CHAPTER 1
INTRODUCTION

1.1 Background

A bridge is a vital infrastructure that facilitates community activities that connect two disconnected areas. Bridges usually cross natural fields such as rivers, valleys, canals, and many others [1, 2]. Bridges, being crucial public infrastructures, need continuous monitoring to ensure their structural health. Over time, the constant load on the bridge can lead to reduced resilience and overall quality. Specifically, in Indonesia, bridges are mostly located in rural areas or areas that are difficult to access. Events such as the collapse of bridges in hard-to-reach areas are very worrying, given the difficult repair process and the damage to communities that live there caused by the loss of access to a region. There are several factors that can cause bridge collapse, such as elasticity, structural deformation, and load. However, the causes of bridge collapse can also be grouped from natural factors and human-derived factors. Natural factors are floods, scour, earthquakes, landslides, and others. While factors of human origin are such as negligence or failure in bridge design, construction, poor maintenance, or bridges that are overloaded [3-5]. In addition, the age of a bridge that has exceeded its lifetime can affect and increase the likelihood of a bridge collapsing [6, 7].

With all the damages and difficulties described above, of course, more effort is needed to maintain the infrastructure and prevent collapse on the bridge. One of the actions that can be taken to monitor the suitability of bridge infrastructure to be maintained and prevent accidents is to carry out Structural Health Monitoring (SHM).

Structural Health Monitoring (SHM) is the process of monitoring the safety condition of a building structure, such as bridges, buildings, and others. The goal is to monitor the condition of structural health and know the damage as soon as possible so that unwanted events can be avoided [8-10]. There are various SHM methods to monitor the condition of the bridge that have been studied, such as using contact sensors and non-contact sensors. Detection using contact sensors can be done by a variety of methods, such as using the Fiber Bragg Grating (FBG) Sensor [11, 12], strain gauge [13-15], and accelerometer [16-18]. In this study [11], SHM was performed by performing detection using the Fiber Bragg Grating (FBG) sensor as a contact-distributed length meter. The experiment was carried out by installing the sensor on the bottom of the bridge that has been loaded with a truck weighing 30 tons, and to identify damage, the study used a Macrostrain-Vector (MSV) which is an assessed vector feature that can facilitate identification. Using the FBG sensor as a distributed length meter will be very helpful in obtaining information related to persistent structural deformation that can subsequently be processed for damage identification and structural control. The results of the study show that the developed distributed length measuring FBG sensor can provide satisfactory measurement and monitoring for large-scale infrastructure, in addition to the local information, stretch distribution, and displacement that can be obtained through these methods. However, this study is still less efficient because it still needs to use a lot of sensors and its installation is not easy. the device's maintenance also needs to be considered.

SHM can also be done by performing detection using a non-contact sensor. Non-contact detection has the advantage of not having to change the structure of the bridge, which is difficult to do. Detection using non-contact sensors can be done by several methods, such as using vision-based sensors [19-22] or using lasers [23, 24]. In the study [19], SHM was performed on bridges with non-contact detection using a vision-based system to detect small displacements on the bridge. The research was carried out by taking images using digital video cameras combined with telescopic lens devices as well as processing the data using algorithms and image processing techniques to process small displacements detected. The experiment was carried out with a laboratory test using a vibrating table that compared the results with a contact sensor, as well as field tests using trucks with varying loads. With this study, a fairly good dynamic resolution was obtained, as well as the advantage that the proposed system is not affected by temperature and humidity. However, the use of this method will be interrupted when the intensity of light is low, such as in nighttime, when there are fogs, or there is a strong wind. In addition to the two methods mentioned, Radio Detection and Ranging (Radar) is also one of the technologies whose use is becoming increasingly widespread and can also be used to perform non-contact SHM.

Radar is an electromagnetic sensor that can detect an object at a distance and is not disturbed by night, fog, clouds, smoke, and most other obstacles [25, 26]. Using radar systems to perform SHM technically will reduce the problem of the spectrum use so that it is easier to realize. In addition, the radar uses less power and is more efficient when compared to the SHM using a contact sensor since with the radar, one device is already sufficient to perform detection related to the SHM, so it does not require the cost and effort of maintaining the sensor.

