DIGITAL SUNSPOT COUNTING FOR LANGKAWI NATIONAL OBSERVATORY IN WHITE LIGHT FULL DISK

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DIGITAL SUNSPOT COUNTING FOR LANGKAWI NATIONAL OBSERVATORY IN WHITE LIGHT FULL DISK

by

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LIST OF ABBREVIATIONS

ANGKASA	-	National Space Agency of Malaysia
AR	-	Active Region
CCD	-	Charge-Couple Device
CME	-	Coronal Mass Ejection
LNO	-	Langkawi National Observatory
NOAA	-	National Oceanic and Atmospheric Administration
R_{ISN}	-	International Relative Sunspot Number
R_{LNO}	-	Sunspot number produced by LNO
ROB	-	Royal Observatory of Belgium
R_{ROB}	-	Sunspot number produced by ROB
RSN	-	Relative Sunspot Number
SDO	-	Solar Dynamic Observatory
SIDC	-	Solar Influences Data Analysis Center
SILSO	-	Solar Index and Long Term Solar Observation
SWPC	-	Space Weather Prediction Center
WDC	-	World Data Center for Sunspot Number
WKSO	-	Watukosek Solar Observatory

PENGIRAAN TOMPOK MATAHARI SECARA DIGITAL UNTUK IMEJ MATAHARI DALAM CAHAYA NAMPAK DI OBSERVATORI NEGARA LANGKAWI

ABSTRAK

Pencerapan tompok Matahari telah dijalankan sejak 400 tahun yang lalu. Tompok Matahari dikira dengan menggunakan kaedah manual iaitu secara visual berdasarkan pencerapan yang dibuat menggunakan pemerhatian mata dan lukisan tompok Matahari secara langsung atau melalui kaedah unjuran. Observatori Negara Langkawi (ONL) mempunyai sistem pencerapan Matahari dan aktif menjalankan pencerapan Matahari sejak tahun 2008. Sistem pencerapan Matahari di ONL dilengkapi dengan instrumentasi teleskop dan kamera CCD yang dapat merekodkan aktiviti Matahari secara digital. Walaupun ONL mengambil data Matahari secara digital, tapi penyelidik di ONL masih lagi mengekalkan kaedah pengiraan tompok Matahari secara visual. Ini adalah untuk mengekalkan konsistensi pengiraan tompok Matahari yang telah diperkenalkan sejak tahun 1800. Walaubagaimanapun, terdapat ketidakseragaman pengiraan tompok disebabkan oleh faktor pencerap dan cuaca. Oleh itu, satu program dibina bagi membolehkan imej kualiti Matahari yang diambil dari ONL ditentukan serta tompok Matahari tersebut dapat dikira secara automatik. Nilai tompok Matahari secara digital dari ONL (R_{LNO}) akan dikaitkan dengan nilai tompok Matahari Antarabangsa (R_{ISN}) yang dikira secara visual daripada Pusat Pengumpulan Data Tompok Matahari di *Solar Index and Long Term Solar Observation (SILSO)*, Belgium. Bagi mencapai objektif ini, satu program pengiraan tompok Matahari digital dan pengkelasan imej kualiti telah dibina menggunakan pengaturcaraan C++. Kaedah morfologi Matematik iaitu *Adaptive Threshold, Canny Edge Detection* dan *Dilation* di gunakan dalam pengaturcaraan pemprosesan imej ini. Hasil daripada kajian ini, nilai korelasi antara R_{LNO} dan R_{ISN} ialah R = 0.883 bagi kesemua 239 data yang digunakan dalam kajian ini. Walaubagaimanapun, nilai korelasi antara R_{LNO} dan R_{ISN} bagi kategori imej yang paling baik (Kategori Q4), nilai korelasinya meningkat kepada R = 0.923. Ini dapat menunjukkan bahawa pengiraan melalui kaedah digital dapat menyamai pengiraan secara manual yang dijalankan oleh pencerap yang jauh lebih pengalaman. Selain itu, karakteristik tompok Matahari gergasi yang dikenali sebagai AR2192 juga dikaji dengan teliti untuk melihat keluasan tompok, kelas magnetik tompok serta klasifikasi kumpulan tompok tersebut dengan kejadian Suar Matahari. Hasil analisis menunjukkan bahawa terdapat hubungan di antara klasifikasi tompok Matahari tersebut dengan kejadian suar Matahari. Ini dapat membantu penyelidik dalam penyelidikan mereka di mana karakteristik tompok Matahari yang dapat memberikan kesan kepada Bumi.

DIGITAL SUNSPOT COUNTING FOR LANGKAWI NATIONAL OBSERVATORY IN WHITE LIGHT FULL DISK

ABSTRACT

For over 400 years, sunspot observation has been consistently collected and it has become the longest-running experiment and still ongoing scientific project. Sunspot numbers are manually counted based on direct visual observation or drawing it through the projection method. Langkawi National Observatory (LNO) has carried out consistent sunspot observation since 2008. LNO is equipped with CCDs and capable of recording sunspot in the form of digital images. From these images, the numbers of sunspots are manually counted by observers to get LNO's daily RSN. Bias from different observers and weather factor like haze or thin cloud cover leads to inconsistency due to different individual visual characteristics. Therefore, this study is to develop an image quality determination and digital sunspot counting method for LNO. Then, the correlation between RSN for LNO (R_{LNO}) will be compared with the international RSN (R_{ISN}) produced by Solar Index and Long Term Solar Observation (SILSO), Belgium. To achieve this objective, a programme had been developed using C++. The morphological tools (*Adaptive Threshold, Canny Edge Detection* and *Dilation*) in the image processing library were used in this study. The correlation value between the digital LNO sunspot counting (R_{LNO}) and the R_{ISN} for 239 data used in this project is R = 0.883. Meanwhile the correlation value between R_{LNO} and the R_{ISN} for very good image category (Category Q4) is R = 0.923. This shows that the consistency of R_{LNO} using digital counting can match with the manual counting made by professional observers with decades of experience. An enormous sunspot known as AR2192 is studied closely to look for its sunspot characteristics like sunspot area, its magnetic class and its sunspot class classification with the flare occurrences. The result shows that there is a correlation with the sunspot characteristics with the flare occurrences. It is hoped that this research can contribute and be useful for researchers to forecast the flare occurrences that influences Earth's space weather.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The sun is a star located at the centre of the Solar Systems. It is a middle-aged star with spectral type of G2. Its distance is 149,598,000 kilometres from Earth. For almost 4.6 billion years, the Sun has created vast amount of energy through nuclear fusion by integrating Hydrogen, produce Helium and others elements with extreme heat and pressure. The Sun provides warmth and light to Earth that enables the planet to support life.

