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# A Study on Fleet Agnostic Health Usage and Monitoring System for Bridging Assets

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## Abstract

This study investigates the viability of integrated sensing and data-driven technology to collect comprehensive health and usage information for bridging assets widely used in military applications. Two systems are developed to monitor the structural loads and determine the health of the bridging assets. Firstly, a sensor-based wireless technology is employed on the bridging components to identify loads and monitor the speed of vehicles travelling on the bridge. Secondly, a vision/algorithm-based system is integrated into the bridges to identify the vehicle crossings, as a vehicle travels through the bridging assets. The image processing technology processes the images acquired from multiple cameras attached to the bridge. An artificial intelligence-based algorithm is employed to achieve image processing outcomes. The vision-based system identifies the different types of vehicles. A data core registers all the data collected from the sensor-based system and vision-based systems. A selective data set such as vehicle loads, and images present in the data core acquired from multiple systems are utilised to display key metrics in user dashboards. The data is fed into the user dashboard to identify risks and augment evidence-based decisions. The data collected from two system sources will also inform maintenance and sustainment decisions.

**Keywords:** Load monitoring, Health Usage and Monitoring, Personnel Safety, Fleet Agnostic, Data Analytics, Asset Management

## Introduction

The Fleet Agnostic Bridge Health Usage and Monitoring System (FABHUMS) is designed to fill a gap in military bridging support capability. Military bridging assets have historically sought to capture and assess the health and usage of bridging assets using manual methods that have heavily relied on labour intensive tasks such as pen and paper. This has resulted in a wide range of issues, hampering the ability to make decisions informed by trusted data. The risk of such an approach directly correlates to the safety of bridging assets, the safety of the personnel that build and use the bridging assets, and the total cost of ownership throughout the assets useful life. An innovative concept to develop technology to identify, assess and manage bridging components was initiated to enhance asset management and safety concerns. A range of research has presented numerous investigations into various intelligent systems to manage the health and usage monitoring of bridging assets that result in a considerable reduction of operation and maintenance costs [1, 2, 3, 4]. Structural Health Monitoring (SHM) is an emerging area of study aimed at continuously monitoring the operation and structural performance of bridges. A SHM system can be used to assess the condition of a bridge by measuring its structural response under the traffic. A typical SHM system requires a multi-disciplinary approach, which includes the following three main components: (i) sensors; (ii)

data collection, transmission, and storage; and (iii) assessment framework (i.e., diagnostic and decision-support tools) [5]. Using SHM systems, the operational and structural state of bridges can be analysed and evaluated, which will enhance the safety, efficiency, and maintenance schedule of bridges [6]. There have been a significant number of studies on the development of various SHM techniques for bridge health monitoring using acceleration (i.e., vibration), strain, displacement, ultrasonic wave, etc. [7]. Among the existing SHM techniques, vibration-based and strain-based techniques are the most prevalent approaches for bridge monitoring. It is because, for a bridge structure, the vibration characteristics (e.g., frequencies, mode shapes) represent the global response of the structure whilst the strain response provides information on the localized behaviour of the bridge structure. It should be mentioned that vibration and strain responses are both related to the performance of bridges such as stiffness, strength, and capacity; therefore, they can be used to assess the safety and operational efficiency of bridge structures.
Wireless systems have been widely used in the structural health monitoring [8,9,10] and have proven track record of monitoring loads and health of fixed bridges and other bridging assets. Similarly, Vision-based algorithms are also utilised to identify the prospective load from objects/vehicles using Machine learning and artificial intelligence across multiple applications [11]. The vehicle detection has been conducted with deep learning and is utilised to predict vehicles using numerous multiple synthetic images [12]. The research found that different variation of images helps to better train the algorithms [13]. Also, there is literature that explains the use of intelligent systems that has been used to collate the meta data acquired from these systems [14,15]. However, a robust system with comprehensive collation of metadata from multiple systems has not been widely reported.
This study entails the integration of sensor-based and vision-based techniques to derive an interactive user tool to assess, manage and maintain the modular bridging components widely used in military applications. The subsequent sections present the details of the systems and technologies developed which form part of the FABHUMS system.

## Health Usage and Monitoring System

### Sensor-Based Monitoring System

In this study, wireless accelerometers and strain gauges are proposed to monitor the health and usage of the bridge. The wireless sensors from Beanair® are selected to provide easy sensor deployment and versatility considering the installation and operation nature of the bridge. The triaxial, ±10g accelerometers can be mounted on the bridge components to measure the frequencies and mode shapes of the bridges, which can be used as a bridge health indicator. In addition, a wireless data acquisition (DAQ) system, which is connected to load cells and strain gauge, can be also deployed onto the bridge to monitor vehicle load and strain response where the changes of stress concentration and cracks are critical.

