AUTOMATED INTELLIGENT REAL-TIME SYSTEM FOR AGGREGATE CLASSIFICATION

by

ZAMANI BIN MD SANI

Thesis submitted in fulfillment of the requirements
for the degree of
Master of Science

May 2009

ACKNOWLEDGEMENT

بسم الله الرحمن الرحيم

All praise to Allah the Almighty, the Most Merciful and the Most Benevolent for his permission and help, for me to complete this research. As for the opportunity given, I would like to convey my deepest appreciation and special thanks to who's directly or indirectly involved in this short journey to accomplish another meaningful event in this life.

I would like to express my sincere gratitude to my Supervisor, Dr Nor Ashidi Mat Isa for his guidance, support on both academically and financially. There are no doubts; the research had been completed on track, due to the excellent cooperation and follow up and effort for both parties and also thanks to my second supervisor Dr Syahrel Suandi.

To my parents, for their effort to understand my decision to continue my MSc studies. Other than that, my personal thanks to all the staffs of School of EE USM, Engineering Campus for their cooperation and support. For my Celis lab mate and friends, Fauzi, Fahmi, Zailani and Subhi together with Azwan and Aznira from robotics lab, I would cherish all the fine moments throughout my Master journey.

Finally, to MOSTI for the eScience fund for the research titled, Development of An Automatic Real Time Intelligent Aggregate Classification System Based on Image Processing and Neural Networks and not to forget the RU grant from School of Electrical and Electronic USM, titled "Imaging" for partially funding the research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A/D – Analog to Digital

AASHTO – American Association of State Highway and Transportation Official

ADO – Activex Data Objects

API – Application Programming Interface

ASTM – American Society for Testing and Materials

BMP – Bitmap

CCD - Charge-Coupled Device

CMOS – Complimentary Metal Oxide Semiconductor

CPU – Central Processing Unit

CSBRG – Clustering Seed Based Region Growing

DBMS – Database Management System

FOV – Field of View

FPS – Frame per Second

GIF – Graphical Interchange Format

GUI – Graphical User Interface

HMLP - Hybrid Multilayer Perceptron

I/O – Input Output

IEEE 1394 – High Performance Serial Bus

IS – International Standard

ISA – Industry Standard Architecture

JPEG – Joint Photographic Expert Group

KM – K-Mean

LED – Light Emitting Diode

LVDS – Low Voltage Differential Signaling

MB – Megabytes

MHz – Megahertz

MKM – Moving K-Mean

MLP - Multilayered Perceptron Networks

MRPE – Modified Recursive Prediction Error

MRPE – Modified Recursive Prediction Error

OEM – Original Equipment Manufacturer

OLEDB – Object Linking and Database

PC – Personal Computer

PCI – Peripheral Component Interconnect

PLC – Programmable Logic Controller

RAM – Random Access Memory

ROI – Region of Interest

RoR VSI – Metso Barmac Rock on the Rock Vertical Shaft Impact

SBRG – Seed Based Region Growing

SBRG – Seed Based Region Growing

SDK – Software Development Kit

SVM – Support Vector Machine

SQL – Structured Query Language

TIFF – Tagged Image File Format

TTL – Transistor to Transistor Logic

USB – Universal Serial Bus

UV – Ultra Violet

VME – Versa Module Eurocard

XML – Mark up Language

Sistem Pengelasan Aggregat Pintar Automatik Secara Masa Nyata

Abstrak

Secara tradisionalnya, pengayak mekanikal dan tolok manual digunakan untuk menentukan kualiti aggregat yang dihasilkan. Selain itu, untuk mendapatkan aggregat yang lebih baik, ia memerlukan beberapa siri ujian mekanikal, kimia dan fizikal yang biasanya dilakukan secara manual yang selalunya mengambil masa, sangat subjektif dan payah. Penyelidikan ini memfokuskan untuk membina sistem pengkelasan pintar secara masa nyata dipanggil NeuralAgg. Ia mengandungi 3 subsistem utama iaitu, sistem penglihatan, sistem pengkelasan pintar dan sistem pengkalan data. Sistem penglihatan dibina dengan kebolehan untuk mengambil imej berkualiti bagi aggregat yang sedang bergerak dan kemudian dihantar ke subsistem kedua secara automatik. Sistem pengkelasan pintar akan memproses dan mengekstrak ciri-ciri aggregat dan kemudian mengkelaskannya kepada bentuk yang bersesuaian. Semua maklumat pengambilan imej dan pengkelasan akan dihantar ke sistem pengkalan data untuk penyimpanan bagi pasca analisis. Semua subsistem diintegrasikan untuk berfungsi sebagai sistem pengkelasan pintar masa nyata, dengan keputusan secara purata sebanyak 1.2 saat diperlukan untuk satu pengkelasan lengkap dengan kejituan sebanyak 87.51%. Penyelidikan ini juga memperkenalkan, algoritma pengelompokan titik benih terubahsuai untuk meningkatkan lagi kebolehan sistem bagi mengkelaskan berbilang aggregat di dalam satu imej. Sistem yang dibina ini mempunyai potensi untuk mengurangkan masa dan beban kerja dan menghasilkan pengkelasan yang lebih tepat. Oleh itu, ia berpotensi untuk meningkatkan proses pengkelasan bentuk di dalam industri penghasilan aggregat dan konkrit.

