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Total-sky Lightning Channel Imager

– A Useful Photographing Instrument for Lightning Detection

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***Abstract*— The Total-sky Lightning Channel Imager (TLCI) is a professional lightning optical monitoring instrument. Based on the total-sky digital imaging technique and fast digital image analysis algorithm, TLCI can detect lightning events in real-time and record the lightning channel images in total-sky range. It is simple in structure and easy for installation. TLCI can provide the lightning monitoring and warning service. The observation data of TLCI can also be applied in the investigation of lightning disaster, evaluation of lightning detection efficiency and location accuracy of the lightning locating systems, analysis on the characteristics of lightning discharge, and so on. In China, several TLCIs have been installed in Beijing, Guangzhou, Chongqing, and Lhasa. A lot of total-sky lightning channel images have been captured.**

Keywords—lightning channel; total-sky; photography; instrument

I. INTRODUCTION

Lightning is a spectacular weather phenomenon occurring in the atmosphere, which is accompanied by transient, large current, high voltage and strong electromagnetic radiation. Lightning often leads to significant disaster accidents, resulting in not only loss of life and personal injury, but also severe economic loss in the industries of aeronautics and astronautics, national defense, power, communication, electronics, petrochemistry, transportation, forestry, etc. A worldwide of 24,000 deaths and 240,000 injuries from lightning per year was estimated by Holle and López [2003] and more than 1,000 lightning-related deaths and injuries per year in China were reported [Zhang et al., 2011]. With the rapid development of social economy and the wide application of information technology in our life, it will be much greater in the damage extent, economic loss, and social influence caused by lightning.

Real-time lightning location data is an important basis for lightning forecasting and warning. The warning of the areas where lightning is going to take place can help us take precaution measures and reduce the damages that may be caused by lightning. In addition, lightning location data is also an important basis for disaster investigation. Detection efficiency and location accuracy of the lightning locating system play a key role in effect of lightning warning, evaluation of lightning warning result and investigation of lightning disaster.

At present, many countries and regions in the world have set up cloud-to-ground (CG) lightning locating networks and some total lightning locating systems are also installed for monitoring lightning in real-time [e.g., Nag et al, 2015]. Some systems can even detect the development of lightning channel [e.g., Rison et al, 1999; Zhang et al., 2010].

Optical observation of lightning has always been an important means to study lightning. Winn et al. [1973] obtained good recordings of daytime lightning flashes on standard inexpensive video tape recorders. A portable, PC-based system has been developed by Parker and Krider [2003] to provide a mobile data-collection platform for making precise time-synchronized optical and electromagnetic measurements of lightning with correlated video imagery. In Mazur et al. [1995], Chen et al. [1999], and Mazur [2002], the video camera was pointed down at an upward looking parabolic mirror to obtain “all-sky” pictures (although some small parts of the field of view were obscured by the camera and its carriage) of the lightning channels.

However, so far there are no apparatuses that can automatically and simultaneously obtain digital images of lightning channel in total-sky all-azimuth range and information on the time of lightning occurrence, lightning type (intra-cloud, IC, or CG lightning), and polarity of cloud-to-ground lightning in the image. Nor are there suitable apparatuses capable of observing and accumulating abundant data to thoroughly evaluate the detection efficiency and location accuracy of the prior art lightning locating systems.

With the rapid development of optoelectronic technology, total-sky range digital real-time imaging becomes possible, and has already been applied in the ground-based automatic observation of cloud [e.g., Yang et al, 2012; Li et al., 2016].

Based on the development of the ground-based total-sky cloud imager (TCI), we proposed a technical solution for total-sky lightning channel optical observation and designed the Total-sky Lightning Channel Imager (TLCI, Lu et al. [2014]).

II. TLCI HARDWARE

TLCI is an automatic lightning channel observation instrument using digital optical imaging technique and fast digital image analysis algorithm, with observation area radius of about 10 km. As shown in Fig. 1, TLCI hardware mainly consists of a photographing device, a housing, a temperature control device, a light shielding device, a control module, a power supply module, a thunderstorm activity sensor, a data acquisition device, a GPS antenna, a GPS timing module and a processing unit.