### Scaled Model Tests

To demonstrate the applicability and benefits of the wireless system, a lab-scale modular bridge model was fabricated, and a monitoring scenario was conducted using wireless accelerometer and strain measurement. More specifically, a foil strain gauge was connected to the wireless DAQ device through a bridge completion module. The sampling frequency was set at 50 Hz for the accelerometer and 10 Hz for the strain gauge in the continuous monitoring mode. A truck model was controlled remotely via a wireless controller at nearly steady moving speed to represent vehicle crossing events. The monitored data was transmitted to a laptop via the BeanGateway. The lab-scale bridge model and the sensor instrumentation are shown in Figure 1.

*Figure 1: The lab-scale modular bridge and the wireless sensing system*

Figure 2 and Figure 3 show the monitored results obtained from the wireless accelerometer and strain gauge. The results demonstrate that the structural responses were successfully captured by the wireless sensing system under the vehicle crossing event.

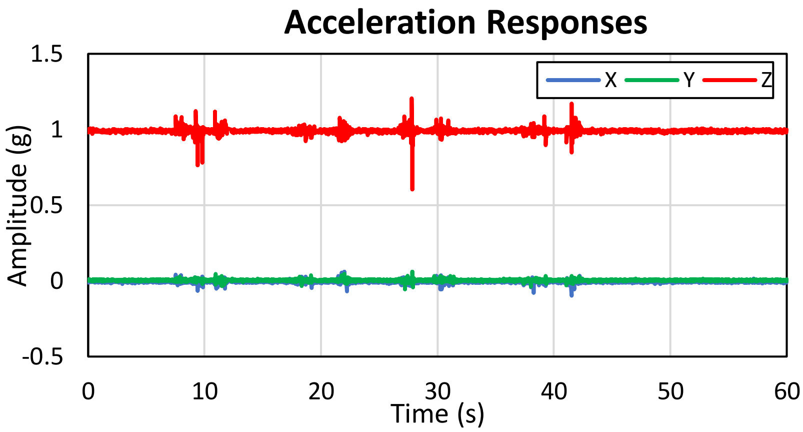


*Figure 2: Typical vibrational responses due to the crossing vehicle*

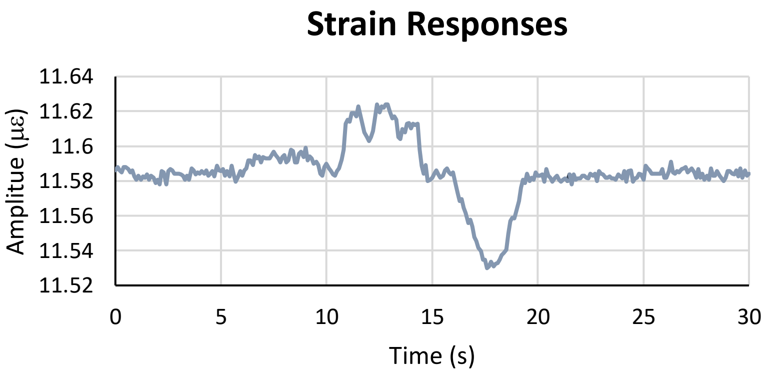


*Figure 3: Typical strain responses due to bending under vehicle's load*

**Preliminary Tests on Modular Bridges**

The wireless sensing system, which was tested in the laboratory, was used in the preliminary field test to evaluate its feasibility and applicability for the real structures (the modular bridge shown at Figure 4).

