CHAPTER 3

INSTRUMENTATION AND EXPERIMENTAL METHODS

One of the oldest disciplines in astronomy is spectroscopy. Astronomical spectroscopy has been a very long in astronomy research and it is a very broad and diverse field with many types of applications, instrumentations, techniques and methods. In this research, the experimental and measurement technique is focusing on the application on CCD technology in the observation and equipment setup.

3.1 Introduction

Instrumentation is somewhat a methodology of handling and controlling tools or devices in order to measure desired parameters. The subsequent sections will highlight on the basic concept and technical aspect of the instruments used in this research. The instruments are the telescope, spectrograph and CCD camera.

3.2 The Telescope

3.2.1 The Optical Part

A telescope is an element of observing with duo roles which are collecting electromagnetic radiation and forming an image. The collecting power of a telescope depends on the objective on why the telescope is being built. Usually, the bigger the telescope, the higher its collecting power. In this research, 20-inch reflector Ritchey-Chrétien Optical System telescope has been used in the observations. This 20-

inch RCOS telescope has magnification power from 63x up to 627x with resolving power of 0.28 arc second and ideal intrinsic visual limiting magnitude of 14.5.

A Ritchey-Chrétien (RC) telescope is a specialized Cassegrain reflector. All reflectors typically have an aberration called coma except for the RC. The hyperbolic mirrors of the RC make this design as coma free. This main reason make most professional observatory to have RC design as their telescope.

Other than coma free, in addition, RC also offers two surfaces for less light loss. Usually, more surfaces in a telescope optical system will degrade the amount of light getting to the focal point. So, in order to make less light loss, RC just have two surfaces which is on primary mirror and secondary mirror hence conserving amount of light at its best. Furthermore, this RC has no refractive elements in its optical system. This is due to glass have the potential to scatter light and also degrading the intensity.

For these reasons, the RC usually an ideal choice for medium to large formats of detector either photographic film or CCD camera where large aberration-free field of view is needed. In addition, the RC is also good at visual work due to its design. The telescope was design in order to create better images over large photographic field. Coma aberration makes it difficult to measure star position and since the RC is coma free, producing round stars are a positive possibilities over the entire field.

The hyperbolic surfaces on both mirror also giving advantages for photography and measuring star position or astrometry.

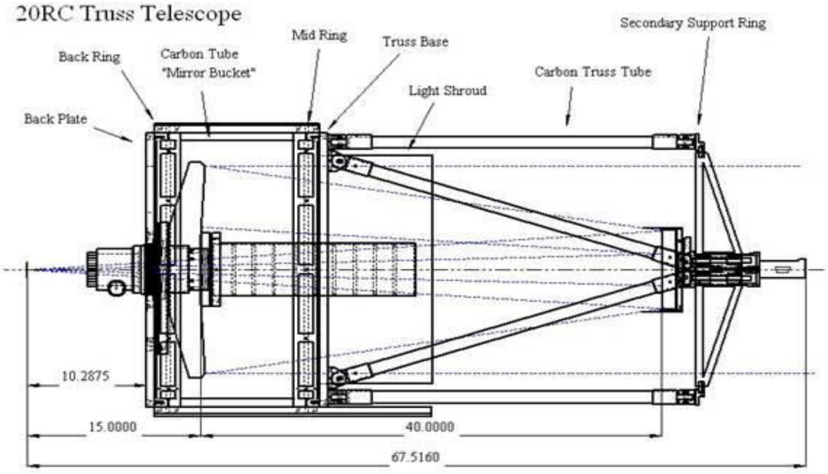


Figure 3.1: A schematic drawing of 20RC Truss Telescope in Langkawi.

Source: Langkawi National Observatory

3.2.2 The Mounting

The telescope was installed on fixed Paramount-ME Robotic Mount. This mount has the ability to track the star movement with sidereal rate and suitable to be used for astronomical survey for whole night. The mount's control system uses brush-less DC Servo motors with its life limited to the service life of the bearings. The approximation of this life period is about 100,000 hours under normal operating conditions. On the contrary, the life of brushed DC Servo motors is limited to the life of the carbon brushes which is about 4,000 to 10,000 hours according to the manufacturer's specification.

Basically, the brush-less motor has more advantages other than its lifespan. It also does not "cog" at any rate which ensures a smooth constant output when tracking. Also, the mount has fast slew speed with consistent torque at all slew rates. A maximum rate of five degrees per second in right ascension and seven degrees per second in declination make the slewing rate fast and saving much time for the observation and exposure time.

Figure 3.2: Paramount ME Robotic Mounting.

Source: S. Bisque

The mount can be control manually and via computer. Joystick is provided in order to slew the telescope manually. However, most of the operation of the mount is controlled by using TheSky software on computer. The software will be discussed further in later section.

3.3 The CCD Camera

Since the invention of charge-coupled device (CCD) at Bell Laboratory in 1970 by Boyle and Smith, it becomes the main choice of detector for astronomical work (Buil, 1991). Thanks to the efficiency of the CCD in collecting light compared to outdated photographic films and plates, especially that the image can be produced figuratively in no time rather than a tiring old process that always take hours. Another bonus of using CCD camera is that the image produced is instantly converted into digital so that it is much easier to be analyzed. Even though CCD is smaller in size compared to photographic plate, which affecting the field of view, the quantum efficiency of CCD is high which is more than 80% rather than photographic plate which is less than 10% (Davenhall et al., 2001). This efficiency value which refers to the fractional number of electron produced for each detected photon.

The basic operation of CCD detector is to convert any incoming light into an electron which then being stored in the detector until it is being read out in order to create image or data to be displayed in the monitor. In general, the CCD performs four kind of tasks to produce image which are charge generation, charge collection, charge transfer and charge detection.

Charge generation is a task that a charge being generated by a phenomenon called photoelectric effect when photos or particles hit certain material, free electron charges are freed.

Then, the electronic charge created by incident photons is being measured. This step is so called charge collection. This step can be simply explained based on the potential well theory.

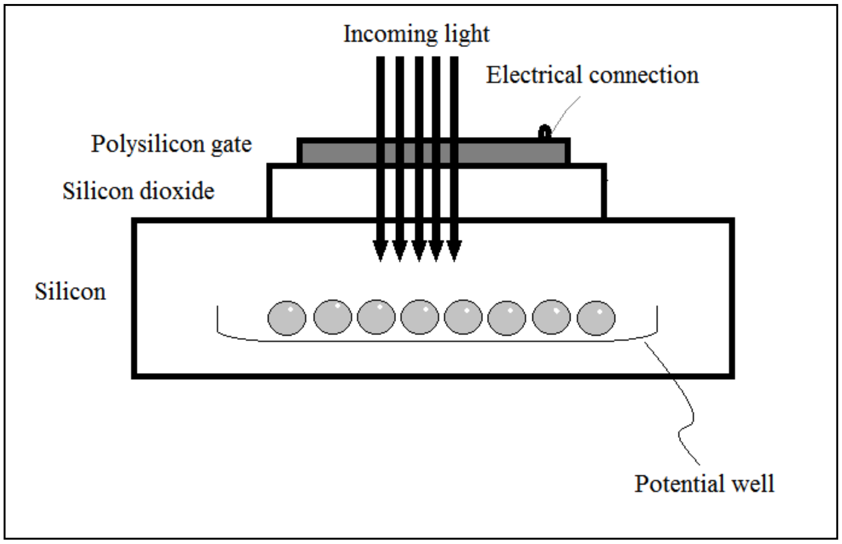


Figure 3.3: A simple illustration on photodetector.

