Advances in Astrophysics, Vol. 4, No. 3, August 2019
https://dx.doi.org/10.22606/adap.2019.43002

A Robotic Camera for Monitoring Meteors Entering the Earth's Atmosphere near the Equator

H.D.S. Amaradasa[1], G.D.K. Mahanama[1], S.S. Abeywickrama[1], A.G.P.D. Alahakoon[1], K.P.S.C. Jayarathna[2], N.C. Wickramasinghe[3*]

[1]Center for Astrobiology in Sri Lanka. Department of Physics, University of Ruhuna, Matara, Sri Lanka
[2]Department of Physics, University of Colombo, Colombo 03, Sri Lanka
[3]University of Buckingham, Buckingham, UK
Email: ncwick@gmail.com

Abstract. The systematic detection and tracking of meteor streams and global fireball events potentially provide a dataset of immense importance to our understanding of passing objects. To this end hemispherical and wide field of view cameras are used in meteor observations with a synchronized network of cameras to record intricate details about meteor activities. In this research a hemispherical robotic camera unit named AWITC was designed to monitor meteors entering earth's atmosphere near Sri Lanka. The unit consists of an astronomy camera with a Complementary Metal Oxide Sensor (CMOS), a fish eye lens, a single board computer, a storage device, internet connectivity and other sensors allowing it to function with minimum human supervision. The images are saved with record of time, date and temperature. The time of the computer can be updated from both internet and GPS connections. The unit has two enclosures for protecting the electronics from solar radiation and rain and all the main devices reside in the internal enclosure. Temperature and humidity sensors are included to monitor the ventilation in the enclosure. A five element YAGI Wi-Fi antenna was designed to extend the wireless connectivity of the unit. The obtained images are saved in the internal storage and a copy is sent to a sever computer. All the software used, are uniquely developed for the unit and the cohesion of hardware and software were tested. The camera unit functioned for eleven months continuously and captured a large number of meteor activities.

Keywords: Meteors, meteor streams, robotic camera, hemispherical, IOT

1 Introduction

A continuous video monitoring of the sky for meteor activity in a given geographical location can serve as a useful astronomical tool and several such international projects have been in place for some time. Most of these projects, however, have been confined to high temperate geographical latitudes with not much coverage of tropical latitudes (Jenniskens, 2006). The motivation of the present programme is to rectify this deficiency. Locating and tracking fireball events over time could lead to datasets from which the existence of new and hitherto unknown cometary and asteroidal meteor streams can be discovered. In the project described in this communication we have endeavoured to add an equatorial node to the international efforts that are already in place for recording meteor events and thus to contribute to an already existing global network that might serve astronomy well.

Wide field photographic techniques have been successfully used for ground-based sky observations in meteor astronomy along with visual and video methods. Generally, these photographic cameras are comprised of a Charged Coupled Device (CCD) as the photon sensor and a wide-angle lens for obtaining a near hemispherical view (field of view of 120º to 180º) of the sky. Multiple camera units functioning synchronized with each unit can photograph stratospheric optical transients with a high spatial and temporal resolution. The California Cameras for All-Sky Meteor Surveillance (CAMS) network (Jenniskens et al. 2011), Fireball Recovery and Interplanetary Observation Network (Rault et al. 2015), Australian Desert Fireball Network (Bland et al. 2011) and Canadian All-Sky Network (Weryk et al. 2008) are some of the meteor monitoring networks which consisted of CCD cameras for hemispherical photography of the sky.

The CCD camera sensor has been used in astronomy as the main optical recording device replacing photographic plates since 1975 (Michael, 2015). However, this low noise analogue sensor required modifications to match the requirements in wide-field, fast and continuous sky monitoring (Kasprowicz et al. 2009). The cameras comprised of CCD sensor required to be connected to a computer with considerable processing power and consumes more power than a Complementary Metal Oxide Semiconductor (CMOS) sensor (Bigas et al. 2006). Traditionally the camera units are controlled by connecting to a separate computer (Long et al. 2006) comprised of an in-situ computer (Walker and Schwarz 2006). The computer is equipped with capturing and analyzing programs for instance OACAPTURE, WSENTINEL, UFO-CAPTURE and METEORSCAN (Atreya et al. 2012).

