PROTOTYPE APPLICATION: PORTABLE AND INTEGRATING BRIDGE INSPECTION AND MAINTENANCE SYSTEM

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ABSTRACT

The bridge inspections are important for the safety and serviceability of the road system.The regular inspection and diligent record-keeping are essential for ensuring the safety of the bridge. This paper propose a prototype Portable and Integrating Bridge Inspection and Maintenance System developed as an iOS application. The application utilized YOLOv8 AI model to identify and localize the damage from images and incorporated the checklist sheet for other obervation, allowing the user to directly track observations on a single device. Furthermore, the application offers to store the damaged detected image & inspection report in mobile device. The application is designed to used even in the remote area with limited connectivity. This innovation will significantly improve the bridge inspection efficiency, accuracy, and data accessibility, hence contributing to bridge maintenance system.

KEYWORDS: Smartphone, YOLOv8, Bridge inspection & maintenance system

1. INTRODUCTION

The bridges are the critical infrastructure which needs the constant routine inspection & maintenance works to ensure its safety and longevity. Unlike developed countries, the many developing countries face challenges in bridge management due to resource constraints, geography, and lack of technical systems. This is especially true in mountainous countries, where bridges connect remote communities and only mode of transportation is via road. Despite the development of Bridge Management System (BMS) in early 90s in advance & large countries such as Japan, US, China & Korea (Jeong et al. 2018), still working on the improvement of traditional bridge inspection method. The traditional approach is time-consuming, susceptible to human error and make the data integration & analysis difficult. Recently, Japan has been assisting the developing countries for implementing the advance technology and capacity development in the field of structure maintenance & management plans (Watanabe et al. 2021). With latest technologies in smartphone and AI provides the fresh prospects to improve the efficiency, precision and incorporation of bridge inspection data. This paper proposes to develop a prototype iOS smartphone application to improve bridge inspections. The main aim of application is to streamline and automate the part of the inspection workflow by incorporating the automatic damage detection using YOLOv8 (You Only Look

Once) AI model and inspection checklist sheet. It helps inspector to capture, analyze and integrate the data directly on a device which will significantly enhance the inspector productivity and data accessibility. This application will also facilitate the report generation, thereby removing the manual transcription and expediting the post-processing activities associated with inspection. Further, the application automatically saves and store the inspection report & images of identified damage on local device by creating separate folder to ensure their organization for future reference even without the internet connection.

In short, this research presents a novel iOS smartphone application prototype applying AI and in-built mobile technology to bridge inspection and maintenance system. This application has the potential to enhance the Bridge Maintenance System (BMS) by leveraging the mobile and AI technologies to digitize and modernize inspections.

2. SMARTPHONE IN BRIDGE INSPECTION & MAINTENANCE SYSTEM

Many researchers have worked towards the digitalization of bridge inspection and maintenance systems on smartphones, as it has the built-in sensors, storage capacities, processor and communication network. One such approach is estimating the bridge frequencies from smartphone acceleration data streams with no prior information about the mass or stiffness of the bridge or vehicle (Sitton et al.2020). Another approach for the use of a smartphone's camera for displacement, deformation, and crack measurement of bridges (Kromanis et al.2019). In this study, they investigated the feasibility of using smartphones to measure structural deformation in laboratory environments by images and videos collected while structures subjected to static, dynamic, and quasi-static loadings which were analyzed with freeware and proprietary software. Figueiredo et al. 2022 developed the smartphone application for Structural Health Monitoring (SHM) of bridge called App4SHM.They use in-built sensors & accelerometers of camera, machine learning (ML) and structural dynamics for damage identification.

Kyung-Hoon Park and Jong-Wan Sun focused on the development and implementation of real-time bridge inspection connected with BMS in Korea (Park & Sun, 2015). The author mainly focused on collecting and analyzing the bridge information periodically to ensure the safety and more efficient bridge management area. The application is linked with the BMS for real-time querying, modifying, and transmitting all the necessary information to improve the efficiency and cost reduction. On 28th Fuzzy System Symposium, the development of the bridge inspection support systems (BISS) by utilizing the smartphone(android) was presented to overcome the traditional bridge inspection method (Ikemoto et al. 2012).The authors emphasize mainly on the user-friendly interface of the application so that it is accessible to both experts and non-experts' users. In 2016, the researcher from Dalian University of Technology, China studies a smartphone-based bridge inspection and management system to improve the efficiency and accuracy of bridge inspection (Ding et al. 2016).The systems allow to collect the data and add site photos directly on their smartphones. After inspection, the system automatically generates an inspection report with technical condition rating for the bridge. In Thailand, Chulalongkorn University studied on the development of User-Centric Bridge Visual Defect Quality Control Assisted Mobile Application mainly to improve the collaboration among multiple individuals in bridge inspections (Kruachottikul et al. 2021).

