the experiments done on the developed system described in the previous chapter. It also has the results from the experiments. More detailed discussions about the results are given in chapter 5.

4.1 – Testing and Comparison two different line detection methods

Both Standard Hough Line Transform and Probabilistic Hough Line transform are popular algorithms. They have their own specialities. Both algorithms' performance depends on environment. Where Probabilistic Hough Line transform performs better, non-probabilistic Hough transform, or Standard Hough Line transform will not perform well. This can happen vice-versa (Kälviäinen et al., 1995).

This means both algorithms needs to be tested, in various environment for their optimal performance, before one of them are implemented in Robotis OP3. In order to run this experiment, image data have been collected form the TORSO-2021 dataset (Bestmann et al., 2021). Total 200 image data have been carefully selected from the data set. There are 100 bright images and 100 dark images among these 200 images. The brightness or luminosity of the images has been determined through histogram analysis.

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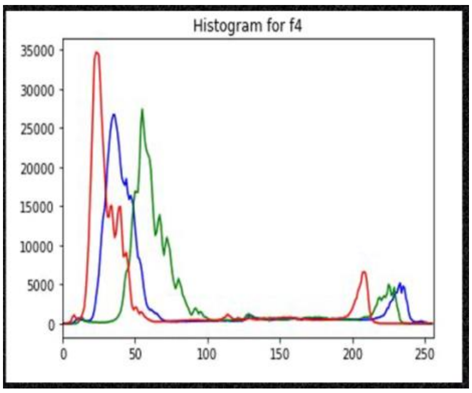

Figure 6: Selected dark image (Bestmann et al., 2021) and Histogram Analysis

An image is considered dark when in histogram, there is a high frequency of RGB value in lower count. This is depicted in the figure above.

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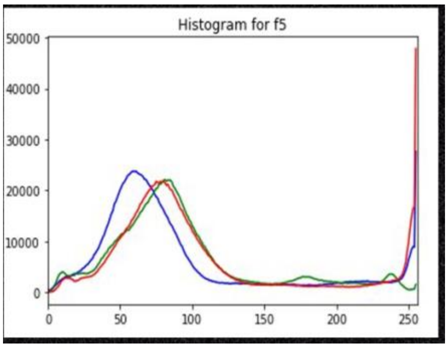

Figure 7: Selected bright image (Bestmann et al., 2021) and Histogram Analysi

An image is considered bright when in histogram, there is a high frequency of RGB values in upper count. This is depicted in the figure above.

After running both algorithms in the selected 200 images, we got the results illustrated in the table below:

Line Detection Algorithm Comparison

	Dark Images (100)	Bright Images (100)	Total (200)
Standard Hough Line Transform	80	63	143
Probabilistic Hough Line Transform	93	78	171
Errors	27	59	86

Table 3: Line detection algorithm comparison

For visual understanding of the result, a graph illustration is given in the figure below:

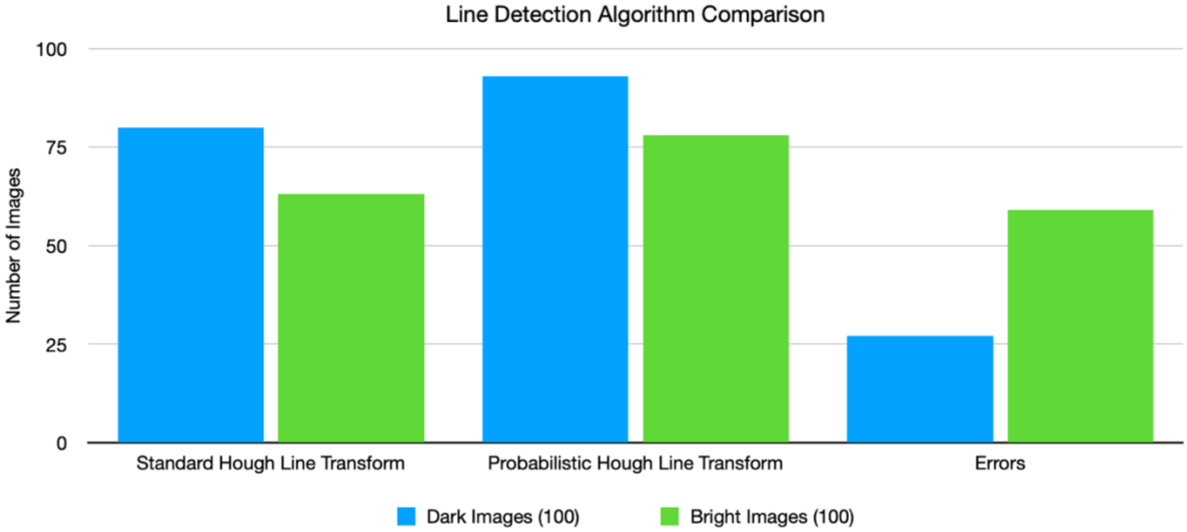

Figure 8: Graphical representation of the line detection algorithm comparison

From the results above, it can be derived that Probabilistic Hough Line Transform performed better than Standard Hough Line Transform algorithm in both dark and bright images. Therefore, the Probabilistic Hough Transform has been chosen as line detection algorithm for Robotis OP3.

4.2 – Testing and evaluation of Probabilistic Hough Transform for line detection

For basic line detection, the probabilistic line transform algorithm is set to a threshold parameter determined based on the quality of the image.

The algorithm generates two sets of coordinates, x and y coordinates for the end and start point of the line that was detected. These coordinates are however, based on the coordinate system that the system assigns within the photo and does not correspond to real life coordinates of the field. This was overcome through an origin mapping technique.

Figure 9: Grid setup on the field

The field is covered with equally spaced markers that act as a spatial detection system for the robot. This is done because there is some problem in the magnetometer of the robot's IMU.