The Sun hosts their own phenomena and activities which is the driver of space weather within the Solar System. Space weather is the study of the Sun's activities which can affect Earth and its surroundings. Sometimes the Sun releases its built-up energy (probably in the magnetic fields) into prominences, solar flares, and coronal mass ejections. These mysterious phenomena occurs in its solar atmosphere and bombards Earth with high energetic particles. Since 17th Century, the solar studies in white light visual telescopic observations have been carried out consistently to determine the sunspot motion, the numbers of sunspots and study its morphological properties (Bhatnagar & Livingston, 2005). These solar activities can give a significant effect towards Earth either positive or negative impact. In this perspective, it is feared that the effects of solar activity have an adverse effect on the Earth, especially disaster resulting from solar storm, when the Sun has reached the maximum phase known as the ' Solar Maximum '.

A solar Maximum phenomenon occurs within every 11 year cycle. It is caused by magnetic field instability in the core of Sun. This phenomenon is an active period of Sun which is lots of sunspots appears, coronal mass ejection and solar flare burst occurs frequently. These activities can cause significant problems to Earth which can damage and interfere with Earth's modern infrastructures and facilities such as telecommunication, power supply and satellite operations. By monitoring the solar activity in all layers of solar atmosphere, through continuous observation of sunspots in photospheric layer and solar flares in chromospheric layer, researchers can predict and forecast the space weather.

Sunspots are dark areas or spots that appear on the Sun's surface which can change its properties every day. The spots are always related with the activity level of the Sun. The physical effects of energy released from the spots varied roughly with the number of the spots. The black spots are now firmly related with the activity of the sun and termed as sunspots activity cycle.

1.2 Research Background

Sunspots can be observed on photosphere layer through a white light filter. Sunspots is a cooler region compared to other regions in the solar surface. It has a strong magnetic field that compresses the other gases underneath. It traps and prevents the gas from coming out to the solar surface. However, the sunspot areas reduce its efficiency, less energy to reach the surface, cools down and appears darker (Raman, 2011; Chris, 2002).

The 1st sunspot observation using a telescope was conducted in the 17th Century. Observations has been done by Thomas Harriot, Christopher Scheiner, Johanes Fabricius, Gallileo Galilei, Samuel Heinrich Schwabe and Johann Caspar Staudach (Clette, Svalgaard, Vaquero, & Cliver, 2014; Bhatnagar, Livingston, 2005). Later in late 1800's, Rudolph Wolf who is a Swiss astronomer at Zurich Observatory made an effort to develop a technique to properly count the sunspot activity called Relative Sunspot Number (RSN). Wolf determined his sunspot numbers using the eight (8) cm Fraunhofer refractor telescope at Zurich Observatory performed by sketching the solar projection technique. Since then, the Sunspot Number was calculated using his formula also known as Wolf Number.

The equatorial region receives lots of sunlight and consistent throughout the year as compared to other higher latitude regions. This is one of the reasons why sunspot activity is actively observed by professionals and amateurs in Malaysia. In the allocation of the Ninth Malaysia Plan (RMK-9), the Government has agreed that the National Space Agency (ANGKASA) will construct the National Observatory in the island of Langkawi with a robotic telescope system. The Langkawi National Observatory (LNO) was officially established in 2006. The objective of this project is to build the first robotic observatory in Malaysia, in an effort to foster R & D capabilities in the field of space science particularly in astronomy. The robotic observatories have two (2) methods of observation which is on-site and online/remote which it can be controlled via the Internet and allow astronomical research to be carried out by trained astronomers from anywhere.

Its location in the North Malaysia is a strategic area because of less cloud coverage and isolated from light pollution. It is equipped with two robotic telescope systems which is stellar observatory and solar observatory. Stellar observatory is reserved for night observation and it can observe galaxies, nebula, planets, moon and comets. Solar Observatory is dedicated for solar observation to observe all solar activities.

The Solar Observatory is equipped with 5 (five) telescopes of different filters to measure and look at the Sun in different wavelengths which are one (1) telescope record the Sun in White Light wavelength, two (2) telescopes to observe the Sun in Hydrogen alpha (H-alpha) wavelength and one (1) telescope equipped with Calcium K-Line (CaK) filter. These telescopes are connected to a Couple-Charge-Device (CCD) Camera to capture images of the Sun. There is also one (1) telescope reserved for visual observations in white light. With the robotic Solar Observatory, researchers can continuously monitor the Sun's activities through sunspot and flare observatory and contribute to international collaboration for solar monitoring.

