

## Design of a Low-Cost Microcontroller-Based Lightning Monitoring Device

Kamau M. Gilbert<sup>1\*</sup>, Kang'ethe M. Samuel<sup>1</sup>, Kamau I. Stanley<sup>1</sup>, Giesen Nick<sup>2</sup>

<sup>1</sup>Faculty of Engineering, Department of Electrical & Electronic Engineering Department, JKUAT, P.O. Box 62000-00200, Nairobi-Kenya

<sup>2</sup>Faculty of Civil Engineering and Geosciences, Water Management Department, Delft University of Technology, Postbus 5 2600 AA Delft, The Netherlands.

*Submitted: 29th July 2014; Published: 3<sup>rd</sup> March 2015*

---

### Abstract

Lightning data is not only important for environment and weather monitoring but also for safety purposes. A device that monitors and keeps track of occurrences of lightning strikes has been developed. A communication interface is established between the sensors, data logging circuit and the microcontroller. The digital outputs of the lightning sensor and data from GPS are processed by the microcontroller and logged onto an SD card. The interface program enables sampling parameters such as distance from the lightning strike, time of strike occurrence and geographical location of the device. For archiving and analysis purposes, the data can be transferred from the SD card to a PC and results displayed using a graphical user interface program. Data gathered shows that, the device can track the frequency and movement of lightning strikes in an area. The device has many advantages as compared to other lightning sensor stations in terms of huge memory, lower power consumption, small size, greater portability and lower cost. The device shall be used in designing lightning network.

**Key words:** Lightning monitoring, Microcontroller, Data logger, Sensor

---

### Introduction

Scientific research requires collection of data in order to study, monitor, analyze describe and understand a particular processes. In the area of lightning, collecting lightning data is complicated by the nature of the strikes. Lightning strikes have a nominal duration of 20 to 50 microseconds, and are typically separated in time by 20 to 100 milliseconds. A flash generally comprises 2 to 4 strokes, but may contain as few as one and as many as ten or more strokes (Cummins, Murphy, Bardo, Hiscox, & Pyle, 1998). This puts a lot of demand on timing. The most advance lightning monitoring systems are the lightning networks, commonly used to gather lightning information over a wide area. Kenya and most developing countries do not have lightning networks. This is because of the complexity associated with design, installing and maintenance of lightning networks which makes them very expensive (Dowd, et al., 2000). In recent years, it has been possible to produce smaller and cheaper lightning sensors that can be integrated with the computing technology. Moreover, growth in technology has made it possible to integrate communication networks with computing technology.

This paper aims to build a low cost yet reliable lightning detector. The detector shall be capable of capturing and recording data on the position of the sensor and the times at which lightning strikes are captured. The lightning sensor of the detector shall capture lightning events and reject any form of disturber signals. The GPS sensor shall capture details on location of the sensor and the times when the strikes occurs. The digital output of the sensors shall be processed by the controller and data logged onto an SD card. The data can be analyzed to understand the frequency and movement of lightning strikes in an area.

---

\*Corresponding author: [kamau.gilbert@students.jkuat.ac.ke](mailto:kamau.gilbert@students.jkuat.ac.ke)

### Lightning Systems and sensing

There exists both orbital and ground based lightning monitoring systems. On orbital satellites, there are Lightning Imaging sensors (Mach, et al., 2007) and optical transient detectors (Christian, et al., 2003). There is high cost associated with powering, launching and maintaining orbital lightning systems.

Use of ground based lightning networks is the most advanced method of gathering lightning data. Lightning networks consist of multiple sensors and communication systems that transmit the lightning data to a central place. At the central place, the data is processed and distributed to users (Cummins, Kridder & Malone, 1998). There is high cost associated in design, implementation and maintenance of the network. As a result, many developing countries do not have a lightning network. At least, the sensor station requires AC voltage of 240 volts to maintain their operation.