Automated Intelligent Real-Time System for Aggregate Classification

Abstract

Traditionally, mechanical sieving and manual gauging are used to determine the quality of the aggregates. Other than that, to get aggregates with better characteristics, it must pass a series of mechanical, chemical and physical which are often perform manually, tends to be slow, highly subjective and laborious. This research focuses on developing an intelligent real-time classification system called NeuralAgg. It consists of 3 major subsystems namely the real-time image capturing system, image processing with intelligent classification system and the database system. The image capturing system is developed with capability of capturing high quality images of moving aggregates and send to the second subsystem automatically. The image processing with intelligent classification system will process the digital image and extract the aggregates' features and classify it based on its shapes. All of this information will then be sent to the database system for data archive for post monitoring purposes. These 3 subsystems are integrated to work in real-time basis which resulted an average of 1.2 seconds is needed for a complete classification process cycle with 87.51% accuracy. This research also introduced a modified Clustering Seed Based Region Growing (CSBRG) method to improve the system's capability in classifying multiple aggregates in an image. The system developed in this study has the potential to significantly reduce the time and workload and produce more accurate classification. Therefore, it will have a great potential to improve the traditional method in shape classification in the aggregate industry, quarry and concrete production.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Traditionally, the inspection processes are usually performed by human inspectors and usually by inspecting samples from a lot. Automated inspection is considerable as human inspectors are not always consistent in their evaluation. An automated visual inspection system could acquire and process images to detect objects and features in order to analyze and determine characteristics of flaws of the objects or other features detected in the images.

Machine vision had been applied to a variety of manufacturing, with the goal of improving quality and productivity in the manufacturing process. The acceptance is quickly throughout the manufacturing sector with machine vision systems now in place in food processing, pharmaceuticals, wood and paper, plastics, metal fabrication and other industries (Fabel, 1997).

Aggregate is one of the major items in producing the concrete beside sand, natural gravel and crushed stone. For aggregates production in the quarry, the machine is specially designed for crushing and separating various sizes of aggregates. Cone type crusher are responsible for producing the majority of final saleable products, the composition, shape and grading of which are specified by various standards authorities (Parkin and Calkin., 1995). The aggregates produced could be categorized to 6 main shapes namely the angular, cubical, elongated, flaky, flaky & elongated and irregular. From these 6 main shapes, the angular and cubical are categorized as good shape of aggregates while the rest are categorized under the bad shape of aggregates. The traditional method for the particles shapes measurement is done manually which is cumbersome and time consuming. A machine vision system could be introduced in the aggregates production for the automated real-time classification purposes. It has the potential of reducing the time and the workload of the traditional methods.

1.2 Online Aggregate Classification System

The aggregate production is changing towards producing high quality aggregates with improvement in its characteristics such as more cubical or equidimensional in shape and better graded or distributed size for 'high strength' concrete. It will be more appealing to the aggregates industry to have an online aggregate classification system when producing the aggregates or blending the aggregates in order to feedback in real time response for better aggregates or concrete production.

In Parkin and Calkin (1995), an intelligent online opto-mechatronic product classifier for sizing and grading the aggregates is being under development. The research objective is to improve the operating efficiency of cone crusher by replacing the traditional methods of machine control with an intelligent mechatronic control system. The system used two orthogonal scanned lasers to digitize the particles or the aggregates and used neural network application for the classification.

