2.1 Digital Images [5][6]

2.1.1 Overview

Human vision is the strongest and the most advanced sense of human senses. It is the source of most of the information provided to the brain about the outside environment. Because of that, humans try to save memories in form of photos. The first successful photo taken by Nicéphore Niépce in 1826 or 1827. The photo was a view from Niépce’s window and it is taken using the exposure of light on some substances for several hours.

Later, digital images are invented by Harry G. Bartholomew and Maynard D. McFarlane in 1920 for the purpose of image transmission at [Bartlane cable picture transmission system](https://en.wikipedia.org/wiki/Bartlane_cable_picture_transmission_system). And now they are used in many popular applications, for example in the field of education they are used in projectors and graphics, and in the medical field they were used as an assistant in the diagnoses of diseases. Many other daily activities use digital images.

2.1.2 Advantages

* The ability to be accessed, edited and processed using a digital computer.
* Minimize the effort used to be done by photographers to obtain an image.
* Digital cameras are very small and portable. That make it possible to be used in mobile phones and other electronic devices.

2.1.3 Disadvantages

Digital images make it easy to manipulate images which can be used for illegal purposes. Also copying and stealing images can waste the effort made by photographers. Legal constrains are made to ensure copyrights, also images may not be considered as a legal evidence in courts because they can be edited.

2.2 Digital Image Processing [4]

Digital image processing is the processing of digital images using digital computer. It has two main applications area, improving pictures for human interpretation (eg. Image enhancement) and processing of image for storing, transmitting and representing it for machine autonomous tasks.

Humans and machines deal with images in different ways. Human prefer images to be sharp and highly detailed. While machines prefer images to be simple and uncluttered.

2.2.1 Difference between Digital Image Processing and Computer Vision

The difference between image processing and computer vision is not clear, since both two have much in common. An idea of differentiation between them based on the input and output of the process is proposed by Rafael Gonzalez and Richard Woods [4]. It categorizes the computerized processes to three types.

First, low-level processing which is characterized by the fact that the inputs and the outputs are all images. It contains all the primitive operations on images. For example image filtering where the input is the noisy image and the output is clear enhanced image.

Second, mid-level processing which is characterized by the fact the inputs are images and the outputs are attributes extracted from these images. For example image segmentation where the input is an image containing both desired and desired information and the output is image containing only the desired data.

Finally, high-level processing which is performing functions associated with the vision. For example optical character recognition where the input is an image containing a character the output is that character.

These types can be considered as stages in the path from image processing at the low-processing to computer vision at the high-level.

2.2.2 Applications of digital image processing and computer vision

* Medical applications:

Some of medical activities that is based on human vision of an acquired images can be replaced by autonomous image processing and computer vision algorithms to give the final results. For example diagnosis of skin diseases, detecting broken bones using X-ray images and tumor extraction from MRI images.

* Photography:

Digital cameras and smartphones use digital image processing to enhance taken images and increase its quality to make them look better.

* Communications:

The time and bandwidth required to transmit an image from one place to another may be significantly reduced using image processing. Images are coded to reduce its size the reconstructed in the receiver. That is the early use of image processing by newspapers, and now it is used to use images over the internet.

* Security cameras:

Security cameras are powered by image processing hardware and software to do some tasks like detecting motion and facial recognition.

* Robotics:

Robots are designed by artificial intelligence algorithms which simulate the human being behavior. Computer vision is a part of artificial intelligence specialized in simulate the human vision.

* Pattern recognition:

A lot of daily used applications use image processing and computer vision to recognize a special patterns. For example fingerprint reader, object detectors and images search engines.

* Optical character recognition:

The ability of a computer to read and understand characters is used in license plate recognition, documents auto reader and a lot of other applications.

2.2.3 Fundamental steps for digital image processing

* Image acquisition:

It’s the process of acquiring and image and convert it to digital form and other preprocessing operations done to the image.

* Image enhancement:

It’s the process of improving image quality to highlight more details. It deals with making images looking good for human vision, this make it very subjective operation.

* Image restoration:

It’s the process of removing defects which degrade an image. It is objective operation since it is based on mathematical and probabilistic models.