CCD camera imagers are made of silicon. According to the illustration Fig 3.3 which exhibit the potential well theory, a thin layer of silicon oxide is grown on a section of silicon and a conductive gate structure is applied over the oxide. Back to the concept of semiconductor, this silicon can generate electron-hole pairs. Each silicon atom is covalently bonded to its nearest neighbour. Thus, in order to break the bond and create an electron hole pair, energy greater than the gap energy is needed. It is about 1.1 eV. This is the part where photoelectric effect comes to help. Incoming light which is in form of photons of electromagnetic radiation with shorter wavelengths, i.e. shorter than 1 µm, can break the covalent bonds in the silicon crystalline lattice and produce electron-hole pairs.

Next, a positive electrical potential is applied to the gate thus create a depletion region where free electrons generated by the incoming photons can be stored. A potential well will continue to collect any free electronic charge until it is filled.

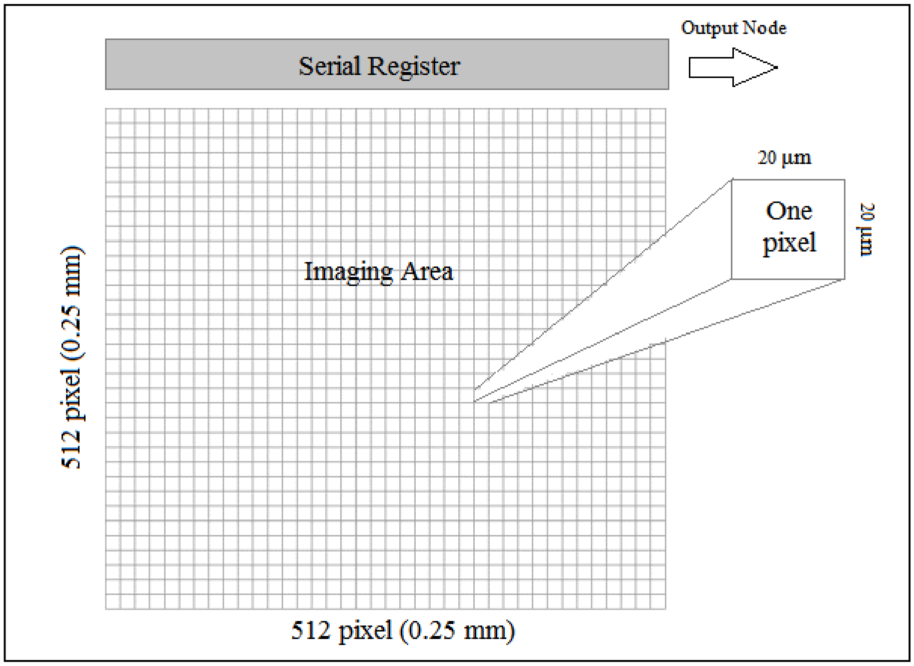


Figure 3.4: Typical 512 x 512 CCD.

A CCD device is commonly composed of an array of potential wells arranged in columns and each of them is capable of storing photon-induced storing charge. Fig 3.4 shows on a typical stylized two-dimensional CCD imager. Imaging area, where the potential wells are located, is arranged in two-dimensional array (x, y) of potential wells and called parallel or vertical register. An image that is focus onto the parallel register creates a pattern of charge in proportion to the total integrated flux incident on each photosite or picture element (pixel). The CCD array can integrate and collect charge over a predescribed period of time which so called as exposure with the total charge collected at a pixel being proportional to the product of flux level and the integration time.

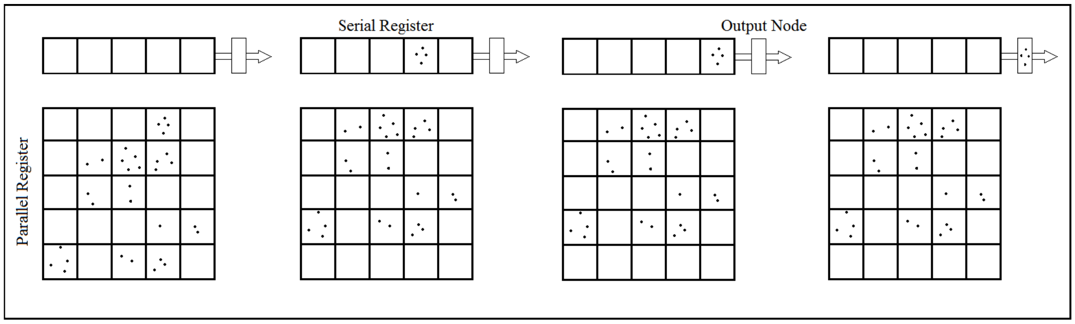


Figure 3.5: CCD readout process.

Then, the next task begins which is charge transfer. During this step, charge transfer is accomplished by manipulating the voltage on the gates in a systematic way so all the charge packets stored in the parallel register will be shifted in parallel one row towards the serial or horizontal register. The serial registers shown in figure 3.5 also known as shift register it is located at the end of each column of parallel register and arranged in one-dimensional CCD. This register collects one line at a time and the transports the charge packets in a serial manner to an on-chip amplifier. Once the charges stored in the top row, they are being shifted from parallel register into the serial register then individually shifted towards the output amplifier.

Lastly, individual charge packets are being converted to an output voltage. This process called charge detection where the output amplifier produced a measurable signal that is proportional to the quantity of the charge in each packet. The voltage for each pixel can be amplified off-chip and digitally encoded and stored in a computer to be reconstructed and displayed on a screen monitor. After the serial register is voided of charge, a second row of charge packets is shifted into that register from parallel register for transport to the output amplifier. As charge is being shifted out of the parallel register, vacant rows are left at the bottom of that register until it is completely empty of any charge. Then, a new exposure can be made and the same process is being repeated.

3.3.1 The Model ST-7E CCD Camera

Every CCD manufactured has its own pros and cons in their performance due to a variety of architectures in developing the CCD. The focus of CCD throughout this research is only considered about the CCD camera model ST-7E.

Figure 3.6: The ST-7E CCD camera with spectrograph coupling.

CCD camera model ST-7E is a front-illuminated CCD where light enters the CCD through a layer of electrically conductive gates of parallel register then the insulation layer before reaching the silicon. There are some drawbacks of front illuminated CCD. One of them is that the light must cross the gate and the insulation before reaching the collection zone. Hence, the efficiency does not exceeding 50% at the peak of spectral sensitivity. Also, the layers crossed become less transparent to wavelength shorter than 450 nm. As a result, it is virtually insensitive below 400nm.

The main job for CCD camera is to detect light and record it as data. There are two kinds of CCD detectors built into this camera. One of them is TC211 which is specifically used for guiding and the other is KAF0401E which is larger in array dimension and smaller in pixel size. This sole purpose for this detector is imaging. Both of them are mounted very close and having the same focal plane which allows the imaging CCD to incorporate while the computer make use of the guiding detector to tracking the object and correct the position of the telescope. The imaging CCD has been built in progressive-scan or full-frame (Berry & Burnell, 2000). It means that the CCD was design to have of a rectangular array of a parallel CCD shift, register, a serial shift register, and a signal sensing output amplifier.

Table 3.1 The comparison of two CCD detectors

Camera	**CCD**	**Array Dimensions**	**Number of Pixels**	**Pixel Sizes**
Guiding	TC211	2.54 x 2.54 mm	192 x 164	13.75 μ x 16 μ
Imaging	KAF0401E	6.91 x 4.61 mm	765 x 510	9 μ x 9 μ

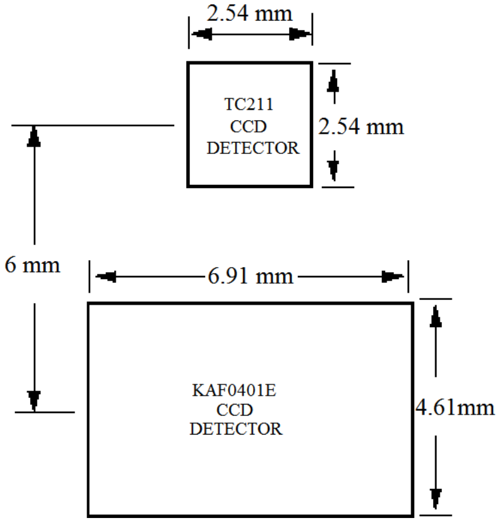


Figure 3.7: The position configuration of two CCD detectors in ST-7E.