Hence, the smartphone base system is capable of boosting work efficiency and data accuracy, improved the cross-team collaboration, meet compliance targets and operational goals and improve the bridge network performance.

3. EDGE AI DAMAGE DETECTION

3.1. Object Detection Using YOLOv8

The object detection is to identify & localize the different categories of objects within the given image or video. It can be done through various techniques like R-CNN, Fast R-CNN, Faster R-CNN, Single Shot detector (SSD) and YOLOv3. John & Meva, 2020, found that YOLO is extremely fast and accurate among those models. In recent years YOLO has been governing the real-time detection system in the field of robotics, driverless cars, agriculture, cancer detection and traffic application.

YOLO stands for You Only Look Once which was developed in 2015 by Joseph Redmon and Ali Farhadi at the University of Washington. The model has evolved through several versions, with each version aiming to improve speed, accuracy, and functionality. YOLOv5 was released by Glenn Jocher and maintained by Ultralytics. It provides a mobile version for iOS, Android and various free integration for labeling, training & deployment. Following three years since the release of YOLOv5, the same author introduced a newer version,YOLOv8 in 2023. In this study, YOLOv8 is considered for damage detection in images captured during bridge inspection because of higher accuracy and computing speed.

3.2. Bridge Damage Object Detection Dataset

According to Bridge Inspection and repair Manual (BIRM) 2006, there are various common defects and deterioration that can occur on bridges. However, this study focused on analyzing the bridge damage related to corrosion, free lime, leakage, cracks and spalling. The available images were utilized to train the model to recognize and identify different types of damage on bridges.The images were labeled using open-source software called makesense.ai. Dataset was split into 80% for training and 20% for validation. The image size was standardized at 640 x 640 pixels for both the training and validation set. **Table 1** provides the breakdown of the dataset, showing the number of images for each damage class in the training and validation sets. The models were trained on the free version of Google Collab using Python 3 runtime type and T4GPU at 32 epochs.

Table 1 Number of datasets.

Sl#	Name of Classes	Training qty(nos.)	Val qty(nos.)
1	Corrosion	2414	165
2	Free lime	1981	397
3	Leakage	1207	107
4	Crack	728	132
5	Spalling	884	104

3.3. Validation of YOLOv8 on Damage Object Detection

The comparison was made between YOLOV5 and YOLOV8 using the identical datasets. The mean Average Precision (mAP) for YOLOv5 after 50 epochs was 44.8% while for YOLOv8 after 32 epochs was 47.5%. It was found that 2.7% increase in the mAP of YOLOv8 compared to YOLOv5 as shown **Table 2**.

Table 2 Result Comparison

YOLO Version	mAP50	Epochs	**Speed**
YOLOv5	44.8	50	1 hours
YOLOv8	47.5	32	1.128 hours.

This indicates that YOLOv8 performed superior in detecting and localizing the damage during bridge inspection. However, considering the number of classes, additional images is required to improve the mAP.

3.4. Deploying Edge Computing AI on iOS

AI model is integrated into the application using CoreML, Apple's machine learning framework for iOS. Apple developer has successfully converted YOLOv3 and YOLOv3-Tiny model to Corel ML format to locate and classify the 80 different types of objects present in a camera frame or images. On other hand, Ultralytics has officially export the pre-trained YOLOv5 model into Core ML format. For personalized dataset, "coco128.yaml" configuration file is modified. Specifically, update the class labels to match the object categories in your dataset and adjust the image paths, for training and validation sets to point to where your datasets images are located. These changes ensure that the model is set up correctly to handle your custom dataset by recognizing the number of object classes and accessing the image data needed for training and validation. To convert the YOLOv8 model to Core ML format, for iOS app integration use the command; `model.export(format='coreml' imgsz=640, nms=True)`. This command specifies exporting as a Core ML model. Enables non-maximum suppression (NMS) refine object detection by keeping only the most confident bounding boxes. This method works only for coremltools version 7.1. Add the Core ML model to your Xcode project. Tested the integrated YOLO model into the application using the images taken from the photo library or live camera and analyze the image for damage detection. **Figure 1** depict the user interface of damage detection and **Figure 2** shown the analyzed image result.