During lightning flash, there is rapid acceleration of charge from lightning channel which produces electromagnetic radiations known as sferics in all frequency bands. These electromagnetic pulses are propagated away from the lightning channel and get directed within the Earth-ionosphere (Wood & Inan, 2004). The energy of radiations can be detected by sensors to determine the presence of a lightning activity. The energy of sferics gets attenuated with time. Attenuation is dependent on the frequency of the sferics. The lowest frequencies travel long distances while the highest frequencies are attenuated within a short distances.

Equation 1 gives the inverse square law applicable to all forms of electromagnetic radiations. It implies that the power of any electromagnetic radiations is inversely proportional to the distance of radiating source (Petty, 2007). The lightning sensor determines the distance to the lightning source by assuming an average strength and comparing that with the measured energy (Austria Microsystems, 2012).

$$\text{Intensity} \propto \frac{1}{\text{distance}^2} \quad (1)$$

### Proposed System

In recent years, it has been possible to produce smaller and cheaper sensors that can be integrated with the computing technology. Moreover, growth in technology has made it possible to integrate communication networks with computing technology. Such networks would make it possible to have cheap and low-cost solutions for tracking individual incidents (Qixin, 2008.)The fact that both sensors and network can be integrated on a computing environment makes it possible to have cheaper systems that can conveniently monitor and record lightning activities. The proposed station uses a maximum of 9V DC which will significantly cuts the power cost when deployed in a lightning network.

### The System Circuit

Using Arduino, a Serial Peripheral Interface (SPI) communication protocol is established which facilitates communication of the lightning sensor and the data logging circuit. SPI is a high-speed, full-duplex, synchronous communication bus (Liul & Wang, 2011). In order to save the space on the soldering board and the chip ports, only four lines are taken by the SPI ports. As indicated in Figure 1 below, the sensor station works using the Master-Slave full duplex mode with the processor as the master device and two slave device. The protocol requires four lines whose components are SCK (clock), SDI (data in), SDO (data out), and SS (Slave select). An additional serial Transistor-Transistor logic (TTL) communication protocol is established between the GPS sensor and the processor.

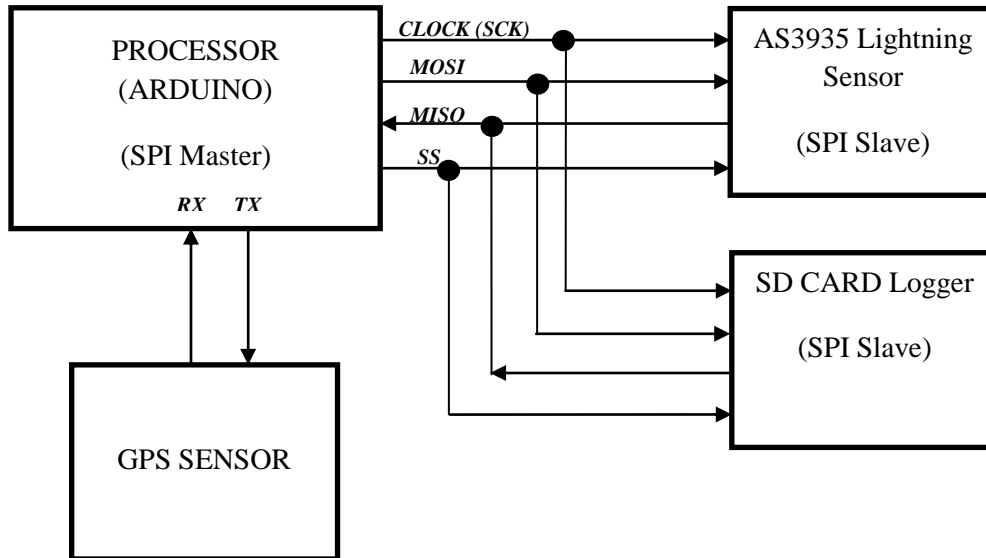


Figure 1: SPI with controller, Lightning Sensor, GPS sensor and the Data logging Circuit