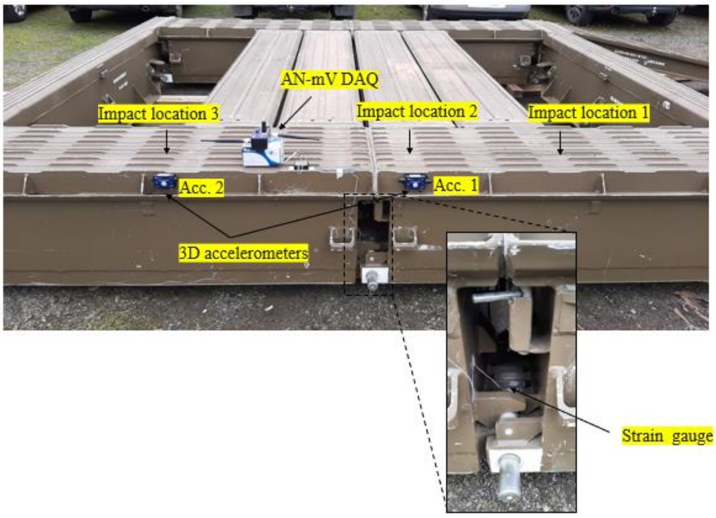


*Figure 4: The sensor layout on the modular bridge*

Two 3D accelerometers and one strain gauge were temporarily installed on the modular bridge for the preliminary testing purposes (see Figure 5) The impulse forces were simulated by jumping at three predefined locations every three seconds. As shown in Figure 8, the acceleration responses were clearly captured in three directions. Note that the distance between the sensor location and the BeanGateway and laptop is about 30 m, which is much further than the setup in the laboratory. This long-distance communication range will allow the wireless system to be used in a remote, portable manner.

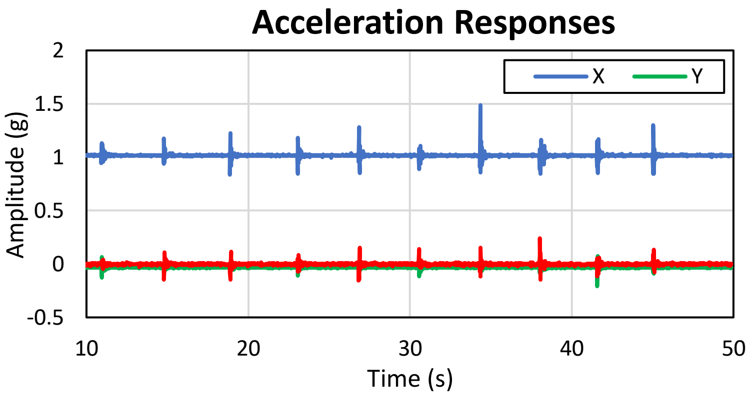


*Figure 5: Acceleration responses under consecutive impulse forces at location 1*

However, the strain gauge did not work properly in the preliminary test. This can be explained by the fact that the load (generated by jumping) is insignificant and did not create any structural load on the bridge structures. Therefore, it cannot produce any measurable structural responses. A real vehicle crossing event should be used in the next field tests.

**Vision-Based Detection System**

The vision-based detection system (VBDS) is an artificial intelligence (AI) based optical sensor system trained to detect and classify the vehicles that traverse its field of view. Vehicles that are detected have a predefined nominal mass which is accumulated against a bridge build allowing the health of individual bridge components to be calculated. The core VBDS hardware components consist of an onboard processing unit and a high-resolution camera.

Training images for the AI will consist of a hybrid of synthetically generated images and real-world representative images. Synthetically generated images are programmatically generated using a gaming engine. In the gaming engine, many 3D environments are modelled each including the multiple bridge types the system is expected to operate on. In the 3D environment, cameras are placed along the bridge and vehicles are programmatically driven across. Still frames are then captured at varying locations as the vehicle passes the camera's field of view. With this setup, multiple environmental factors can be modified such as lighting and shadows, background terrain and vehicle scrim (camouflage). The result of this approach is that tens of thousands of unique photo-realistic images can be generated and automatically tagged with a bounding box and label in a short amount of time.

To augment the synthetically generated images, real-world vehicles are also photographed, and hand-labelled. This strengthens the relationship between the trained model's accuracy results and its performance in the real world as it will be validated against these real-world images during training.

To increase the AI models ability to generalise and successfully detect vehicles with modifications it has never seen before, image augmentation is performed on the training dataset. This is a process of selecting a small subset of random images and applying a transformation to them. These transformations include colour shifting, image rotation and skewing and contrast modification. The idea behind these modifications is that they will weigh the model's decision making more heavily towards the shape of the object and less towards the colours of the objects. Furthermore, a multi-stage neural network is used to optimise speed and accuracy of FABHUMS.

**Data Analysis Engine and User Interface**

The FABHUMS Data Core and Data Analysis Engine (DAE) subsystems enable vehicle crossing data to be tracked against individual bridge components used in multiple bridge builds. This is used to generate component health information and recommendations accessible to operators through a Graphical User Interface (GUI).

The Data Core consists of a database and associated GUI that stores and displays information about bridge components, their approved bridge build configurations, records of components being used in bridge builds, as well as the vehicle crossing data captured by the Sensor-Based Monitoring System and VBDS. Closely tied to the Data Core is the DAE, an algorithm that makes bridge health and usage recommendations based on a predefined set of rules including Original Equipment Manufacturer (OEM) recommendations.