In 2008, LNO started the continuous sunspot observation and analysis of sunspot number. It has joined the collaboration in solar physics programme with Watukosek Solar Observatory (WKSO) in Surabaya, Indonesia in 2007. Researchers at LNO had training, transfer of knowledge and capacity building in solar research with WKSO researchers. WKSO is an established observatory in sunspot and flare observation from 1985 until today. Since its establishment in 1983, WKSO has conducted various activities beginning with a stratospheric balloon launch in 1983. It started its routine observation in the form of sunspot sketch from 1985 and along with solar flare monitoring.

1.3 Problem Statement

Langkawi National Observatory (LNO) established the sunspot monitoring programme using their solar telescope system in 2008. They captured the full-disk image of the Sun in White Light wavelength to monitor the solar activity by continuous observation of sunspot. Researchers at LNO had a series of training with Watukosek Solar Observatory (WKSO), Indonesia on observation technique, solar physics and also sunspot analysis.

WKSO has been using the sunspot sketch technique which dates back from 1987. They use a 150mm diameter refractor telescope with a single base equatorial mount. The sketches are produced using the projection technique. The sunspot analysis is then manually analyse which is the observer needs to count the spots using their eyes, visually from the sketches they make. Then the data were added in their own sunspot software in ASCII format data for sunspot monitoring and analysis which is based on international standards.

LNO analyses the sunspots using digital images but counts the spots manually, similar to WKSO. There are some inconsistencies during analysis due to several factors: observers and metrological or weather. Observers have a very important role during observing. They need to capture the images correctly, exposing it within the linearity of the CCD's response. They need to determine the proper exposure duration based on the intensity of the images and the altitude of the sun during observation. Observers mistakes sometimes causes slightly out-of-focus solar images during observation and it will make sunspots not sharp and blurred edges. Lastly, during the sunspot analysis, different observers also tend to see and count spots differently than others because of varying visual capacity between observers. The pilot station for sunspot counting at Specola Solare Observatory in Locarno, Switzerland begins to drifts due to the observer.

The external factors that can cause inconsistencies in solar images which is out of our control are weather. Thin clouds and humid atmosphere causes the solar disc to deform minutely making it shift in and out of focus for different parts of the image, similar to a mirage. The cloud could also change from thin to thick clouds which can block the sun. It also causes the image appear soft and not properly focus.

Therefore, to minimize the inconsistency of sunspot counting and analysis, an automatic digital counting method is needed. This programme can categorize the image quality and then count the spots within their sunspot group select by observer.

However, there is some limitation of this research. As this research is to study an alternative way to count the sunspots, it will take some time to be accepted by the international committee like World Data Center (WDC) of Sunspot in Belgium. It is also a risk if this digital counting method is not accepted. The need to a close relationship with WDC and introducing them some preliminary results and further test the robustness of this method is definitely needed.

If this programme is deploy to other observatories, another limitation is also to know what instruments were used at respective observatory to capture the solar images. This is to make sure the program can be adjusted to the particular observatory and the data is consistent before it can be deployed, as different instruments will produce results that will be unique to every one of them.

1.4 Research Objective

In this thesis, the main aim of the study is described as below: -

1. To develop a program that can determine the image quality of the sun and count the spots automatically, consistently.

2. To test the developed software and test it using digital white-light solar image from Langkawi National Observatory (LNO) and then, the spot counts will be the input to determine the RSN for LNO.
3. To compare and correlate the RSN from LNO with the International Sunspot Number (ISN) from the World Data Centre, Solar Index and Long Term Solar Observation (SILSO), Belgium.

Beyond that, there is a study to identify the correlation sunspot characteristics like sunspot area, its magnetic class and its sunspot classification with the flare occurrences.

1.5 Research Question

This thesis is focused on sunspot digital counting using digital images from Langkawi National Observatory (LNO), Malaysia. Currently, the researchers at LNO count the sunspot manually and there is no development yet for automatic or computerized sunspot counting in Malaysia.

This would lead us to few related doubts;

1. What is the image analysis that can be used to determine the quality of the image taken using the instruments at Langkawi National Observatory (LNO)?
2. What are the image processing techniques that can be used to assist researchers in identifying the spots and count the spots automatically in the selected sunspots group?
3. How accurate and consistent is the digital sunspot counting method compared to manual counting?

This thesis also discusses on sunspot characteristics that may influence Earth with: -