When the SPI master wants to send data to a slave, it will pull the SS line low for selecting slave. It then activates the clock signal which is usable between the master and the slave at same time. The master transmits the data to the MOSI (master's SDO and slave's SDI) line and receives the data from the MISO (master's SDI and slave's SDO) line at the time. SPI is a serial communication protocol, that data is transmitted bit by bit. The clock pulse is provided by SCK. SDI and SDO use this pulse to make the data transmission. Data output is through the master's SDO line at the falling or rising edge of the clock, and can be read by slave in the falling or rising edge. So 8-bit data transfer need at least 8 times the clock signal changes (Ananthula, Kumar, & Bhandari, 2012). The code for the integrated system is available upon request.

### Processor

The main component here is the ATmega1280 microprocessor, which is equipped with 128 Kb of flash memory and processing speed of up to 16 MHZ. The microprocessor not only controls the system, but also synchronizes all the module operations. The microprocessor is based on an Open Source Hardware project called Arduino. Arduino comprises of a programmable microcontroller development platform, a programming development environment for creating custom microcontroller software, and expansion capability through add-on boards (Fisher & Gould, 2012). All electronic and circuit-board component specifications, including the programming software, are open-source and freely available for anyone to modify or use. Additionally, Arduino boards come with a library for interfacing SPI. The Arduino is programmed using Arduino IDE software that utilizes C language.

### Lightning Sensor

The AS3935 is a fully integrated programmable lightning sensor IC that detects the presence and approaching hazardous lightning activity in the vicinity. It provides estimation on the distance to the head of storm, where the leading edge of the storm is defined as the minimum distance from the sensor to the closest edge of the storm. (AS3935 Franklin Lightning Sensor IC datasheet, 2012). Figure 2 below shows the block diagram of the AS3935. The external antenna amplifies and demodulates the received signal. It is connected directly to the Analog Front-end (AFE). The watchdog monitors the output of the AFE continuously. In the event of an incoming signal, it alerts the integrated lightning algorithm block. The incoming signal is validated by the lightning algorithm block. This is done by checking the incoming

signal pattern and calculating the signal energy. Upon verification, AS3935 provides the processor unit with a distance estimate to the head of the storm. The demodulated signal, can be distinguished if it is man-made disturber or true lightning signal by the lightning algorithm block. If the signal received is classified as a disturber the event is rejected and the sensor goes back to listening mode. However, if the signal is identified to be a true lightning strike, the statistical distance estimation block estimate the distance to the head of storm.