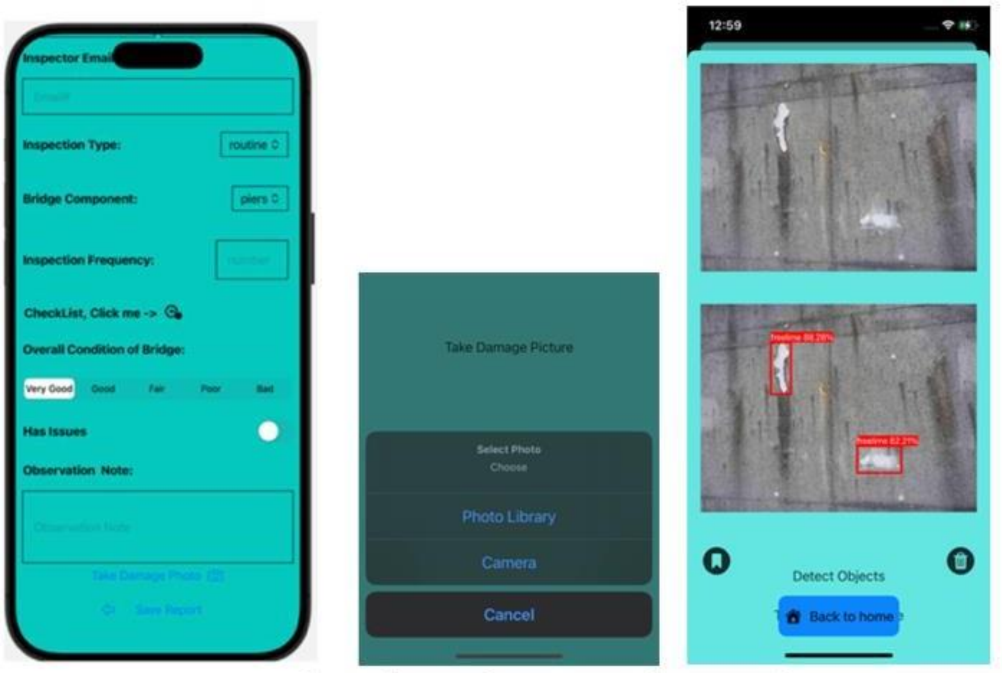

Figure 1 User-interface of Damaged Detection

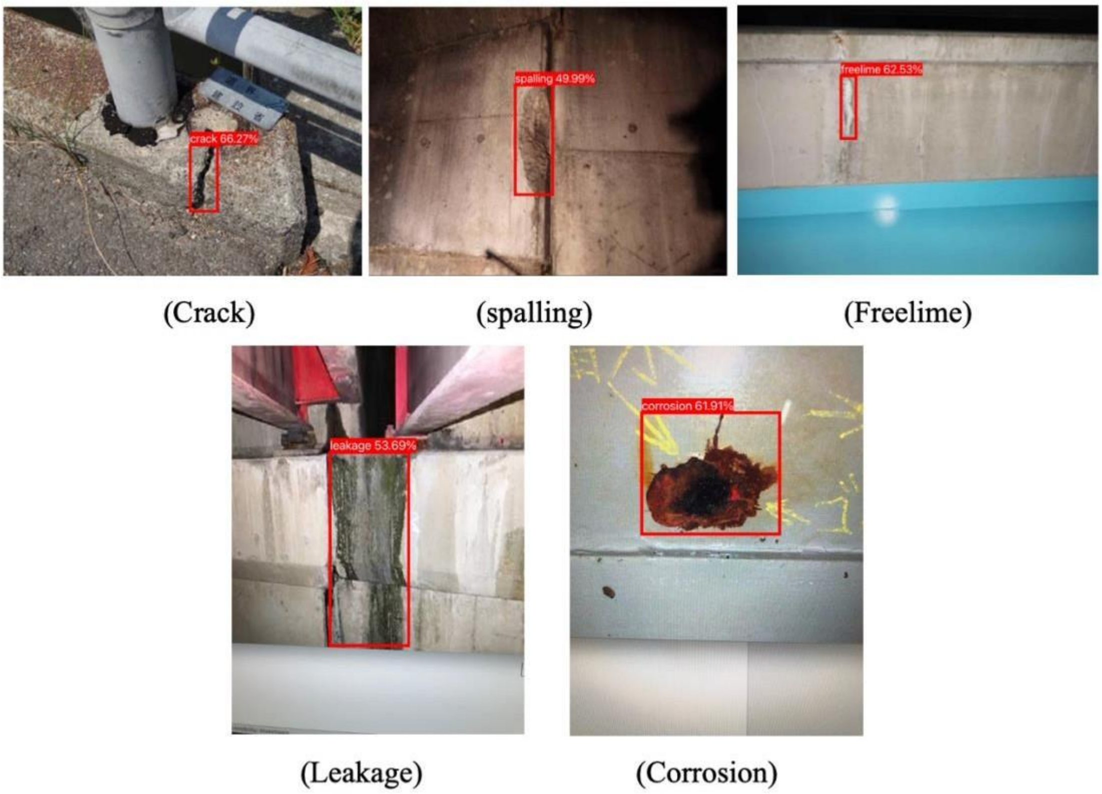

Figure 2 Analyzed Image

4. DAMAGE ASSEMENT WITHIN INTEGRATED CHEAKLIST

The bridge structural damage assessment is facilated by a comprehensive analysis built into the application.The checklist is based on the “Technical Manual on Inspection and Diagnosis of Bridge” issued by Department of Surface Transport of Bhutan. Accordingly, total rating of bridge is calculated in consideration of factors affecting collapsing of bridges and ultimate load carrying capacity. The total condition rating for all bridges in Bhutan is derived from scores obtained in different categories. **Table 3** demonstrates the determination of overall rating of bridges.

Table 3 Determination of total condition of bridges

Determination category	Contents of determination
A (very good)	The structure is not damaged
B (Good)	The structure is damaged but not dangerous for users
C (Fair)	The structure is damaged and getting dangerous for the user in near future.
D (Poor)	The structure is severely damaged and dangerous for user.
E (Bad)	The structure is completely destroyed and unusable.

The application has a inspection form with checklist interface as shown in **Figure 3.** This interface allows the inspectots to conduct on-sute assessments against the integrated checklist. In addition, inspectors can provide the new findings and comments.Based on the visual observations, the overall condition of the bridge is determoned and recorded.

Figure 3 UI of Inspection Form & Checklist

5. FILE MANAGEMENT

The main purpose of saving the files on local device is due to reliability and gives access to the files anytime, anywhere regardless of limited connectivity. Moreover, local storage provides full control over data and making it easier to manage the sensitive information. It can also seamlessly integrate with cloud storage to enhance the data access and sharing flexibility. **Figure 4** depicts how the analyzed images are stored on the mobile device. The UI of Inspection Form is converted to PDF using UIGraphicsPDFRenderer. Then inspection report is saved within the same project (**Figure 5**).