* Color image processing:

It’s the processes deals with colors models and color processing in digital form

* Wavelets and multi-resolution processing:

It’s the processes where source image is processed at multiple resolutions and the filtering is applied and combined at all these resolutions

* Compression:

It’s the process of minimizing the storage required to save the image (image size).

* Morphological processing:

It’s the processes of digital images related to the shape of the image and the relative positions of its pixels.

* Segmentation:

It’s the process of extracting the region of interests from an image. It is one of the most difficult tasks in image processing, but also the most important one since further operations success can depend on the accuracy of segmentation.

* Representation and description:

It’s the process is converting the image data to a form suitable for computer processing.

* Recognition:

It’s the process of extracting information from the input image (eg. Assigning labels to objects in an image)

Not all of these steps are required for all image processing applications, some applications use some steps and others use other steps.

2.3 Python [1]

2.3.1 Overview

Python is a high-level general purpose programming language, created by [Guido van Rossum](https://en.wikipedia.org/wiki/Guido_van_Rossum) and released in 1991.

Since early days it was designed based on two features, code readability and the ability to program in fewer lines of codes. This design philosophy makes python very popular in short period. Since 2003 python has been ranked on top 10 most popular programming language by [TIOBE Programming Community Index](https://en.wikipedia.org/wiki/TIOBE_Programming_Community_Index), and the top programming language by IEEE Spectrum ranking as posted on 18 July 2017.

2.3.2 Features

* Python provides a dynamic type system which allow a variable data type to be changed during the execution of the program and doesn’t required a variable to be declared and initialized before using it.
* Python provides an automatic memory management using both reference counting and cycle detecting garage collector.
* Python supports many [programming paradigms](https://en.wikipedia.org/wiki/Programming_paradigm). It is meant to be an object-oriented programming and structured programming language, but also it supports other paradigms like [functional programming](https://en.wikipedia.org/wiki/Functional_programming) and [aspect-oriented programming](https://en.wikipedia.org/wiki/Aspect-oriented_programming). Also other paradigms can be supported using extensions.
* Python is available in all major operating systems, and many other operating systems.
* Python was built so that the core of the language doesn’t contains all of its functionality. Extensibility of Python provide a small language core with a very large library can be used when needed.
* Python simplicity in programming appear on the philosophy that anything in python can be done in one preferable way, making code choices not available in python. This make it easy to learn python than other languages, since there is few limited option to do any certain task.

2.3.3 Applications

[Python Package Index](https://en.wikipedia.org/wiki/Python_Package_Index) is the official repository for python third-party software and it contains over one hundred thousand packages which can be used for a large number of applications.

Some of Python applications are:

* Graphical user interface.
* Web frameworks.
* Multimedia.
* Databases.
* Networking and communications.
* Scripting and automation.
* System administration.
* Scientific purposes.
* Test processing.
* Image Processing, which is the application presented by this thesis.

2.4 OpenCV [2]

2.4.1 Overview

OpenCV is a programming library which is used for image processing, computer vision and machine learning applications.

OpenCV was initially developed by Intel in 1999, and the first alpha version was released in 2000 at [IEEE Conference on Computer Vision and Pattern Recognition](https://en.wikipedia.org/wiki/Conference_on_Computer_Vision_and_Pattern_Recognition).

2.4.2 Features

* OpenCV is a cross-platform library. It supports many operating systems which are  [Windows](https://en.wikipedia.org/wiki/Microsoft_Windows), [Linux](https://en.wikipedia.org/wiki/Linux), [macOS](https://en.wikipedia.org/wiki/MacOS" \o "MacOS), [FreeBSD](https://en.wikipedia.org/wiki/FreeBSD), [NetBSD](https://en.wikipedia.org/wiki/NetBSD" \o "NetBSD) and [OpenBSD](https://en.wikipedia.org/wiki/OpenBSD) for desktop operating systems and  [Android](https://en.wikipedia.org/wiki/Android_(operating_system)), [iOS](https://en.wikipedia.org/wiki/IOS" \o "IOS), [Maemo](https://en.wikipedia.org/wiki/Maemo" \o "Maemo) and [BlackBerry 10](https://en.wikipedia.org/wiki/BlackBerry_10) for mobile operating systems.
* OpenCV is open source and free to use under [open-source](https://en.wikipedia.org/wiki/Open-source) [BSD license](https://en.wikipedia.org/wiki/BSD_license).
* OpenCV supports three of the most popular programming language which are C++, Python and Java.