In determining the shape and size for the aggregates, Maerz and Zhou (1998, 1999 and 2004) had used the digital image processing called WinShape. Other than that, Mora and Kwan (2000) had explored the possibilities of using the digital image processing method in concrete production. The research was looking on the aggregates size and shape analysis based on the image processing and features extraction methods.

A study on the results and prospects in grading the aggregates by using a machine vision had been conducted by Murtagh et al. (2005). Images of mixed aggregates being captured and went through the image segmentation process. In the process, the texture features were being used and it was an effective solution for allowing larger pieces of aggregate to be measured and later the wavelet entropy features being used to supervise the classification of class assignment for both finer and coarse aggregates. The algorithmic robustness and stability were noted in the studies from point of view in the construction industries.

The research by Isa et al. (2008) is looking on the suitable features selection for the Hybrid Multilayer Perceptron (HMLP) and Multilayered Perceptron Networks (MLP) in identifying shape aggregates, where the input data for the neural network were obtained from the image analyses which are the area, perimeter, Hu's moment and Zernike's moment of the aggregate's area and perimeter. The classification was performed by the hybrid HMLP network trained using Modified Recursive Prediction Algorithm. Performance analysis of the HMLP network was compared with the standard MLP network trained using four different training algorithms. The experimental result show that the performance on both HMLP and MLP networks are better using the moments extracted based on object's perimeter compared to object's area.

1.3 Problem Statement and Motivation

From the research done by Isa et al. (2008), the image capturing system is developed and operated manually. The process of capturing the image would need to go through manual setup before the process can be started. It also requires the user to put the aggregate one by one for image capturing thus taking sometime in the manual acquiring process. For this, an automated vision system to perform a real-time imaging by using a conveyer and a sensor is the best solution to improve the current method. It will improve the image capturing process thus reduces the time and energy.

Presently, the conventional method which is by manual classification and paper records for storing the information would be easy to lose or mix up the information with other data. The methods involve determining and counting aggregates one by one which would seriously consuming time and effort to record the information into the log on the aggregate produced. In addition, with no database system to store all the information and the images of the aggregates by the machine, it is hardly for the engineers to determine the quality of concrete produced by specific crusher. The determination of system performance based on the quantity of high quality aggregates from all total aggregates produced, would take longer time and there are possibilities to have inaccurate data for system analysis. Thus, an electronic database system is seen as the best application to replace the conventional method to ease the data archiving process and furthermore will improve the data integrity as the data does not deteriorate throughout time.

The classification engine developed by Isa et al. (2008) only allows classification of an aggregate per image. For multiple aggregates captured in single image, the algorithm had a limitation as the classification will be inaccurate. The algorithm cannot recognize if there are multiple aggregates in the image and eventually will always consider it as one aggregate. One of the options for the improvement is the modification of the image processing technique where the system could cluster the aggregates the image and create a new image consists of an individual aggregate before sending to classification engine. With the improvement, more aggregates could be captured in an image and later can be classified correctly by using the existing classification engine.

Traditionally, the process of particles shapes measurement for aggregates had to be done manually where mechanical sieving and manual gauging are used to determine the size and shape of the aggregates (Kwan et al., 2001). However, during the process, there is still margin or errors for example, an elongated aggregate with length greater than aperture size can pass through the sieve and also a relatively flaky aggregate can pass through the sieve aperture, which is square in shape and diagonally the sieve size. With this, it is potentially affecting the quality of concrete produce later, thus wasting the energy and resources as no real time monitoring system to alert the users during the process for online feedback. For this, a complete automated online machine vision system with its own application classification engine and database system would be the best application to be developed and integrated. With the correct integration and process flow, the system developed could be used for online classification system which able to provide real-time feedback. This could help in the aggregate production area and concrete making industries where processes could be monitored online, resulted to faster response and improving the quality of the aggregates and the concrete.

1.4 Objective of the Research

Based on the aforementioned problem in Section 1.3, the objectives of the research can be divided into two as follows:

1. To develop an intelligent automated visual inspection system for real-time imaging and aggregates classification with a database system for data storage purposes.
2. To improve the classification engine developed by Isa et al. (2008) to enable the classification process for multiple aggregates in one image.