The advent of digital electronics, real-time image processing and Internet of Things technology (IoT) has emerged as a potential to advance the technology of photographic meteor detection. Specially aspects such as automation, remote detection and big data analysis (Saluja et al. 2012) in the meteor detection cameras can thus be modified. Continuous sky monitoring requires big data and multiple camera units functioning in a chronological synchronization as well as fast communication between the camera units as well as a server. Hence, this research describes a development of a robotic hemispherical camera unit named Autonomous Wide-field Internet of Things camera unit (AWITC). The AWTIC unit comprises of an astronomy camera (ASI120MC) with a CMOS sensor in place of the main optical recording device and an in-situ Single Board Computer (SBC) with sub-variant electronics. Inexpensiveness, capacity to function with minimum human supervision, portability and ability to perform in all weather conditions were considered in designing the AWTIC unit. Three AWTIC units were established in Sri Lanka (6°04'24.00" N, 80°12'15.60" E, 6.9271° N, 79.8612° E, 6.9271° N, 79.8612° E) of latitudes where hardly any meteor detection network had been functioning. Therefore, the network is expected to fill a void between Southern hemispherical and Northern hemispherical meteor detection networks illustrating that a global meteor detection is possible.

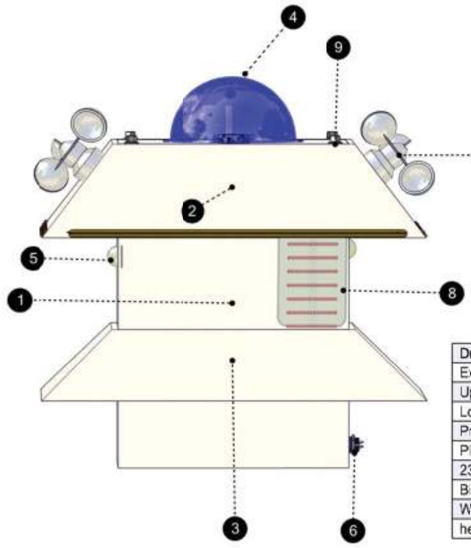
2 Methodology

2.1 Design

The AWITC unit comprises of a single board computer and sub-variant electronics so that the unit acts as a peripheral of network which can communicate with a remote server. This eliminates the requirement of human supervision or external computer allowing the camera unit to execute the software which controls the data acquisition, storing, transmission and other utility actions. The AWITC unit is connected to 230V, 50 Hz mains electricity for power and a switched-mode power supply which converts the supply to an output of 12V, 2A to the electronics. However, to ensure the continuous function of the device an internal battery backup is placed in the system which can run the device safely during a power failure of the mains supply. The status of the battery will be updated to the main server and if the battery level is low the device will come to a hibernation mode where only security and communication systems run. When maintaining a large network of camera units each device can be connected as a node using the Internet of Things technology (IoT). A machine to machine connectivity protocol was designed to connect the units to the main server. A user can remotely log into the AWITC unit for troubleshooting and the in situ single board computer is programmed to create a log of all the error reports. The battery backup circuit and communication system have separate processors, thus any malfunction will be reported in the main server promptly.

The camera unit is comprised of two enclosures wherein an external enclosure (Figure 1) protects the unit from weather and inner enclosure houses the electronics. The external enclosure includes a clear plastic dome on the top of the enclosure for allowing wide-field view of the camera lens and a cubical of volume 25×17×17 cm^3. The cube is made from insulated aluminum panels and a secondary roof-like structure is placed in the upper and lower perimeter of the enclosure in such a way that the structure shades the ventilation holes of the enclosure. The internal structure is made from plastic which is 17×17×17 cm^3 cube.

A cooling fan (Figure 2) is attached at the upper corner of the internal enclosure which switches on depending on the internal temperature. The inner enclosure maintains an insulation gap with the external surface and all the electronics are mounted in the internal enclosure. In the air gap between internal and external enclosures a cage made from aluminum mesh is placed which acts as a Faraday cage to protect the device from EMP signals.

