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Field Trials of an AI-AR-based System for Remote Bridge Inspection by Drone*

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Abstract. Bridge inspections are important to ensure the safety of users of these critical transportation infrastructures and avoid tragedies that could be caused by the collapse of these infrastructures. This paper describes the results of field trials of an advanced system for remotely guided inspection of bridges by a drone, which relies on artificial intelligence and augmented reality to achieve it. Results indicate that a high speed network link is critical to achieve good performance.

Keywords: Bridge inspection · Remote guidance · Concrete bridges · drone · UAV, artificial intelligence (AI), augmented reality (AR), field trial.

1 Introduction

Regular and proactive inspections of bridges and overpasses (which are structurally equivalent to bridges) are important to ensure the safety of users of these critical transportation infrastructures and avoid tragedies such as the recent collapse of the Morandi bridge in Italy [2]. The use of *unmanned aerial vehicle (UAV)* commonly referred to as *drones* combined with AI to perform bridge inspections is an emerging topic [7, 5]. This paper describes the results of field trials of such an advanced system for remotely guided bridge inspection that also combines AR to achieve it. It is a specific case of remote guidance, as described in [9]. It combines the benefits of drones (easy access to hard-to-reach areas and fast visual scanning), Artificial Intelligence (AI) (automated defect detection) and Augmented Reality (AR) (overlaying digital information over real images, thus allowing to combine real and virtual information within the same field-of view). Figure 1 illustrates such a use case. The figure contains the different system components, which are discussed in details in the next section.

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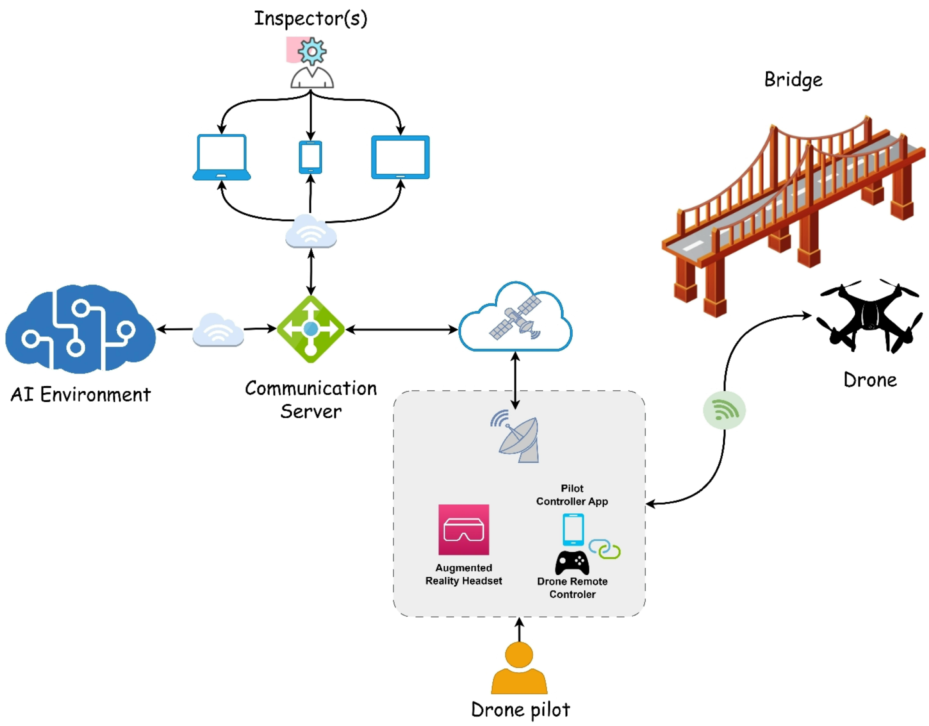

Fig. 1. Illustration of the AI-AR remote inspection system

2 System Overview

The remote bridge inspection system presented in this paper comprises a collection of multiple components working together to achieve an effective, accurate and safe assessment of such infrastructure. As shown in the figure 1, the drone is capturing detailed imagery of the bridge. The drone's pilot is equipped with an augmented reality headset that assist him/her during the inspection. An AI environment is set up to process the data collected in real time in order to detect surface defects. Then, the inspectors and drone pilot can visualize the augmented video stream. Communications between the subsystems are handled by a server and satellite link.

2.1 Drone

To capture the video stream of the bridge that will be processed to detect surface defects, the drone (DJI Mini 2) has been used for this task as illustrated in the Figure 2. This drone has the characteristics of being both lightweight and able to capture high resolution imagery.