The first objective can be further divided into three sub-objectives as follows;

a) Development of an automated vision system

A vision system is developed which consists of a charge-coupled device (CCD) camera, proximity sensor and conveyer for aggregates capturing system. All these items will be integrated to work as a vision system and will be able to acquire excellent quality of images from both static and dynamic objects for the image processing and classification system.

b) Development of a database system for aggregates

A single-tier database application is developed for the data archive of the aggregates information. The database is updated online for the post classification information. By using the database system, user will be able to retrieve information for any post related studies.

c) **Full integration for machine vision system, image classification system and database system for online system to use in a real-time application**

The integration involves these three subsystems, to work as a single online system and to complete the cycle real-fast. The complete system would be able to do a real-time image capturing, image processing with classification and data archiving for post classification process for post studies. The complete system can be used in aggregates making industry and it would be able to determine either the performance of the impact crusher machine or the quality of the concrete that would be produced in real time basis.

The second objective of the research is to overcome the limitation of the classification engine developed by Isa et al. (2008) due to its capability to classify only an aggregate per image. The limitation is for an image with multiple aggregates as the classification will be inaccurate. The proposed additional method will employ the modified version of seed based region growing (SBRG) which is capable to interpret the number of aggregates in an image and later send it for processing by using the existing classification algorithm.

1.5 Scope of the Research

The scope of research on the current study is mainly to develop a real-time imaging capturing system with real-time classification and data archiving. The system will be functioning as an automated aggregation classification system which involves the image acquiring of the aggregates and process it for classification.

In the first main objective, a vision system is developed and able to perform real-time imaging by using a charge-couple device (CCD), sensor and its lighting strategy to get the best image. It will explore the system hardware setup with the best specification to perform the image acquiring process, to obtain a very high quality picture. Excellent images will ease up the image processing process later. The system would use the software development kit (SDK) from the camera manufacturer to be integrated in the system in order to control the operation of the CCD camera for image acquiring and image properties.

Development of a single-tier database application and its capability to store all the information for the classification are also being explored. Microsoft Access application is used to develop the database and able to work as a data centre where the information is archived and can be retrieved easily for post analysis and studies. The system should also be an online system where it will be updated in real-time manner from the classification engine and from the machine vision system so the data could be monitored and get the response online.

Two different software languages are used for the development of the system. The Microsoft Visual Studio used to control the machine vision system and Borland C++ Builder used to develop both image classification algorithm and the database application. All of these programs are being developed in a single local computer. The 3 subsystems are integrated to work automatically as the main objective is to produce a real-time application. Text file are used for the data recording of the test events information and later send to the database. Time stamped for each process is collected and stored to the database system in order to analyze the average time needed for different processes and stages. The time stamp will be analyzed to look on the overall time performance for the main process application. This could result the prediction of each of the process and the time needed for a full complete process. In addition, the information for event status and the results of the aggregates will also being saved in the database. The classification is done based on the shapes of the aggregates. The images stored inside the database will be stored in Joint Photographic Expert Group format (JPEG) as it is lower in size.

The enabling of the multiple aggregates classification is an improvement from the previous algorithm developed by Isa et al. (2008) and it is an additional scope in this research. The limitation is due to the classification algorithm is not able to classify multiple aggregates captured in a single image. Thus, the improvement will be done in the segmentation algorithm, where the system is able to recognize multiple aggregates in a single image. A modified seed based region growing algorithm is explored for the purpose. The method will be added in the existing algorithm to overcome the limitation.

In this research, the image of untouched aggregates with each other in the image will be used.

1.6 Thesis Outline

Generally the thesis is divided into 5 main chapters. The first chapter will be the introduction of the current research. The objective and the scope will also be discussed in this chapter.

The Second chapter discussed on the literature review. It starts with the introduction of the aggregates used in the construction industry and later it will be lingering on the evolution and the latest research and discussion related to the current research. The important aspects, rules and methods which are suitable to be used in the development and adapted inside the research will be scrutinized and extracted. This would cover the process on how to develop a machine vision system, systems integration in real time process, image processing methodology and database application.

Chapter 3 revolves on the steps taken on building the machine vision system. This included the best selection of the equipments based on the specification of the hardware for achieving the real time application system. A local database development for the aggregates data storage discussed in the same chapter. Both results for the machine vision system and the database including the utilities are presented in the same chapter.

In Chapter 4, the image processing algorithms are discussed for the improvement on the previously developed algorithms by Isa et al. (2008). Other than that it will also discuss the steps used to integrate the machine vision system, intelligent classification system and database system. Neural network application will also be discussed briefly in the chapter since the algorithm used in the image classification employed neural network as the core. The test strategy in validating the new developed system is compared with the existing system also will be discussed. Results for both image processing and the integration results are presented in this chapter. In addition, the discussion in designing the correlation studies between the original system versus the new developed system (the manual process and automated real-time process) is included in this chapter. All the results also will be published based on the proposed methodology. This includes the real-time process results plus the database application result.