2.4.3 OpenCV vs. Matlab [3]

OpenCV and Matlab are both from the most popular tools used in image processing and computer vision. However, the comparison between the two has always been a subject of discussion. Here advantages of each over the other is discussed.

OpenCV has advantages over Matlab which are:

* Speed:

Since Matlab is written in Java and Java is built on C, Matlab code is interpreted to Java then to C to generate machine language code. This long path of language conversions make OpenCV much faster since it is written in C/C++ directly.

* Resources:

Matlab take over a gigabyte of ram to process a videos, while OpenCV can take only about 70 megabyte for the same operation.

* Cost:

Matlab is very costly since its base only costs over two thousand dollars. OpenCV on the other hand is open source and free to use.

* Portability:

Matlab has to be imported specifically to the operating system to be able to run on it. While OpenCV can be downloaded and used in any device can run C language.

Matlab also has advantages over OpenCV which are:

* Easiness:

Matlab is considered more easy to use, since it is high-level language there is no need to do lower level languages task (eg. Memory management). However, OpenCV supports programming languages other than C/C++. This can make OpenCV even easier to use than Matlab, but this will decrease the speed of execution discussed earlier.

* Memory management:

Again Matlab has automatic memory management system because it is a high level language. And OpenCV require a manual memory management when it is used by C/C++ and this can be avoid using other languages like Python.

* Great matrix library:

Digital images are treated as a matrices which is the main theory of operation of Matlab and a lot of built-in functions are available.

* Integration with OpenCV:

Matlab can interface with OpenCV, a thing can’t be done using OpenCV.

* Great documentation:

OpenCV require a prior knowledge of C++ or python to work with. While Matlab documentation can make it easier for beginners to understand it and start with.

The decision of choosing either OpenCV or Matlab is based on the desired application and the specification and resources available.

2.5 Sudanese license plates [9]

License plate is an identifier for a vehicle. It is invented in France in 1893 at Paris Police Ordinance.

All countries require license plates to uniquely identify any vehicle. The government is the only manufacturer of the plates and it is not allowed for other to do it because it is equivalent to [forging](https://en.wikipedia.org/wiki/Forgery) an official document.

Sudanese license plates are categorized into number of groups which are different in color and contents of the plate. This categorization is based on the use of the vehicle itself. There are private vehicles with white plates, commercial passengers’ vehicles with green plates, commercial goods vehicles with black plates, police vehicles with blue plates and many others like governmental vehicles, United Nations vehicles, embassies vehicles and others.

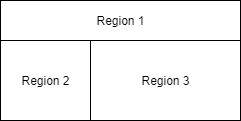
Here, the area of interest is private vehicles’ plates. Its size is 0.3m×0.15m without the outer black frame and 0.31m×0.16m with the frame. And it can be divided to three regions containing the information of the plate.

The first region is on the upper part of the plate, and it contains the name of the country in English “Sudan” and in Arabic “السودان”.

The second region is on the left part of the plate, and it contains one letter or more representing an abbreviation of the state the car is licensed in and one digit number. The abbreviation on this region is represented in Arabic letters and in English letters right below it. Also the number is written in Indian form and Arabic form below it.

The third region is on the right part of the plate, and it contains one to five digits number in Indian form and the same number in Arabic form below it but in smaller size.

The border between the second and third regions is a silver colored bar in in the old version of the plate or a text in Arabic “جمهورية السودان”, which mean “The Republic of Sudan” in the newer version of the plate. Both versions are currently used.



[[[[[[[[[[[[[]]]]]]]]]]]]]]]]]]]]

2.6 License plate recognition system [8]

2.6.1 Overview

License plate recognition system is a system designed with the ability to read cars’ license plates. It is invented in 1976 at Police Scientific Development Branch in the UK. These types of systems doesn’t became popular until the 1990’s when they became accurate, fast and cheap.