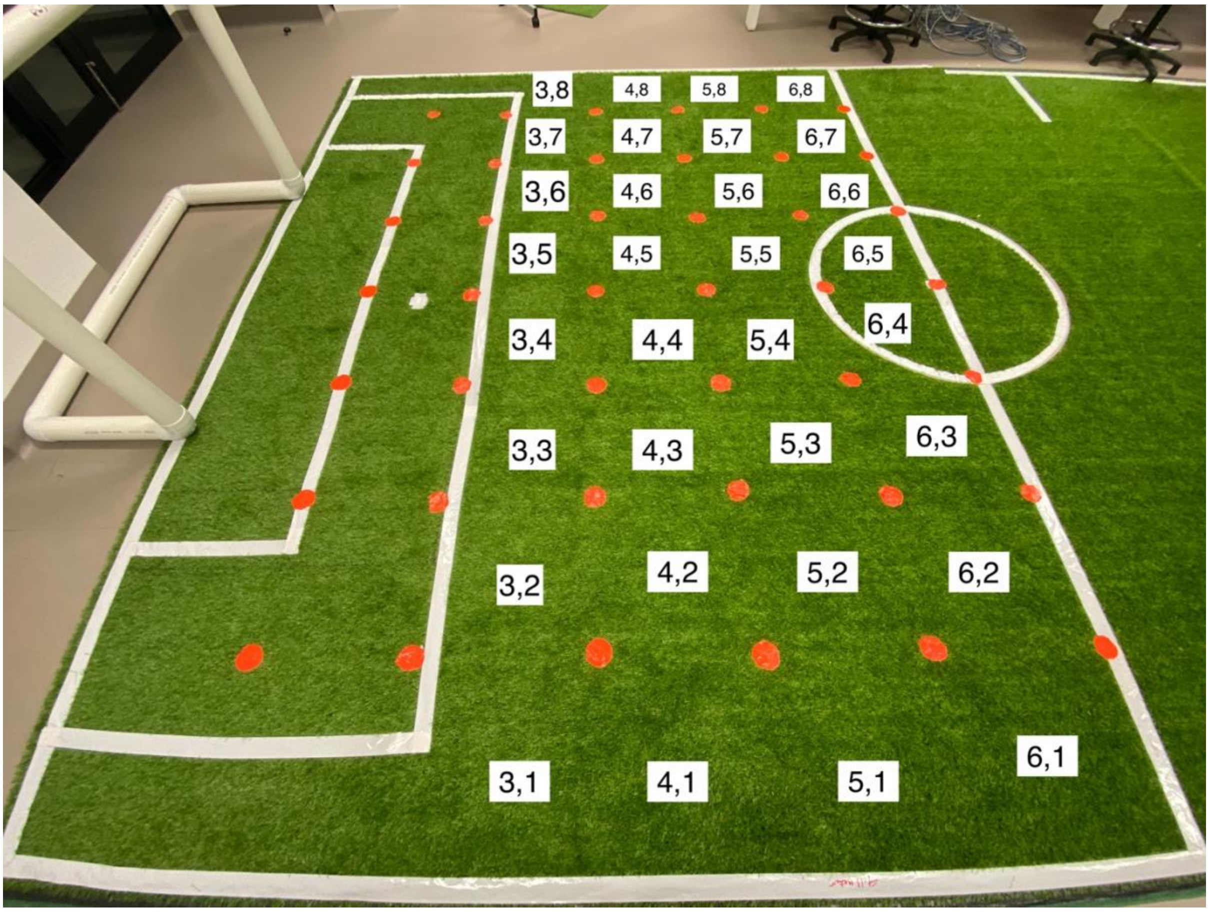

Figure 10: Robot's position coordinates

The Robotis Op3 robot was placed in the coordinates shown in the figure above to capture image data. Robot captured the image data from a standing position where the camera height was recorded 20 inches high. Each coordinate numbers matches the serial number of the images taken. These numbers can be found in the tables below. Once the pictures are taken, the markers were used to manually assign an origin deviation factor. This factor is then used to convert all coordinates within the photo to real life coordinates from the field. This step was important as it allowed us to compare the lines that were detected to the 'true' coordinates of the lines from the field for an accurate calculation of error. The true coordinates that were measured manually on the field served as the golden standard against which the algorithms were compared. Since the line detection algorithm just provides the coordinates for the start and end of the line within the photo, it was important for us to devise a conversion factor so we could perform a direct comparison.

Figure 11: Selected line for algorithm testing

As shown in the image above, the line that the algorithm is attempting to detect is fed into the system from a range of angles and distances. The line is then detected and voted upon and once the votes cross the threshold, the output coordinates are received.