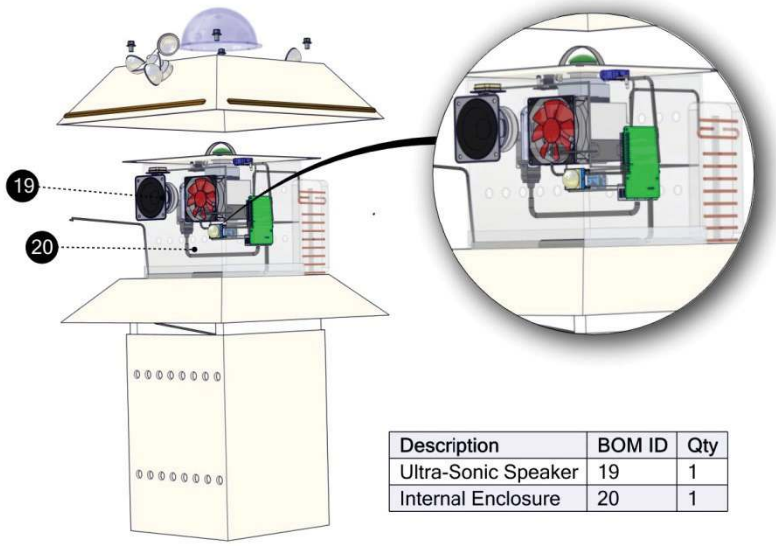


Description	BOM ID	Qty
External Enclosure	1	1
Upper Rain Cover	2	1
Lower Rain Cover	3	1
Protective Dome	4	1
PIR sensor	5	2
230V Power inlet	6	1
Bird Scarer	7	2
Wi-Fi Antenna	8	1
hex flange machine screw_am blue	9	4

Figure 1. External view of the AWTIC unit (Computer Aided Design)

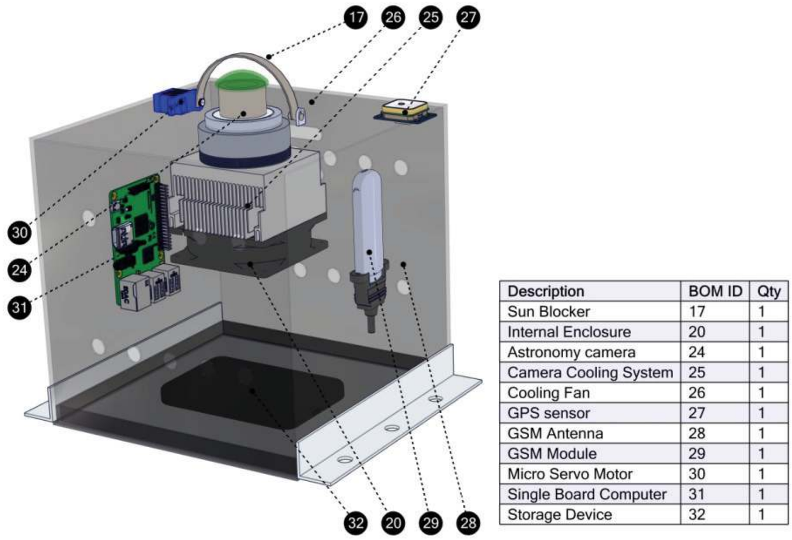
Two passive infrared sensors are mounted in the edges of the external enclosure so that an ultrasonic alarm sound is triggered to scare off birds and other intruding animals. For further protection two aluminum strips are attached in the exterior of the enclosure which are connected to a high voltage pulse to discourage contact. An external directional antenna is attached to the HSDPA modem in the camera unit so that network reception is improved. The camera unit is comprised of a Bluetooth and Wi-Fi device and is flexible to available facilities. Inside the dome a small strip with arc shape (Figure 3, Annotation 17), made of aluminum is connected to a servo motor where the strip is pivoted from two places. The strip blocks the East-West meridian view of the sky where the sun moves across the sky. The servo motor is programmed to rotate the strip relative to the sun's position and when the sun is below the horizon the strip is turned down to unblock the view. A light sensor is placed near the camera to obtain the changes of sky light level, where consequently the camera exposure time is changed. The camera unit is composed of a Global Positioning System (GPS) sensor and a time module to keep the local time. It unit is programmed to acquire the exact time from the internet to ensure data is recorded with the time domain details. The camera is a completely autonomous and requires only power and network connection to function continuously according to an assigned program. The program can be modified to meet the requirement of the user which will set up photographic parameters such as exposure time, gain, white balance and data acquisition frequencies and functional parameters of the camera unit. The functional parameters allow the user to change the functionality of the processing unit and other sub-variant electronics according to user preference. This includes controlling of data transmission such as selecting network connectivity of the unit, data transmission rate, end receiver of the data and encryption.

Further the unit's functionality such as management of battery time, enabling and disabling of the ventilation fan, sun shading mechanism, vandal protection system, synchronization of the clock with other units can all be controlled remotely. This type of broad remote controlling feature is not available in the counterparts of the AWTIC unit. The AWTIC makes reasoned decisions based on the software instruction in functions such as obtaining images, controlling the sunshade, managing power, establishment of communication with the server, acquiring time and synchronizing with other camera units, controlling the internal temperature of the enclosure, and activating vandal protecting system.