Fig. 2. DJI Mini 2 Drone.

2.2 Communication modules

A Starlink system and a communication server are responsible for the communications between the different parts of the inspection system. The Starlink system links the onsite modules with the communication server as shown in Figure 1. As illustrated in Figure 3, the Starlink kit includes an antenna and modem. It provides a high speed connection, especially in rural areas where traditional broadband services might be unavailable or unreliable.

Fig. 3. Illustration of the satellite antenna deployed onsite

In the other side, a communication server is deployed to regulate the communications on the system. As shown in Figure 1, the communication server handles both raw and augmented stream video at the same time between the different endpoints.

2.3 AI Environment

It includes the Nvidia Triton Inference server, which is an optimized platform that hosts deep learning models for defect detection. The detection model is YOLOX [3] which is already trained on bridge defects. To speed up the inference during the inspection process, these two components are deployed on a laptop equipped with an Nvidia GPU.

2.4 AR Subsystem

It includes a Microsoft HoloLens 2 optical-see-through AR headset for the drone's pilot, as illustrated in the Figure 4.

Fig. 4. Illustration of gesture control through the AR headset

In addition, an augmented realty application is deployed on this headset to provide an effective control assistance and environment awareness to the pilot during the inspection process. The AR based interface that the pilot can see during the process is shown in Figure 5.

Fig. 5. Illustration of the drone in operation as seen from the AR headset

2.5 Inspector web interface

The web interface that is used by the inspector(s) is illustrated in Figure 6. We can see that it displays various flight parameters, the drone's Battery level and location on a map. It also allows the inspector to pass from a raw video display to an augmented video display.

Fig. 6. Illustration of the web interface of inspector(s)

3 Flight plan

In order to safely fly the drone for the field trials, a flight plan has been established. This flight plan defines the conditions under which the drone could be flown.

3.1 Flight test procedure

Test area The test area is a concrete bridge located in the city of Gatineau. This bridge is illustrated in 7.

Weather limits No rain, No fog. Maximum wind speeds of 20 km/h and a temperature above the water freezing point (0 °C).

Contingencies/Cease test When battery level is under 30%, the drone will be landed for recharge.

Fig. 7. Illustration of bridge in the test area

Pre-flight Ensure all the equipment is available. Ensure that all the devices are properly charged. The equipment list goes as follows:

1. Drone
2. Drone's remote control
3. Smartphone
4. Drone spare batteries
5. Spare propeller blades
6. Drone battery charger and cable
7. Phone charger and cable
8. Electrical power station
9. Anemometer
10. Take-off/landing platform
11. First aid kit
12. Fire blanket
13. Visibility vest
14. Gloves
15. Laptop
16. A paper copy of the flight plan
17. Satellite link antenna and router

In-flight No flight above 122 m (400 feet high). Take-off from the side of the bridge. No flying directly above the bridge, people or vehicles. Always flying with a line-of-sight between the pilot and the drone. Ensure a minimum distance of 1.5 m between the drone and the bridge.

Privacy issues To avoid privacy issues, video recording will be stopped when vehicles or pedestrians enter the field-of-view of the camera.

4 Field trials

Two field trials have been conducted to test all the components of the system.

4.1 Flight conditions

The flights were performed in the afternoon with the following weather conditions:

1. Temperature: 18 degrees Celsius
2. Wind: 10 km/h
3. Sky: Sunny
4. Humidity: 53% relative humidity (RH)

4.2 Setup

Field trial 1: The setup of the system went well except for the planned satellite communication link (see Figure 3) which failed.

Field trial 2: To avoid the previous problem, we relied on 5G cell phone network link to deploy the system (as shown in Figure 8).