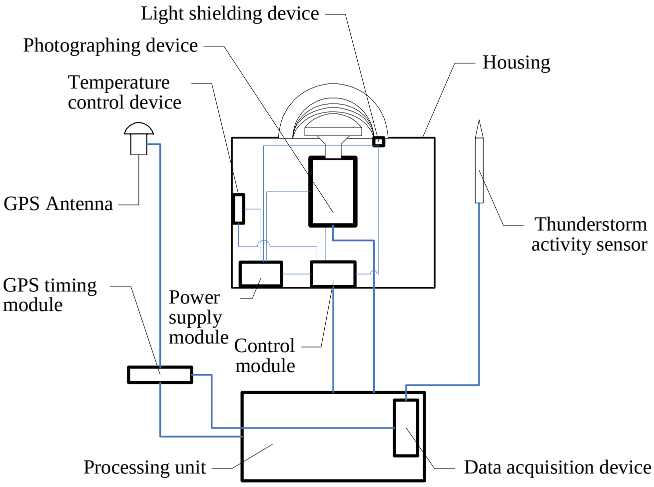


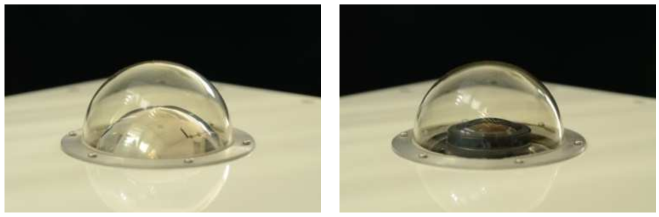
Figure 1. Hardware schematics of TLCI

The photographing device of TLCI comprises a digital industrial camera and a fisheye lens. The industrial camera was adopted because of its stability and controllability. The view angle of the fisheye lens is at least 180°. The imaging plane of the photographing device is horizontally disposed. In order to realize the field of view (FOV) with the elevation angle from 0° to 90° and the azimuth angle from 0° to 360°, the fisheye lens is disposed above an upper surface of the housing and has a light axis pointing towards the zenith direction.

The housing is double layer heat insulation and sealing structure, which is good to reducing the impact of ambient temperature on the device. The top of the housing has an opening, where a transparent protective cover is mounted. The housing has a separate power supply module, temperature control module and control module.

The light shielding device is located between the protective cover and the photographing device, which only automatically opens for image acquisition according to the command, for the sake of effectively improving utilization efficiency and extending service life. The light shielding device comprises a motor, a light shielding valve unit and two limit switches. The light shielding valve unit consists of a set of spherical valves. The limit switches are used to limit the rotational position of the light shielding valve unit.

The processing unit sends “open” or “close” command to the light shielding device through the control module. The control module controls the motor to rotate based on the “close” command so as to close the light shielding valve unit for covering the photographing device (as seen in Fig. 2a), and controls the motor to rotate reversely based on the “open” command so as to open the light shielding valve unit for not covering the photographing device. When the light shielding device opens completely, the FOV of the photographing device is not affected at all (as seen in Fig. 2b), and then the photographing device can capture total-sky digital images and transmit the images directly to the processing unit.



(a) (b)

Figure 2. The shielding device of TLCI

(a) closed and (b) opened status

The representative parameters of the thunderstorm activity were picked by the thunderstorm activity sensor (e.g., corona current sensor, electric field mill). The processing unit receives the data through data acquisition device and judges whether there exists thunderstorm activity within the range observed by the TLCI. In actual use, the thunderstorm activity sensor may be any sensor known in the art capable of sensing the representative parameter, for instance, a fast/slow electric field change antenna, a magnetic antenna and a photodiode, which is consider that many thunderstorm activity monitoring instruments have been used, take full advantage of these instruments can effectively improve use efficiency, reduce duplication of investment.

The equipment also comprises a GPS antenna and a GPS timing module. The GPS timing module is used to time the processing unit periodically and obtain accurate trigger time information in response to external trigger signals and send the time stamp to the processing unit.