1. What characteristics of sunspot that may be an indicator of the solar flare occurrences?

1.6 Research Methodology

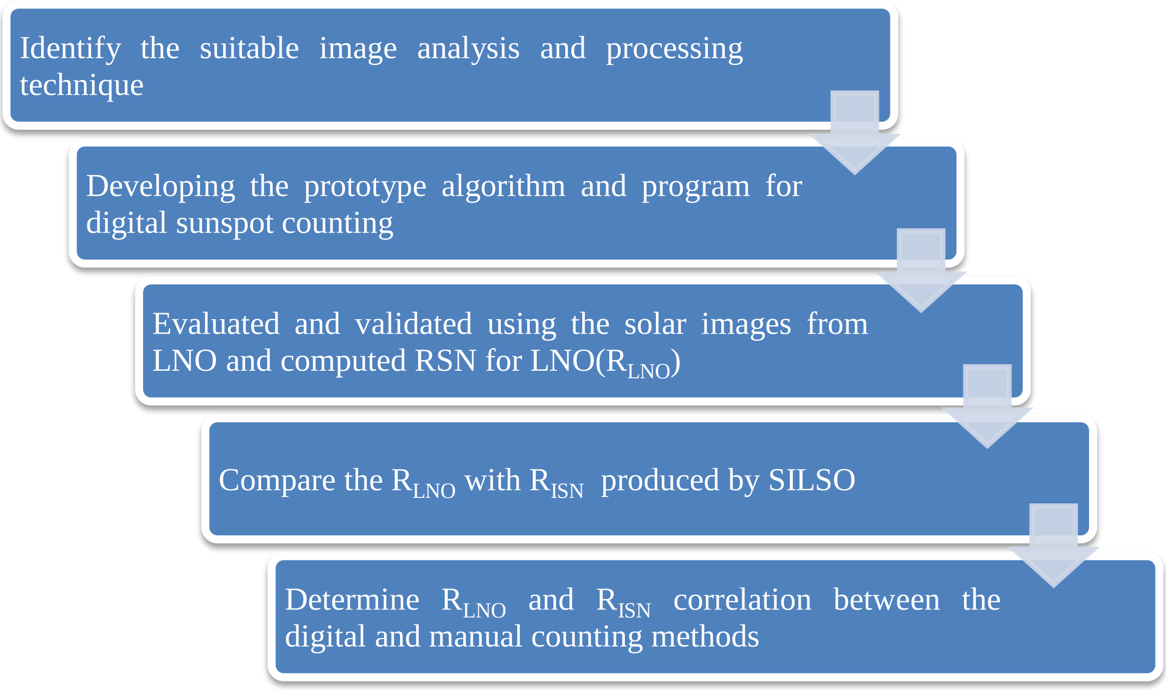

Figure 1.1: Flowchart of the overall research methodology process

Figure 1.1 above show the steps in the overall research methodology in this research. First of all, we need to identify the suitable image analysis and processing technique that can be used to determine the image quality and identify the spots. After that, developing the prototype algorithm and program for digital sunspot counting. The program will then need to be evaluated and validated using the solar images from LNO and computed RSN for LNO. Lastly, we will compare the RSN with ISN produced by

SILSO. LNO RSN and ISN data will be explored in details to determine their correlation between the digital and manual counting methods.

For the sunspot characteristics, data from National Oceanic and Atmospheric Administration (NOAA) Space Weather Prediction Center (SWPC) was used and then identify the characteristic which can correlate with the most significant solar flare events in 2014.

1.7 Significant of Research

The result of this study can be used by researchers and the development of programs or software to improve and build systematic software and consistent for early warning system for Malaysia space weather alert. The importance of this study is to examine the effectiveness of digital sunspot counting compare to manual counting. The result of this study will hopefully assist the solar researchers in development of tools that can help them to produce a highly reliable and consistent sunspot counting RSN for LNO. This project also can be deployed to other observatories in Malaysia so that the digital sunspot count contributions from Malaysia can be achieved.

This is the first start of the development for an early warning system on space weather prediction using digital image analysis in Malaysia. As astronomy and astrophysics fields are still fairly new in Malaysia, with this research, hopefully it will attract more interest of researchers to get involved in Sun-Earth relationships especially in optical solar data. This research is also part of an effort to support the government to equip the agency for the preparedness of the space weather effect on earth in general. It also can strengthen the local expertise in their respective fields. In addition, this study will improve and tied the international cooperation complementariness in monitor the activity.

1.8 Expected Output

This study aims to help solar researches in Malaysia to be able to produce daily RSN consistently. This can contribute to the international network for sunspot long term data collections. It is hoped that other researchers can use this study and to continue this research more extensively and develop other applications using the same concept. The ultimate goal is that it can one day be used as a candidate to become a digital reference for sunspot counting in Malaysia.

1.9 Summary

Therefore, this chapter is the overall of the introduction, motivation, problems and research methodology for this project. Based on the problems, the needs to developed a programmed that can identify the image quality of the images taken and automatic count the sunspot by reducing an observer's error with the use of cutting-edge technology. The next chapter will discuss the Solar structure and the sunspot characteristics as it is the subject interest on this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the literature review covering all the main aspects that affect and influence the study that has been conducted. It covers the Sun and its features, history of sunspot observation from early days of the telescope until the recent techniques, the sunspot characteristics and sunspot observation in Malaysia.

2.2 Solar

Solar or Sun is the star located at the middle of the Solar System. It lightens up the entire Solar Systems and plays a big role in our lives. It provides us with warmth and energy on Earth. Sun is an extraordinary star with a diameter of 1,392,000 kilometres. Its diameter is 9 times larger than Jupiter and 109 times larger than the Earth. It also weighs 330,000 heavier than Earth even though it's composition is made up of 92.1% Hydrogen, 7.8% Helium and 0.1% heavy element. The Sun accounts for almost all the mass in Solar Systems, leaving about 0.2% for all planets and everything else. The Sun is so massive and its strong gravitational pull make the planets and many smaller bodies like asteroids keep orbiting around it.

Almost 90% the lifetime of our Sun will be in the main sequence stars category. Every day, the Sun will burn up Hydrogen to produces Helium and other elements in a process known as fusion. Each second, the Sun is able to transform 700 billion tons of Hydrogen to 695 billion tons of Helium and the remaining five (5) billion tons are release as energy in many forms.

2.2.1 Anatomy of the Sun

Unlike Earth, the Sun is a gigantic ball of hot gas. It is divided into six (6) layers which are the core, radiation zone, convective zone, photosphere, chromospheres and outer most layer, the corona. The anatomy of the Sun is described in Figure 2.1. Energy is produced at the core. At the core, the Hydrogen fuses together under extreme heat and pressure to produce Helium and energy in the form of photons. The energy then propagates outward through a slow process known as radiative diffusion where photons are continuously absorbed and re-emitted by the dense solar matter over and over again (Koskinen, 2011). The energy takes around 170,000 years to move from the core to the convective zone.

After that, this energy (photons) will continue to move outward into the convection layer. Here, the energy is transported through the passage of plasma and as the hot gases arise, the cooler ones will fall back towards the Sun’s interior. This process is called as the convection process, hence the layer's name. The energy here will circulate continuously on its way to photosphere layer.