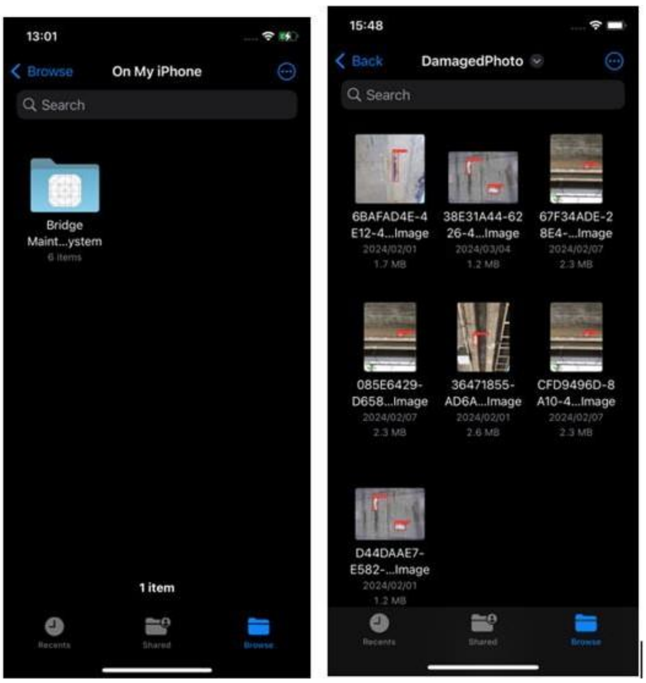

Figure 4 Analyzed Image Stored on Device

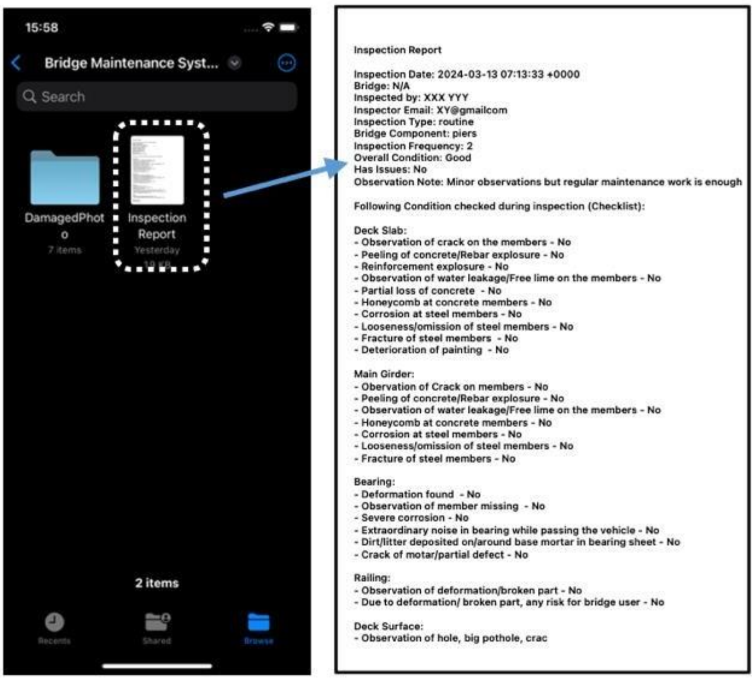

Figure 5 Generated Inspection Report Save on Device

6. HIERARCHY OF APPLICATION

Figure 6 outline the structure and workflow of an application for bridge inspection and maintenance system.The users need to create or register the account. It has three main vew "Add Bridge", " View Existing Bridge" and "Inspection Form". Eacch list of bridge will display the details such as its name, location and geomerty information alone with its image. With "Add Bridge" button, the user is directed to "Bridge Inventor Sheet" where they must provide the current location (**Figure 7**) for bridge identification , its real time image and other geometry infromation. The newly added bridge will display alongside the existing list **(Figure 8).** Allowing the inspector to select the bridge from the list during the inspection. In bridge inspection form, the details of inspector need to be provided and it is connected to Damaged Detection and Checklist Form. Later, inspector can save the data directly into their local device or server as per their convenience. But this study emphases on saving the data to local device only.

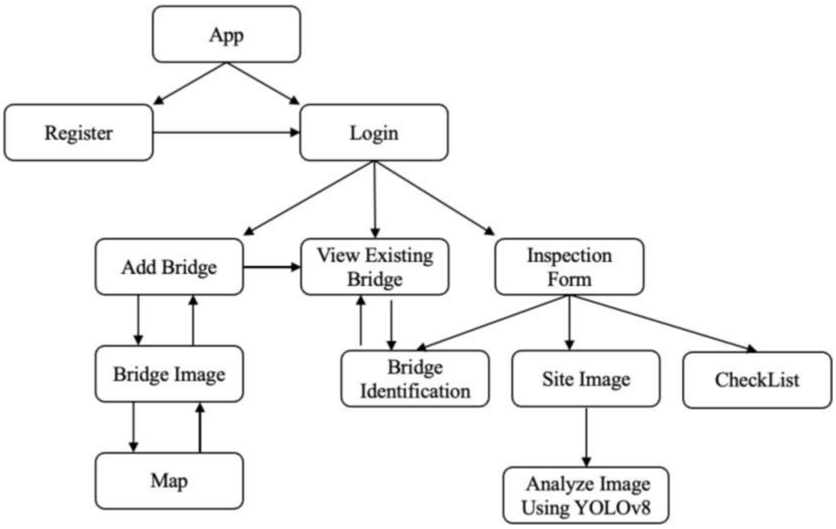

Figure 6 Outline of application.