	Measured				Real				Normalised measured value				
Image Position Index	X1	Y1	X2	Y2	X1	Y1	X2	Y2	X1	Y1	X2	Y2	RMSE (Average)
3.1	13.6	54.7	204.2	53.2	0.48	1.98	7.5	1.98	0.56	2.11	7.65	2.0	0.432
3.2	4.4	17.2	63.3	16.9	0.48	1.98	7.5	1.98	0.50	2.02	7.48	1.96	0.094
3.3	15.2	31.1	91.01	30.89	1.01	2.0	6.0	2.02	0.79	1.86	6.01	1.88	0.521
3.4	7.2	14.34	41.92	14.11	1.01	2.0	6.0	2.02	1.12	2.20	5.89	2.17	0.350
3.5	22.02	15.12	36.62	15.31	3.00	2.00	5.00	2.00	3.00	2.02	5.05	2.12	0.202
3.6	92.12	62.29	149.99	61.60	3.00	2.00	5.00	2.00	3.13	1.89	4.88	1.89	0.144
3.7	5.5	10.22	32.33	10.65	1.01	2.0	6.0	2.02	1.21	2.11	6.09	2.26	0.439
3.8	24.2	97.89	363.43	99.0	0.48	1.98	7.5	1.98	0.49	2.01	7.58	1.97	0.110
4.1	4.12	8.55	24.77	8.017	1.01	2.0	6.0	2.02	1.09	2.03	6.00	1.79	0.250
4.2	9.1	36.67	137.11	35.99	0.48	1.98	7.5	1.98	0.52	1.90	7.44	1.89	0.67*
4.3	21.96	15.27	35.66	14.89	3.00	2.00	5.00	2.00	3.10	2.02	5.15	2.11	0.297
4.4	12.02	9.09	19.99	8.63	3.00	2.00	5.00	2.00	3.01	1.91	5.05	2.02	0.332
4.5	45.2	180.9	675.39	181.8	0.48	1.98	7.5	1.98	0.44	2.00	7.39	2.09	0.480
4.6	3.19	12.43	46.10	12.92	0.48	1.98	7.5	1.98	0.54	2.21	7.89	2.19	0.500
4.7	9.22	19.02	55.20	18.88	1.01	2.0	6.0	2.02	1.11	2.02	5.89	2.21	0.481
4.8	45.3	32.6	77.67	32.2	3.00	2.00	5.00	2.00	3.13	2.00	5.0	2.01	0.500
5.1	93.12	62.29	155.21	62.42	3.00	2.00	5.00	2.00	2.98	2.01	4.89	2.22	0.195
5.2	54.1	212.43	810.45	211.95	0.48	1.98	7.5	1.98	0.51	2.21	7.52	2.15	0.501
5.3	12.7	51.01	195.80	51.00	0.48	1.98	7.5	1.98	0.43	1.89	7.38	1.92	0.64*
5.4	27.1	108.5	392.92	108.44	0.48	1.98	7.5	1.98	0.55	1.90	7.54	2.01	0.229
5.5	9.0	17.98	53.48	17.69	1.01	2.0	6.0	2.02	0.90	1.84	5.89	1.98	0.452
5.6	12.2	24.66	73.8	24.52	1.01	2.0	6.0	2.02	1.16	2.23	6.4	2.22	0.72*
5.7	12.72	9.89	19.98	9.79	3.00	2.00	5.00	2.00	2.98	1.99	5.12	1.89	0.21
5.8	94.66	65.29	152.4	66.02	3.00	2.00	5.00	2.00	3.01	2.02	5.14	2.22	0.301
6.1	3.3	6.87	19.40	6.09	1.01	2.0	6.0	2.02	1.1	2.33	6.99	2.42	0.96*
6.2	23.22	87.10	345.12	86.89	0.48	1.98	7.5	1.98	0.55	2.00	7.49	2.01	0.120.
6.3	16.7	33.86	102.4	33.71	1.01	2.0	6.0	2.02	1.00	1.99	6.02	1.01	0.076
6.4	45.3	30.6	75.52	30.2	3.00	2.00	5.00	2.00	3.12	2.01	5.15	2.19	0.110
6.5	41.3	82.71	248.13	83.06	1.01	2.0	6.0	2.02	0.92	1.89	6.07	1.94	0.431
6.6	7.8	31.87	119.67	32.16	0.48	1.98	7.5	1.98	0.49	2.10	7.68	2.07	0.332
6.7	7.1	28.54	105.4	28.23	0.48	1.98	7.5	1.98	0.53	2.04	7.55	2.10	0.441
6.8	22.1	88.6	331.6	89.0	0.48	1.98	7.5	1.98	0.50	1.99	7.48	1.93	0.210

Table 4: RMSE of line detection algorithm

4.3 - Testing and evaluation of Circular Hough Transform for circle detection

In the case of the circle detection algorithm, the coordinates of the centre of the circle were received from the algorithm after the parameter of the max radius was set to a positive number that is within a given range so that the algorithm does not accidentally detect effects such as lens flare as the centre circle of the field. This centre is then converted into a real-life coordinate using the same origin deviation factor as the above algorithm to calculate mean error.