Chapter 5 is the last chapter for the thesis. It will provide the conclusion on the entire objectives for the research. It includes how the developed system would be able to work as a classification system in the aggregates industry. Suggestions for future works and improvements which can be implemented are also provided in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Aggregate is one of the main quarry products used for highway construction, railway ballast and concrete. The characteristics of the aggregate such as shape and surface texture would affect the quality of the concrete produced (Kamarulzaman, 2002). Currently, these parameters are determined by manual sampling which are laborious and time consuming. Due to the long time consuming in aggregates classification, it had encouraged several researchers to develop new methods to analyze aggregate images by using digital image processing to shorten the time for classification thus making it more cost effective, and faster compared to the old process. Few researches in the area of digital images processing had been conducted and it was proven feasible to determine these characteristics with shorter time compared to the traditional methods. In the future, it is very attractive to explore the advantages of real time classification system and the data information storage for the aggregates, making it more automated to provide real time feedback and simplifying the analysis in the future. Thus, it is very appealing to design and implement a real-time machine vision system in the future, providing a real-time feedback when producing aggregates or for the blending operations.

2.2 Aggregates

Aggregates are one of the major components in the concrete production. The crush rock with the Granite and Limestone are still remained the main rocks used in the aggregates production (Barry, 1998). It is a fast growing and emerging industry as one of the most demanding with a lot of expectations to fulfill the needs and the requirement for various industries and domestic purposes.

2.2.1. Shape Factor in the Concrete Making

Concrete is the most widely used construction material (Ramachandran, 2000; Ramli, 1991). The characteristics of the aggregates such as the shape, size and color do play an important role in the development of high strength concrete. Other than that, the properties such as the nature and the degree of the stratification of rock deposit, the type of crushing plant used and the size reduction ratio greatly influence the shape of aggregates particles and the quality of fresh and hardened concrete.

The most current trend in aggregate production is changing towards producing high quality aggregates with improvement in its characteristics such as more cubical or equidimensional in shape and better graded or distributed size for ‘high strength’ concrete (Kwan et al., 2001). Also, improvement in the shape has been proven to be a major factor in the reduction of the water to cement ratio needed to produce a concrete mixture (Rao and Prasad, 2002). Similarly, Hudson (1995) found that this high quality aggregates has the ability to decrease the cost of production and placement of concrete and hence the characteristic of the concrete such as strength and overall quality.

Stronger or high quality aggregates tend to produce stronger concrete as the weak planes and structures are being reduced. These aggregates can also reduce the water to cement ratio needed to produce a concrete mixture and producing higher density and strength concrete while the lower quality aggregates such as elongated would has less surface area per unit volume and therefore packed tighter when consolidated (Rao and Prasad, 2002).

There are different types of aggregate's shapes produced from the quarry but not all the shapes could produce a high quality concrete (Hamer, 1991). Example from the Metso Barmac Rock on the Rock Vertical Shaft Impact (RoR VSI) crusher, Rajeswari et al., (2002,2003) had classified the aggregates into six groups of shapes namely cubical and angular which falls under the high quality aggregates while irregular, flaky, elongated and flaky & elongated are classified under the low quality aggregates. The six shapes of aggregates are shown in Figure 2.1.

In the British Standard BS812, Section 105.1 and Section 105.2, (British Standard Institution, 1989) the flakiness and elongation of an aggregate sample are measured indirectly in terms of flakiness or elongation indices, which are respectively defined as percentage of mass particle classified as flaky or elongated. The particles are classified as flaky or elongated according to the rather arbitrary assumption that a particle is flaky if its thickness is less than 0.6 the sieve size and the particle is elongated if its length is greater than 1.8 times than the sieve size.