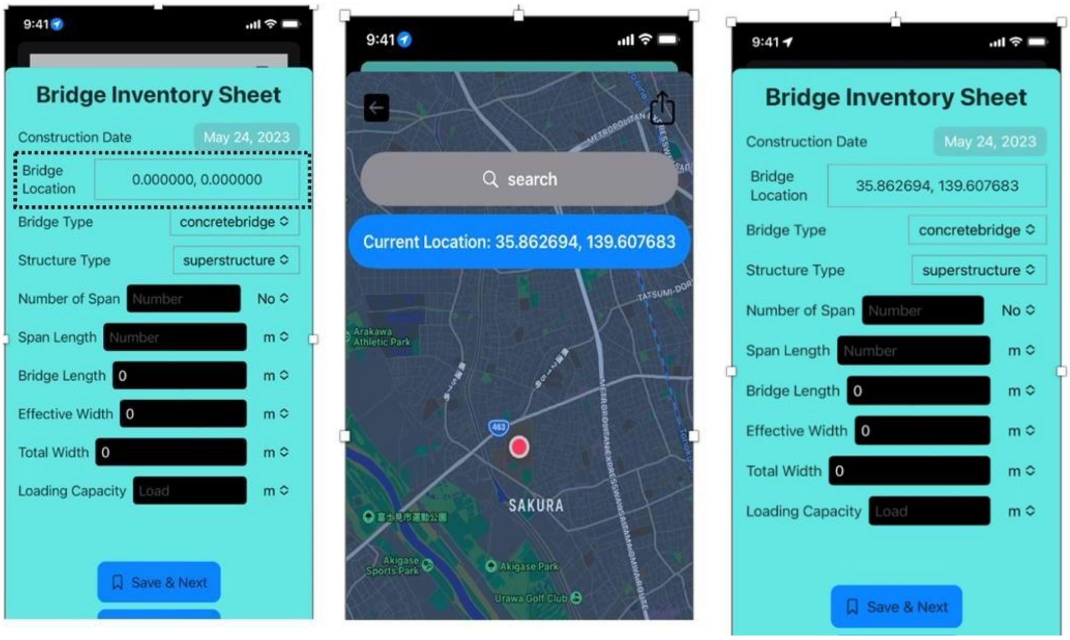

Figure 7 Current Location

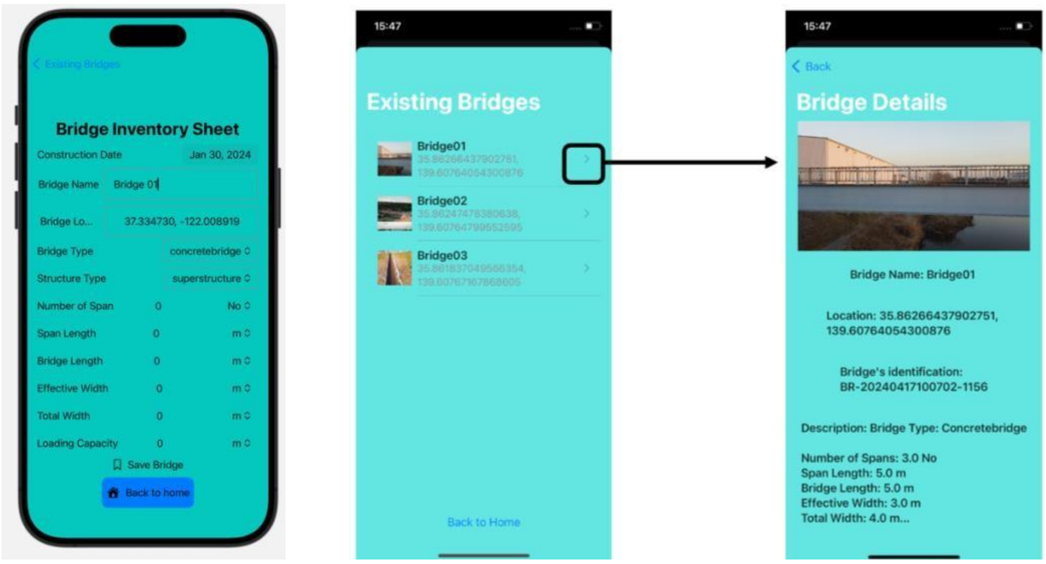

Figure 8 User Interface of Adding New Bridge

7. CONCLUSION

In conclusion, the prototype application developed for Bridge Inspection & Maintenance System to enhance the conventional method of bridge system throught the integration of AI-based object detection capabilities and digital inspection checklist. The main goals were to incorprate the YOLOv8 model automated object detection, implement a bridge inspection checklist within the application, and enable local storage of inspection documents on the device, regardless of location.

The developed prototype application has shown a great potential of combining the AI algorithms for object detection in on-site camera images. The tool is fitted with automatic defect detection capability making it easier for inspectors to carry out the reliable assessments more faster. The second layer contains digital checklists instead of paper forms after evaluations take place which focuses on ensuring all inspection points are covered during maintenance activities. Additionally, it can store the pictures and report locally on the device in separate folders for easy organization in limited ineternet connectivity.

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