Specifically in a full-frame CCD, the exposure is driven by a mechanical shutter. The resultant charges are shifted one row at a time to serial register. After a row is read out by the serial register next row is shifted to the register for read out. The process is repeated until all rows are transferred, at which point the array is ready for the next exposure.

Just like other typical CCD cameras, they work at optimum efficiency at low temperature especially below 0° C. The reason of this is by reason of the thermal heating that generating the noise. The CCD is cooled down by a thermoelectric cooler which pumps heat out of the CCD. Then, the heat is dumped into the air using radiators and a built-in fan. However, there is one other point to ponder which is the forming of frost originated from surrounding humidity on the CCD plate due to the low temperature. Hence, ST-7E is designed with CCD or thermoelectric cooler mounted in a windowed hermetic chamber sealed with an O-ring.

Normally, the larger the pixel size of the CCD, the capacity is larger. The full well capacity for the imaging CCD is 45,000 electrons per pixel. However, the electrons generated still can exceed the capacity of the pixel if the amount of light falls onto a pixel is too much during the integration time thus becoming saturated. Once the pixel is saturated, the exceeding electrons will spill into the neighbouring pixels. This occurrence is called blooming.

A good match between pixel size, focal length and seeing condition helps to optimize the resolution and the sensitivity of the imaging CCD. Usually, smaller pixels and CCDs need shorter focal length telescope in order to produce the same field of view with larger CCDs with longer telescope focal length. However, if the pixel dimensions gets smaller, the pixel size also decreasing, and so does the resolution. Therefore, in order to get an optimum CCD cameras and telescope with seeing conditions, it is required to let the seeing be divided in half and choose a pixel size that offers that half amount of sky coverage.

So as to determine the sky coverage per pixel with any pixel size and focal length of telescope, the equation is useful:

$$\text{Field of view per pixel}= \frac{206265''\times\text{CCD pixel size (mm)}}{\text{focal length (mm)}}\text{arc seconds}$$

3.3.2 CCD Noise

Just like computer, CCD consists of many embedded electronic circuits. So, expectedly, it also generates unwanted noise. Noise contributes to uncertainty of estimation for some quantity or variables in measurement. Since all CCD cameras consist of electronic circuits, noise is something that can be assumed as uninvited acquaintance. The effect of this noise on the performance of the CCD is described as the signal-to-noise ratio (SNR). It is the ratio of the measured signal upon the overall measured noise on a particular pixel.

The primary sources of noise in CCD camera are photon noise, preamplifier noise and dark current noise. To understand our signal we must first understand these noises and how to differentiate it (Howell, 2000).

Firstly, the photon noise derived from the nature of the photon itself. The total number of photons emitted by a source over a period varies abiding by Poisson distribution. This property is being measured by the CCD thus giving the same character. As a result, the photon noise can be calculated as:

$$\text{Noise} = \sqrt{\text{signal}}$$

This photon noise cannot be avoided in imaging systems.

Secondly, the preamplifier noise which is also known as read-out noise. This type of noise is generated by the on-chip output amplifier. In detail, the noise is the uncertainty presents during quantifying the electronic signal on the CCD. By having a careful condition during operation, this noise can be reduced.

Thirdly, the dark noise. This noise arises from dark current which is thermally generated charge from thermal energy within the silicon lattice. It is also called dark current. The thermal electrons are generated also according to Poisson relationship for a given temperature and exposure. Even though the noise component cannot be avoided, it still can be measured and reduced from data. The noise can be decreased by assigning a cool temperature for CCD from room temperature with about 25 ^{o}C in difference.

Hence, the total noise of CCD can be taken as:

$$\text{Total noise}=\sqrt{\text{photon noise}^2+\text{pre-amplifier noise}^2+\text{dark noise}^2}$$

3.3.3 CCD Characteristics

There are some terms that were used in characterising the ST-7E. They are conversion factor, read-out noise, CCD linearity, CCD uniformity, and dark current.

Conversion factor or gain is a way of knowing the number of electrons represented by each count of analogue-to-digital unit (ADU) or electrons per ADU. The pre-amplifier noise and dark noise of the CCD can be determined by this information. Read-out noise is the irreducible bottom line for noise in a CCD chip. It is the random variation in the output of the CCD when no signal is present. It is customarily expressed as the root-mean-square variation in the number of electrons detected by the CCD.

CCD linearity is a measure on consistency of CCD responds to the light over its well depth. In ideal case, the images are cleaned which is accurately dark-subtracted and flat-fielded. But, CCDs turn out to be nonlinear when the charge wells on the CCD reaching saturation phase (Berry & Burnell, 2000).

Different with CCD linearity, CCD uniformity is regarding to the variation in the sensitivity of the photosites towards the incident light. Across the whole CCD, the variations between neighbouring pixels are usually less than 1% but some can reach up to 10%.

Dark current is the electron that is accumulated from thermally generated electrons that grows linearly with time which is unexpectedly generated in the CCD even when the detector does not receive any incoming light. The rate of dark current can be decreased by having the CCD to be cool down.

3.4 The Spectrograph

The main purpose of spectroscopy is to disperse electromagnetic radiation as a function of wavelength. Since light is also part of electromagnetic radiation, optical spectroscopy is the one that focus on the visible wavelength only. Light from stars gathered in a telescope will be focused at a single point. Hence, it is required to have auxiliary optical element to disperse the light so that different wavelengths can be let fall on different positions on the detector. Such devices are called spectroscopes when used visually and spectrographs when the spectrum is recorded on photographic film or with an electronic digital imaging device.

Spectrographs are vital astronomical tools for analyzing the spectra of stars and other celestial objects. They are usually mounted at the Cassegrain focus point of reflecting or refracting telescope. The basic concepts of a spectrograph including the fundamental components make this equipment very useful. There are an entrance, a collimator, a dispersing element, a focusing element and a detector.

An entrance is a component where the light is getting into the spectrograph. There are several types of entrances such as objective prism, grating-prism and slit.

Prism is a typical optical element with transparent and flat surfaces that can refract light. Prism should have at least two surfaces with an angle between them and that refraction angle of the light passing through the surface depends on materials which was created with different refractive indices. The refraction inside the prism and the difference in wavelength makes the light disperse. Hence, in objective spectrograph, a prism is places in front of a telescope to disperse the light before it enters the telescope. Then, the dispersed light is brought to focus as a spectrum. This spectrograph can be used to survey and catalogue large numbers of stars in a short time.

Grating-prism or so called grism is a transmission grating combined with a prism. This system usually corrects some of the optical aberrations produced by the grating. It is placed in the beam of light converging towards focus. The grating disperses the light into spectrum and prism refracts the beam so that the spectrum is formed directly behind the grism.

Slit spectrograph, however, allows light from the telescope to be focused onto it before going to the dispersing element and detector. The dispersing element in this type of spectrograph is ideal for making medium to high dispersion spectra with precisely calibrated wavelength (Berry & Burnell, 2000). Alternatively, the slit can be used to select part of the source of an extended object and thus prevent the list from overlapping (Martinez, 1994).

The collimator is used to turn the diverging bundle of rays from the slit into a single parallel beam. In order to get this, the distance between the slit and the collimator should be equal to the collimator's focal length.