When selecting a suitable database paradigm to implement within the FABHUMS Data Core, the combination of structured and unstructured data stored in and generated by the system was considered. Data associated with bridge components and their approved configurations is an example of structured data following a fixed predictable schema, while usage data generated by the Sensor-Based Monitoring System and VBDS may contain unstructured data such as images, video or discrete-time series datasets. In addition, the Data Core has the flexibility to accommodate new data sources and sensing technologies as they emerge through the iterative design and development processes for FABHUMS. Following a review of management approaches for structured and unstructured data in other Internet of Things (IoT) applications [8, 9], a hybrid model combining traditional SQL relational databases with a NoSQL document object model was selected. This incorporates the advantages of an SQL database in linking bridge components and associated usage data over time, with the support for unstructured data sources provided by NoSQL databases.

Screenshots of the prototype GUI are shown in Figures 6, 7 and 8 demonstrating how bridge configuration, health and usage data captured by FABHUMS is displayed to the operator when building and monitoring traffic for a particular bridge build. The system is agnostic to the type of bridge system and can support various bridging assets from multiple OEMs in various configuration.

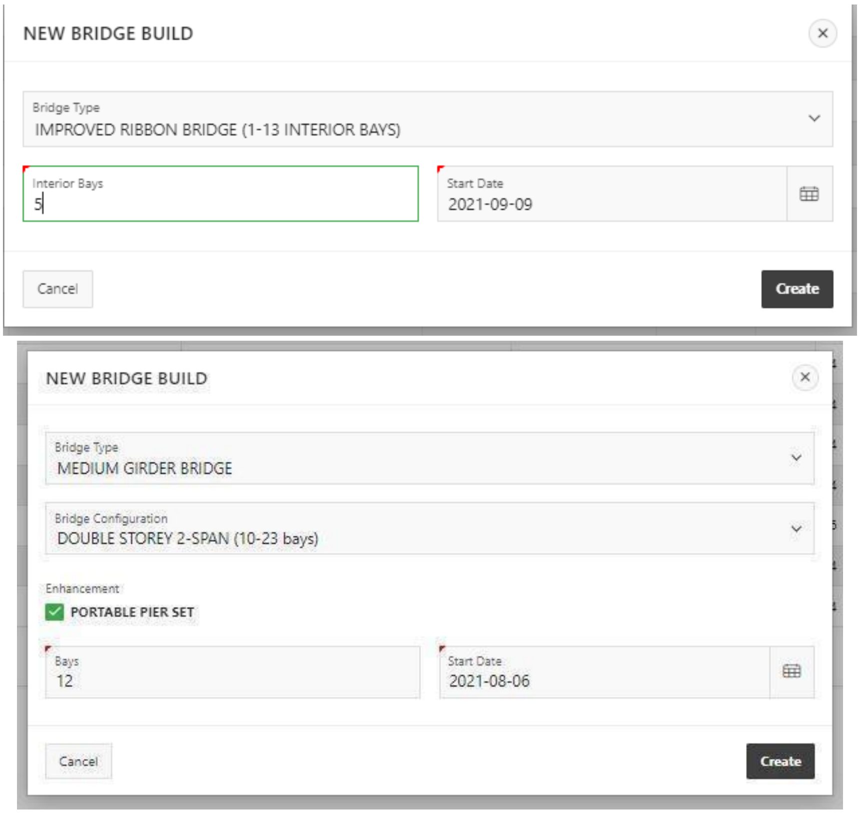


Figure 6 - GUI menu for specifying the configuration of a new bridge build to be monitored by FABHUMS.

