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High-Speed video observations on fork lightning events in Malaysia

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ABSTRACT

Malaysia is one of the countries with the highest lightning strikes incidence in the world. Yet, Malaysians are still taking a proper lightning protection indifferent manner. This might be due to lack of knowledge on lightning characteristics. Therefore, this study presents an unusual lightning phenomenon with multiple grounding points that might cause a disastrous event, called fork lightning. Three different patterns of fork lightning mechanism were successfully recorded by using high speed camera with 2800 frame per second. Temporal analysis of the lightning progress had been conducted on the samples based only on the recordings by using Wondershare Filmora video editor. The samples of fork lightning images were acquired among 37 of negative lightning events recorded in this study. The first sample of fork lightning fully established the forked branch 0.35 ms before the return stroke occurred. Whereas, second fork lightning established its forked branch 0.35 ms after the return stroke. Both forked branches for third sample simultaneously fully established with the return stroke event. Obviously, these events had striking the ground in up to ten milliseconds. Thus, there is always a possibility that they might cause serious damage and should not be neglected in designing a lightning protection system.

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1. INTRODUCTION

Malaysia is still lack of lightning protection awareness as there are numbers of buildings did not install lightning rod at every corner of a cuboid shape building. Since Malaysia was recognised as the third highest lightning rate country in the world [1], this situation is very worrying and proper action should be taken to enhance knowledge on lightning properties. For instance, a research done by Phan [2] was very useful in reducing number of faults in transmission line due to lightning strikes. Interestingly, an experimental work done by Ullah et al [3] proved that lightning strike behaviour were different for different structure of buildings. Therefore, a suitable lightning protection system should be installed at a suitable part of a building. Besides, lightning strikes protection systems need proper and good material for the earthing system. As in research reported by Hasni et al [4], bauxite is more useful for portable grounding system application better than kaolin material. The comparison was done by using the lightning flashover data that strike the selected grounding material. Yet, these researches more useful in designing earthing rod and surge arrester. Lightning properties should be investigated in more details in order to provide a proper lightning protection like circuit breaker and surge protective devices. Therefore, more studies on lightning mechanism and characteristics must be conducted to enhance the knowledge on the lightning properties.

A complete progress of a lightning consists of a preliminary breakdown, followed by stepped leader and return stroke. Normally, the first return stroke is always come in branching channel and only one main channel strike the ground [5, 6]. But, if a branch capable to reach the ground before the main channel fully neutralized in the return stroke, it will create multiple grounding termination for the lightning. This was inferred in a research done by Kong et al from China by using a high speed camera [7]. In fact Kong had an aggressive team whose conducted many researches on multiple ground lightning by using high speed since 2003 [8-10]. Actually, high speed camera was employed in early 80's by Guo and Krider [11] to observe a first return stroke of lightning event with two grounding points from the same stepped leader. Valine also teamed up with Krider in 2002 [12] to analyze factors that induce multiple grounding lightning. The analysis was done by using both video images and simultaneous electric field data. Recently, Fan et al [13] estimated the distance between three grounding points of a lightning which was averagely 512.7 m. By using the corresponding electric field data, they obtained that the average time interval between the pulses was 3.8 µs. Multiple ground lightning is indeed more severe than a single point. Therefore, multiple ground lightning such as fork lightning is an important subject to be explored and analyzed. Hitherto, this subject has never been reported in Malaysia. Previous researches done in Malaysia were focusing on lightning characteristics both for negative [14-16] and positive lightning [17, 18]. Most of the experimental works on lightning researches done in Malaysia were set up by using parallel plat antenna and oscilloscope to retrieve the electric field data. By using high speed camera, this study presented the mechanism of fork lightning to enhance knowledge on these unusual lightning events. The temporal analysis was estimated solely based on camera images.

