

Remote sensing of sea state through a Polaroid

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ABSTRACT

The visible light reflected from a wind-roughened sea surface contains information about the sea state in the form of its polarisation status. Each sea state is characterised by a specific wave-slope distribution depending upon the nature of surface winds. This in turn, imparts unique polarisation characteristics to the light reflected from a wind-roughened sea surface in accordance with Fresnel's reflection laws as established by earlier studies. In this paper, we discuss the significance of surface reflected light in the context of using it for remote sensing of sea state. We propose the design for an instrument that will view the wind-roughened sea surface over a period of time and compute the fraction of plane polarised light received by it. The results then can be related to the sea state and the wind speed prevailing over the sea. The instrument can be made to view the sea surface at any look angle though the angles in the range of 30-40 and 65-70 degrees are found to be preferable for better resolution of sea states. The proposed instrument can be mounted on an observation tower, aircraft or a satellite. The range of wind speeds that can be sensed by the proposed instrument is 0-60 knots.

INTRODUCTION

Light received by an optical sensor looking at the sea surface consists of three main components, namely, the ocean colour, the surface reflected light and the atmospheric haze. Ocean colour is that radiation, which had previously entered into the seawater and has been backscattered and emerged out of the sea surface. Spectral character of ocean colour gets altered as a result of its interaction with the seawater and its various constituents. On the other hand, the surface reflected light does not interact with seawater or its constituents and thus retains its original spectral character to a large extent. It however contains information about the sea surface particularly, its physical shape. The atmospheric haze is that light which gets backscattered by the atmosphere into the direction of the sensor. The haze never reaches the sea-surface and thus contains no information about the sea-surface or its interiors. This description can be summarised through Fig 1.

The ocean colour is used for remote sensing of chlorophyll, suspended sediments and yellow organic dissolved matter. The surface reflected light and atmospheric haze both serve noise in the analysis of ocean colour. Most of the software that is developed for remote sensing of ocean colour deals with removal of this noise rather than analysis of ocean colour. The surface reflected light is generally not considered significant in optical remote sensing and is rarely measured. It is discarded along with atmospheric haze as noise. The present paper deals exclusively with the surface reflected light and shows that it is possible to remotely sense the sea state with an instrument that measures it through a variety of look angles. We describe essential components of such an instrument in the paper.

There have been many early attempts in the past to study the surface reflected light as a signal that conveys useful information about the sea surface. As early as in 1954, Burt (1954) had used polarisation characteristics of reflected light to estimate near accurate albedo of the sea as a function of wind speed. Assuming ocean to be flat and lying beneath a standard Rayleigh atmosphere, Fraser and Walker (1968) estimated intensity and degree of polarisation at the top of the atmosphere. Through an extensive study of aerial photographs of sun-glitter pattern on the seas surface, Cox (1974) showed that the specularly reflected light from the sea can be directly related to the sea state. Takashima and Masuda (1985) have computed the polarisation status of diffuse reflected light and shown it to be related to the atmospheric conditions while Sathe and Vaithyanathan (1994) have proposed a model to accurately compute directional properties of

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wind-roughened sea surface that includes contribution due to foam. Henderson et. al. (1997) have computed polarised emissivity of wind-roughened sea surface using a Monte carlo model. In all such studies, the surface reflected light becomes the signal while ocean colour serves as noise.

Further, all such studies that estimate the sea surface reflectance from Fresnel's laws assume that all light incident on the sea, both direct and that coming from the clouds to be unpolarised. The marginal polarisation characteristics acquired (if any) by light by multiple scattering while passing through atmosphere and ocean would be in innumerable varying planes and such a light would become indistinguishable from ordinary unpolarised light.

A wind-roughened sea has a dynamic surface whose slope fluctuates in space and time. This imparts to the reflected beam of light a continuously varying polarisation status. As long as the source of upwelling light is reflection (as against ocean colour), Fresnel's laws of reflectance hold. They imply that the perpendicular component of polarisation P_r would always exceed the parallel component P_i in reflected radiation regardless of its direction. When the incidence angle happens to equal Brewster's angle (52.13°), the resulting reflected beam of light has only the perpendicular component P_r . In other words, the reflected light is plane polarised. Assuming the wave-slope distribution of the sea surface to be Gaussian, such a probability (namely, the probability of incident beam of light arriving at the sea surface at Brewster's angle) can be determined. This probability is a function of sea state and the look angle. See Sathe and Ajoy Kumar (1990) for a development of such probability functions associated with a variety of wind speeds and look angles. In this paper, we propose an instrument that looks at the sea surface in a given look angle and computes the probability of receiving plane polarised light and thereby computes the sea state.