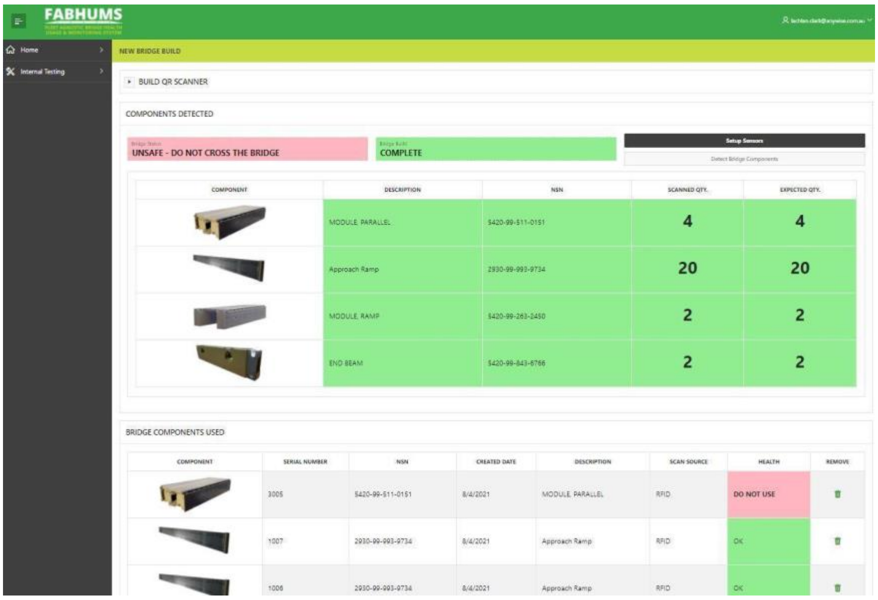


Figure 7 - GUI screen for scanning in modular bridge components to a bridge build.

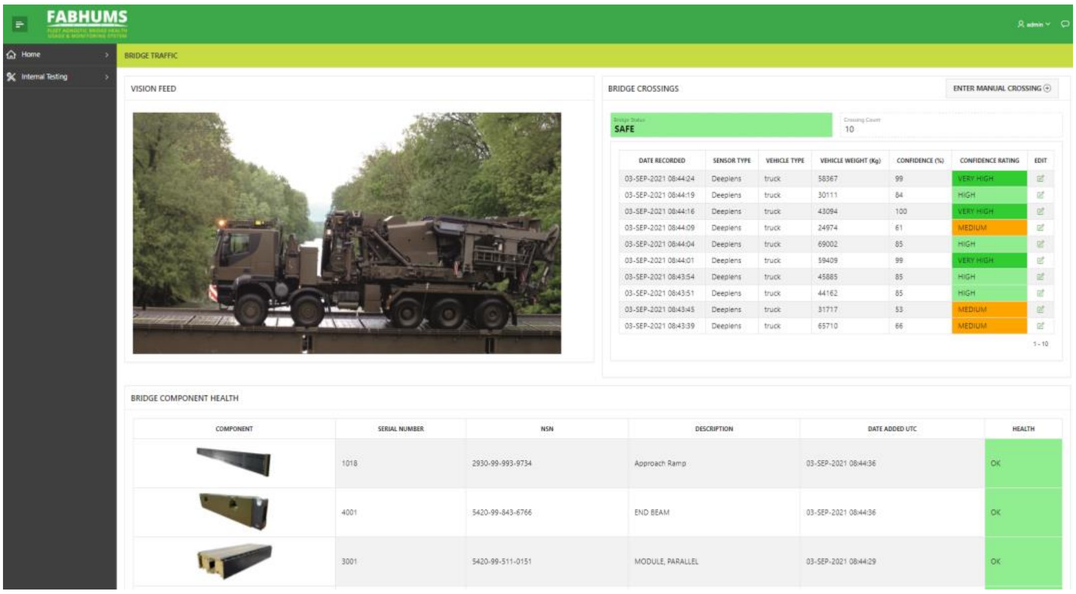


Figure 8 - GUI screen for monitoring vehicle traffic for a bridge build.

Vehicle crossings are continuously tracked in the top-right panel and the health of each component in the build is updated accordingly in the bottom panel. In this fictional scenario, the system is detecting one component has exceeded its safe usage limit, thus flagging a safety concern to the user of this bridge. An area of further investigation is the bridge component health recommendation system within the DAE. While this currently produces health recommendations based on fixed thresholds on the number of vehicle crossings tied to each bridge component, it is expected that the health of each component will be a function of several other factors. These include the configurations of the bridges they are used, such as their length or presence of approved structural enhancements, as well as the load characteristics of each crossing, including the weight and axel count of each vehicle.

## Conclusion

Three different subsystems were incorporated into a Fleet Agnostic Bridge Health and Usage Monitoring System. The sensor-based system, vision-based system and data analysis engine were developed and tested in simulated and real-life environments to acquire and collate the suitability of the system for bridging assets. The initial testing and development have presented substantial results that the system can capture traffic data as well as record and store component level data for military bridging assets. The data acquired from various subsystems and analysed by the data analysis engine assists the decision-making process for safety of personnel, maintenance, and sustainment of the existing assets. The graphical user interface is capable of alerting users to safety concerns and suggesting smarter asset management and maintenance strategies. A further investigation will be conducted for the systems to develop and deliver a robust system for health-monitoring of the bridging assets in extended research and development stages.

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