Description	BOM ID	Qty
Ultra-Sonic Speaker	19	1
Internal Enclosure	20	1

Figure 2. Exploded view of the AWTIC unit indicating external and internal components



Description	BOM ID	Qty
Sun Blocker	17	1
Internal Enclosure	20	1
Astronomy camera	24	1
Camera Cooling System	25	1
Cooling Fan	26	1
GPS sensor	27	1
GSM Antenna	28	1
GSM Module	29	1
Micro Servo Motor	30	1
Single Board Computer	31	1
Storage Device	32	1

Figure 3. Internal view of the AWTIC unit illustrating internal electronics

2.2 Camera and Computer

The main imaging device used in the unit is the ASI120MC astronomy camera. The camera has an 8.46 mm Complementary Metal Oxide Semiconductor (CMOS) AR0130CS color sensor and a resolution of 1.2 Mega Pixels 1280×960. Pixel Size of the camera is 3.75 µm and has an exposure range of 64 µs-1000s. The camera uses 5V Direct Current (DC) supply which can be powered from a USB socket. The sensor had a peak quantum efficiency of 75% which extended the sensitivity upper infra-red region of the spectrum (Figure 4).

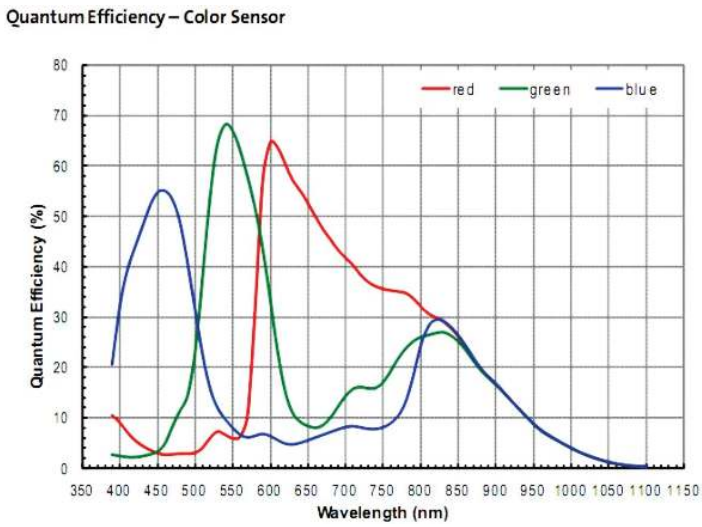


Figure 4. Quantum efficiency of the CMOS sensor (Source: ZWO Optics)

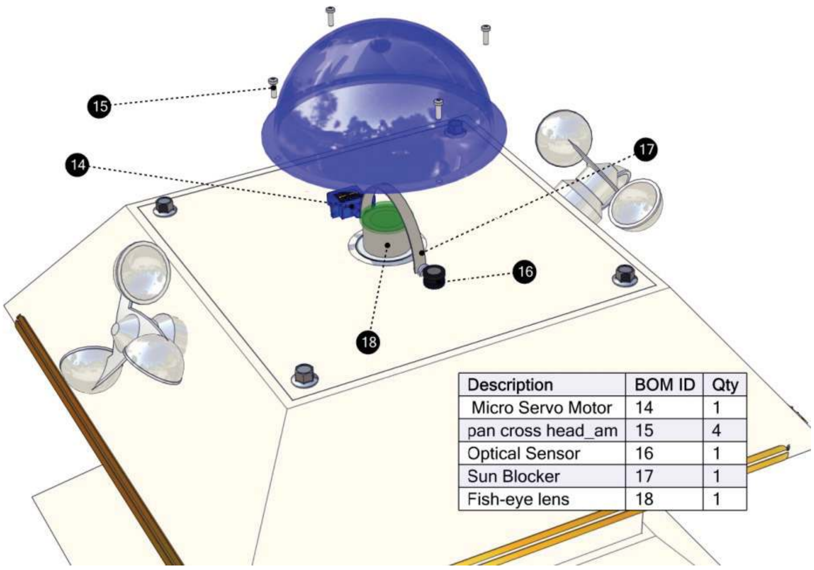


Figure 5. Annotations17 indicates the sun shading mechanism

The camera uses a 5V Direct Current (DC) supply which can be powered from USB socket. The sensor has a peak quantum efficiency of 75% and an extend sensitivity in the upper infra-red region of the spectrum (Figure 4). For obtaining the required hemispherical view a F/2 1.25 mm focal length fish eye lens was used with the camera. The lens has a 185° field of view, hence the camera and lens combination is capable of obtaining All-Sky images. For controlling the camera, a single board computer named a Raspberry Pi was used. It has a Quad Core 1.2 GHz Broadcom BCM2837 64bit central processing unit, 1 GB RAM was deployed with a wireless network connection and Local Area Network connection on board. The camera communicates with the Raspberry Pi computer through a USB 2.0 interface. An external hard drive with a capacity of 1 TB is connected to the computer and therefore captured images can be stored. The device accesses the internet from a WLAN network for transferring images to the server.