It should be mentioned that the filter is often required in lightning optical observation to reduce the effect of the bright background in daylight condition. For example, one or several neutral density filters were often used for capturing color lightning images, and the narrowband interference filter was often used in monochrome lightning optical observation. For TLCI, a 656 nm filter with a bandwidth of 10 nm was adopted. The maximum exposure duration is often adopted for an available framing rate, e.g., 25 ms for 40 frames per second.

Sometimes we also used TCI (capturing color image for total-sky cloud observation, not special for lightning observation, without narrowband interference filter) equipment to capture lightning images. In this situation, short exposure duration that much less than the maximum duration might be adopted to avoid saturation during the daytime.

III. TLCI SOFTWARE AND OPERATIONAL MODE

A. Software functions

The software interface of TLCI is shown in Fig. 3, which has the following main functions:

Figure 3. Software interface of TLCI

- consecutively obtain and display total-sky digital images, detect lightning channel(s) and store images using the specified parameters in real-time;
- monitor and control the status of the camera;
- monitor and control the movement of the light shielding device;
- set the information of the observation site (longitude, latitude, height, etc.);
- set the operational parameters (exposure duration, gain, pre-trigger time, recording length, image format, etc.);
- set the ROI area for lightning channel detection;
- two operational modes: automatic and manual;
- in automatic mode, can receive remote control command via network to start or stop consecutive observation.

B. Operation modes and working states

As stated above, TLCI has two modes of operation: automatic mode and manual mode. In automatic mode, all of manual operations are prohibited, such as parameters setting and manual control of the light shielding device; the system automatically detects the thunderstorm activity around or receives remote control command and adjusts working states all-day. In manual mode, user can manually controls the status of the camera, sets the operational parameters, and sets the ROI area for lightning channel detection, etc.

Furthermore, in automatic mode, TLCI has two working states: ordinary monitoring state and lightning observation state. In ordinary monitoring state, the data acquisition device is in a low-speed real-time data acquiring mode, while in observation state, the device is in a high-speed real-time data acquiring mode.

For convenience, the corona current is selected as the representative parameter of the thunderstorm activity to describe the detailed working process of TLCI. The flowchart of TLCI observation is show in Fig. 4.

When the corona current indicates there is no thunderstorm activity within the range observed by the TLCI, the processing unit will set the system in the ordinary monitoring state, the control module in the housing will shut down the photographing device, close the light shielding device, and set the data acquisition device in low-speed mode (for instance, 100 S/s). In this state, the processing unit acquires and analyzes the corona current waveform in real-time for judging whether there exists thunderstorm activity.