2. RESEARCH METHOD

The data presented in this report was obtained at Technology Campus, Universiti Teknikal Malaysia Melaka (UTeM). The experiment was conducted by using a parallel plate antenna which integrated with high speed digital video camera to acquire lightning signal. Figure 1 illustrated the block diagram of the experimental work for this study. The antenna and electronic circuits were placed at approximately 20 meters away from the control room which equipped with PicoScope and PC. The electronic circuit consist of buffer and fast field RC filter circuit. RG58 coaxial BNC cable was used to connect the antenna and the circuits and also to connect the output of the circuits and the PicoScope. While the high-speed camera and the Picoscope were connected to PC via USB cable. The parallel plate antenna used to sense fast field radiation signal from the lightning. The output from the electronic circuit was driven to a PicoScope operated at 8-bit resolution with bandwidth of 20 MHz to 200 MHz. This antenna set up was to identify the type of CG flashes recorded. Whether it was positive or negative depends on the electric field radiation pattern recorded and displayed by using PicoScope software in PC. This study adopted atmospheric sign convention, where a negative return stroke would produce a positive field change and vice versa. A high-speed camera, Chronos model with maximum frame rate of 1.4 gigapixels per second was set up to capture lightning images that occurred simultaneously with the electric field acquired by using the antenna. The camera resolution, frame rate and exposure were 800 x 600 pixels, 2800 frame per second and 348.06 µs, respectively. Each trigger pulse was initiated manually by depressing a hand-held switch when a flash occurred. This manual set up was a kind of challenge in conducting this lightning observation by using high speed camera. Then, all the videos recorded were played back by using Wondershare Filmora video editor in PC and temporal analysis on the lightning images were done frame by frame with 1 frame equivalent to 348.06 µs.

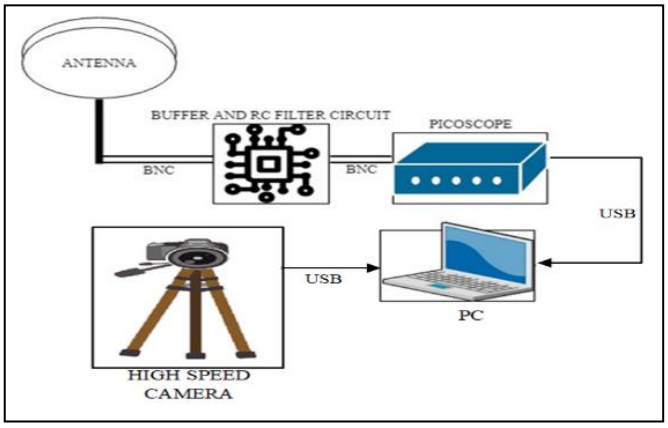
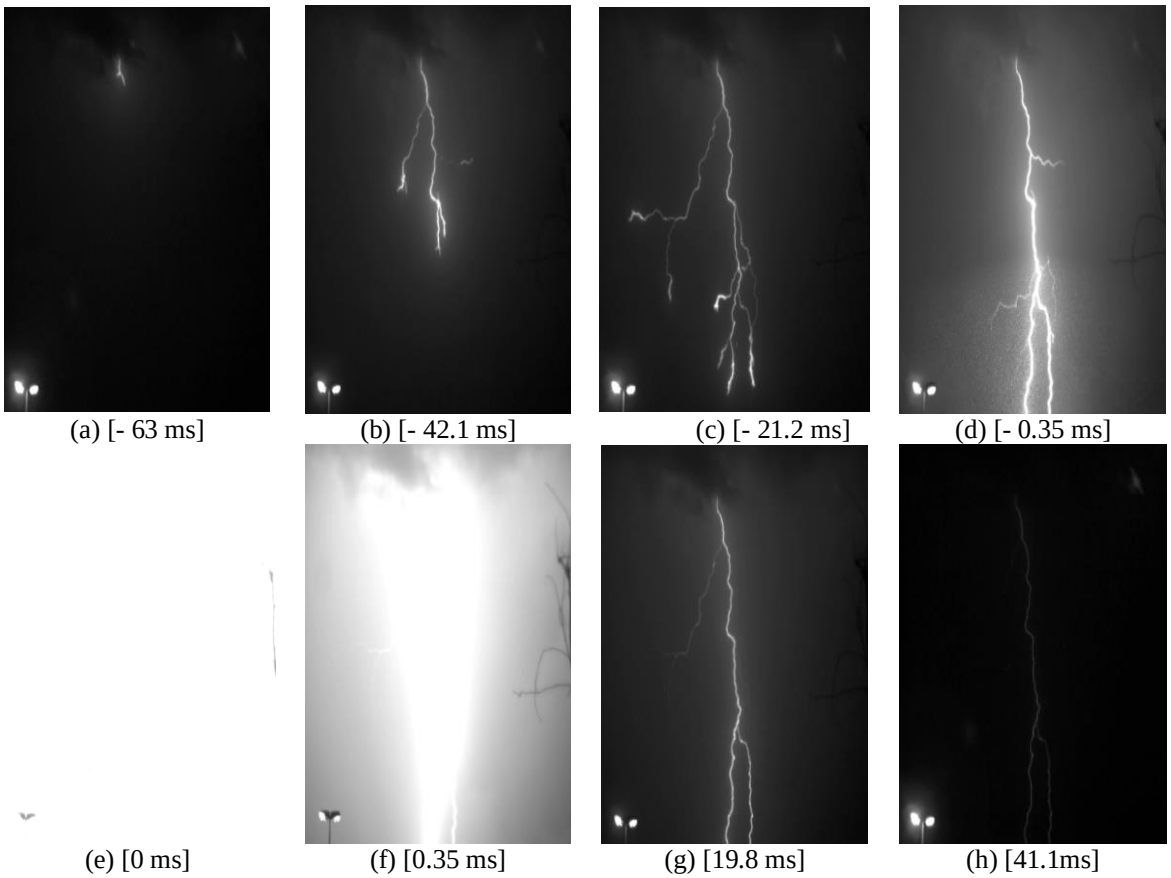