Radar can be implemented with various types of wave forms, one of which is Frequency Modulated Continuous Wave (FMCW) radar. The FMCW radar is a special type of radar sensor that emits continuous transmission signals such as the Continuous Wave (CW) radar, only the FMCW radar can change the frequency of its operation during measurement, i.e., the transmission signal is modulated in frequencies or in phases and on the FMCW radar is measured the phase or frequency difference between the transmitted and received signals [27]. FMCW is considered more suitable for use in this study because by emitting signals continuously on the bridge then relevant informations to detect small displacement profiles can be obtained, so that SHM can be done maximally.

In previous studies [28], SHM experiments were conducted on bridges using FMCW radar based on Front-End radar and Data Acquisition Cards with the principle of 3D movement measurement. The experiments were conducted to identify multi-targets modeled with three targets at different distances. The results of the study suggest that the system can detect small displacement at millimeter-level and can be done for multi-target detection. However, the research has hardware limitations and does not use the radar prototypes as much as the interferometric radar used in the research [29, 30], in addition, the study did not conduct direct experiments on the actual object but only modeled the bridge with the corner cube at the experiment site, so that the designed system was less relevant to the actual circumstances.

The study [31] also conducted SHM on bridge infrastructure using ground-based interferometric radar system modeled with the Real-Aperture Radar (RAR) sensor IBIS-S to detect multi-target on three positions with four bridge perspectives. The type of interferometric radar is chosen because it can measure phases with a sensitivity that is only a small fraction of its wavelength, shortened to the level of millimeters, in addition to which the movement can also be measured. The IBIS-S sensor was chosen because it is a commercial radar system that can be used in measurement cases with a central frequency of 17.2 GHz and a maximum bandwidth of 300 MHz and resolution range of 0.5 meters. Thus, with this specification, it can be assessed to meet the needs of the field in detail. The result is that the dynamic behavior of the bridge as well as the maximum movement of bridge can be obtained in detail. However, RAR can only predicts radar Line of Sight (LoS) so it requires many radars from different perspectives to get a full picture. From both the research that has been explained, it can be concluded that the radar system can be used to perform SHM with a variety of specified qualifications. However, no research has been conducted on SHM using FMCW radar and modeled it as close to real conditions as on a civil bridge or railway bridge.

In determining the health of a bridge structure, there are certain parameters that are commonly used in the civilian scope, one of which is displacement. Displacement is the displacement or attachment of the bridge structure that occurs when the bridge supports a load or works under the influence of external forces such as when there are traffic loads and environmental loads [32]. Displacement causes changes in the shape or position of the bridge structural elements. When a bridge is loaded, the structure will respond by making a displacement called displacement to balance the forces acting on the bridge, and the process is normal [33]. However, there is a standard that states the safe limit of displacement that can be experienced by a bridge. Excessive displacement will cause structural problems or material fatigue that need further review and attention [34]. So that there are parties who are specifically responsible for carrying out maintenance and supervision by measuring displacements at various important points in the bridge structure, so that the performance of the bridge structure can be in accordance with applicable standards.

The usefulness of displacement as one of the bridge health parameters will be utilized in this study so that the health of the bridge can be detected properly. Specifically, the center point of the bridge is the point with the largest displacement [35], but inspectors also sometimes need displacement values at several points for the purpose of understanding more comprehensively the health and safety of the bridge structure. By knowing the displacement value at many points, weak points in the bridge can be identified. In a bridge structure it is very likely that there are several areas with different levels of stress and strain. So, by detecting at many points, bridge inspectors can be helped to identify specific locations that are prone to deformation. In addition, detecting displacements at many points can help evaluate structural integrity by comparing the state of the bridge based on measurement results over time and help inspectors to better understand the load distribution of the designed bridge, thus allowing inspectors to make decisions regarding load restrictions or repairs if needed.

This thesis proposes a method to obtain displacement distribution profiles on bridges which is done by detecting small shifts at many points along the bridge span. The displacement distribution profile will be useful to support the SHM process on the bridge and facilitate the authorities in monitoring the safety of the structure. To obtain displacements on the bridge, FMCW Radar with a frequency of 24 GHz is proposed, with a procedure where the radar is simply directed at one point, the center point of the bridge, but information on displacement values can be extracted at other points along the bridge span. The use of radar was chosen because based on the literature study conducted, non-contact sensors have the advantage of not disturbing the structure and the installation and maintenance process is relatively easier when compared to contact sensors, besides that radar-based non-contact sensors are also easy to operate. Furthermore, the displacement detection process at many points on the bridge is also possible based on the literature study.