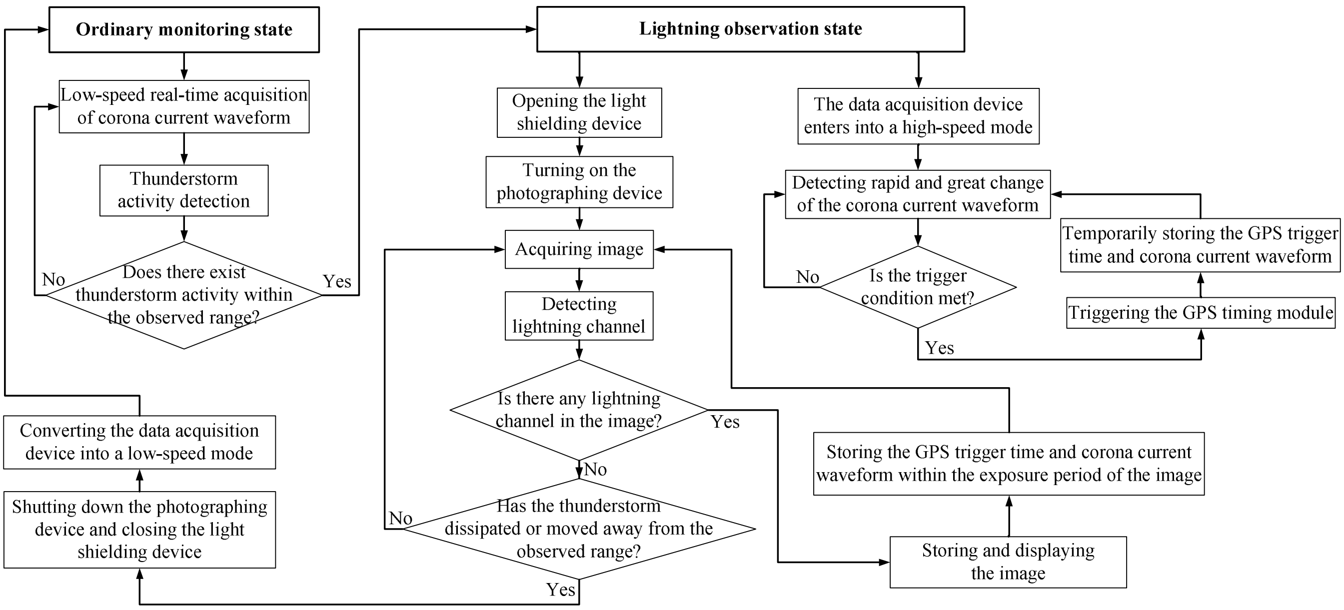


Figure 4. The flowchart of TLCI observation

If thunderstorm activity exists around the TLCI, the processing unit will convert the system into the lightning observation state and set the data acquisition device in high-speed (for instance, 1MS/s), the control module will open the light shielding device and turn on the photographing device. In the lightning observation state, the processing unit acquires the total-sky digital images consecutively and detects whether there is lightning channel(s) in the image by specially designed lightning event detection algorithm in real-time.

When a digital image that contains lightning channel(s) is detected, the processing unit will store and display the image, record the corona current waveform (showing rapid and large magnitude change within the exposure period of the image), and store the GPS trigger time from the GPS timing module. When the sensed data and image analysis indicates the thunderstorm has dissipated or moved away from the observed range, the processing unit will shut down the photographing device, close the light shielding device, and set the data acquisition device into low-speed mode, i.e., the working state of the TLCI will be converted into the ordinary monitoring state.

IV. APPLICATION OF TLCI

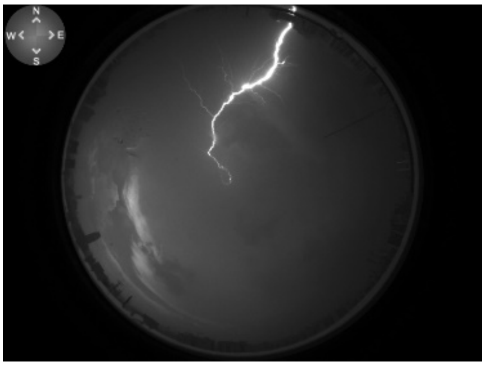
Several TLCIs have been installed in Beijing, Guangzhou, Chongqing, and Lhasa, in China. Fig. 5a and Fig. 5b show the in-situ installed TLCI in Guangzhou and Lhasa, respectively. Fig. 6 shows six examples of total-sky lightning channel images captured by TLCI.

(a) (b)

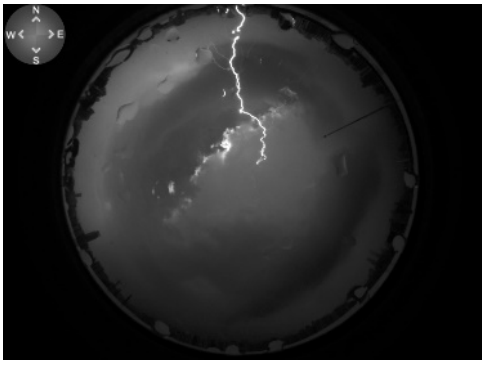
Figure 5. In-situ devices. (a) in Guangzhou and (b) in Lhasa

From Fig. 6, it can be seen that TLCI can not only capture the images of CG lightning flashes (Fig. 6a-d), but also can capture the images of IC lightning (Fig. 6e, 6f). Especially for those CG lightning flashes with multiple grounding points (Fig. 3, Fig. 6c, 6d), the advantage of TLCI, real total-sky FOV without any shading, ensures the successful photographing for all grounding points.