Figure 1. Block diagram of the experimental work

3. RESULTS AND DISCUSSION

Based on the electrical field radiation, 37 of negative lightning events were recorded in this study. Among them, there were fork lightning events recorded by using the high-speed video camera. Fork lightning event was categorized as unusual as bead lightning, ribbon lightning, and ball lightning [19]. This report presented three fork lightning which two flashes occurred on 26th November 2018 and the third sample occurred on 7th December 2018. The brightest or flooded image in the frame was considered as return stroke event and the first return stroke occurred at 0 ms of the lightning duration. In Cooray's book, mentioned an unusual lightning which divided like a fork at its lowest section and strike at two different point. Normally two branches of the lightning touch the ground within few microsecond of each other other [20]. It is called fork lightning and was found earlier by a few researchers [12, 21]. Figure 2 shows the first sample of fork lightning for this study which recorded around midnight. The step leader started to form 63 ms before the return stroke occurred as illustrated in Figure 2 (a). Figure 2 (b) shows the leader branching and the stepping behaviours until the forked branch established at 21.2 ms before return stroke as in Figure 2 (c). In Figure 2 (d), the conducting channel became brighter as it approached to the ground to meet upward streamer. Then, return stroke formed and produced flooded image in the recording frame as shown in Figure 2 (e). From Figure 2 (f) and (g) can be observed that both ends terminated simultaneously to the ground. Both ends persist until the event fully disappeared after 41.1 ms. This observation is similar to lightning image recorded in South Dakota by Warner [22] where both of the forked ends terminated to the ground at the same time.