The photosphere is the lowest atmospheric layer of the Sun that can be seen visually. The thickness is approximately 500 km and the temperature in this region is roughly around 6600°K, while the "coldest" can drop to 4300°K. There are several unique features that that be seen at the photospheric layer which are granulations, faculae and sunspots.

Above the photosphere, there is a layer called the chromosphere in reddish-pink colour. The colour is the emission strength at 656.3 nm; the wavelength of the Hydrogen-alpha line in solar spectrum. The chromophere's thickness is about 2000 km and the temperature is typically around 10,000°K. Observers can see unique features at this layer such as filaments, prominences, plagues and solar flares. Filaments are dark threads and it shows the magnetic features at the solar surface. When the sun rotates and reaches near the solar limb, the filaments appear brighter from the black space background and called as prominences. Another chromospheric feature is solar flare. Solar flare is the sudden brightening of the chromosphere that may last for a few minutes to a few hours. The brightening of this region is due to the instant release of energy within the magnetic field of a sunspot group (Jenkins, 2009).

The outer most layer of sun is the corona which its temperature is a baffling 200 times hotter than the Sun's surface. Temperature of corona ranges from 500,000°K to 2,000,000°K. This layer can be seen clearly during a total solar eclipse, with the naked eye.

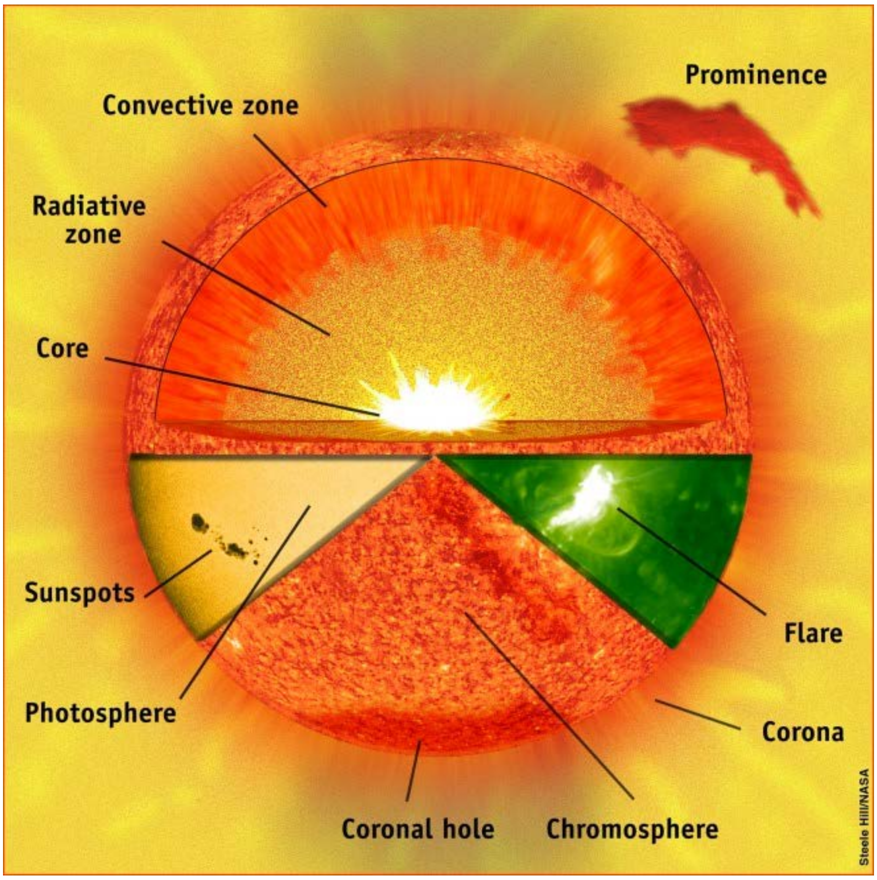

Figure 2.1: Anatomy of the Sun

Source: https://www.thesuntoday.org/the-sun/solar-structure/

2.2.2 Solar Cycle and Solar Activity

The Sun has many activities that attract researcher's interest to study. Solar activities are usually linked to its cycle through the counts of sunspots number. The number of sunspots is not constant and varies during these solar cycles - maximum and minimum. The solar cycle was discovered by Heinrich Schwabe in 1843 after observing the sunspot numbers and its patterns for 10 years. Then, further observations confirmed his conclusion and now widely known and accepted as the 11 year sunspot cycle (Bhatnagar & Livingston, 2005). Now, the solar cycle is a well-established fact.

The beginning of a solar cycle is called solar minimum. During solar minimum, most sunspots will appear in high latitudes far from the sun's equator. The number of sunspots is also low and there are times when there is not a single sunspot visible on solar disk. On average, solar minimum activity takes about 4.8 years to peak and another 6.2 years to decline before its minimum again (Jenkins, 2009).

When the sun starts reaching the solar maximum phase, daily sunspot number will increase and the spots will appear closer to the equator. During solar maximum, lots of eruption like solar flares and Coronal Mass Ejection (CME) happen and it make the higher effects of space weather on Earth. The sunspots can appear complex in large groups and in big sizes during the solar maximum.