	Measured		Real		Normalised		
Image position index	X1	Y1	X1	Y1	X1	Y1	RMSE (Average)
3.1C	14.2	9.3	6.0	4.0	4.9	3.3	1.82*
3.2C	22.6	15.22	6.0	4.0	5.7	3.67	0.78*
3.3C	45.3	32.6	6.0	4.0	5.8	3.78	0.34
3.4C	33.1	22.09	6.0	4.0	6.02	4.11	0.281
3.5C	16.1	11.92	6.0	4.0	6.23	5.44	0.48
3.6C	2.3	0.4	6.0	4.0	4.98	2.22	3.77*
3.7C	71.92	50.11	6.0	4.0	6.44	4.24	0.55
3.8C	23.32	16.01	6.0	4.0	6.10	5.15	0.88*
5.1C	44.1	31.9	6.0	4.0	6.02	4.84	0.45
5.2C	12.22	9.89	6.0	4.0	6.94	4.11	0.39
5.3C	93.12	62.29	6.0	4.0	5.71	4.91	0.46
5.4C	101.23	66.98	6.0	4.0	6.12	4.05	0.31
5.5C	72.12	51.60	6.0	4.0	6.01	4.00	0.10
5.6C	14.9	11.22	6.0	4.0	6.90	3.24	1.25*
5.7C	122.67	84.33	6.0	4.0	6.13	4.24	0.90*
5.8C	146.12	97.54	6.0	4.0	7.44	3.14	0.88*

Table 5: RMSE of circle detection algorithm

4.4 Testing and evaluation for intersection detection method

Intersection detection is done similarly with the exception that instead of two points from the ending and starting of the line, the intersection point calculated from the result of the system of linear equations is transformed into a real-life coordinate. The true value is manually measured on field and an error in measurement is established between the true value and the algorithm.

	Measured		Real		Normalised		
Image position index	X1	Y1	X1	Y1	X1	Y1	RMSE
3.8	17.44	34.90	3.25	6.50	3.22	6.35	0.42
5.7	16.22	8.01	4.25	2.00	4.20	1.90	0.23
6.7	15.39	5.10	6.25	2.00	6.35	1.98	0.49
3.2	22.19	11.109	6.25	3.00	6.23	3.11	0.44

Table 6: RMSE of intersection detection

All three algorithms underwent an RMSE analysis and 0.5 was decided as the threshold value.

CHAPTER 5 – DISCUSSION

5.1 - Interpretation and analysis of the line detection methods' result

From the line detection algorithm comparison result, we can understand that the Probabilistic Hough Line Transform algorithm is performing better on both bright and dark images. This is probably because of its nature of selecting random subsets of edge pixels and forming a line based on that. This is a very effective and less computationally expensive method. However, depending on the environment, the results show false line detection. On the other hand, the Standard Hough Line Transform algorithm is less prone to this error because it uses all edge pixels to detect a line. However, this algorithm is more prone to giving off the wrong measurement of the lines. Sometimes it does not detect any line at all. Since the comparison analysis suggests the Probabilistic Hough Transform is the better inline detector. This has been chosen as the algorithm for the straight line detection system in Robotis OP3.

5.2 - Interpretation and analysis of the field marking detection algorithms' results

The results were fairly indicative of expected performance from the line detection algorithm. The RMSE analysis was performed in order to see how close the detected lines were to reality. Since the golden standard was set as the ground measurements were made manually, this was the point of comparison for the coordinates. Both x and y coordinate result errors were calculated separately and averaged together. The results showed the following