The dispersing element is important in a spectrograph, without it, it is not a spectrograph. The dispersing element is an optical component that split the light into its component wavelength. There are two main types of dispersing element which are prism and grating diffraction.

Prism is a transparent optical element which refracts light. Since light is composed of various wavelengths, when light enters the prism; it will be refracted differently and exits the prism at slightly different angles. The short wavelength will undergoes greater refraction. Thus, the red has undergone less dispersion than the blue wavelength at the output surface of the prism. Even though prisms are quite efficient which allows all the light entering it to exit but their dispersion is irrational hence making the spectrum to be non-linear. The refracting nature of prism causes the red lines in red wavelength region to be closely space and concentrated than in the blue region. Hence, this output characteristics would give some difficulties' during wavelength calibration process.

Grating is a fine grooves embedded adjacently on a glass or a metal substrate. A typical grating usually consist of thousands lines per inch. It is the most commonly used as dispersing element in spectrographs. The principle of grating is based on the interference effects which produced by thousands of apertures instead of two in a simple interference basic.

Grating has two types which are reflection grating and transmission grating. In a reflection grating, mirrors are used instead of the apertures so it reflects the diffracted light in the same direction it comes from. Normally, reflection gratings are flat but there is also a reflection grating with special concave surface in order to be a single optical element that can both disperse light into a spectrum and converge it to focus. The mirrors are bound to make a groove at each of the individual mirrors to give an effect like the single aperture but with single aperture, the light would concentrate into zero order, which is not a spectrum. To solve this, the individual mirrors have to be tilted so that the single aperture maximum is directed towards the order of spectrum that is of interest. This is called 'blazing the grating', and can concentrate up to 90% of the incoming light into the desired spectrum. The advantage of blazed reflection grating is the decrease of overlapping with different orders. For transmission grating, diffraction grating is used to allow the beam of light to pass through the apertures and form the spectrum behind the grating. The apertures are used to produce the spectrum and generate up to ten or more different orders and reducing the intensities of the incoming light up to 90% or more (Kitchin, 2010).

3.4.1 Self Guided Spectrograph

The spectrograph used in the research has been design for working with ST-7E CCD camera as detector. It is using a slit as light entrances and flat reflection gratings to disperse the light into spectrum. This spectrogram is an Ebert-Fastie configuration, with one spherical mirror serve both as collimator and camera lens. It is a common design and used widely by researchers.

The spectrograph has eight mirrors to reflect light from the telescope in such way so that the spectrum can be viewed and recorder by the CCD camera at the back of the bulk of spectrograph. Most of the optical parts in the spectrograph are fixed except the focusing lens to the detector.

One advantage of this spectrograph is that the image position can be view to ensure it is on the slit as it supposed to before it being recorded. In this research, the spectrum is being recorded by the imaging CCD, oriented long-ways so the spectrum falls across 763 pixels with a height about 16 pixels for stellar sources. Spectral coverage is about 750 Å per frame for high-resolution grating or 3200 Å per frame for low-resolution grating.

Figure 3.8: The spectrograph without the cover.

The configuration of the Santa Barbara Instrument Group (SBIG) Self Guided Spectrograph is fixed for the usage of ST-7/8 CCD camera. It is useful since the camera has two built-in CCDs inside, one for star or light source guiding and the other for the imaging. Both CCDs view the same field and has the same focal length. The attached spectrograph with the CCD camera is fed at the back of the telescope before observation being done. The object of interest then viewed on the guiding CCD at the same time with the slit. The slit is backlit by the LED during the setup to render it clearly visible in the guiding CCD.

The target is put manually into the slit using the telescope controls and focused by the telescope. The slit is tilted 80^o-85^o to the optical axis of the telescope so as to reflect back the light off the slit and can be imaged onto the guiding CCD. The guiding CCD has an important part since it generates a direct image of the star field to be aimed by the spectrograph. This view is used to obtain, focus and center images onto the slit. The imaging CCD serves only to grab and record a spectrum across a few rows of pixels and does not shows a straight view of the field upon which the spectrograph is projected.

The spectrograph is also containing a series of lenses and mirrors to reflect light from the telescope to the guiding CCD. At the same time, the same light from the telescope is being passed through a slit, to a collimator, then go to the diffraction grating to be dispersed and reflected back to the imaging CCD. The design of the mirrors is free from any chromatic aberration so it is appropriate to in forming a good spectrum. Below is the illustration on how the light path from telescope being reflected and transmitted within the spectrograph.

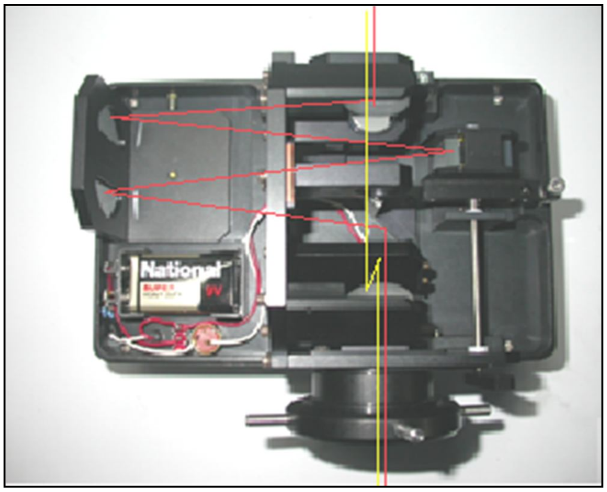


Figure 3.9: The plan view illustrating the path of light from the input (telescope - below) to the output (CCD - above). Red is the light path for imaging while yellow is the light path for guiding CCD.

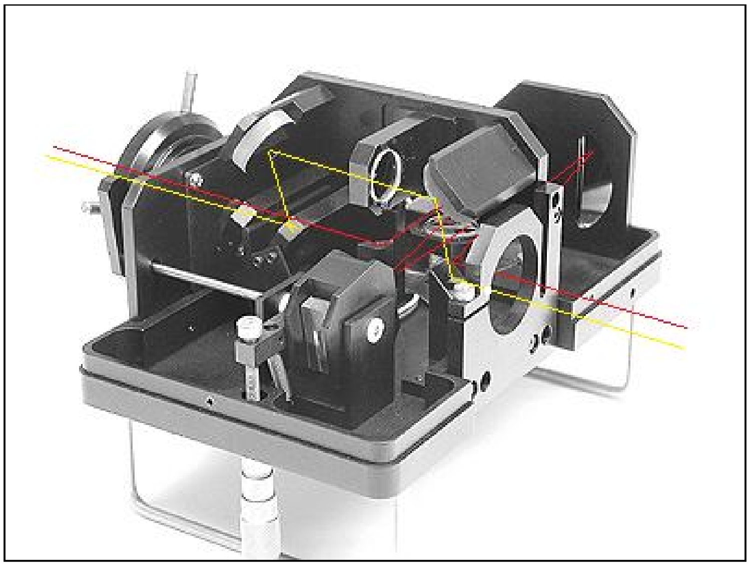


Figure 3.10: The illustration of the path of light from the source (left) to the output (right). Red is the light path for imaging while yellow is the light path for guiding CCD.

At the base of the spectrograph, there is a small window. The purpose of this widow is to allow light from reference wavelength source such as neon lamp for wavelength calibration.

The spectrograph is also equipped with two reflection ratings on both side of a rotating carousel that can be controlled by an external lever. One of the gratings has 600 lines per millimeter which is high resolution. It can produce a spectrum with 1 Å per pixel. The low-resolution grating has 150 lines per millimeter and produce a 4 Å per pixel spectrum. Appendix B gives the values on dispersion and resolution of the spectrograph.

Figure 3.11: The micrometer screw outside the spectrograph.