2.3 Sensors and Power Supply; Technical Details

A mobile broadband modem is connected with the Raspberry Pi computer, so that the device can be accessed remotely. This secondary connection is used to monitor the status of the device if it does not upload or connect to the server. The Raspberry Pi computer has an in-build Wi-Fi connection with an internal antenna. When placed in the enclosure, the signal reception of the RPi was very low. Hence an external antenna was designed and replaced the internal antenna in the RPi computer. The designed antenna is a five element, quarter wave YAGI antenna, and the antenna was connected to the computer using a 10 cm long 75 Ω coaxial cable. The antenna was placed outside the enclosure and for the protection of the antenna a plastic cover was added.

A stand-alone GPS receiver with 162 dBm tracking sensitivity was interfaced with the Raspberry Pi computer to acquire time for updating the clock of the Raspberry Pi. The device was designed to obtain images in synchronization with multiple devices so that accurate time was acquired from the GPS sensor. The humidity and temperature inside the device was monitored using a polymer capacitor sensor. Humidity and temperature variation inside the device were used to identify the efficiency of ventilation of the enclosure. A cooling fan was placed between external and internal enclosures to enhance the ventilation. Three Metal Oxide Varistors (MOVs) were connected parallel to the mains supply for protecting the electronics of the device from surge voltages. The camera unit was constructed to place in high altitude locations where the camera has an unobstructed view, but placing in such locations makes the camera unit vulnerable to surge voltages and Electromagnetic Pulses (EMP) generated by lightning. Because the power cable runs from the camera unit to the mains supply it is highly likely to induce surge voltages. The surge voltage protection unit stops the surge voltages while the Faraday cage around the internal enclosure protects the camera unit from EMP. When functioning, the camera unit consumes 10 W and a battery backup system can power the entire unit for 10 hours in case of an interruption in the mains supply. As the camera unit is constructed to place in remote locations away from urban areas, power interruptions are expected when the backup power system plays a crucial role. The SBC is continuously monitoring the battery level and whenever the mains power is not restored, SBC will switch off the main functions of the camera unit such as data acquisition and processing. If the battery is low the SBC is programmed to run only the utility functions of the unit such as GPS, transferring of status reports etc.

2.4 Enclosure and Data Transmission

The device was designed to place outdoors and required to function regardless of the weather therefore a special consideration was given to enclosure design. There are two enclosures; an internal enclosure made of plastic housing the camera, computer, external hard drive and other sensors and an external enclosure designed to protect the internal enclosure from rain, heat and other elements. For the fabricating material of the enclosure, cladding was used. The type of cladding sheets used composed of two aluminum layers and a thermal insulating polymer layer in between. The optimum working temperature of the RPi computer is 48 °C, therefore the internal temperature below 48 °C was required. As the device is exposed to solar radiation directly in daytime, the external enclosure will heat rapidly. The internal enclosure was isolated from the external enclosure, and the cavity between was filled with insulating wool so as to prevent the heat transfer from conduction. Both inside and outside enclosures have holes to allow proper air circulation inside the device. As shown in Figure 1, two lines of shades cover the holes so that the device will be protected from rain. A plastic dome protects the upper part of the device where the fisheye lens and the camera are placed.

The AWTIC unit was designed to place in remote locations and invariably far from available Wi-Fi networks. Hence an external antenna was designed and replaced the internal antenna so as to enhance the range of the WLAN receiver.

The designed antenna is a five-element, quarter-wave YAGI antenna, and the antenna was connected to the SBC using a 10 cm long 75 Ω coaxial cable. This new antenna is highly directional with a 70-degree field, thus enabling to point it toward the available Wi-Fi access point. During the tests the antenna was capable of increasing the gain of the signal from 50% to 80%. The antenna was placed outside the enclosure wherein the protection and pointing of the antenna is secured using a plastic cover.