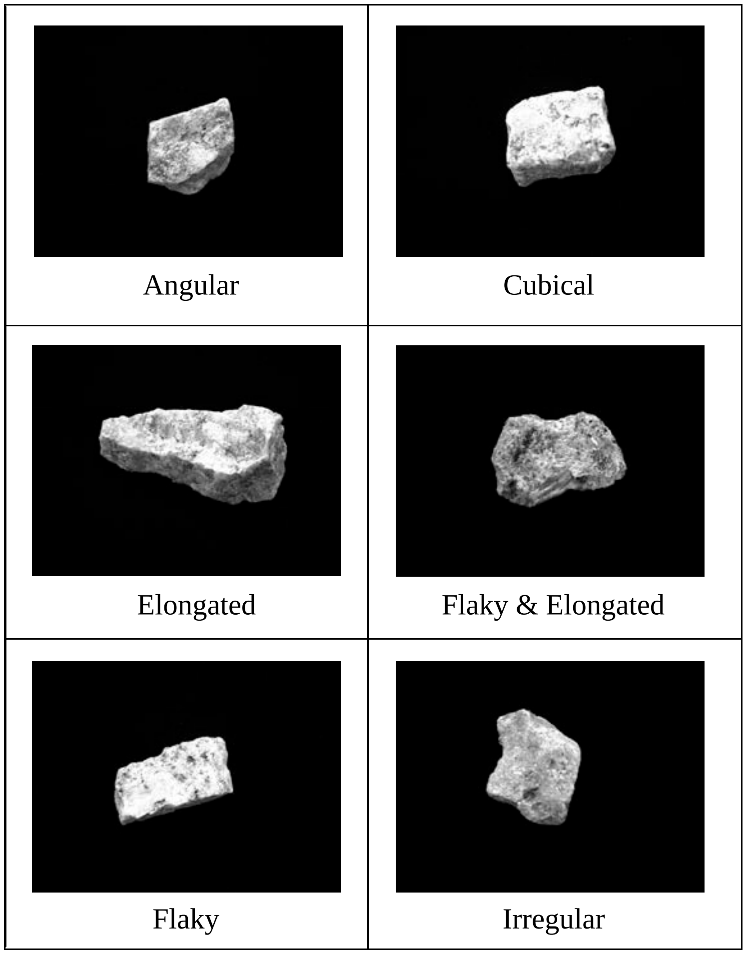

Figure 2.1: Six shapes of aggregates

2.2.2 Producing Good Shape of Aggregates

Donza et al. (2002) reported that the shape of aggregates depends on the nature and the degree of stratification of rock deposit, the type of crushing plant used and the size reduction ratio. The production of high quality aggregates in terms of improved shape and graded size is dependant on the crushing technology utilized and the two main methods of reducing rock to the desired final product are by impact and compression crushing. In breakage mechanism study by Nikolov (2002) for the different type of crushers such as cone, jaw and impact crushers, it has been concluded that the fragmentation process in cone and jaw crusher is relatively slow and is based on the application of a compression stress on a part of the particles' surfaces while the impact breakage takes place at a much shorter time scale and implies a dynamic crack propagation that leads to a much faster failure of the particles. The larger particles should break more easily because they contain larger micro cracks if compared with the smaller particles and furthermore the impact generates compressive and tensile shock waves travelling throughout the particles.

Kojovic (1995) had reviewed the work done by Marwick in 1942 for the variations in shapes of crushed products concluded that the machines with low reduction ratios tend to give better cubical or equidimensional products by the following order: impact, jaw, roll and cone crusher. The shape of particles depends on many factors such as the rock type, breakage energy, crusher type and the machine design. Claims were made that machines with low reduction ratios tend to give better cubical products. In producing more cubical or non flaky aggregates, Kojovic (1995) summarize and point out as follows;

i) Impactors are superior to compressive breakers

ii) A low reduction ratio is favorable

iii) Choke feeding should be employed for cone crushers

iv) Rocks on Rock Vertical Shaft Impactors have proven to produce the best cubical aggregate combined with ideal surface texture.

2.2.2 Conventional Process in Aggregates Classification

Traditionally, the size and shape analysis of coarse aggregates are done by mechanical sieving and manual gauging as detailed in the British Standard BS812, Section 103.1 (1985), BS812, Section 105.1 (1989) and BS812, Section 105.2 (1990). Generally, in sieving operation, also known as the "gradation analysis", the aggregates are placed on the sieves which are stacked up with the smallest one at the bottom and then, shaken for a period of time. The objective is to have the aggregates passing through, until they are retained on the sieves which are too small for them to pass. Then the quantity of each size fraction is measured by weighing. However, there are points that need to be considered from the process, where particles passing through a sieve can actually have one dimension that is larger than the size of the sieve apertures. For example, an elongated particle with length greater than aperture size can pass through the sieve. Other than that, a relatively flaky particle can pass through the sieve aperture, which in square in shape and diagonally the sieve size. Thus, there were still margins of errors when using the traditional classification method.