There are two types of license plate recognition systems. The first type has the required hardware to acquire the image and process it to read the license plate all in one place and this type is used for real time applications. The second type use servers, the system only contain hardware capable for acquiring the image and send it to server to process it later.

2.6.2 Components

* Hardware

The hardware of license plate recognition system is different Depending on the type of the system and the purpose of using it. It may only be a camera and connections hardware in case of servers system or a full system of camera and microprocessor or other electronic chips in case of real time systems.

* Software

Optical character recognition is the main technology used in license plate recognition systems. Optical character recognition is an application of image processing and computer vision and designed to identify characters.

2.6.3 Algorithm

Most of license plate recognition systems use the same steps of operation. Some systems use less or more of these steps to get the desired results depending on the result desired by the system.

The main algorithm used by almost all license plate recognition systems consist of three steps:

* License plate detection
* Character segmentation
* Character recognition

If an image of the car is considered to be provided to the system the first step will be to detect the location of the license plate and determine its coordinates. After the extraction of the plate the resulted image is segmented so that each image segment contain one character or one digit number. Finally optical character recognition is used to identify each character on the plate and produce the output of the system which is the number of the plate.

Other steps may be required, image acquisition is required for a full end-to-end systems using a camera to capture the image of the car. Preprocessing is also very helpful for captured images to increase quality and make the next operations very easy and accurate. License plate correction of angle and orientation is usually done after detecting the location of the plate. Other post-processing is sometimes used for further need of the image.

[[[[[[[[[[[[[[[[[[[[[[]]]]]]]]]]]]]]]]]]]]]]]]]]

2.6.4 Difficulties

License plate recognition systems are facing a lot of difficulties and challenges. Software and sometimes hardware are used to avoid these difficulties. Some of them are:

* Low quality and poor resolution of the image due to limited hardware capabilities and the images are taken from a long distance.
* Blurred images can’t usually been recognized by humans, and computer vision is not yet more powerful than human vision. Blurred images are produced by a camera trying to capture a moving object.
* Poor lighting and low contrast due to exposure of light and shadows. Image processing is used to overcome these problems using algorithms like histogram equalization.
* License plates are not always clean and ready to get captured. Also, sometimes decorative items might be used in the cars and this limits the ability of the system.
* Systems are usually designed locally because license plates design can be different from countries and sometimes between states (this is not the case in Sudan).

2.6.5 Applications

* Law enforcement:

License plate recognition systems are used in many countries like Australia, Canada, Germany, United Kingdom and United States to detect black listed cars. Black listed cars may be stolen cars, unregistered cars, unlicensed cars or the cars with no insurance.

* Average speed limit enforcement:

A license plate recognition system consisting from two cameras located in proper distance can be used to calculate the average speed of a certain vehicle along that distance. This is the case in Australia, Austria, Belgium, France, Italy, Netherlands, Spain, South Africa, UK, Kuwait and Dubai city in UAE.

* Enterprises

Private sector companies and facilities may not be able to access to governmental databases and information, but they can build license plate recognition systems using their own databases of customers, vendors, VIP’s and specific banned people.

* Traffic control:

License plate recognition systems may also be used to monitor the flow of vehicles to get information about number of vehicle crossing a certain road in a certain amount of time, the periods and areas of low and high congestions and the locations and causes of traffic jams.

2.7 Neural Network [7]

2.7.1 Overview

Artificial neural networks are methods of information processing designed to simulate the learning activity done by the brain. Since brain can learn using connected neurons and adjusting synaptic connections to make connections stronger, neural networks work the same using neurons connected together and adjusting the connections weights.

Neural networks were produced by Warren McCulloch and Walter Pits in 1943 before computers became available, this make this field’s development very slow at the beginning.

2.7.2 Advantages

* Adaptive learning by examples using training data and continuum learning while operating which increase the accuracy and speed of the system.
* Self-organization and representation of data during learning.
* It can be very fast in operation which make it possible to be used in real time applications.
* Generalization and error correction because no specific algorithm is predefined to the system.