2.5 Software

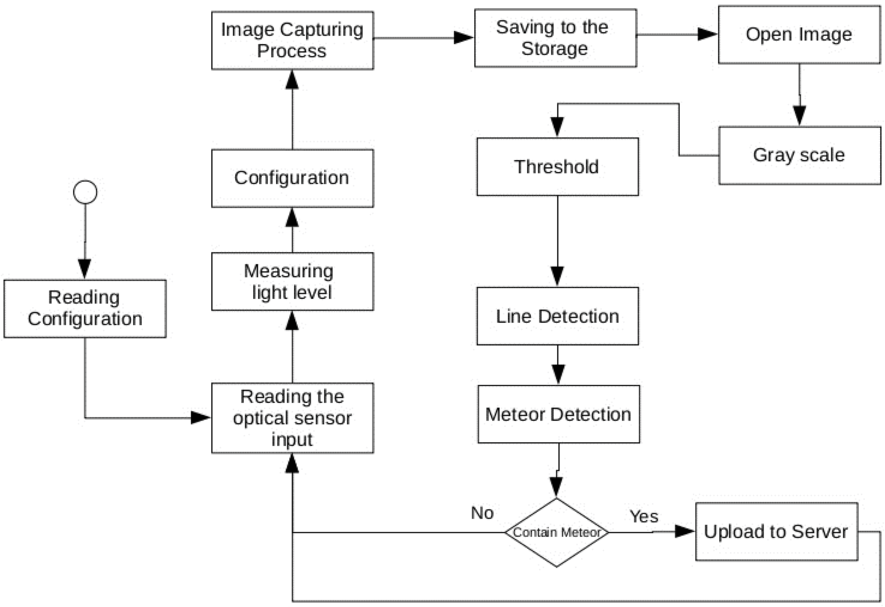


Figure 6. Flow chart of the main computer program

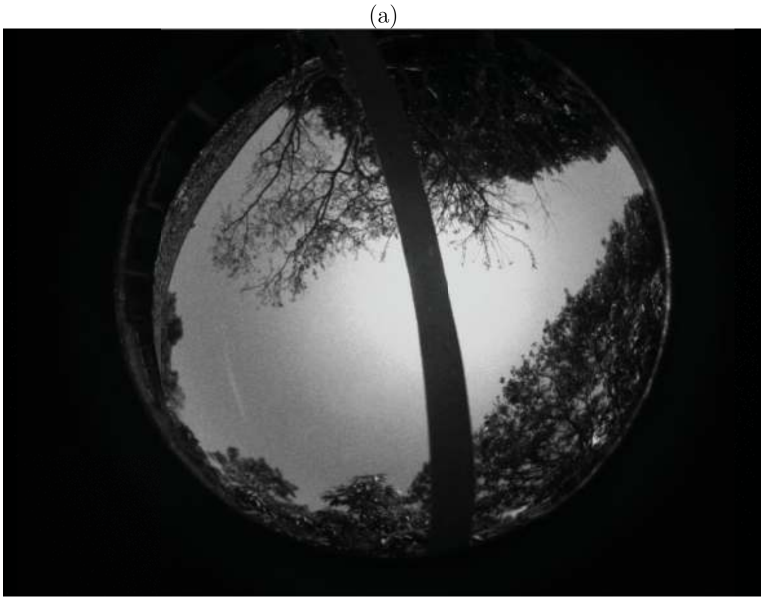
The RPi computer board used in the device uses a Linux-based operating system (OS) named Raspbian. For this project Raspbian Stretch Light 4.9 kernel version was utilized. Initially an open source software named "OACAPTURE 1.3.0" was used to capture images from the camera. The ASI120MC camera included a Software Development Kit (SDK) released by the manufacturer, so a specific software program for capturing images was developed for the AWITC. In the capturing program (Figure 6), three different settings for capturing images were defined depending on the light level of the sky. For daytime and nighttime 5ms and 8s exposure times were used. The third exposure setting with varying exposure time was defined to obtain images at dusk and dawn. A secondary optical sensor (Lux meter) is integrated with the camera to measure the light level during dusk, dawn and during a full moon. The images are obtained in raw format information on time, date and temperature of the camera chip which are stored with the images. The temperature of the camera chip is used in processing the night time images. Long exposure settings in the night time images cause thermal fixed pattern noise, thus a look-up table which contains images named "dark frames" with related to the temperature was created. (A dark frame is an image captured with the lens capped.) Several dark frames were averaged to create a master dark frame. Then the master dark frames are subtracted from the images related to temperature to correct the fixed pattern noise. The program for storing the images save the data in the external hard drive and also check for corrupted data. The storage device (1TB hard drive) saves the data for a month and periodically clean the data to make space. The data transferring program communicates with the server and transfer data using Hyper Text Transfer Protocol (HTTP). A secondary program runs so as to obtain the time from the GPS device and check the time with the server to update the time in the RPi computer. When multiple devices are connected, the program ensures that the all devices are synchronized. This allows to image a meteor incident from multiple cameras at the same time so that the trajectory of the meteor can be calculated accurately.

