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Earthquake Early Warning (EEW) System: System Architecture, Data Modelling, and User Interface Design

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ABSTRACT

Earthquake Early Warning Systems (EEWSs) development is essential to provide service to stakeholders and the public. The service is the information access regarding the information on the earthquake source area and its impact on the surrounding environment. This study aims to conduct a systematic literature review of peer-published studies focusing on the development of earthquake Early Warning Systems (EEWSs). The method of systematic review is well-established in research by Kitchenham et al. (2005). It is used to analyze the literature and answer defined research questions systematically. We found 16 papers related to system architecture, data modelling and user interface design of Earthquake Early Warning Systems (EEWSs) published in 2009-2020. Research that discusses data modelling is 6%, the user interface design is 38%, and system architecture is 56%. Overall, our findings show that the system architecture, data modelling and user interface of the development of Earthquake Early Warning Systems (EEWSs) in several countries have significant similarities. It can be modelled as a framework for the development of Earthquake Early Warning Systems (EEWSs).

Keywords : Earthquake Early Warning Systems, Systematic Review, System Development

I. INTRODUCTION

Quick response to earthquake disasters in emergency operations is essential to reduce the impact of damage and disaster victims. Emergency operations for the community's security and critical infrastructure need to be carried out quickly and accurately. To support the success of the emergency operation, the government began to develop Earthquake Early Warning Systems (EEWSs) [1]–[3]. EEWS is an information system developed to quickly provide information about the potential damage caused by an earthquake. This system is expected to be an effective strategy to reduce the impact of earthquakes by providing real-time earthquake information to the public and related stakeholders [4]–[6].

In Japan, the mobile-based EEWS was implemented by the Japan Meteorological Agency (JMA, https://www.jma.go.jp/jma/indexe.html) and had been functioning well since 2007 with the involvement of three major cellular telephone companies. Notification information by JMA can be easily disseminated to the public through this mobile-based EEWS. In the United States, the University of California is developing the MyShake App, a mobile-based EEW. This application can recognize earthquake shocks by using sensors on smartphone devices. This information is then collected to the data processing centre to find detailed information about the earthquake [7]–[10].

In Taiwan, the government developed a Cell Broadcast Services (CBS) system to provide earthquake warnings. This system distributes notifications to users in the form of location information, strength and intensity of earthquakes that occur in the local area [11]. In Indonesia, earthquake disaster mitigation applications have been developed by involving users (public), The Meteorological, Climatological, and Geophysical Agency (BMKG for short) and administrators [12], [13].

In Mexico, the government collaboration with an agency called CIRES (*Centro de Instrumentación y Registro Sísmico, A.C.*), developed a system for sending earthquake alerts based on data from 100 sensors in Mexican territory. Finally, the government developed an application called SkyAlert based on mobile. When an earthquake occurs and is detected by the nearest SkyAlert sensor, this application will send earthquake information to application users. Currently, users of the SkyAlert application in Mexico have reached more than 5.8 million users [14], [15]. In Italy, a mobile application for Android devices has been developed named PRESTo (PRObabilistic and Evolutionary early warning SysTem). This application was developed to provide information to users about early warnings for earthquakes that occur in an area [1], [16]–[18].

The internet-based application is one of the candidate devices that can be used to develop the Earthquake Early Warning Systems (EEWSs). Stakeholders and the public can access information quickly regarding the information on the earthquake source area and its impact on the surrounding environment [19]–[22]. Based on the background above, this paper is aimed to review the research paper related to Earthquake Early Warning Systems (EEWSs) and presented the result in system architecture, data modelling and user interface design.

II. METHODS AND MATERIAL

This study is a literature review study following the guidelines published by Kitchenham et. al. (2005). The guidelines consist of three stages, namely planning, conduction, and reporting reviews, which can be used for methods for systematic literature review research [23]–[25].

Figure 1. Research method

As a planning stage, research questions need to be defined based on the objectives and research problems. Therefore, the research questions in this study include:

RQ1: How is the current research on the Earthquake Early Warning (EEW) System development?
RQ2: What is the current state of EEW system research based on the classification of system architecture, data modelling and user interface design?