A micrometer screw is located on the outside of the spectrograph. The purpose screw is to control the tilt of the grating so that the desired wavelength can be seen in the imaging CCD. This can be done while doing wavelength calibration with element light source.

The slit can be backlit by LED from behind especially to make it bright in order to be seen in the guiding CCD. The battery-powered LED can be controlled by an external switch so that the LED can be switched off whenever it is not necessary because it can disturb and spoil the image data. It is important to check the LED battery and inserting the suitable slit before the spectrograph is attached to the telescope. In this case, 72 microns wide or 8 arcseconds 80 inch focal length. The most vital thing is to make sure the slit is aligned and focused. The slit in the guiding CCD can be seen whenever the LED is lit on or if there are surrounding light in front of the telescope coupling. The alignment is being done by adjusting the second fold mirror. Once the slit is located at the center of the guiding CCD, it is aligned. The slit also need to be focused by adjusting the focus achromatic lens. The focused slit image is sharp with 1 or 2 pixel wide. The mirrors inside the spectrograph also needed to be aligned so that the light and the spectrum of the star can be detected by CCD camera.

The second thing that is needed to be done is focusing the spectrometer. Once the slit is in the correct position, it is easy to capture the spectrum of calibration lamp. Place neon or mercury lamp at the small window below and capture the spectral line image by using the imaging CCD detector with focus mode. The spectrometer can be focused by adjusting the spherical mirror towards or away the grating until the spectral line image is sharp. Even though all adjustment is very tedious, it must been done or the data is trash.

3.5 The Software

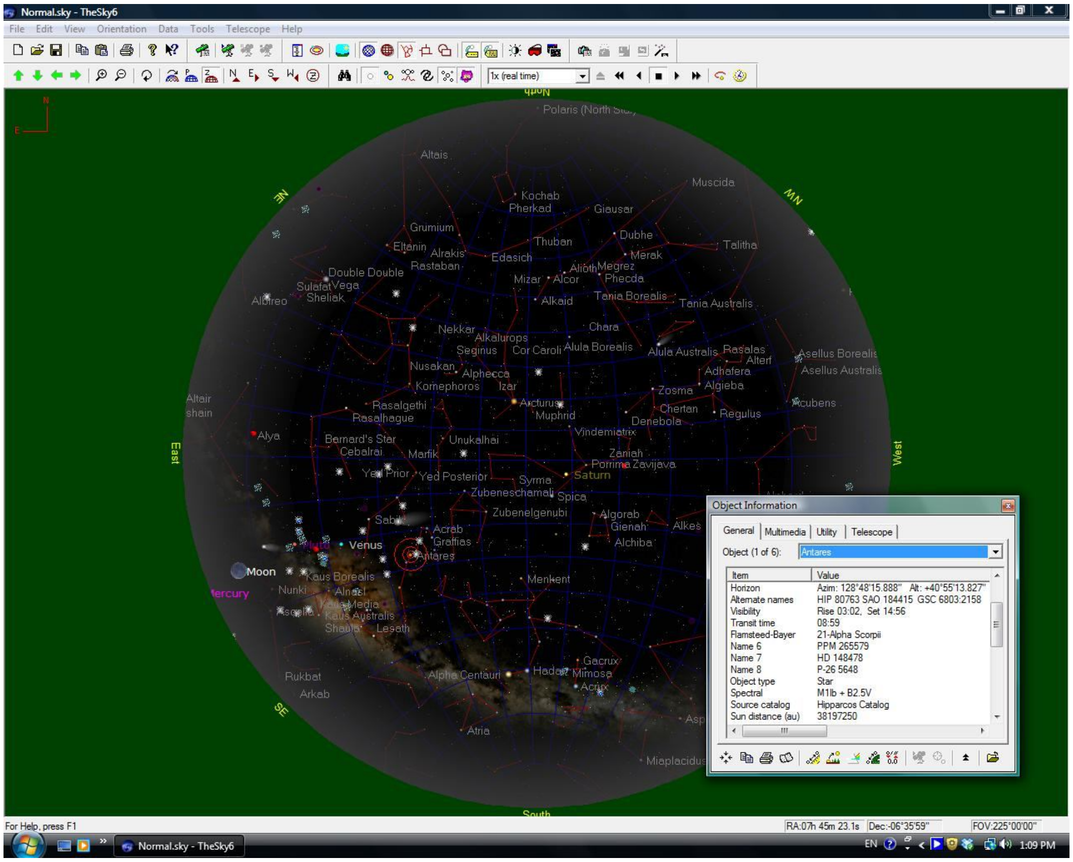
In this modern world where digital technology accompanies in every aspect of life, the astronomical world is not exempted. Most of the works are using computer in assisting the handling, controlling, tracking, recording, data saving and analyzing. Hence, software is one of the elements that cannot be avoided while doing astronomical works and processes.

3.5.1 The Sky6

TheSky6 software is interactive software released by Software Bisque, Inc. The main purpose of this Microsoft Windows-based software is to aid astronomers from various backgrounds, from professional astronomers to amateur astrophotographers, from postgraduate astronomy students to backyard astronomy beginners. The software contains various useful applications and features. One main feature is the real-time sky chart. The chart shows a visual night sky that can be seen from a given coordinate on earth. It also can be changed according to any desired location all around the earth and desired time and season.

The good part of this software is that it can be used to drive the robotic mount and at the same time as the telescope control center. It is no wonder this software is widely used in most observatories in the whole world.

The Sky6 also consists of extensive databases that can be updated with lots of information on planets and stellar to galaxies and many deep sky bodies.



Object Information

General | Multimedia | Utility | Telescope

Object (1 of 6): Antares

Item	Value
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Visibility	Rise 03:02, Set 14:56
Transit time	08:59
Flamsteed-Bayer	21-Alpha Scorpii
Name 6	PPM 265579
Name 7	HD 148478
Name 8	P-26 5648
Object type	Star
Spectral	M1Ib + B2.5V
Source catalog	Hipparcos Catalog
Sun distance (au)	38197250

Figure 3.12: The software interface that shows the interactive star chart.

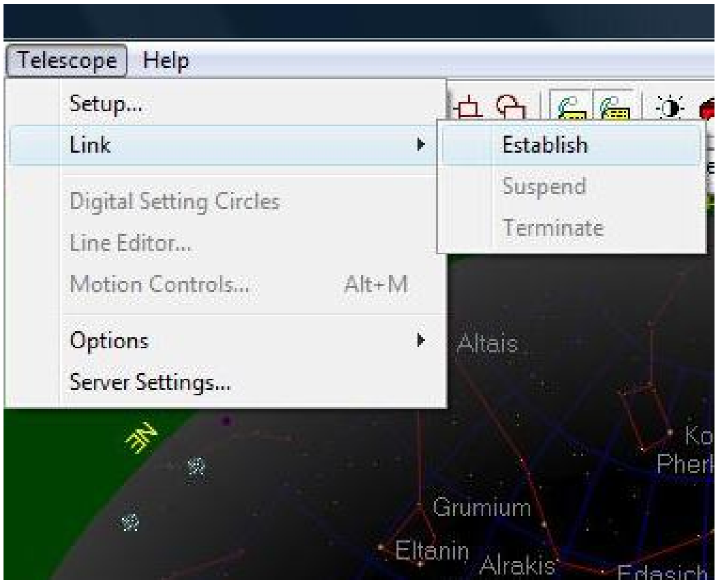
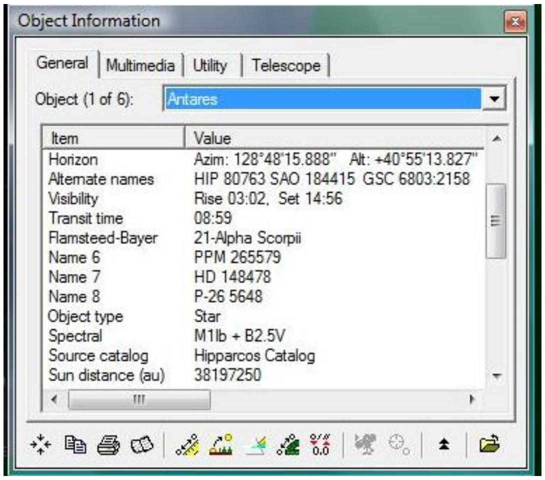


Figure 3.13: The software option to connect with telescope. The telescope cable has to be made sure is connected first with the telescope.