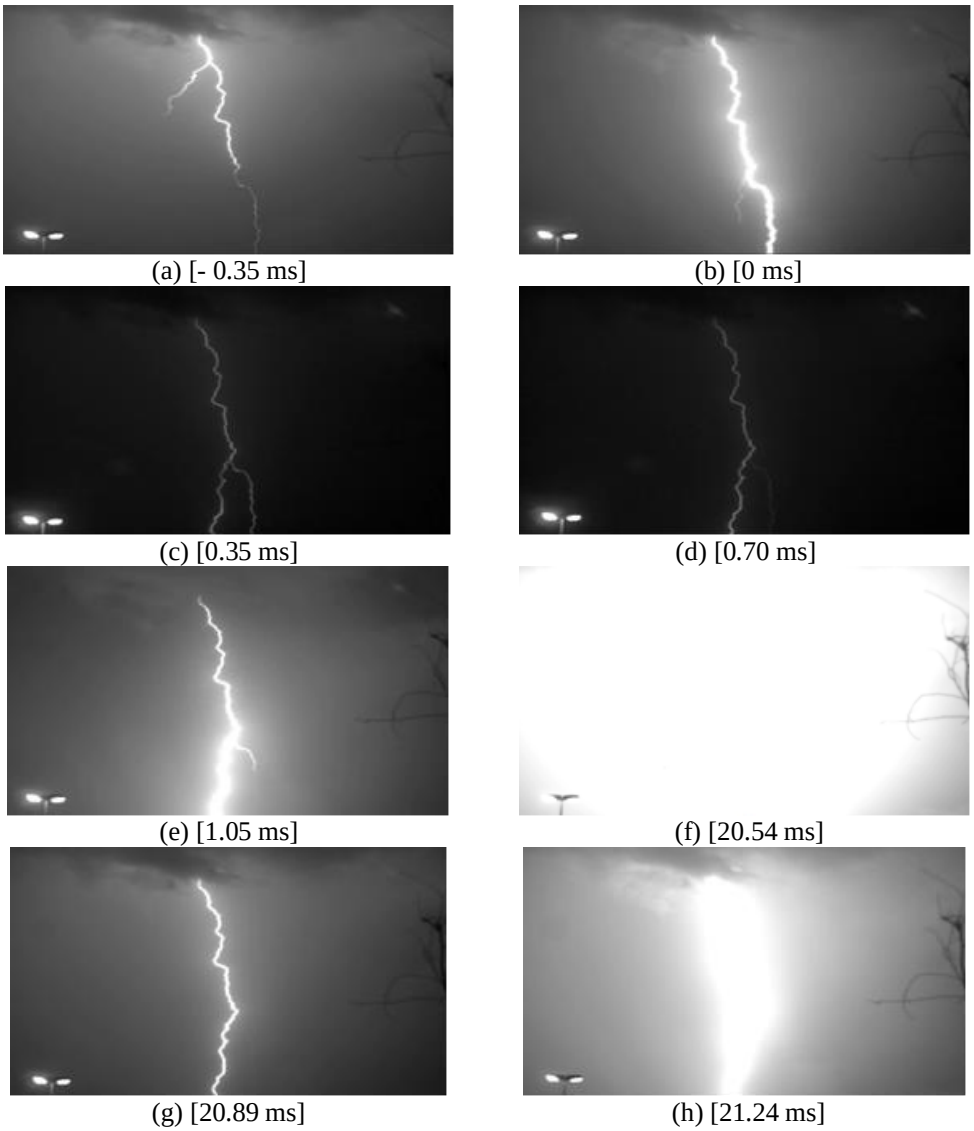
(a) [- 63 ms] (b) [- 42.1 ms] (c) [- 21.2 ms] (d) [- 0.35 ms]

(e) [0 ms] (f) [0.35 ms] (g) [19.8 ms] (h) [41.1ms]

Figure 2. First fork lightning formation occurred on 26th November 2018

Second sample shown in Figure 3 occurred after 270 ms of the first fork lightning event aforementioned. They used the same conducting channel. Yet, this sample had less branching behaviour as shown in Figure 3 (a). Interestingly, this sample consists of three return strokes. As the first return stroke was captured in Figure 3 (b) with the upper branch disappeared during the return stroke and start to fork towards the left side of the channel. In Figure 3 (c), it produced forked branch and terminated to the ground after 0.35 ms of the first return stroke. After 0.70 ms, the right branch disappeared as in Figure 3 (d) and in Figure 3 (e),

the left branch became more luminous. Then after 20.54 ms of the return stroke as shown in Figure 3 (f), second return stroke occurred and produced a flooded image in the recording. In Figure 3 (g), left branch was still dominant and right branch no longer appeared. Before disappearing, the third return stroke occurred through the left branch channel 21.24 ms after the first return stroke as presented in Figure 3 (h). This sample was similar to researches done in Arizona byValine [12] and Jiang [23] from China. They categorized this type of fork lightning as altered channel flashes as there was alternate stepping of the branches sharing a root of the conducting channel. A brief forked lightning was recorded on 7th December 2018 during daytime of thunderstorm. Both ends of the forked conducting channel terminated simultaneously as shown in Figure 4 (a). Recorded in Figure 4 (b), the right branch disappeared leaving the left side just within 0.35ms after the fork lightning event occured. It persisted until the whole channel became less luminous as in Figure 4 (c). Then, it was fully vanished right after another frame of recording. This finding was identical to the images recorded by Wurden [24] in Arizona and Maslowski [25] in Poland. Only one branch of the fork lightning will survive as a conducting channel before disappearing in microsecond of time.