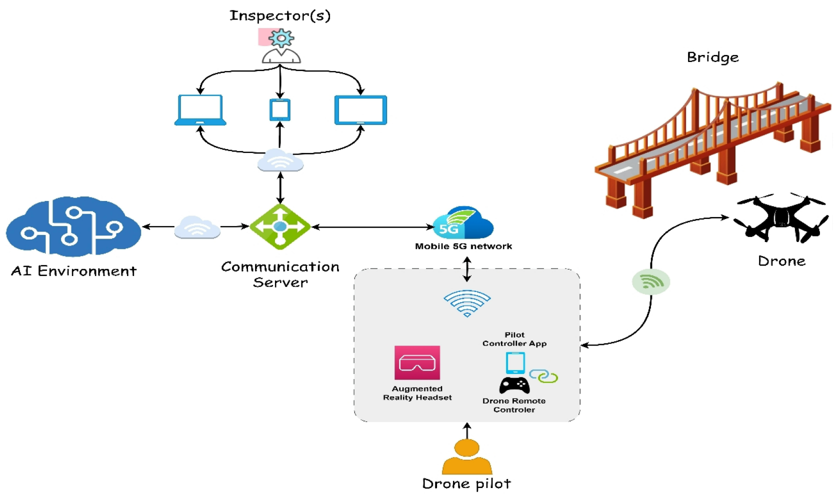

Fig. 8. Illustration of the system with cell phone link

4.3 Results

First trial: As indicated previously, the satellite connection between the onsite drone setup and the communication server failed to be established during the first trial. This could be explained by the fact that the communication server follows an access control list policy that grants or denies the access to its resources for security concerns. In addition, the onsite drone setup is allocated an IP address that is related to its geolocation and from time-to-time this IP address changes for resilience, as network capacity increases, or when new countries are added to the network. Consequently, the communication server denies access to requests sent via this satellite network.

Second trial: Figure 5 illustrates the drone in operation as seen from the AR headset. The view from the AR headset includes pilot view point overlaid with an interactive interface. This interface displays the live video stream captured by the drone's camera on either raw or augmented version. The latter one highlights the bridge surface defects detected by the AI module of the system. The switch between both video streams is controlled by a toggle button in the AR headset's view, as illustrated in Figure 5. This toggle is controlled by the pilot using hand gesture, as illustrated in Figure 4. The overlaid interface also shows real-time drone's information, such as its battery level and its altitude.

5 Discussion

The drone technology used here is for a remote guidance collaboration scenario involving a remote helper (the inspector) guiding in real time a local worker (the drone's pilot) in performing tasks on physical objects (the bridge) [6, 9]. Since inspectors work in teams, the drone's pilot might well be also an inspector too. The scenario envisioned is illustrated in Figures 8 and 9 and is described in details in [7].

6 Future work

Setting up a Virtual Private Network on top of this satellite network is an envisioned solution that could fix the previous connection issue. The proposed system is illustrated in Figure 9. This VPN-based approach will increase the security and privacy level of the system, and it can improve the internet connection speed in some cases by bypassing congestion or network throttling imposed by internet service providers.

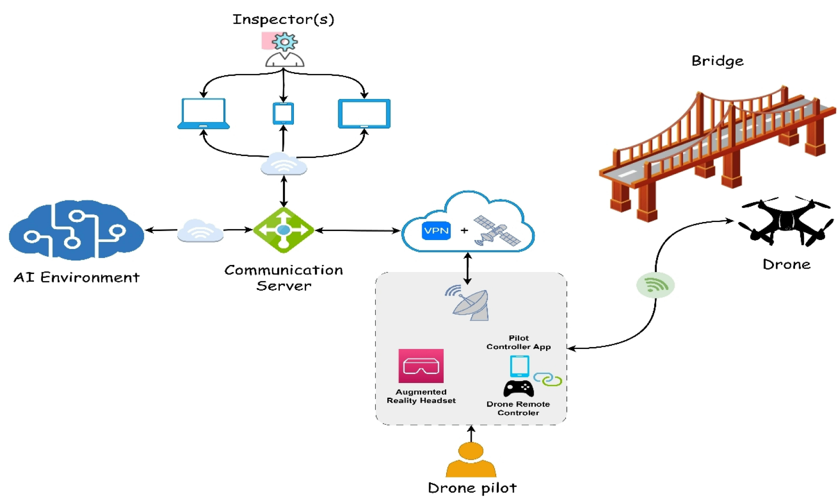

Fig. 9. Illustration of the system with satellite link and the VPN

New field trials will have to be conducted. The flight will initially involve a functional satellite link that will provide a faster network speed. Bidirectional network speed of about 13 Mbps could be reached using this method. The system is illustrated in figure 9. In addition to increasing network speed, optimization of the video stream is also envisioned. Later on, subject-matter experts, i.e. real inspectors, will be involved, in order to assess the benefits of the system in assisting their task. This is to validate the potential of this technology for real-world concrete bridge inspection, a task already described in [8]. Some further work could also be done to improve the current AI module that detect bridge surface defect by using models such as SMDD-NET [4]. Also, a recent systematic review of visual defect detection on concrete bridges helped to create a basis to leverage on for the next steps [1].

7 Conclusion

This paper presented the results of field trials conducted on an AI-AR based system for remote visual inspection of concrete bridges. It also presents a plan for future field trials based on the results of this first field trial. Results indicate that a high speed network link is critical to achieve good performance.

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