2.7.3 Applications

* Neural networks is used in the prediction and forecasting in many applications. For example in sales predications and risk management.
* In the medical fields neural networks is used in modelling parts of human body and automatic diagnoses of diseases using similar diseases.
* In business neural networks can be used to determine the best way of marketing and forecasting profits and losses.

2.8 Related work

2.8.1 License plate detection

License plate detection is the process of locating the region in the image that contain the license plate and the process of extraction and normalization of the plate. This considered the most difficult task in license plate recognition systems since plates can be different in size, shapes and colors, also the angle of the image and the orientation of the plate make it even more difficult.

Usually, the detection process is designed only to work in certain conditions. For example, most of the systems are designed to obtain the plate of specific country or region where all plates has the same size and colors, others also constraint the image of the vehicle to be in certain distance and angle.

Edge detection is one of the most popular algorithms used in locating the license plates. In [1] work, vertical edge detection by Sobel operator is used to obtain vertical edges of the image. Then prior knowledge of the local plate dimensions (width to height ratio) is used to find candidate regions where higher probabilities of license plate exist. If there are more than one candidates, black to white ratio is used to choose the best candidate. In [3] work, double edge detection is used vertically and horizontally. Since license plates usually contains a lot of black and white variation, the highest density region of edges is considered to be the best license plate candidate.

Color processing can also be uses when the plates have a specific color. In [2] work, projection of the blue color which is the color of Beijing’s plates is done vertically and horizontally. Peaks of blue colors are used to find an accurate rectangle containing the license plate. Also, in [4] work, the colors of the plate is mainly used to detect its location in the image.

In [6] work, projection of the binary image is used to obtain the license plate location by calculating the peak of the projection.

In [5] paper, many algorithms are proposed. Vertical edge detection with Sobel operator and a threshold value of density of vertical lines is used to detect the plate. Fuzzy logic uses red, green and blue edges. Hue, Saturation and Intensity HSI is obtained to generate the fuzzy map and obtain the license plate location using colors values. . Hough transform combined with contour analysis is also proposed. Contours analysis is used to detect closed loop lines and then Hough transform is used to detect parallel lines which have higher probability to be the license plate. This technique considered one of the most accurate and robust techniques but the fact that it requires a lot of computations make it less time efficient and not suitable for real time systems.

In other approaches, frequency domain is used rather than the spatial domain to process the image. In [7] work, the detection of the plate is based on the extraction of areas having a high density of mono-oriented gradient.

2.8.2 Character segmentation

Character segmentation is the process of partitioning the image of the license plate into individual characters that can be recognized by the system. The segmentation importance comes from the fact that a more efficient and accurate segmentation will result easier and more accurate character recognition.

One of the most popular image segmentation algorithms is vertical projection. It is used in [1][2][3][5] by obtaining the image vertical projection and then analyzing it to segment the characters, that is done by looking for a peak-to-valley in the projection which gives higher probability of the border between characters.

In [9] work, connected components algorithm is used to segment the characters based on thresholded binary image. This algorithm is accurate in case of characters that are constructed from one components and free of dots and dashes. Also this can take more computations than the projection techniques but will produce a better result in case of noisy images.

A more alternative solution is presented by [10] to avoid the segmentation process at all and jump to recognize all letters at once, this solution might take more computations and more time to complete. Also, in case the letters doesn’t construct any meaningful word which is the case in licese plate recognition systems, it make it harder to use artificial intelligence and machine learning techniques to obtain correct results.

2.8.3 Character recognition

Character recognition is the process of assigning a label to a character image representing that character. It is a sort of classification, where the input character image is classified to the best matching character.

Most of license plates systems use template matching algorithm to classify images to correct labels. This is the case in [1][2][3][4][5]. It depends of using a template images of a predefined characters and test the input image to all the templates and find the closest result.

In [6] classification is done by minimum distance measure using differ-weight average method of template image and Euclidean distance.

Modifications to template matching technique is done to increase the efficacy and make it more robust to noisy and distorted input images. That is done in [2] work, where neural networks used to train the system for better and faster results. In [5] work, a combination of template matching and machine learning algorithms is used. Support vector machine by using one versus others is used with descriptors to classify characters.