BASIC CONCEPTS

Sea state is characterised by how rough the sea is. By roughness we mean the non-smooth nature of the sea surface. A calm sea has no waves, not even ripples. Waves can be steep or gentle. Steepness of wave is quantified as wave slope. Gentle waves can have very small wave slopes ($<10^\circ$) while steep waves can have slopes approaching 90° . Winds that blow on the sea surface are the primary cause of wave. For every wind speed at the sea surface, there is an associated wave slope that can be computed by Cox and Munk Law by the well known relationship, $\tan^2(\phi) = 0.003 + 0.0512*W$. $\tan^2(\phi)$ in this relationship is the mean square wave slope and W is the mean wind speed in meters per second. Assuming further that the wave slope distribution around its mean $\tan(\phi)$ is Gaussian, the probability function $p(\theta)$ for occurrence of any given wave-slope $\tan(\theta)$ can be computed from the expression $p(\theta) = \exp(0.5x*\tan^2(\theta)/\tan^2(\phi))$.

Thus, we can compute the probability of occurrence of any wave slope ($\tan(\theta)$) under a given wave slope distribution ($\tan(\phi)$), which in turn, is governed by the prevailing wind speed on the sea surface. This algorithm is used to compute the probability of occurrence of that wave slope which will reflect light in Brewster's angle (52.13°). This is to say that the reflected light will be plane polarised containing only the perpendicular component of polarisation, P_r . Such probability functions will vary with every look angle. We reproduce here through Fig 2 and Fig 3, the probability functions derived earlier by Sathe and Ajoy Kumar (1990) for a variety of wind speeds viz., 0 through 60 knots at intervals of 2 knots and for look angles varying from 0 to 90 degrees. 0° means sensor looking vertically down while 90° means sensor on the horizon looking at sea surface horizontally, which is only an academic possibility. One can see from Figures 2 and 3 that most appropriate viewing angles for remote sensing of sea state are in the range of 30-40 and 65-75 degrees as they have a higher average slope and comparatively high values for probability function $p(\theta)$. The range 30-40 has an advantage over the range 65-75 degrees because it shortens the path that reflected light travels from sea surface to sensor.

These probability functions listed in Fig. 2 and Fig. 3 have validity in both space and time. If a sensor is looking at a large footprint, the probability function indicates the fraction of area within the footprint, which will reflect plane

polarised light towards the sensor. Instead, if the sensor is looking at a fixed point on the sea surface over a period of time, the probability function indicates the fraction of time that the sensor will receive plane polarised light.

THE INSTRUMENT

The schematic diagram of the proposed instrument is given in Fig. 4 while technical specifications are given in Table 1. It is a lightweight instrument that can be carried by hand easily to any place where it needs to be mounted. It views a fixed point on the sea surface through a polaroid at two look angles namely, 35° and 70° as they are most suitable for resolving the wave slope as discussed earlier. The instrument is proposed to look at that point on the sea surface which is in line of sight for the given look angle. It views the sea surface continuously for a period of 200 seconds in quick mode or 600 seconds in regular mode and determines the fraction of time that it received plane polarised light perpendicular to the plane of incidence. It then relates this information to the wind speed over the sea surface. It gets the input from both look angles, namely, 35° and 75° and outputs separate winds for each look angle and/or outputs a single value of average wind speed. When mounted on a satellite, looking at 35° covers entirely different region than looking at 75° . Hence we have the provision to give separate outputs for two look angles.

DESCRIPTION OF COMPONENTS

1.1. Mounting frame

The mounting frame consists of a cylindrical frame with long focus optical lens of focal length 100 cm to receive the backscattering radiation from sea. The incident radiation on lens is then focused to a rotating polaroid. The mounting frame houses optical shutters with preset aperture time of 200 sec / 600 sec and photo multiplier assemblies. The horizontal and vertical movements of the frame is controlled by direct-drive, brushless, slotless torque micro-motors with electronic locking gear assemblies. The housing is having a gimbal mounted head. The head is rotatable by the gimbal positioner so that the device can view any angle within $\sim 20 - 75^\circ$ elevation of nadir at any azimuthal angle. The configuration thus supports conical, cross-track, along-track, fixed-angle stare and all observation modes.