At the implementation stage, we chose keywords to answer each research question. We use keywords to search for relevant publications in the following databases: ACM Digital library, Google Scholar, IEEE Explore, ISI Web of Science and ScienceDirect.

Any research publications published in the last ten years that answered our research questions were directly considered for inclusion in the research data. The publication must have been published in the form of a reputable journal paper or conference proceedings.
This study focuses on system architecture, data modelling, and user interface design for the Earthquake Early Warning (EEW) System. Therefore, we also exclude studies that only discuss factors or lessons learned on developing and implementing the Earthquake Early Warning (EEW) System.

III. RESULTS AND DISCUSSION

This research collected data from research databases and found several related works that explained the mobile application model design for earthquake early warning system. We found as many sixteen publications ($n = 16$) for this study from 2009 until 2020 as depicted in Figure and Table below.

TABLE I
RESEARCH DATA (N=16)

Source	Author	Year
[26]	Tanaka et al.	2009
[27]	Brown et al.	2011
[28]	Peng et al.	2011
[29]	Satriano et al.	2011
[30]	Fujinawa & Noda	2013
[31]	Given et al.	2014
[7]	Kong et al.	2016
[32]	Rahadian et al.	2018
[33]	Kolathayar et al.	2018
[12].	Yuwono et al.	2019
[34]	Hobbs & Rollins	2019
[1].	Colombelli et al.	2020
[35]	Pamudji et al.	2020
[36]	Fazeli et al.	2020
[37]	Suzianti et al.	2020
[38]	Velazquez et al.	2020

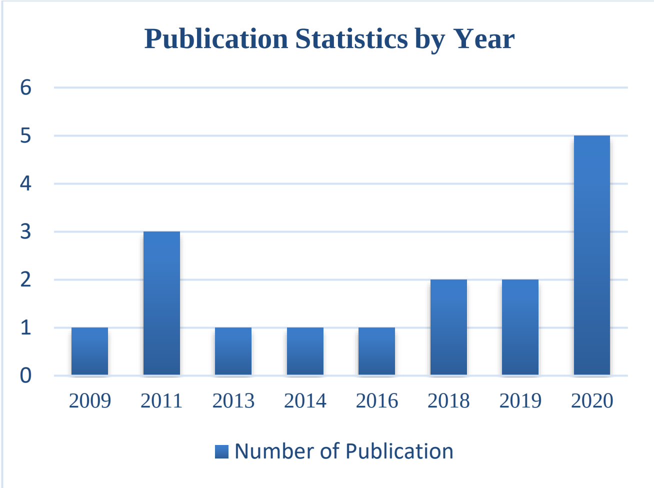


Figure 2. Publication statistics by year

We also categorize publications by location or case studies were conducted. We found 8 location categories, including Global, China, India, Indonesia, Iran, Italy, Japan and the United States. The locations of the most publications were Indonesia ($n = 4$) and the United States ($n = 4$) as depicted in Figure below.

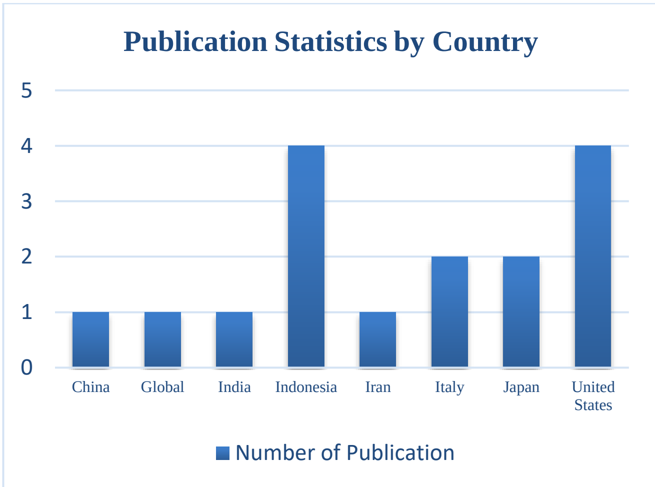


Figure 3. Publication statistics by country

In addition, to make it easier to determine specific topics regarding developing an early warning system (EWS), we group publications based on system components [39]–[41]. There are three categories that we group, including data modelling, system architecture and user interface design.