Richard Carrington and Gustav Spörer discovered that sunspots latitude changes over time but generally usually appear between the equator to ±35° latitude. The average sunspot latitude decreases steadily from early to end of solar cycle (Bhatnagar & Livingston, 2005). There are sometimes small and short-lived spots will be seen at higher than 40 latitude. This latitude drift of sunspot is called the butterfly diagram. This is shows in Figure 2.2 below:-

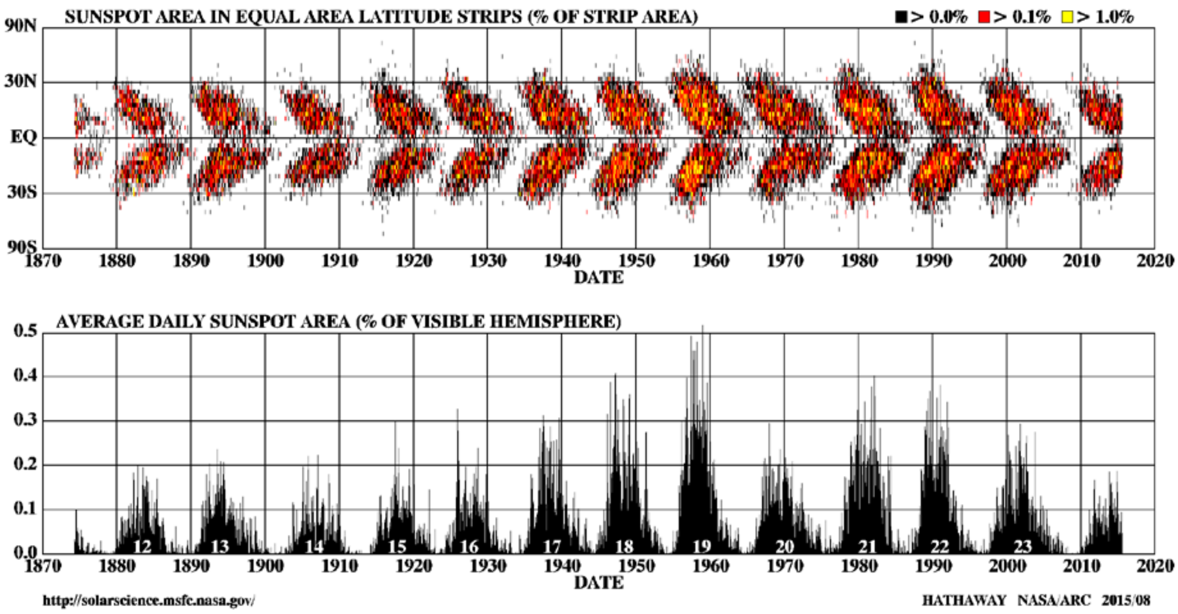

Figure 2.2: Butterfly diagram and average daily sunspot area

Source : http://solarscience.msfc.nasa.gov/SunspotCycle.shtml

2.2.3 Space Weather Effect

The sun will always throw bursts of plasma energy particles into our Solar System. An eruption usually originates from sunspots, solar flares, prominences, coronal hole and Coronal Mass Ejection (CME), will scatter high energetic particles into the interplanetary space of the Solar System including Earth. Space weather can be described as conditions on the Sun that implicate consequences and influence space-borne and ground-based technologies (Moldwin, 2008) especially Earth. The most disruptions caused by space weather will affect technologies that are satellite based because it provides weather information, military surveillance, TV broadcastings and other communications signals, credit card transmissions, navigation data and many more modern lifestyles. Nowadays people who rely on these technologies will be vulnerable to space weather events.

Table 2.1: Time sequence of solar events (Marusek, 2007 & Raman, 2011)

Solar Events	Estimated Arrival Time	Effect Duration
Solar radiation	8 minute	-
Solar Flares	8 minute	1 – 2 Hours
Coronal Mass Ejection	2 – 4 days	Days

There are several severe events for the effect of space weather to Earth which that have been recorded as shown in Table 2.2.

Table 2.2: Historical solar flare event that effect Earth (Marusek, 2007 & Talib, 2011)

Year	Major Events that effect Earth
1859	• Carrington Events – Telegraph failure in US and Europe
1989	• Power-grid collapsed due to transformer blow. Six million people were affected for 9 hours blackout. • Explosion and gas pipeline rupture at Trans-Siberian Railway
2003	• 50,000 people affected for an hour blackout in Sweden. • 15 transformer damage in South Africa.

There are several effects of space weather to the Earth. Aurora is one (1) of the space weather effects which are also known as northern and southern light. This spectacular sky phenomenon happens when electrons particles and ions from the Sun interacts with Earth atmospheric particles. These particles usually enter Earth's upper atmosphere near the polar region following our geomagnetic field lines. It produces colourful skies and it can be seen in between 60 to 80 degree latitude. However, not all is beautiful as we start to depend more and more on space based technologies. There are some harmful examples of space weather to technology on Earth as shown in Figure 2.3 and explained as below: -

a) Communication and Navigation Systems (High Frequencies)

Particles from the Sun will be harmful to communication and navigation systems. There will be a fluctuation signals in High Frequency (HF) radio communication. The ionosphere will experience sudden variations of density as the particle ionize this layer further. This will interrupt HF communication and also GPS signals as signals will need to pass unexpected propagation path. All solar events will also interrupt satellite operations. Those particles can cause the physical damage to satellite-borne components and computers. All satellite operators, will be warned either to shut down their satellite for a certain amount of time or turn the satellite's solar panel away from the Sun during the solar events.

b) Electric Power

Sometimes the Earth magnetic field will be unstable due to the space weather events. The electric current will be induced into the conductor, generally long powerlines. Therefore, the power plants will receive additional power than what they are designed for and this will be harmful to electric transmission equipments and transformer.

c) Pipelines

Geomagnetic field will fluctuate during the impact and this fluctuation will induce current to long pipelines. This will accelerate the corrosion rate of pipelines. The induce currents also can make the flow meters to transmit the false readings of the flow rate of oil/gas in pipelines.

d) Radiation to human

Astronauts in space are directly affected and exposed to the high solar radiation dose and particles in the events of space walk outside the Space Station. Therefore, during the solar storm, it is compulsory for all astronauts to be inside the space stations. Besides that, airlines flying at high-latitude polar flights path will expose crew and passengers on board with high amount of radiations during the solar events. The penetrations of high energy particle into living cells can potentially lead to cancer. As a result, the aviation industries also regularly monitor space weather activities.