In general, the popped up information windows shows information such as celestial coordinates, rise and set time, the magnitude of the object and alternative catalogue names. Another plus is that it shows the information on spectral type for stars as reference. Hence, it is easier to plan the target stars right before the observation session.

Information on magnitude also assisting the preparation since the exposure time is depending on the magnitude of the star. The higher the magnitude of a star, the longer the exposure especially when the light is being dispersed, the intensity of the original light is reduced. So, by using that information, we can relate the exposure time for each star in a night so that the observation session goes on smoothly.



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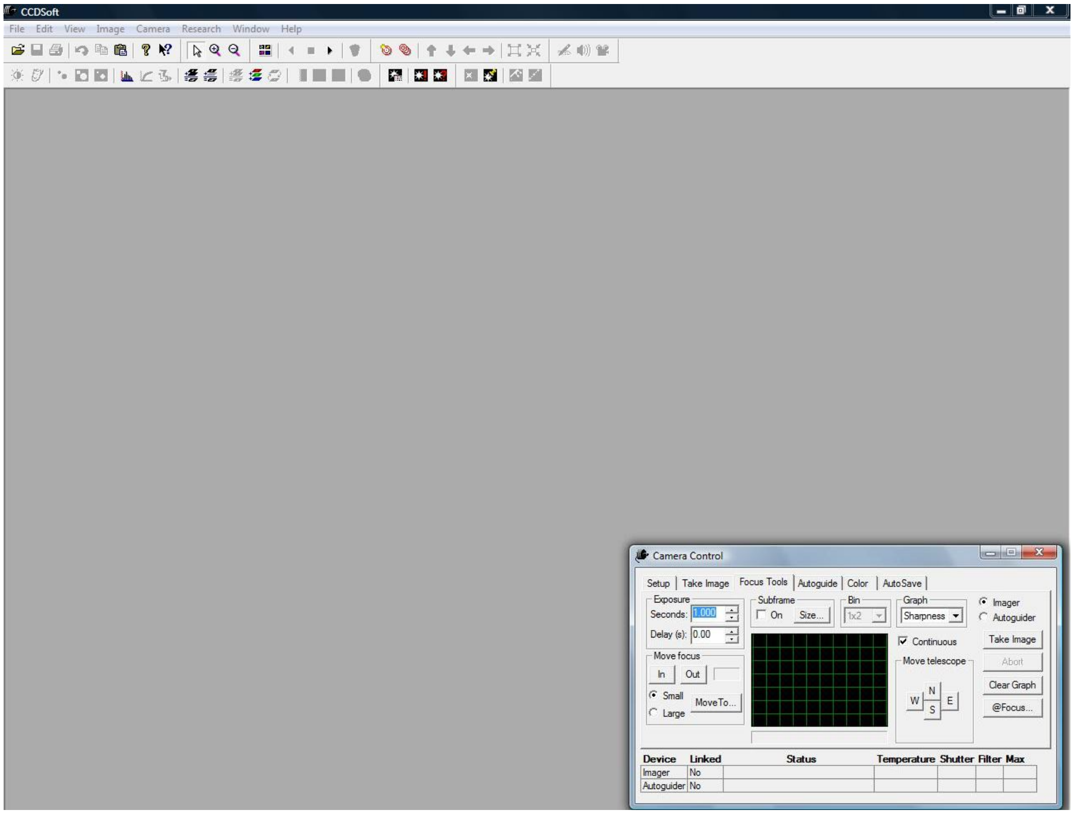
Name 8	P-26 5648
Object type	Star
Spectral	M1Ib + B2.5V
Source catalog	Hipparcos Catalog
Sun distance (au)	38197250

Figure 3.14: The information on celestial objects popped up whenever the object is being clicked.

3.5.2 CCDSoft

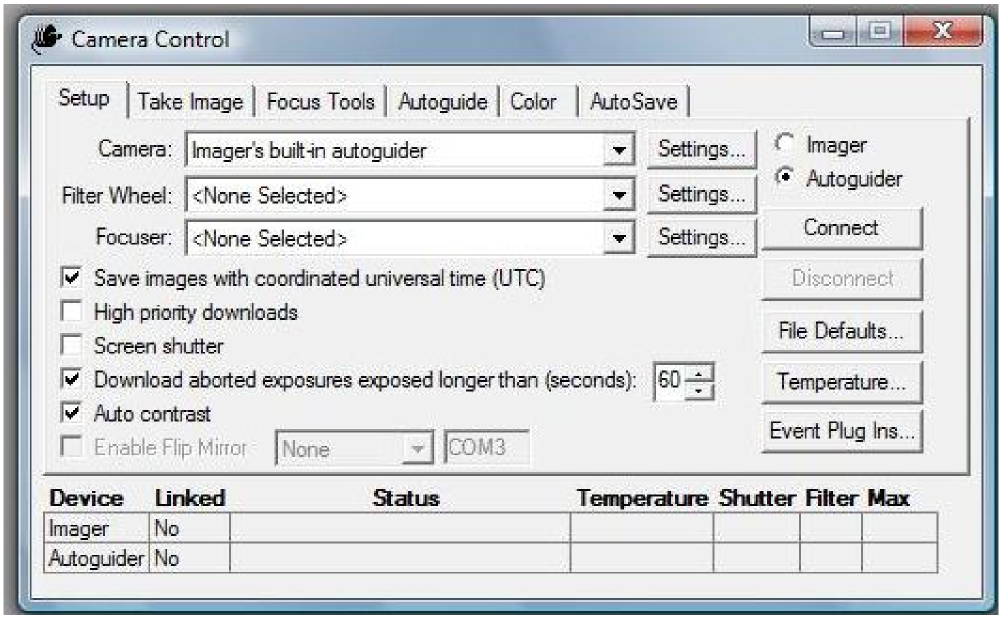
CCDSoft is another software that is released by Software Bisque, Inc. It is mainly used for CCD camera control, image processing and data reduction. Hence, it is a good software application for astronomers. Furthermore, CCDSoft works well with The Sky6 in controlling telescope, filter wheels and CCD camera.



Seconds: 1.000
Delay (s): 0.00
☐ On
1x2
Sharpness
● Imager
○ Autoguider
☑ Continuous
● Small
○ Large

Device	Linked	Status	Temperature	Shutter	Filter	Max
Imager	No					
Autoguider	No					

Figure 3.15: The CCDSoft software interface with popped up camera control operating windows.