Additionally, a report by Maerz and Zhou (1999) stated that aggregates with better characteristics, particularly needed in the construction sector. To achieve this, the aggregates must pass a stringent series of mechanical, chemical and physical tests, in order to demonstrate that they will perform satisfactorily and meet or exceed specifications. Examples of such mechanical tests are abrasion resistance, durability and resistance to polishing. Chemical tests include sulfate soundness and organic content; while the physical tests include aggregate grading (determination of size distribution), aggregate shape, angularity, sphericity, roundness and surface texture. The test procedures for many of these tests have been well established and are specified for example, the American Society for Testing and Material standards (ASTM), American Association of State Highway and Transportation Official standards (AASHTO) or Superpave guidelines.

2.3 Machine Vision System

Machine vision has been applied to variety of manufacturing challenges in the last two decades. The implementation goal is to improve quality and productivity in the manufacturing process. In the beginning, semiconductor and electronics manufacturers were early major players which currently account for about half of the machine vision applications found on the factory floor. The acceptance is growing quickly throughout the manufacturing sector, with machine vision systems now in place in food processing, pharmaceuticals, wood and paper, plastics, metal fabrication and other industries (Fabel, 1997). A brief history of a machine vision system as follows (Machine Vision Co. UK, 2008);

Late 1940s/early 1950s

- Military had been using the image analysis for the artificial intelligence application in the image analysis

Late 1960s/1970s

- The first development of the real usage of image processing application for industrial by Massachusetts Institute of Technology (MIT) which is the Block Micro World project driving a robot arm

1980s

- The grayscale machine vision algorithms had been developed and single board image processors available
- Cameras for industrial application started for manufacturing and continue with the mass adoption of machine vision system by semiconductor manufacturer.

1990s

- Machine vision industry continue with massive growth fuelled by availability of industrial systems
- Smart cameras available using proprietary processing chips with the speed up of using the standard PC technology and windows operating system for machine vision.

2000s

- Ergonomic system solutions for factory integration is developed
- The FireWire (IEEE 1394) digital camera technology started to be adopted by the machine vision industry and the market continues to expand rapidly.

2.3.1 Basic Concept of Vision System

Machine vision covers computer science, optics, mechanical engineering, and industrial automation. Unlike computer vision which is mainly focused on machine-based image processing, machine vision integrates image capture systems with digital input/output devices and computer networks to control manufacturing equipment such as robotic arms (Machine Vision Co. UK, 2008). The interrelationship of machine vision, image processing and computational vision is shown in Figure 2.2.

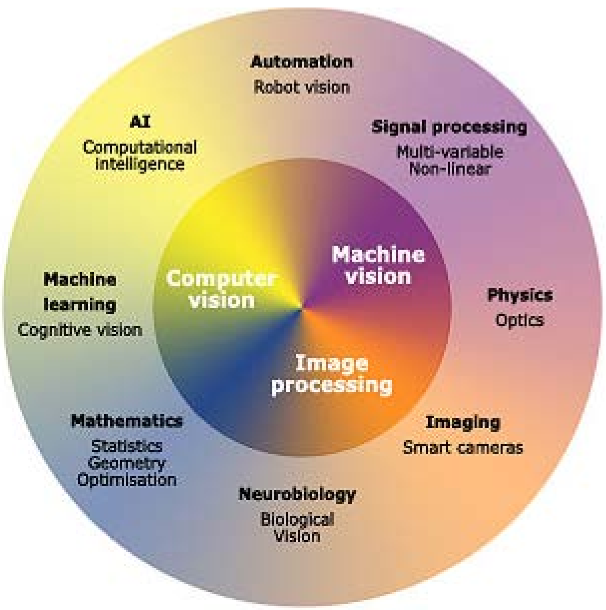

Figure 2.2: Interrelationship of machine vision, image processing and computational vision (Machine Vision Co. UK, 2008)

A typical machine vision system consists of most of the following components which are digital or analog camera, Input/Output hardware, sensor for part detection and a program to process images and detect relevant features (Machine Vision Co. UK, 2008). In addition, Fabel (1997) also list down the common components for a machine vision system with to date improvement for each of the items.