1.2 Problems Formulation

The FMCW radar is a radar system with the advantage of reducing the use of the bandwidth spectrum, so it is easy to realize for more efficient measurements. Nevertheless, its use to detect small displacements on bridge infrastructure as a means of obtaining a small profile displacement along the bridge stretch that is later useful for monitoring the condition of bridge structures or performing SHMs still needs to be studied. In line with the need for studies related to the method of detecting small displacement profiles on the bridge infrastructure, it is necessary to further study the appropriate method for processing FMCW radar output data so that the information of small displacement profiles can be extracted well. Further investigation and analysis will be carried out regarding the FMCW radar's ability to streamline SHMs by detecting small displacements at one or more points to predict small dislocations at other points. It can be concluded that this thesis responds to the problem related to the need for multi-point detection methods for SHM by using an easily realizable bandwidth spectrum.

1.3 Objective

The purpose of the proposed thesis research is to design and develop a method of measurement and data processing using a radar system that can be used to detect small displacement profiles to perform SHM along the stretch of the bridge structure, as well as a method to analyze the detection patterns of small displace at one or more points to predict small dislocation at other points as a measure of SHM efficiency on the bridge. So that SHM can be done more efficiently by using only one radar system device.

1.4 Hypothesis

In the study [28], SHM experiments were conducted on bridge infrastructure using FMCW radar based on Front-End radar and Data Acquisition Card with the principle of 3D movement measurement. The experiment was conducted to identify multi-point models modeled with three targets at different distances. However, they do not carry out experiments directly on the actual object. Furthermore, research [31] also conducted SHM on bridge infrastructure using a ground-based microwave interferometric radar system based on LFMCW to detect multi-target with three reference points.

Both studies described have stated that small displacement detection can be done using FMCW radar technology or other types of radar. However, in previous studies, no one has studied detecting small displacement profiles using FMCW radar with the ability to extract small displace profiles along the bridge infrastructure stretches in the laboratory or in the field directly. The expected result is that the proposed radar system can detect small displacement profiles on bridge infrastructure with the capability of extraction of detection profiles so that SHM efficiency can be achieved.

1.5 Research Methodology

This research uses the principle of engineering method because the development or research is based on real problems in the field of structural health monitoring of railway bridges. In detail, the entire process carried out based on the engineering method principle has been elaborated in this book. Broadly speaking, the research method based on the engineering method principle will be explained as follows:

1. Define The Problem

   To start the engineering method process, the process of defining the problem refers to the problem that is the main concern. In this research, bridges are the main focus to solve the problem that specifically railroad bridges do not have qualified tools and there is no tool that can detect damage efficiently and thoroughly. Based on these problems, it is necessary to properly identify the obstacles or shortcomings as well as the characteristics of the problem and the ultimate goal of the research. This stage will help to understand the challenges as well as the best solution to overcome this problem.

2. Background Research

   Background research was conducted to investigate the problems occurring in the bridge infrastructure. Starting from the causes and problems of damage that commonly occur and the absence of adequate tools. This process is also carried out to understand the causes and what the impact of bridge damage is.

3. Specify Requirements

   After the problem and its background are understood, then further in this process a literature study process will be carried out to review the use of technologies that have been used previously to determine the health of bridge structures. Based on the literature study, the determination of technical requirements, the desired functional capabilities of the tool, and the expected performance can be formulated and will be realized in this research.

4. Develop a Prototype Solution

   After knowing what kind of methods and requirements are expected to overcome the problems raised in the research, a method was developed to determine the deflection distribution profile by utilizing radar technology tools. With the provisions as described in the previous sub-chapter, first a simulation process will be carried out before the tool will be implemented to determine the performance of the radar based on the proposed method. And finally, the tool will be developed and further testing will be carried out.

5. Testing

   Based on the developed method, tests will be conducted both in the laboratory and in relevant environments. The results of both will determine whether the provisions of the developed method can fulfill the desire to overcome the problems raised. However, if the test results have met the objectives of the research, then the research process has been completed.

6. Conclusion

   When the developed method has met the objectives and has been able to overcome the problems raised, the results will be analyzed so that the performance, advantages, and limitations of the designed method can be known.