1. The probabilistic Hough transform algorithm got within the 0.5 threshold of RMSE, 29 out of 32 times. The errors of the measurements between that of the algorithm and that of the manually measured real life coordinates were not significant more than 90% of the time. The samples were chosen so as to represent as much of a wide selection of angles and lighting conditions as possible to simulate real life scenario. The results suggest that the algorithm is very much a viable option to detect lines inside the field.
2. The results of the Hough circle transform were not as encouraging. The errors were much more than the threshold most of the time and the coordinates of the circle that was detected was significantly off the true centre. This is predicted to have been because of the issues arising with edge detection in the algorithm. The circle is also very large relatively causing the images to have distorted angles and poor edge detection as a result. Furthermore, the evaluation used the centre as the mode of testing error and even a small change in the detection of the circle can throw off the centre point by a long margin. This may have contributed to the relatively high error seen in the circle detection algorithm.
3. Intersection detection worked as intended with all four of the test cases coming in under the

threshold value of 0.5. The intersection point was confirmed to be within the photo and outputted appropriately.

There are, however, significant caveats to the results that were observed. Primarily, the algorithm had roughly uniform lighting within the university test environment. This meant that the field was almost always universally lit from all angles at a consistent intensity. This may not be the case in a true real-life scenario where lighting conditions and shadows can vary wildly.

There are also subsequent drawbacks within the algorithm. The sample size of 32 photos is much too small for a comprehensive evaluation of algorithms. There are also further conditional and circumstantial drawbacks through to the lack of gyroscope and positional awareness within the robot that makes the distinction between specific intersections next to impossible without positional markers.

In a nutshell, the data shows that the algorithms are effective in determining accurately the position and orientation of lines on the field. However, a much better edge detection system or an entirely different algorithm may be required for circle detection. Further study that incorporates a lot more sample images and multiple algorithms running on the same data would be required to determine whether probabilistic Hough transform really is the consistent fast detection system we are looking for in Robocup. The intersection detection algorithm has a drawback. When one of the detected lines is completely vertical, the algorithm can’t solve the system of linear equations. This is because the vertical line gives infinite values of the slope parameter m. Further studies are required to solve this problem.

CHAPTER 6 – CONCLUSION

This thesis describes and analyses the work done on the vision system for the Robotis OP3 to recognise different field markers, setting the groundwork for future research and development of these systems.

The vision network developed in this thesis was focused to detect 3 important types of field markings in a soccer field, which includes straight lines, centre circles and straight-line intersections. The image data were pre-processed with colour conversion, Gaussian filter, and Canny edge detector before they are fed to the detection algorithms. All these pre-processing methods were implemented for denoising purposes. Median filter was used for circle detection as it proved to be better in denoising images with circles. To detect the straight lines, two popular line detection algorithms, Hough Line Transform and Probabilistic Hough Line Transform were chosen. Comparison analysis shows the Probabilistic Hough Line Transform performs better than Hough Line Transform when applied in different lighting conditions. RMSE evaluation result of Probabilistic Hough Transform shows that the algorithm is a viable option to detect straight lines in the field. It also shows that line detection works well when detecting a single line from different angles. The results from circle detection algorithms show that it does not confuse the centre circle with any other circular objects like the soccer ball itself. However, when the robot is too close to the circle, it can't detect the accurate measurement of the circle. This may be because of the ellipse getting too wide. The intersection detection algorithm performed very well with more than 90% accuracy. However, if a detected line seems to be completely vertical, it gives error because of the infinite value of the slope m. In future work, this vision network could be enhanced by integrating the Histogram Equalization colour enhancement technique. This will allow the markings to be detected when they become underexposed. The problem with the infinite value in the vertical line may be solved by designing the algorithm to skip intersection detection when any of the detected lines are completely vertical.

In future work, machine learning technology can be implemented to detect these field markings. New object detection system like YOLO v5 can be used. Convolutional Neural Networks (CNN) based systems are also a good option. These systems can be used not only for field marking detection but also for the detection of other objects such as the soccer ball, opposition players and goalposts.

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APPENDICES

Appendix A – Straight lines and intersections Image data from ROBOTIS OP3 camera

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Appendix B – Centre Circle image data from ROBTIS OP3 camera

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