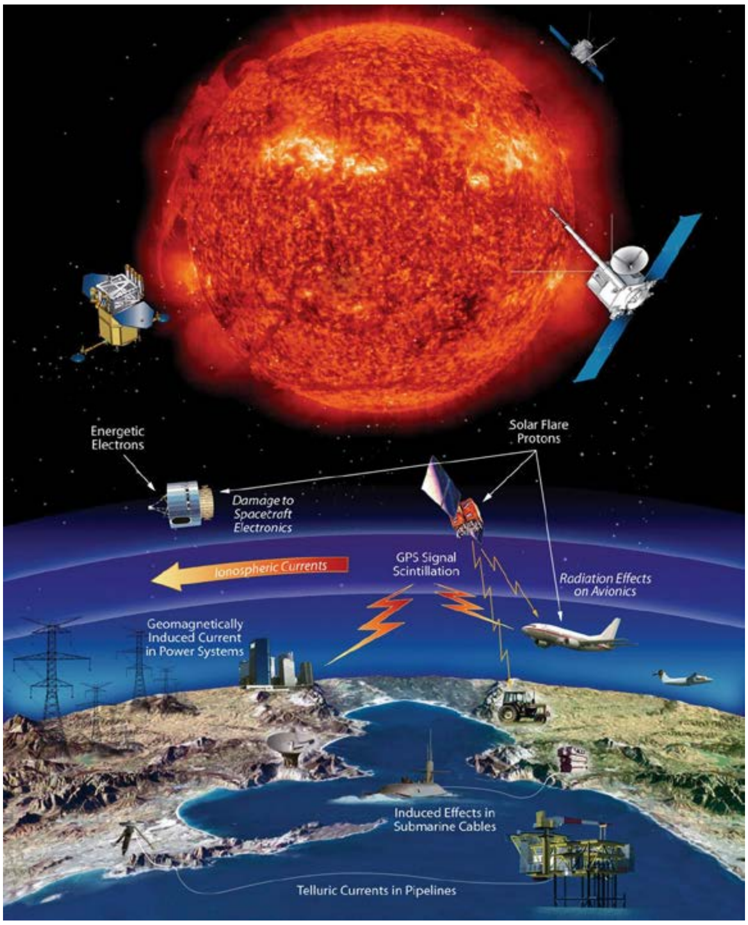

Figure 2.3: Space weather effect on Earth

Source : www.nasa.gov/mission_pages/sunearth/science/Tech-affects.html

Therefore, it becomes important for scientists and related organizations to monitor solar activity especially sunspot activities and evolution because it is the root that drives space weather. By monitoring the solar activities, researchers can provide early warnings particularly to organizations which manage the satellite systems, communications and navigation along with others who will be impacted by space weather.

2.3 Sunspot

The most noticeable features that can be seen on the Sun are the sunspots. Sunspot will stand out in contrast to its surrounding area on the photosphere. These dark features have fascinated astronomers for centuries and have studied it in great details. It occurs where the sun's magnetic field loops up out of the solar surface and cool it slightly. Therefore, it will make the surface appear less bright compared to the surroundings. The sunspots appear dark because its temperature is about 2000°C lower from the normal photosphere temperature. The sunspot data have been collected in terms of drawings and photographs for nearly over 400 years data. This is one (1) of the longest data collection and running scientific projects ever made for research (Owens, 2013).

Sunspots varies in shapes, size and changes its positions daily. It can be a single sunspot, isolated spots and can also become complex groups. The sunspot numbers can be a few numbers to a hundred and it is depending on their solar activity. The sunspot appearances are not same each day – forming and decaying. This makes observers and researchers always keen to observe solar on a daily basis.

2.3.1 History of sunspot observation

Astronomers have monitored and recognize the changes of the sunspot surface by observing it without any visual aid since the fourth century. They noticed that the Solar surface is yellow in colour and at times have a black spot. There are some good records of historical naked eye sunspots detection from very early Chinese, Japanese and Korean astronomers (Vaquero, 2007 & Bhatnagar & Livingston, 2005)

Beginning from the 16th Century, Galileo Galilei, Christopher Scheiner, Thomas Harriot and Johann Goldsmid have explored and observed the Solar surface closely using the newly developed telescope. They project the image of Sun from a two (2) inch diameter metal tube and about a yard long to a piece of paper. Then they trace the sunspot image. They noticed that there are black spots on the disk of the Sun and it changes its position westward, daily.

From the daily observations, Galileo conclude that spot on the Solar disk are not planets due to its irregular shapes. The extensive study of sunspot was made by Christopher Scheiner. He found that the Sun rotates on its own axis in roughly 27 days. He identifies that the sunspots rotate rapidly at low-latitude as compared to the high-latitudes (Clark, Yallop, Richard, Emerson, & Rudd, 1979). This is now what we call solar differential rotation.

Telescopic instruments has led to other the sunspot discoveries. Other than the telescope, another important scientific instrument was the camera obscura. Camera obscura has also been used for sunspot observations in the early 17th Century. The first sunspot camera obscura observation was done by Kepler (Vaquero, 2007). He detected small spots on the solar disk and think that was a planet Mercury. Few years later, he realize that small spot was not Mercury but a sunspot. Since the 17th Century, researchers from all over the world monitor and count sunspots manually using the telescope via an eyepiece projection or direct viewing of the Sun, and a paper and pencil for sketching the visible sunspot on the solar disk systematically. It was a scientifically useful daily data collection of sunspots and proven valuable to this day.