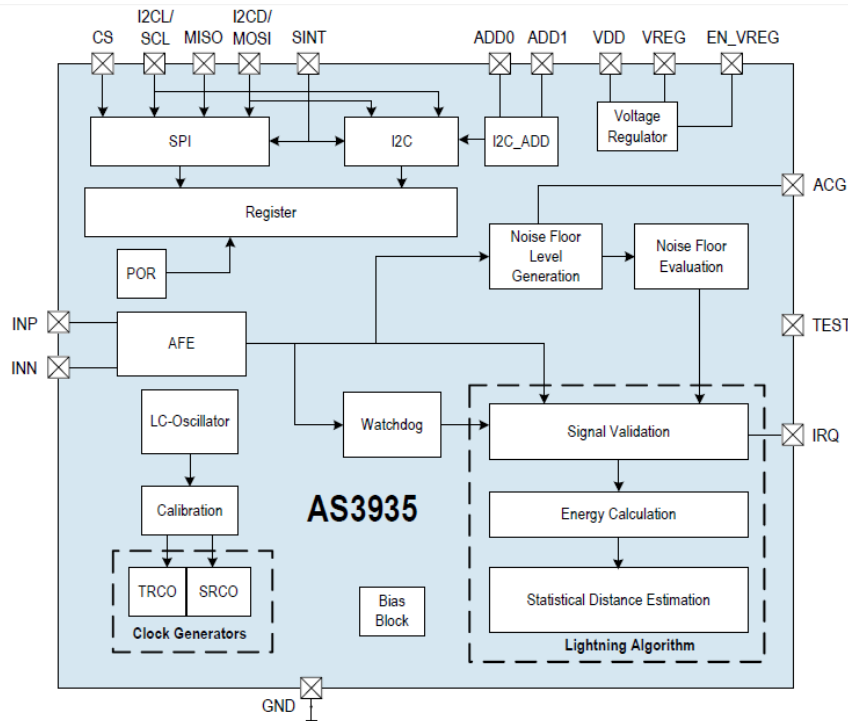


Figure 2: Block diagram of AS3935

AS3935 has three operating modes; power-down mode, listening mode and signal verification. In the power-down mode, the power is switched off and the current consumption is minimum. In the listening mode, noise floor generation, the watchdog, the AFE, the TRCO, the bias block and the voltage regulator (if it is enabled) are running. The sensor enters signal verification mode whenever dynamic activities are picked by antenna. The incoming signal has to cross a certain threshold for signal verification mode to be activated. The IC leaves this mode if the analysis of a single lightning event is finished or if the incoming signal is classified as a disturber. If the received signal is classified as lightning event, energy calculation is done and AS3935 provides distance estimation. If the received signal is classified as disturber, AS3935 automatically goes back to the listening mode and an interrupt will be generated.

### GPS sensor

With the instant position of high-speed satellite as the known initial data, the basic principle of GPS positioning is to adopt the spatial distance intersection method to determine the location of the points to be measured (Huang, et al., 2013). When the GPS receiver obtains longitude, latitude, altitude, time and speed information of geographic location through GPS positioning solution method, distributes information in a distinctive data format so that the calculated navigation information can be transmitted to the peripherals. GPS is equipped with a serial port (TTL or RS-232 level) to enable the transmission.

The GPS breakout shown in figure 3 is built around the MTK3339 chipset, a high-quality module that can track a maximum of 22 satellites on 66 channels. It has a receiver with sensitivity of -165 dB when tracking, and a built in antenna. It can do up to 10 location updates a second for high speed, high

sensitivity tracking or logging. The power usage is low, only 20 mA during navigation. The GPS module is used to pick data on date, time, altitude and location.

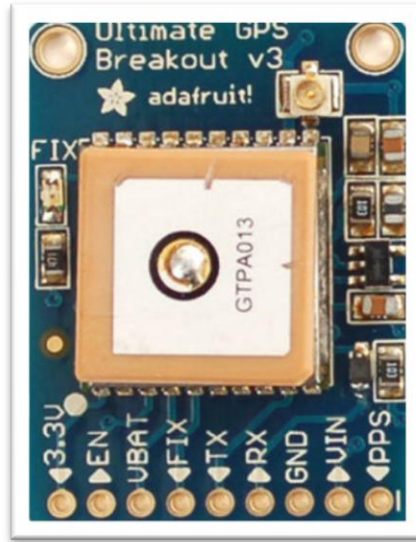


Figure 3: GPS Sensor

**Data Logging Circuit**

An SD data logging shield is connected to the microcontroller to facilitate storage the sensor’s readings. An SD card is inserted to the card slot of the shield in figure 4. The interface between the microcontroller and the SD card holder is SPI. The data received is stored in comma-separated values (CSV) files.



Figure 4 Data Logging Shield

**Time Keeping Circuits**

The system records time from two independent circuits that runs simultaneously. There is the GPS time and real-time clock (RTC). The most accurate time is from GPS which is picked from satellites. The RTC chip, attached to the SD card shield, provides less accurate time but is powered by an external coin battery which ensures that time track is kept even when the GPS is not picking satellite signals, or when the sensor station is not powered. Both times are captured whenever a signal is detected by the lightning sensor.