1.2. Polaroids

The Polaroids sensor consists of a rotating quarter waveplate, a fixed polarizer and a photodiode. The waveplate transforms the input polarization depending on the actual rotating angle. The polarizer only transmits the portion of light which is parallel to the transmission axis. So the polarization modulation is converted into an amplitude modulation. The photo detector supplies a current that is proportional to the optical power. A Fourier transformation is used to accurately calculate both the state of polarization (SOP) as well as the degree of polarization (DOP).

This proposed system will analyze the state of polarization and the degree of polarization of optical signals in either free space. The resulting data can be viewed using the Graphical User Interface. The state of the input polarization is completely characterized by different representations. The polarization data is presented in a number of forms, on the Poincaré sphere, as Stokes parameters or as a polarization ellipse.

1.3 Batteries

Many new types of batteries are now available. It is proposed to use the batteries having high specific energy, low maintenance and high throughput. Life cycles may be more 1000 cycles and shelf life of about 5 years for the above instrument. Lithium ion is a good choice for the above instrument, and is particularly attractive from the number of

recharge cycles, and the high power density it offers. Need to freeze this choice. A good example of a lithium Ion cell is from Lithion Inc. which is being used. The cell has fairly flat discharge profile (at C/5 rate), 3.6 V, 35Ah, and weighs 0.87 kg. It has pulse current capability of 150 Amps, and sustained max current of 70 amps.

1.3.1 Battery weight

The weight of batteries is a function of the endurance time. In the best scenario, the instrument should have an endurance time of 30 hrs (without a battery recharge or replacement) based on a typical use and a 1 hr usage of the instrument . But this may not be possible given the power density of state-of -the art battery technology. So we shall settle for an endurance time of 3 hrs, before the batteries need to be changed. Fuel cells are the clear winner as a power source that will meet the requirements of this instrument. They have 7 times the energy density of lead acids, and twice that of lithium ion cells . Major breakthroughs in miniaturizing fuel cells are happening in the last year, and it will take another year before mass production of the PEFC will be possible. For example a stack of 6 cells with a surface area of 16 cmxcm and depth of 1 cm can deliver 5 Watts @ 3V at a current of 1.7 A.

The PEFC uses a very thin film ($\sim < 1$ micron) porous membrane of polymer electrolyte sandwiched between platinum anode and cathode, and a conductive grid to connect the cell pores on the membrane. Hydrogen oxidizes (loses electrons, becomes an ion), and together with oxygen diffuses through the PEFC membrane to the cathode. Electrons are routed directly through the load and then to the cathode. They (ions + oxygen + electrons) all recombine, and produce water at the cathode.

1.4 Solar panels

The solar panels proposed will be used as the battery back up and will charge the batteries during the daytime. Most of the power requirements will be met by the solar panels. The solar panels will be a electro-mechanically controlled for deployment. The micro motor will control the functions of the opening and closing of the solar panels. The functional details of the solar panels for this instrument is beyond the scope of this paper.

1.5 Data logger

Data logger is used to store the polarization state of the received radiation and after ADC The number of data points to be acquired can be chosen by the user. A user configurable number of samples are stored in a ring buffer until the trigger pulse is given. All acquired data before and after the trigger pulse are displayed in a display device. Therefore, a real-time monitoring of the system's polarization behavior can be realized with this measurement system. The measured data can be recorded in an ASCII format.

1.6 Output display device

The output display device will be connected to a portable hand held LCD device with options for portable PC with softwares running and activating the process. The sensor unit will have a programmable microcontroller with ROM memory to store the instructions sets downloaded via task scheduler from external PC.

1.7 Storage device

The storage media consists of Hard drives , Flash memory ,ROM and RAM memory devices suitably controlled by programmable micro controller. The data of polarization states can be stored upto 10 GB.