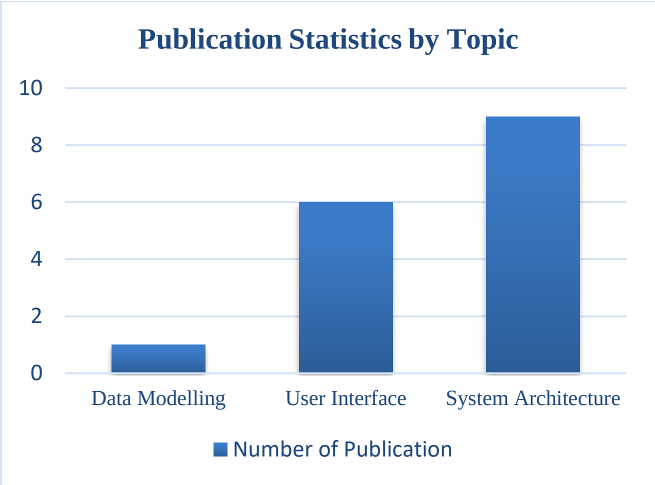


Figure 4. Publication statistics by topic

One of the interested system architecture is ShakeAlert system architecture. This system is an application that monitors ground motion to detect earthquakes and alerts other people and machines, enabling them to take action before the strength of the earthquake increases [31]. Architecture of ShakeAlert system can be seen in Figure below.

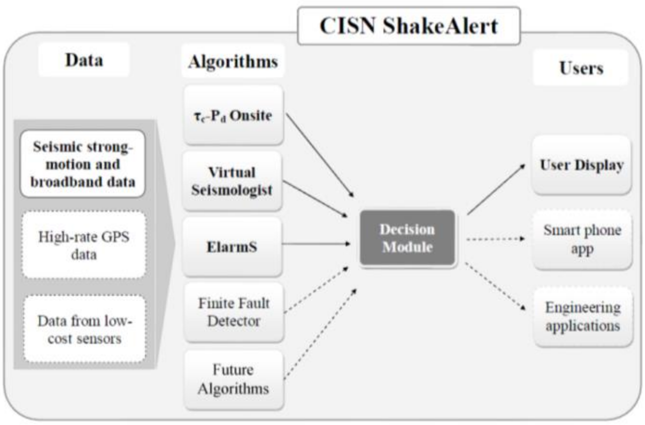


Figure 5. ShakeAlert System Architecture [31].

Moreover, the example data modelling is earthquake early warning system is proposed by Yuwono et al. (2019). This research describes earthquake disaster mitigation applications in Indonesia. This paper describes an application data model that involves users (general public), Meteorological, Climatological, and Geophysical Agency or the Meteorology, Climatology, and Geophysics Agency (BMKG for short) and administrators [12].

Users can access the latest earthquake information, earthquake area maps, earthquake statistics and receive earthquake alerts if they are in a dangerous area. In addition, BMKG, as a source or provider of data, plays a role in providing detailed earthquake statistical information for each region of Indonesia [12].