**Result and Discussion**

The functionality of the sensor station is analyzed by gathering lightning data using two sensor stations placed on the same location. Table 1 shows the data that was captured at Oraimutia village on 3<sup>rd</sup> May 2014.

Table 1 Comparison of strike distance measurements of two sensors placed on the same location

SENSOR STATION 1			SENSOR STATION 2	
GPS time	Distance (km)		GPS time	Distance (km)
6:10:25 PM	18		6:10:25 PM	20
6:11:23 PM	18		6:21:31 PM	20
6:15:31 PM	18		6:27:25 PM	18
6:21:22 PM	18		6:28:22 PM	18
6:27:25 PM	14		6:28:31 PM	18
6:27:52 PM	14		6:28:52 PM	18
6:28:52 PM	14		6:29:27 PM	16
6:29:27 PM	14		6:30:57 PM	16
6:30:47 PM	14		6:31:07 PM	16
6:30:57 PM	14		6:31:11 PM	10
6:31:07 PM	14		6:31:17 PM	10
6:31:17 PM	14		6:31:20 PM	8
6:31:20 PM	6		6:31:27 PM	8
6:31:27 PM	6		6:32:02 PM	6
6:32:04 PM	6		6:32:04 PM	6
6:32:22 PM	6		6:32:49 PM	5
6:32:32 PM	5			
6:32:49 PM	5			

The graph on figure 5 shows the distances recorded by the two sensors over a period of 40 minutes. It is observed that the sensor stations were able to track lightning strikes in Oraimuta. The pattern shows that strikes were approaching the location of the sensor station.

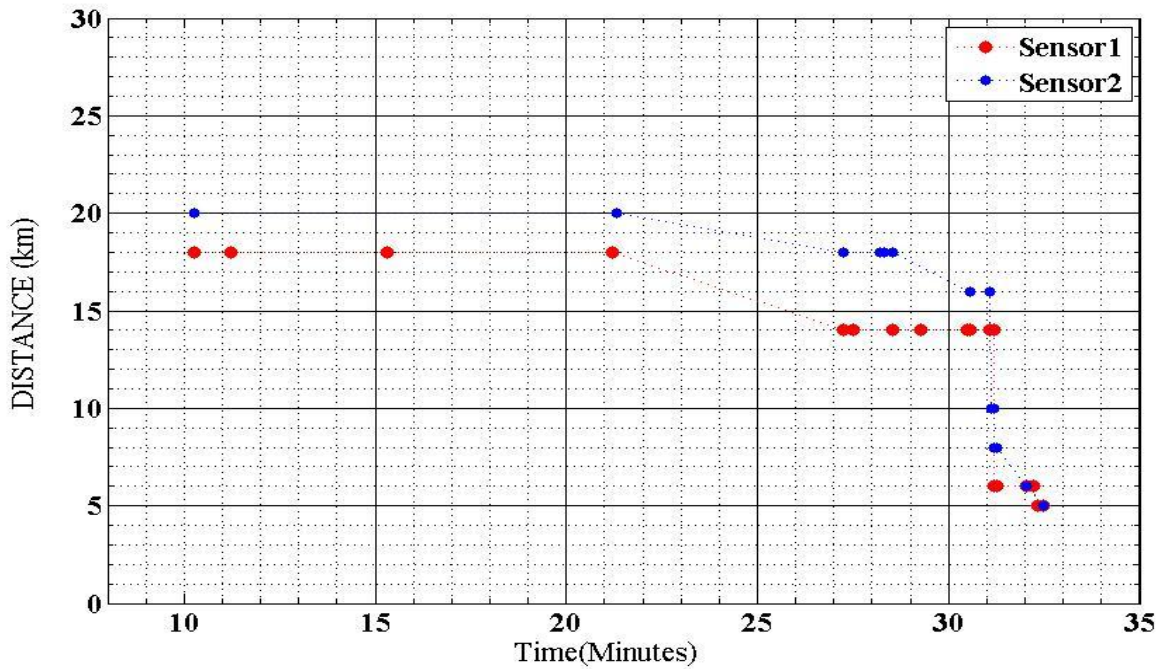


Figure 5 Lightning location information in Oraimutia area on May 3<sup>rd</sup>, 2014 between 6:00pm and 6:35pm.