2.3.2 Modern Sunspot Observation

Nowadays, with the advent of digital technology in capturing the solar activities is extremely helpful. The use of Charge-Couple Device (CCD) or digital cameras and digital image processing techniques opens limitless new potential to imaging the photosphere. This also reduces the inconsistency of sunspot count due to observers error.

Many observatories are now continuing the sunspot observation using both methods simultaneously which are hand sketches and using digital images like at the Royal Observatory of Belgium and Ebro Observatory, Spain. Most of the observatories intend to develop the automatic sunspot identification using morphological tools in image processing. In a meeting with the principal researcher of the Sunspot Index and Longterm Solar Observation (SILSO) at the SIDC, Professor Frederic Clette in 2015 had informed that even though the new technique using the digital image is helpful but the needs of human intervention to identify and classify the sunspot groups is still essential. This will keep the consistency of the existing 400 years sunspot count that they keep.

Besides ground based solar telescopes, recently there are emergence of dedicated solar telescope spacecraft such as Solar Dynamic Observatory (SDO) and Solar Terrestrial Relation Observatory (STEREO). Ground based observation is dependent on atmospheric disturbance such as seeing and cloud cover while spacecraft counterparts are not. These dedicated spacecrafts also do not experience night time so observations are done round the clock, another benefit of these advancement. Data from these space-based observatories will provide extra details on the solar activities in different wavelength for example magnetogram to look into each active region's magnetic field.

2.4 Sunspot features

There are plenty of unique features on the photosphere layer that can be seen using white-light filters as shown in Figure 2.4 below: -

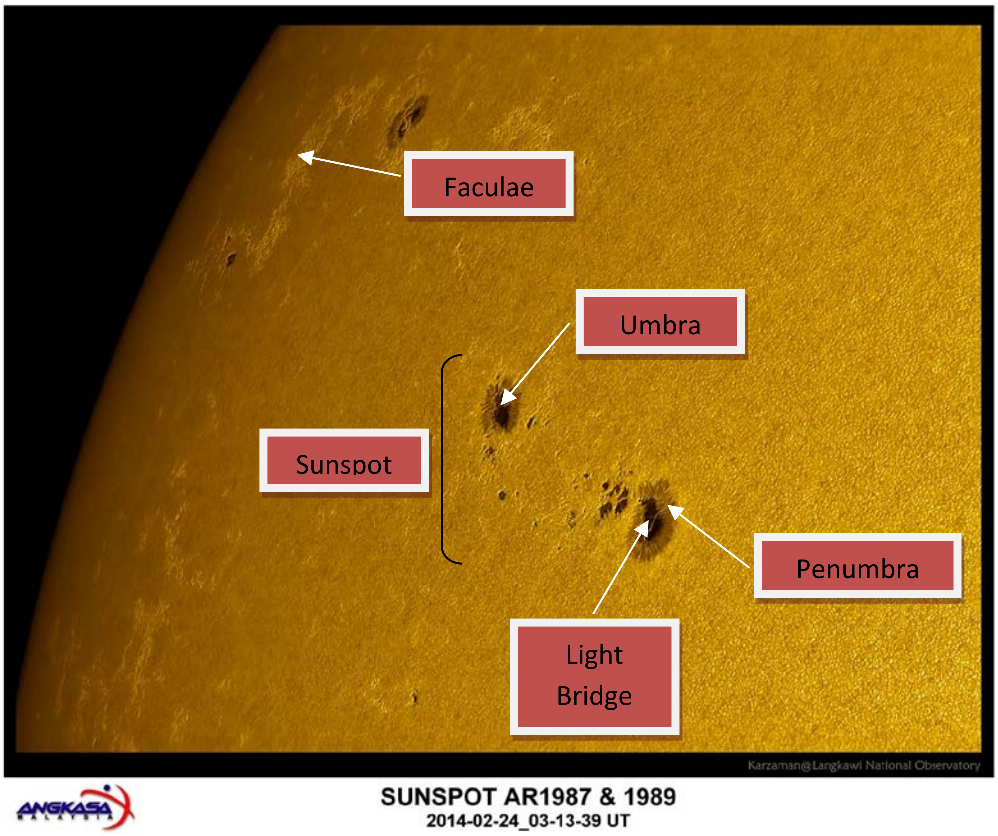

Figure 2.4: Photosphere layer features taken from LNO

Sunspot zone where most of the spots develop lies between 35° north and south of the solar equator. The sunspot is a noticeable form of magnetic field concentration of the Sun. The magnetic fields come out to the solar surface from the sunspots due to suppressed convection below it. Sunspots tend to appears in pairs - magnetic north pole and magnetic south pole. In large group of sunspots, it often consists of small spots and a pair of large spots. The second spot can be seen but their magnetic fields can be detected in chromosphere layer (Kitchin, 2002). In 1908, it is firmly confirmed that the magnetic field is the root of the cause of sunspot phenomena by George Ellery Hale (Solanki, 2003).

2.4.1 Sunspot Umbra

Sunspots mostly have two (2) different shades of grey. The darker spots are always in the center and sometimes alone. These dark spots are what is called the umbra. The dark area represents the magnetic fields interruptions and temperature changes beneath the surface.

2.4.2 Sunspot Penumbra

As we look closely into the sunspots, the spots have a lighter grey region surrounding the dark area. This area is called penumbra. Penumbra has a fine structure like a dark thread.

2.4.3 Light Bridge

Light bridge can be seen as a bright line dividing the umbra and sometimes penumbra. As the sunspots become older, bigger and mature, this intense light bridge may develop and the spots descending towards it end of life cycle.

2.4.4 Faculae

Faculae are bright patches on the photosphere and are the precursors of sunspot groups. It appears in and around the single sunspot or big sunspot groups. However, not all faculae will have sunspots. Faculae have a weak magnetic strength and give