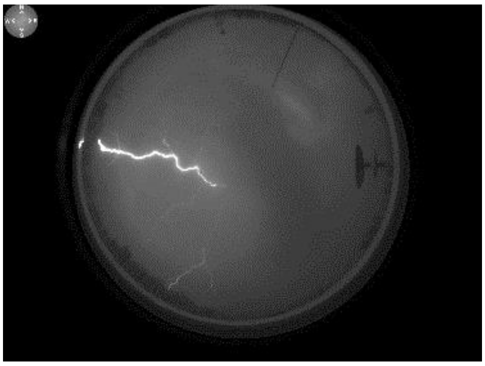
A single TLCI can only provide the azimuth and elevation information of lightning channel in two-dimension. Cooperated with thunder observation or the geographical distribution of tall buildings (for instance, in Guangzhou urban area, Lu et al., [2012, 2013]), a single TLCI observation data can also be used to determine the grounding point of the CG lightning that terminates on tall buildings. The data can be used to evaluate the performance of lightning locating system.



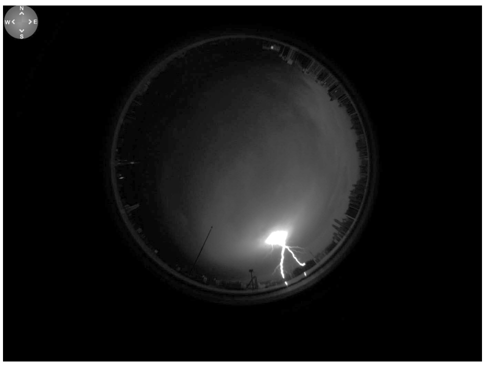
(a)



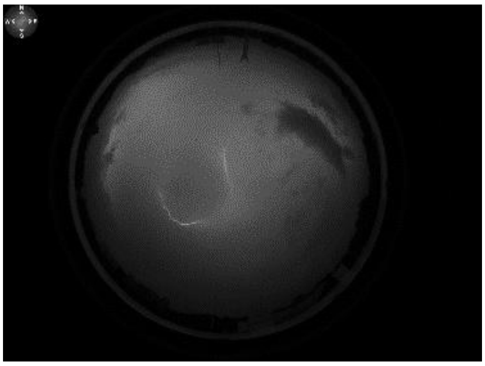
(b)



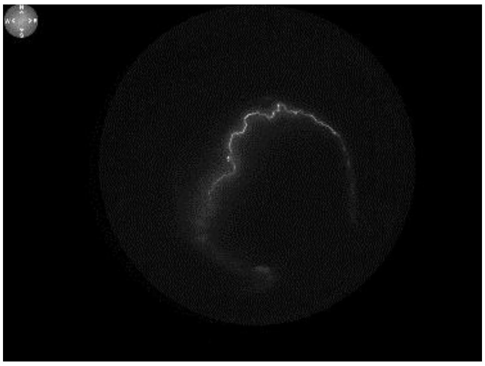
(c)



(d)



(e)



(f)

Figure 6. Six examples captured by TLCI. (a) and (b), CG lightning flash with single grounding point; (c) and (d), CG lightning flash with multiple grounding points; (e) and (f), IC lightning

By installing two or more TLCIs with a certain distance (e.g., 1 km, 2 km) and using the three-dimensional (3-D) reconstruction method based on dual-station optical observation data (e.g., Gao et al., [2014]; Lu et al., [2015]), the 3-D features of the lightning channel can be obtained, which can be used to evaluate the result of 3-D lightning locating system.

The total-sky FOV of TLCI makes it easier to accumulate abundant lightning data than the lightning optical observation system with small FOV. TLCI records intuitive lightning channel images, which can be used to not only analyze lightning characteristics and evaluate the lightning locating system, but also provide lightning warning service for lightning-sensitive area and useful information for lightning disaster investigation. Therefore, the TLCI has a good application prospect.

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