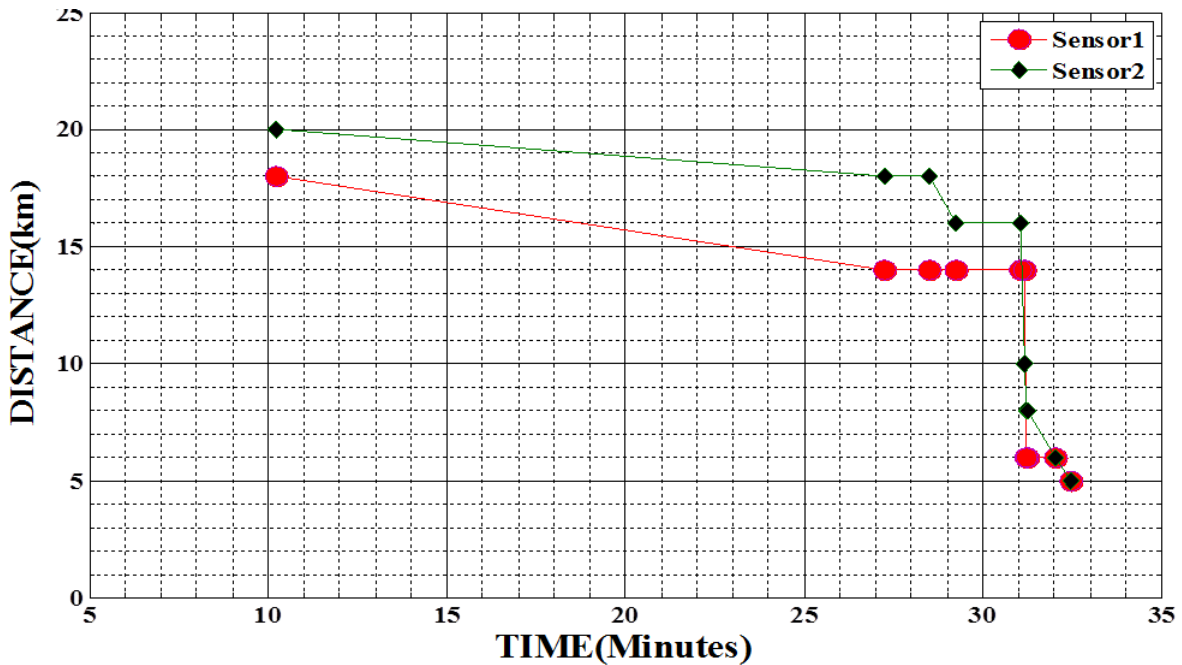


Figure 5 Lightning location information in Oraimutia area on May 3<sup>rd</sup>, 2014 for coinciding strikes between 6:00pm and 6:35pm

Figure 6 shows comparison of strike distance measured for coinciding strikes. It is observed that at the distances when lightning strikes are small the accuracy of the device is high compared to when the distance is large. The two sensor systems have a deviation of about 2Km when the sensors detect lightning beyond 14km. When the distance is less than 6km, the two sensor stations roughly records the same distance. The lightning pattern shows that strikes started at a low frequency then increased to a climax then stopped abruptly.

### Conclusion

A framework has been presented that incorporates use of microcontroller and sensors to gather lightning data. The microcontroller controls the system and synchronizes all the module operations. The lightning sensor is used to pick lightning distance and the GPS sensor is used to pick time and location of the system. A circuit for automatically storing the data has been included. The proposed device is tested in a lightning environment and the result shows that it can be relied to gather data on frequency, distance and movement of lightning strikes in an area. Deploying the proposed device in a lightning network offers the possibility of getting lightning location coordinate of lightning strike. Multiple synchronized sensors could be placed in different locations to capture a single lightning event simultaneously. The location can then be calculated by multilateration.