(a) [- 0.35 ms] (b) [0 ms]

(c) [0.35 ms] (d) [0.70 ms]

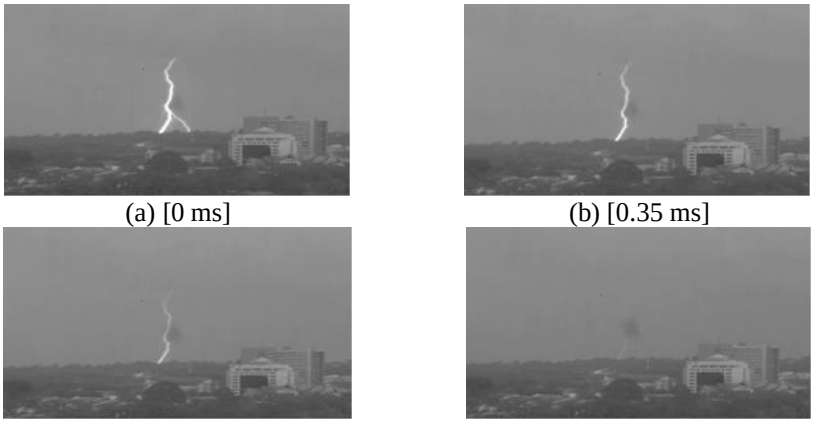
(e) [1.05 ms] (f) [20.54 ms]

(g) [20.89 ms] (h) [21.24 ms]

Figure 3. Second fork lightning formation occurred on 26th November 2018

This study obtained 8.1 % of fork lightning occurrences. As mentioned before, fork lightning was considered as an unusual event. This is proven in a few comprehensive studies done in several countries as tabulated in Table 1. All of the researchers mentioned in Table 1 obtained less than 16% of fork lightning occurrences. By using 59 samples of lightning, Kong [9] obtained 15.3% of lightning occurrences in China.

With further analysis, he able to conclude that flashes with multiple striking points on the ground within a short time may be a common phenomenon in a lightning discharge process. During summer 1997 in Arizona, Valine [12] had analyzed 386 data samples and the fork lightning occurrences percentage was 9.6%. All of the samples were then categorized into four types based on the channel termination. Namely, single channel flashes, multiple channel flashes, new channel flashes and altered channel flashes. Whereas Antune [26] deduced that four fork lightning might occur per day after having analyzed 357 lightning samples acquired during two consecutive summers in 2012 and 2013. The experimental work acquired 6.2% of fork lightning occurrences in Brazil. Besides from the aforementioned findings of researches done by using high speed camera, there are in fact more subjects on lightning events can be explored. As presented by Ballarotti [27] and Tran [28], the method used in this field campaign was very helpful and important to investigate lightning mechanism and characteristics.



(a) [0 ms] (b) [0.35 ms]

(c) [0.7 ms] (d) [1.04ms]

Figure 4. Third fork lightning formation occurred on 7th December 2018

Table 1. Percentage of fork lightning occurrence

Author	Country	Samples	Percentage of fork lightning
This study	Malaysia	37	8.1%
Antunes [26]	Brazil	357	6.2%
Valine [12]	Arizona	386	9.6%
Kong [9]	China	59	15.3%

4. CONCLUSION

This experimental work was successfully observed three fork lightning evolutions and enhances knowledge on the temporal characteristics of the events. First sample established the forked branch 0.35 ms before return stroke. While the second fork lightning took 0.35 ms after the return stroke occurred to fully establish the forked branch. Both branches of the fork lightning in the third sample were observed to touch the ground simultaneously with the return stroke. All of the types were similar to research findings reported by other researchers from several countries as aforementioned. Besides than lightning evolution, we can learn more on a lightning termination location and unusual mechanism by using video recording. Therefore, high speed camera will be very helpful to examine video observation and electric field record in future works. More comprehensive analysis can be conducted such as to produce a statistic on the lightning continuing current duration per day. This finding is important to learn more on lightning fatal behavior and contribute more on the lightning characteristics knowledge which is very useful in lightning protection design. Hitherto, there is no study on fork lightning has been reported and this is the first of its kind in Malaysia.

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