3 Results and Discussion

Three AWITC units were established and their performance was analyzed. The three units functioned continuously for 11 months and uploaded data to the server. For this time period, consistency of the enclosure, hardware and software of the device were assessed. The device functioned twenty-four hours per day with no malfunction.

The camera images in night time showed many optical transient events.

(a)

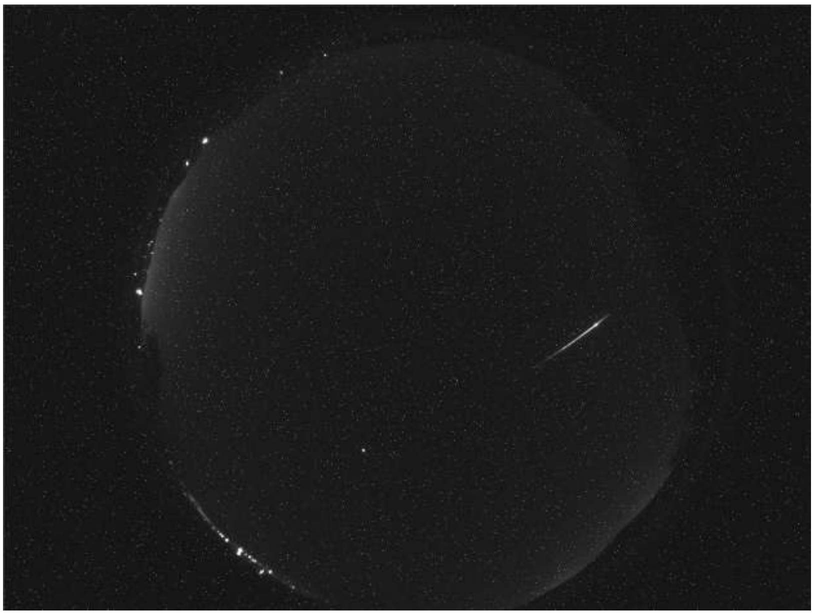


(b)

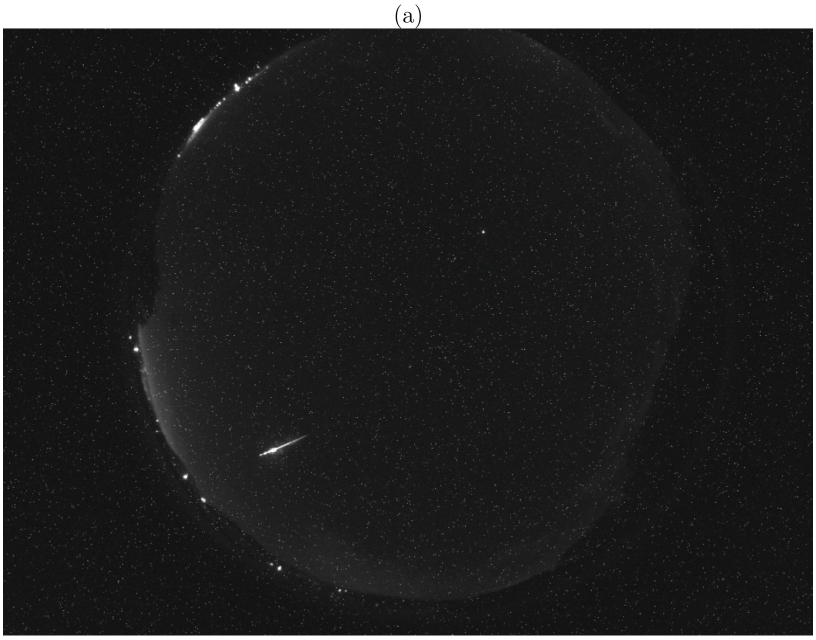
Figure 7. Upper image (a) indicates saturated sensor when shading is absent whilst in the lower image (b) the sun shading mechanism is activated thus, day time imaging is possible.