SCOPE AND LIMITATIONS OF THE INSTRUMENT

The main source of noise that will interfere with the signal is the intervening atmosphere between the sensor and the sea surface. The multiple scattering of light due to aerosols and other atmospheric constituents results in back-scattering of a large fraction of light before it may even reach the sea surface. On account of this constant haze or 'airlight' received by the sensor, the intensity of light may never fall to zero even when it is receiving plane polarised light. The ocean colour emanating from within the sea will also add to this noise. Since these components are unpolarised, they will not interfere with the results but they will certainly weaken the signal. This constrain may be overcome by a technique commonly known as the "haze removal" as applied to other passive sensors in which one method used is to subtract the smallest radiance value from all other measurements.

Multiple reflection of light at the sea surface is ignored in the present work. However, we do not expect its effect to be significant. It is ignored by most workers who study the sea surface reflectance (see Sathe and Ajoy Kumar, 1990). Foam on the sea surface may also add to the noise, similar to the 'airlight' discussed above. The instrument also cannot be used on board a ship because it needs a stable platform from which to view the sea surface through a specified look angle. However, ships do not need such devices as they already have anemometers on board.

The main advantage of the instrument is that it is portable and can sense the sea surface wind from a distance. It can be mounted on an observation tower, aircraft or a satellite. It needs little power and its output can be stored on a magnetic media. If mounted on a satellite, the output can be transmitted along with other radiance values to a ground receiving station.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. S. R. Shetye Director, National Institute of Oceanography for giving us the facilities in the institute to carry on our studies and for his encouragement and guidance.

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Figure 3 : Probability function of receiving plane polarised light from a wind-roughened sea surface for look angles varying from 50 to 90°

Figure 4 :The schematic diagram of the proposed instrument.

TABLE 1

TECHNICAL SPECIFICATIONS OF THE PROPOSED INSTRUMENT

Size (excluding mounting frame)	10 cm *6 cm * 3 cm
Weight	12.5 kg
Power requirements	12V DC
Input power range	- 60 dBm to 10 dBm
Solar panels	Double folds 24x24 cells array
Output	Wind speed upto 0.1 k
Look angles	35° and 70°
Batteries	Solar powered 12 V
observation time	200 seconds for quick mode 600 seconds for regular mode
Repeativity	Every 15 minutes in auto mode
Memory	Approximately 8 days
Storage device	FLASH memory

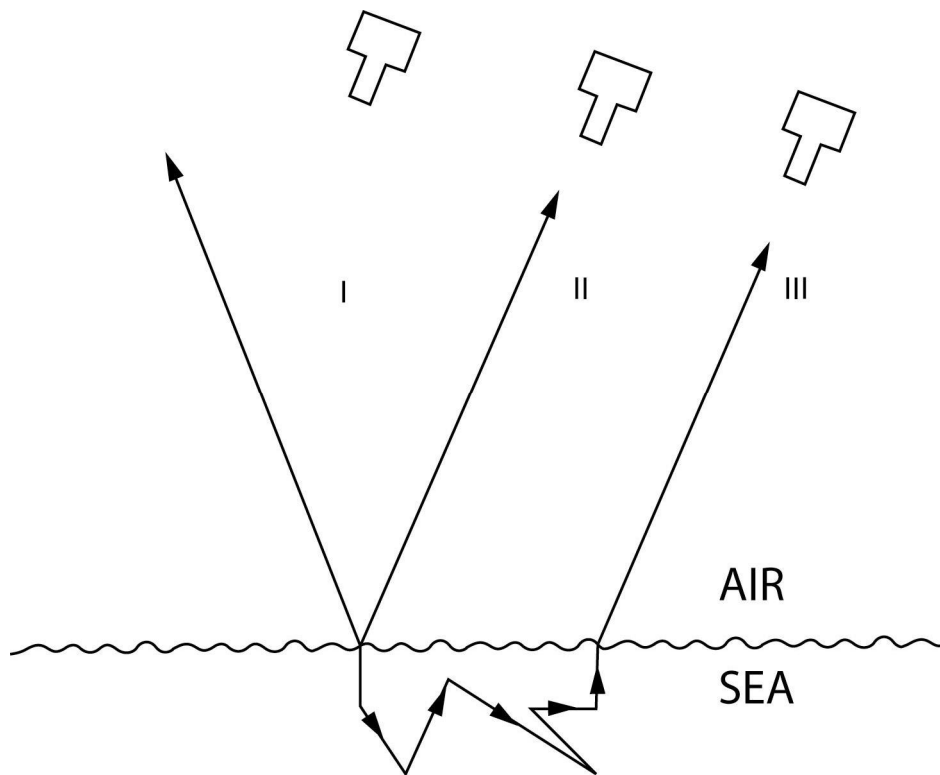


Figure 1: The three main components of light received by an optical sensor over the sea viz., (I) the atmospheric back scattered radiation, (II) the surface reflected radiation and (III) the ocean colour.