Camera: Imager's built-in autoguider

Filter Wheel: <None Selected>

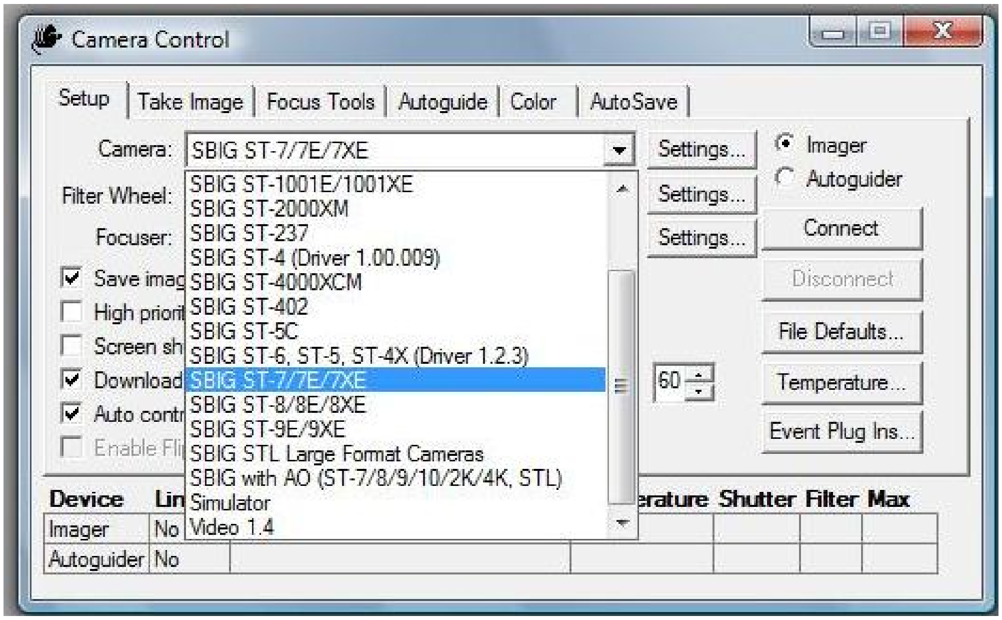
Focuser: <None Selected>

○ Imager
● Autoguider

☑ Save images with coordinated universal time (UTC)
☐ High priority downloads
☐ Screen shutter
☑ Download aborted exposures exposed longer than (seconds): 60
☑ Auto contrast
☐ Enable Flip Mirror None COM3

Device	Linked	Status	Temperature	Shutter	Filter	Max
Imager	No					
Autoguider	No					

Figure 3.16: Camera Control windows have various options to control the CCD.



Camera: SBIG ST-7/7E/7XE

Filter Wheel:

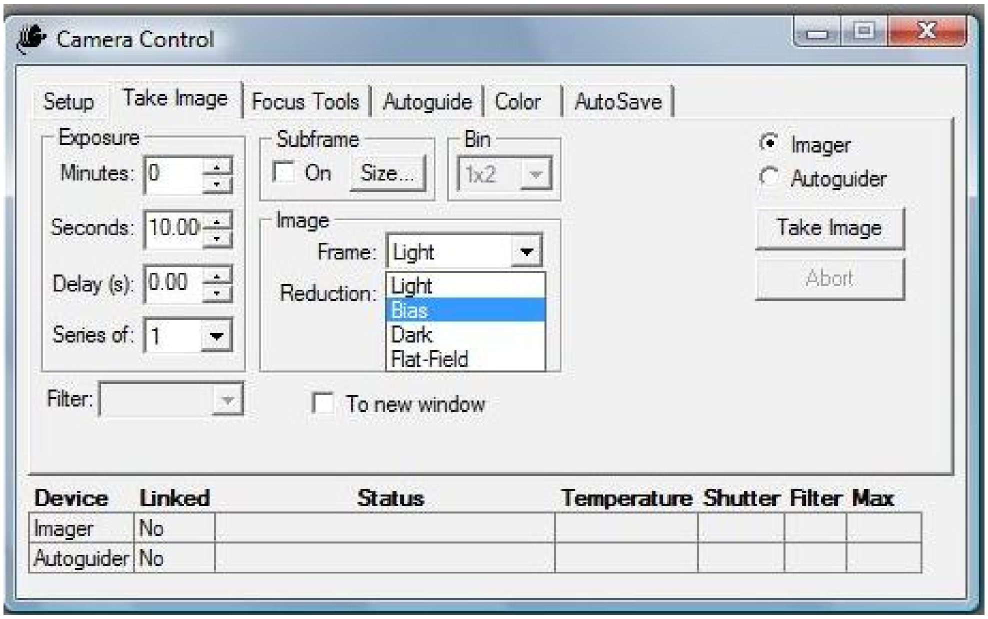
Focuser:

● Imager
○ Autoguider

SBIG ST-1001E/1001XE
SBIG ST-2000XM
SBIG ST-237
SBIG ST-4 (Driver 1.00.009)
SBIG ST-4000XCM
SBIG ST-402
SBIG ST-5C
SBIG ST-6, ST-5, ST-4X (Driver 1.2.3)
SBIG ST-7/7E/7XE
SBIG ST-8/8E/8XE
SBIG ST-9E/9XE
SBIG STL Large Format Cameras
SBIG with AO (ST-7/8/9/10/2K/4K, STL)
Simulator
Video 1.4

60

Figure 3.17: The CCDSoft already have various options of camera to be integrated with.



Minutes: 0

Seconds: 10.00

Delay (s): 0.00

Series of: 1

☐ On

Bin: 1x2

Frame: Light

☐ To new window

● Imager

○ Autoguider

Device	Linked	Status	Temperature	Shutter	Filter	Max
Imager	No					
Autoguider	No					

Figure 3.18: Frame option in the software.

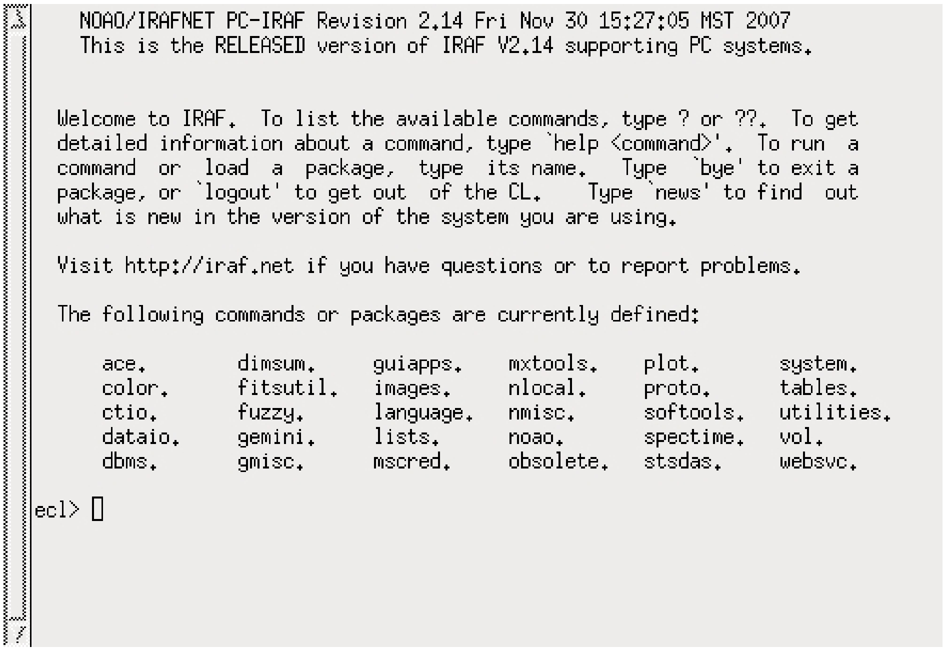
The software also has temperature control of the CCD so that the camera can be cool down by just a click away. Of course, there is some time needed for the temperature to drop. It is advisably to drop the temperature a few degrees at a time (e.g. 5^{o}C) and repeat it until the targeted temperature is achieved rather than just set it directly to the wanted temperature because the process will make the cooler struggle more.

Autosave function is another good feature that CCDSoft has. It saves time if there are continuous frames to be captured. The software also names the files with number of frame sequence, added prefix according to star names or coordinates and frame type. Hence, it is easier to relate with log note or compare the files.