Figure 8 shows two large fireballs captured on 12/06/2018 and 21/07/2018 by one of the AWTIC units. The meteor travelled from West to South direction and the estimated visible time was around two seconds. The data of 26/01/2018 analyzed and identified twenty-five optical transients despite a cloudy sky. The camera images in daytime were over-exposed due to variation of light level during the daytime. This problem was eliminated by introducing a sun shading mechanism (Figure 7).

On two occasions the device ceased to function; on the first occasion it was found that the external hard drive required more power to operate. The hard drive was powered from the USB the RPi computer which can output 4.4 V 100 mA.



(a)



(b)

Figure 8. Upper and lower images indicate two Fireballs captured from the network: the lower (b) is a dark frame subtracted image whilst the upper image (a) is a RAW file.

On the second occasion the data capturing program had stopped working. It was found that the camera configuration settings defined in the dawn and dusk period were not optimal thus causing the camera to stop working. The gain, gamma level, brightness settings etc. were reconfigured after tests were carried out during dawn and dusk to measure the light level.

The temperature sensor in the internal enclosure indicated that the temperature of the device varies between 20-40 °C. During the daytime, when the solar radiation is maximum, the internal temperature varied between 32-40 °C. Hence it was presumed that the enclosure was functioning as expected shielding the device from solar radiation and maintaining temperature below 48°C. The humidity inside the device varies between 60-100% so a moisture absorbing chemical was introduced to lower the humidity level of the internal enclosure. It was found that the device remained intact from rain water during heavy rains but water condensation occurred inside the camera dome blocking the view of the camera for a while. This was rectified by enhancing the air circulation inside the dome.

4 Conclusions

The main objective of this research was to develop a hemispherical camera unit which is autonomous yet economical and to fabricate multiple camera units for establishing a comprehensive meteor network in Sri Lanka. Three camera units were fabricated and one unit was placed on a roof top of the Department of Physics, University of Ruhuna, Matara, Sri Lanka. The camera functioned continuously for three months and the performance of the hardware and software of the unit was assessed. The camera obtained images of the sky both in the night and in daytime. The optimum exposure time, gain and brightness settings of the camera for night time, dawn, dusk and day time were identified. The light level in the daytime varied significantly therefore the continuous capturing mode in the camera was used. The enclosure designed for the device was capable of protecting the internal electronics from solar radiation and rain. A cooling fan was introduced to enhance the air circulation inside the enclosure. During time period of our study the device had recorded numerous optical transients and, on some days, the number of recorded optical transients were as high as eighty. Hence it can be concluded that the robotic AWITC unit has the capacity to carryout photographic meteor detection over this region of the sky on a continuous basis.

Acknowledgements. National Research Council (NRC) Grant NRC 16-012 is acknowledged for financial support.

References

1. Jenniskens, P., 2006. Meteor showers and their parent comets (Cambridge University Press)
2. Jenniskens P., Gural P. S., Dynneson L., Grigsby B. J., Newman K. E., Borden M., Koop M., Holman D., 2011, Icarus, 216, 40
3. Rault, J. L. et al. (2015) 'FRIPON, the French fireball network', 10.
4. Bland, P. A. et al. (2004) 'The desert fireball network', Astronomy and Geophysics, 45(5), pp. 1–4. doi: 10.1046/j.1468-4004.2003.45520.x.
5. Weryk R. J., Brown P. G., Domokos A., Edwards W. N., Krzeminski Z., Nudds S. H., Welch D. L., Earth Moon Planets, 102, 241
6. Kasprowicz, G. et al. (2009) 'CCD detectors for wide field optical astronomy', 1(2), pp. 82–84.
7. Michael lesser (2015) 'A Summary of Charge-Coupled Devices for Astronomy', pp. 1097–1104.
8. Bigas, M. et al. (2006) 'Review of CMOS image sensors', 37(26), pp. 433–451. doi: 10.1016/j.mejo.2005.07.002.
9. Long, C. N. et al. (2006) 'Retrieving Cloud Characteristics from Ground-Based Daytime Color All-Sky Images'.
10. Walker, D. E. and Schwarz, (2006) 'Monitoring the night sky with the Cerro Tololo All-Sky camera for the TMT and LSST projects', 6267(2006), pp. 1–10. doi: 10.1117/12.671567.
11. Atreya, P. et al. (2012) 'CCD modification to obtain high-precision orbits of meteoroids 1 I N T RO D U C T I O N', 2844, pp. 2840–2844. doi: 10.1111/j.1365-2966.2012.21092.x.
12. Saluja P.B.P et al. (2012) 'Cloud Computing for Internet of Things & Sensing Based Applications', pp. 374–380.