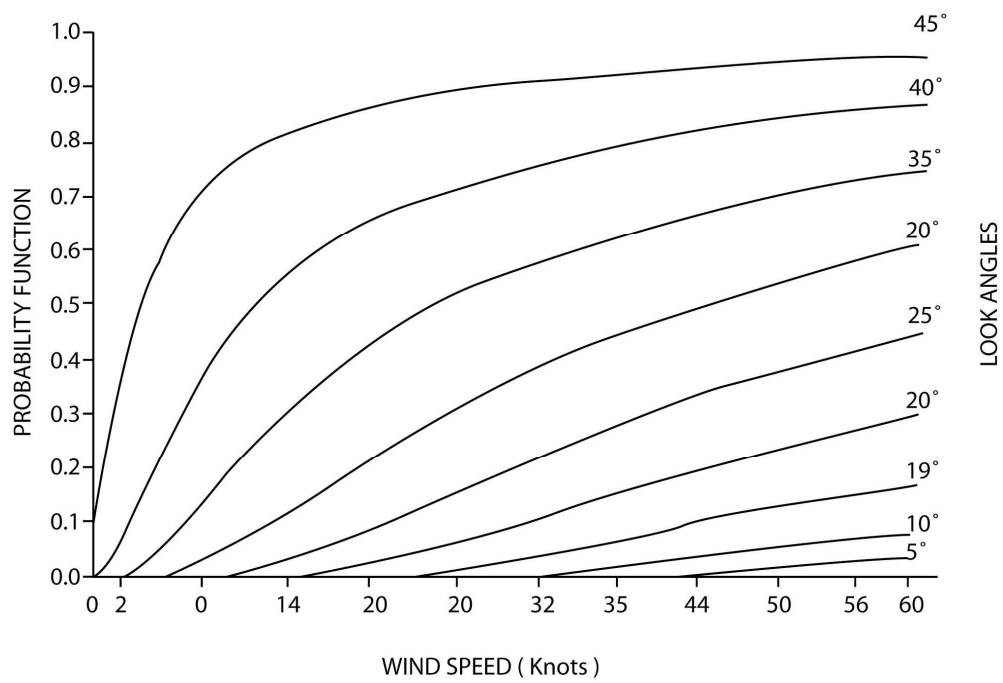


Figure 2: Probability functions of receiving plane polarised light from a wind-roughned sea (wind speeds from 0 to 60 knots) for different look angles varying from 5 to 45 degrees.