3.5.3 IRAF

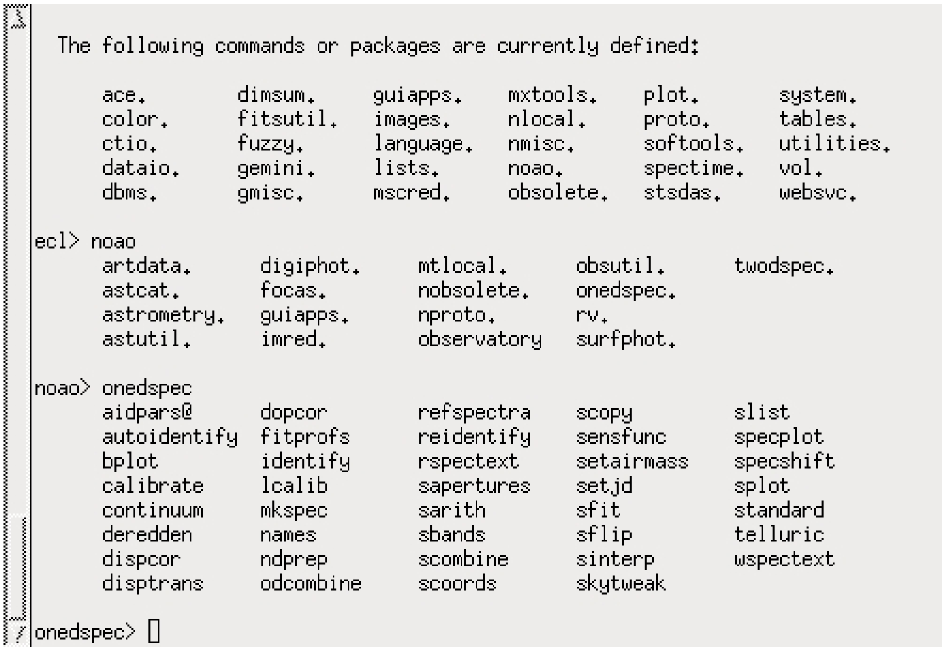
The Image Reduction and Analysis Facility or IRAF is a software system offered by National Optical Astronomy Observatory (NOAO) of the United States. The main idea of this software is for data reduction and analysis especially for optical astronomy data, with image processing and graphics application. The system can be installed and used on computer with UNIX-like operating systems such as Linux. This facility is also possible to be used on Microsoft Windows with aid of command-line interface namely Cygwin.

Users have to use command language (also known as tasks) to control which program to run. The command language handles all communications to the user terminal and all applications programs run as concurrent sub processes of the command language process. A graphics kernel process is also linked to the command language as a sub process.



```
   NOAO/IRAFNET PC-IRAF Revision 2.14 Fri Nov 30 15:27:05 MST 2007
   This is the RELEASED version of IRAF V2.14 supporting PC systems.


  Welcome to IRAF.  To list the available commands, type ? or ??.  To get
  detailed information about a command, type `help <command>'.  To run  a
  command  or  load  a  package,  type  its name.   Type  `bye' to exit a
  package, or `logout' to get out  of the CL.    Type `news' to find  out
  what is new in the version of the system you are using.

  Visit http://iraf.net if you have questions or to report problems.

  The following commands or packages are currently defined:

      ace.        dimsum.     guiapps.    mxtools.    plot.       system.
      color.      fitsutil.   images.     nlocal.     proto.      tables.
      ctio.       fuzzy.      language.   nmisc.      softools.   utilities.
      dataio.     gemini.     lists.      noao.       spectime.   vol.
      dbms.       gmisc.      mscred.     obsolete.   stsdas.     websvc.

ecl> ▯
```

Figure 3.19: Various commands and packages are offered in the software.



```
  The following commands or packages are currently defined:

      ace.        dimsum.     guiapps.    mxtools.    plot.       system.
      color.      fitsutil.   images.     nlocal.     proto.      tables.
      ctio.       fuzzy.      language.   nmisc.      softools.   utilities.
      dataio.     gemini.     lists.      noao.       spectime.   vol.
      dbms.       gmisc.      mscred.     obsolete.   stsdas.     websvc.

ecl> noao
      artdata.      digiphot.     mtlocal.      obsutil.      twodspec.
      astcat.       focas.        nobsolete.    onedspec.
      astrometry.   guiapps.      nproto.       rv.
      astutil.      imred.        observatory   surfphot.

noao> onedspec
      aidpars@      dopcor        refspectra    scopy         slist
      autoidentify  fitprofs      reidentify    sensfunc      specplot
      bplot         identify      rspectext     setairmass    specshift
      calibrate     lcalib        sapertures    setjd         splot
      continuum     mkspec        sarith        sfit          standard
      deredden      names         sbands        sflip         telluric
      dispcor       ndprep        scombine      sinterp       wspectext
      disptrans     odcombine     scoords       skytweak

onedspec> []
```

Figure 3.20: Tasks within ‘noao’ package.

There is a special suite package in IRAF namely ‘noao’ which is very suitable for data from spectroscopy. There are essential reduction operations that derived from basic arithmetic function in order to achieve clean spectral data, extract the spectrum and calibrate the wavelength.

The program is able to perfrm the image reading in one, two or three dimensions. Furthermore, this program also able to do measurable calculation including the root mean square value, full width at half maximum.

IRAF reads compatibly for .fits or .imh file format while also reads and generate .dat file as log or text record.

3.6 Experimental Setup and Method

3.6.1 The instrumental setup

The telescope used in this work is 20 inch Ritchey-Chrétien Telescope which is installed to the Paramount ME robotic mounting. To start operating the paramount, the serial port cable needs to be connected from the paramount to the computer. By using The Sky6 software, the telescope can be directly slewed to the targeted object in the sky. T-point of the telescope needs to be updated once in a while. The main purpose is to make sure the telescope always point to the right object and right direction whenever it is commanded. If not, we might easily confuse the targeted star with others since it is hard to differentiate the stars in monochromatic CCD monitor except the magnitude.

After the spectrograph and CCD camera are attached to the telescope, the telescope needs to rebalance again by adjusting the position of the counterweight at the counterweight shaft on the telescope. This process is to avoid any unbalance on the telescope due to the additional instrument weights attached on it. The unbalance can cause damage to the paramount gear. Lastly, operate the telescope by link the power via the computer.

At the same time, the CCD camera can be switched on by linking it with the software provided. Then, the cooling process needs to be done first. While waiting for the cooling takes place, preparation on the folder directory and log update can be done. Once the desired temperature is reach, the camera is ready to be used.

The spectrograph needs to be watched all the time because wavelength calibration frame needs to be done once in a while during the same observation session. Usually, for every star directed, one wavelength calibration frame is captured to ensure the spectrum is not drift away. Hence, the small window at the bottom of the spectrograph is required to be closed whenever the wavelength calibration frame is done.

Figure 3.21: The telescope, the spectrograph and the CCD camera are all attached together in Langkawi National Observatory.

3.6.2 Data Processing

Additional frames have been taken during observation session other than raw data. They are bias frames, dark frames, flat-field images and calibration spectral reference frame. All of those frames are captured by using CCDSoft software. The raw data contain "detector signatures" which is consisting of DC-offset and dark noise generated from thermal current. These features had to be removed from the data by doing data reduction. Hence, the raw data are needed to be subtracted from its bias and dark frames. Another feature exists in raw data is pixel variations and optical defects. In order to have linear data which is zero counts equal zero light, that images has to be divided with flat-field frame.

$$\text{Clean Data}=\left(\frac{(\text{Raw-Bias})\text{-}(\text{Dark-Bias})}{(\text{Flat-Bias})}\right)$$

Chapter 4 will discuss more on the data reduction process with the analysis from the observed data.