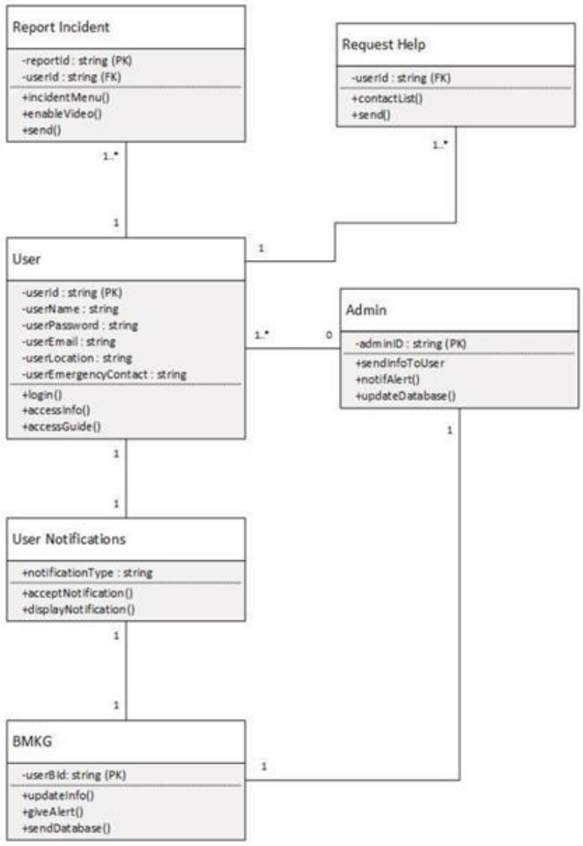
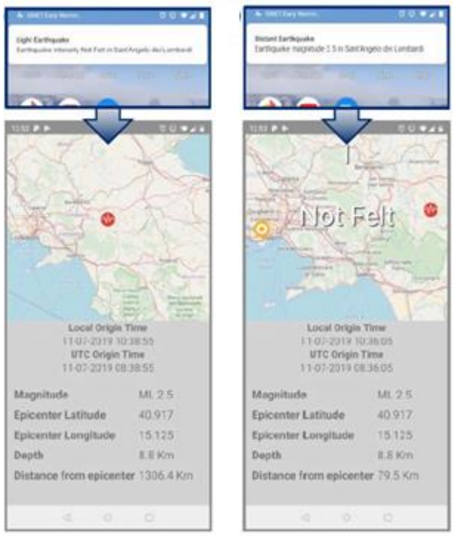


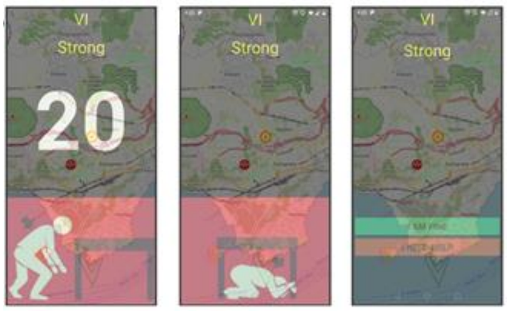
Figure 6. Data modelling of earthquake EWS [12]

Figure 7 is the user interface design of PRESTo (PRObabilistic and Evolutionary early warning SysTem) [1]. Figure 7.a is an example of the application screen design when working in active mode without warning activation, warning that the case of a distant event, a warning that the case of a closed event where the expected shock does not exceed the threshold. The user interface design is made in a pop-up notification that appears on the application when an alert is sent. The user interface design is also equipped with maps using the services of OpenStreetMaps.

While Figure 7.b is an example of a user interface design when a warning indicating a shock has occurred, instructions on how to anticipate what needs to be done, and an earthquake shock warning has passed. There are also two buttons (green and red) to communicate the user's condition and position to other users in the User interface design.



(a)



(b)

Figure 7. User interface design of earthquake EWS [1]

IV. CONCLUSION

This research is systematic literature review study on the development of earthquake Early Warning Systems (EEWSs). The method of this research is well-established method of systematic literature review by Kitchenham et al. (2005). As the result, we obtained 16 papers published in 2009-2020 related to system architecture, data modelling and user interface design of Earthquake Early Warning Systems (EEWSs). Publication data that presented data modelling is 6%, the user interface design is 38%, and system architecture is 56%. Overall, our findings show that the system architecture, data modelling and user interface of the development of Earthquake Early Warning Systems (EEWSs) in several countries have significant similarities. It can be modelled as a framework for the development of Earthquake Early Warning Systems (EEWSs).

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