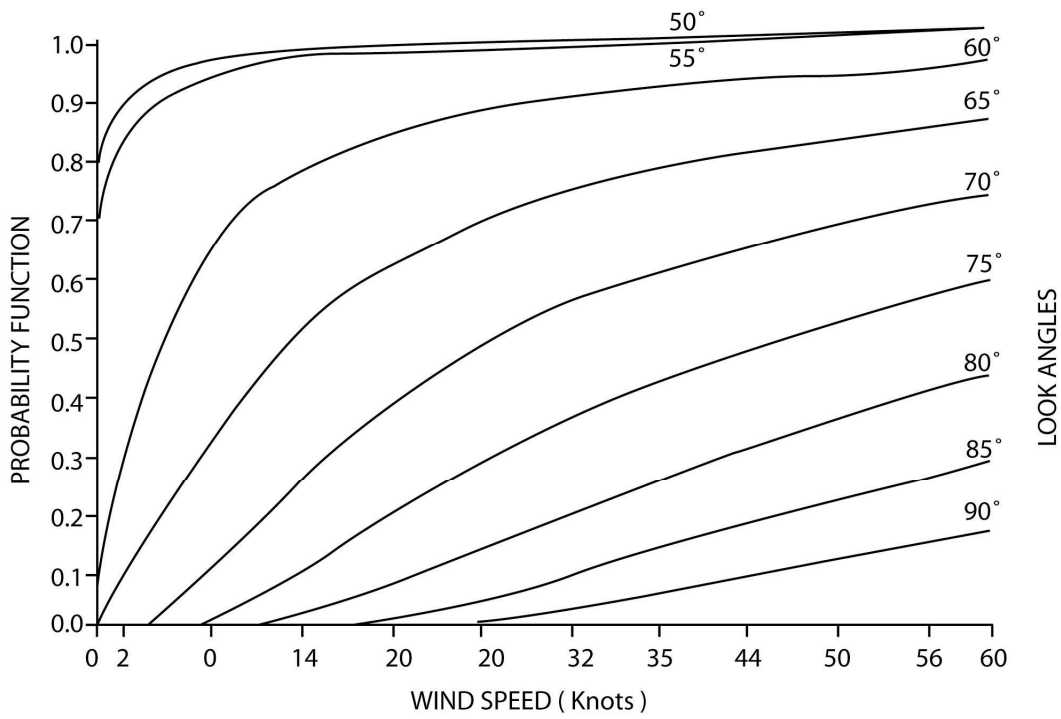


Figure 3 : Probability functions of receiving plane polarised light from a wind – roughned sea (wind speeds from 0 to 60 knots) for diffreent look angles varying from 50 to 90 degrees.

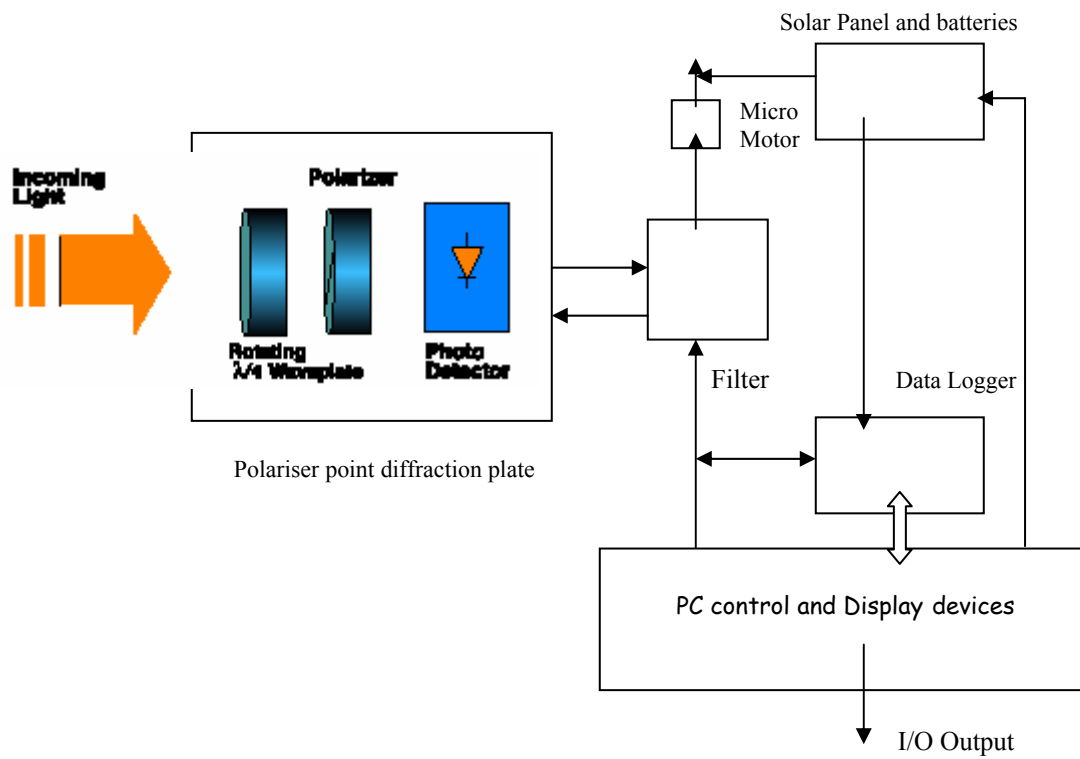


Figure 4 : Schematic Diagram of the proposed Instrument