### References

- Alade, O. M. (2012, July). Standardization of attenuation formula for radio waves propagation through free space (LOS) communication links. *Science Journal of Physics*, 2012, 7.
- Ananthula, S., Kumar, K., & Bhandari, J. K. (2012). Design and Verification of Serial Peripheral Interface. *International Journal of Engineering Development and Research*, 130-136.
- Austria Microsystems. (2012, April). AS3935 Franklin Lightning Sensor IC datasheet. *AS3935 datasheet*.
- Christian, H., Blakeslee, R., Boccippio, D., Boeck, W., Buecheler, D., Driscoll, K., Goodman, S., Hall, J., Koshak, W., Mach, D. & Stewart, M. (2003). Global fire frequency and distribution of lightning observed from space by the Optical Transient Detector, *Journal of Geophys. Res.*, 108 (8), 4005.
- Cohen, M., Inan, U. S., & Said, R. K. (2010, January 22). Geolocation of terrestrial gamma-ray flash source lightning. *Geophysical Research Letters*, 37, 1-5. doi:doi:10.1029/2009GL041753
- Cummins, K., Kridder, P & Malone, M. (1998, November). The U.S. National Lightning Detection Network and Application of Cloud-to-Ground Lightning Data by Electric Power Utilities, *IEEE Transactions on Electromagnetic Compatibility*, 40 (4), 465-480.
- Cummins, K., Murphy, M., Bardo, E., Hiscox, W., & Pyle, R. (1998). A Combined TOA/MDF Technology Upgrade of the U.S. National Lightning Detection Network. *Journal of Geophysical Research*, 103(D8), 9035-9044.
- Dowd, P., Perreault, J. Chu, J., Hoffmeister, D., Minnich, R., Burns, D., . . . Stone, D. (2000). *Lightning Network and System Architecture*. New York: State University.
- Fisher, D. K., & Gould, P. J. (2012). Open-Source Hardware is a Low-Cost Alternative for Scientific Instrumentation Research. *Modern Instrumentation*, 8-20. doi:http://dx.doi.org/10.4236/mi.2012.12002
- Greenberg, E., & Price, C. (2004). A global lightning location algorithm based on the electromagnetic signature in the Schumann resonance band. *J. Geophys. Res.*, 109.
- Huang, F., Li, Z., Lu, X., Sheng, W., Sun, L., Wei, X., & Liu, G. (2013, August). GPS Navigation Information Processing and Display Based on VC++. *International Journal of Signal Processing, Image Processing and Pattern Recognition*, 6(4), 333-344.
- Liul, T., & Wang, Y. (2011, June 24-26). IP design of universal multiple devices SPI interface. *IEEE International Conference on Anti-Counterfeiting, Security and Identification (ASID)*, 169-172. doi:10.1109/ASID.2011.5967443
- Mach, D., Christian, H., Blakeslee, R., Boccippio, D., Goodman, S. & Boeck, W. (2007). Performance assessment of the Optical Transient Detector and Lightning Imaging Sensor. *Journal of Geophys.* 112



- Petty, V. R. (2007). *A framework for Radio Frequency Spectrum Measurement and Analysis*. Arbor: Proquest information and learning company.
- Qixin. (2008). Lightning: A Hard Real-Time, Fast, and Lightweight Low-End Wireless Sensor Election Protocol for Acoustic Events Localization. *IEEE Transactions on Mobile Computing*, 7(5), 570-584.
- Wood, T., & Inan, U. (2004, August). Localization of individual lightning discharges via directional and temporal triangulation of spheric measurement at two distant sites. *Journal of Geophysical Research*, 109, 1-13.