a) Cameras – The CCD camera dimension becomes smaller, lighter and less expensive. Images capture sharper and more accurate. The new dual output cameras also produce images twice as fast from the previous model.

b) Frame grabbers - The specialized analog to digital (A/D) converters change video or still images into digital information. Today's frame grabbers offer greater stability and accuracy than earlier models, and some can even handle image processing and enhancement on the fly, using digital signal-processing techniques.

c) Personal Computers (PCs) - PCs technology had accelerated in the last decades which can handle machine vision's demands. With 132 MB/second PCI bus transfer speeds and more than 100 MHz Pentium microprocessors. PCs are now routinely embedded into equipment on the factory floor. The distributed intelligence made possible by PC technology has contributed immeasurably to the pace and effectiveness of factory automation.

d) Software - Graphical user interfaces and libraries of high-level software modules operating in standard environments such as Windows have eased the development process and made machine vision a user-friendly tool. Leading edge software suppliers have begun to provide object-oriented application development tools that will speed application development even more.

e) New technologies - High-speed serial data ports such as the Universal Serial Bus and Fire Wire High Performance Serial Bus (IEEE 1394) will speed data transfer and information throughput, increasing the overall capability of machine vision systems. USB has already been adopted as an industry standard by PC and peripheral vendors, and will make it simpler to connect digital cameras to powerful embedded PCs. However, reaching real-time video rates will require the higher-speed Fire Wire.

Other than that, a machine vision system is also defines as a system which makes use of high specification video camera to take the image of part being inspected, a light source which pick out the relevant features to be inspected and a processing unit to analyze the image taken. It generally consists of a pressure or optical sensor, a camera, a lighting system, a central processing unit (CPU), associated software for processing images, and an I/O system for connecting to a larger network. The expectation from a visual system is to perform the following operations; the image acquisition and analysis, the recognition of certain features or objects within that image and the exploitation and imposition of environmental constraints (Golnabi and Asadpour, 2007).

In a typical machine vision application, a video camera positioned so it can capture an image of the item to be inspected, then sends it to the vision computer. The vision system rapidly analyzes the image. For example, it might find where the item is located in the field of view, and check the tolerance of its critical dimensions. When the require computation is complete, the inspection result is then communicated to other equipment such as a Programmable Logic Controller (PLC) (commonly used to control industrial machinery). Alternatively the data is stored for future analysis. This process is repeated for each new item moves into position in front of the video camera. Unlike manual inspection, the vision system always applies the same rules objectively, and never tires at doing its programmed task. The vision system will usually have some form of operator control. For instance a video monitor or flat-panel display may be used to show images of parts and inspection statistics, with mouse or keypad input for the operator to select commands for starting and stopping the inspection, loading the configuration setup for specific parts and calibrating the vision algorithm for new parts (Imaging and Sensing, 2003).

For the machine vision technology, Ejiri (1990) discussed four types of machine vision technology. They are based on pattern matching, feature parameter, window and slit light methods. In pattern matching the unknown input image is directly compared with standard patterns or templates for each character. These templates can be regarded as factual knowledge of characters and thus separation of the knowledge from the procedure is in common use. For the feature parameter method, it will extract several geometric features from an object pattern. The features include the area, peripheral length, number of holes and moments. Thus the object can be represented as a point in *n*-dimensional feature space and compared with the standard region of each object to find the closest object category. In window method, selected portions of an object image can be used to recognize object category, position and orientation. Object areas in the windows are the basic for the decision when the windows are appropriately placed in the image field. Finally the slit light method which projects a slit light beam from one direction and observes the object's reflection from another direction. Triangulation gives the distance between the object and the observation point.

The type of application and the task required from a system is important in designing a machine vision system. In general, the expected functions from a vision system are the exploitation and imposition of the environmental constraint of a scene, the capturing of the images, analysis of those captured images, and recognition of certain objects and features within each image and initiation of subsequent actions in order to accept or reject the corresponding objects (Golnabi and Asadpour, 2007). The first step to determine the success of an application will involves the process to locate the part within the camera's field of view. While it sounds simple enough, locating parts in today production environment can be extremely challenge for a vision system. For a real time application, fast image acquisition and fast post processing task would really speed up the entire process. However, speed would not be only the major factor, as the design should consider on how to integrate the system and acquire high quality images even with either a static or dynamic objects, to ease the post digital image processing later. Therefore, the hardware selection and integration plus the design techniques would be critical processes in order to make sure an online real time machine goal is achieved.