IKAROS: a UAV-based integrated system for monitoring road defects and managing vehicle traffic and emergencies on road transport networks

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ABSTRACT

In recent years, there has been a notable rise in the adoption of Unmanned Aerial Vehicles (UAVs) for infrastructure inspection. This study focuses on presenting IKAROS, an integrated system that harnesses the combined capabilities of multiple UAVs and deep learning (DL) tools to improve the efficiency of road transport network inspections, facilitate the detection of road defects, and manage traffic emergencies. Specifically, we introduce the IKAROS system, outlining its key components and functionalities, with a particular emphasis on the applied technologies and the interconnections of its various systems. In addition, we provide an overview of the pilot site and address the challenges associated with real-world implementation.

CCS CONCEPTS

• **Computing methodologies** → **Object detection**; **Scene understanding**.

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KEYWORDS

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1 INTRODUCTION

Conventional methods for inspecting road network infrastructure typically involve the use of heavy construction machinery such as lifts and cranes, along with ropes and harness access equipment, which can expose workers to significant safety hazards. Moreover, these methods are often time-consuming and expensive, necessitating operations within narrow time frames of low traffic, such as during night hours. Therefore, it is crucial to adopt innovative inspection methods that improve inspection capabilities while minimizing safety risks [5].

UAVs offer numerous advantages in remote sensing data acquisition processes. By leveraging drone technology, we can safely gather data from areas that are otherwise difficult or impossible to access, due to remoteness or safety concerns. In addition, UAVs allow the efficient acquisition of imagery without the need for short-term traffic arrangements, which often involve bureaucratic permits, traffic congestion, accidents, and increased carbon emissions. Consequently, UAVs could be a cost-effective and efficient method of obtaining high-quality image data, including spatial, textural, and chromatic information of the structures under inspection [1, 2].

The IKAROS system is a UAV-based integrated system for monitoring road defects and managing vehicle traffic and emergency on road transport networks. The present work presents the overall system, its individual components, and the field measurement process in the Egnatia Odos pilot site.

2 SYSTEM COMPONENTS AND FUNCTIONALITIES

The IKAROS system consists of the following main components:

- **Machine Vision Subsystem:** The subsystem relies on advanced machine learning and computer vision technologies [3, 4, 7, 8]. Its main objective is the processing and analysis of images collected from the sensors of the IKAROS project (optical and hyperspectral). Furthermore, the aim of this subsystem is to apply machine learning and artificial intelligence methods to the processed visual data, to enable automatic functions for monitoring road infrastructure. It is evident that the machine vision subsystem is the heart of the IKAROS system, since it underpins the system's intelligence, as derived from the primary data of the optical sensors.
- **Communications Subsystem:** The communications subsystem is responsible for the system's communication protocols. These communication protocols are based on three different categories. The first refers to an autonomous communication network between the unmanned aerial vehicle and the ground control station, known as the Drone Area Network (DAN). The second category pertains to the communication network of the swarm of unmanned aerial vehicles, called the Swarm Area Network (SAN). Finally, the last category concerns a broader communication network, referred to as the Wide Area Network (WAN).
- **Unmanned Aerial Vehicles Subsystem:** This subsystem is responsible for the operation of the swarm of unmanned aerial vehicles. It is equipped with suitable sensors to collect optical and hyperspectral data, which are used by the machine vision subsystem for automated monitoring of the road network. It also features automatic control technologies for efficient navigation of the swarm of unmanned vehicles.

Based on the above subsystems, the developed IKAROS system offers the following functionalities:

- **Integrated and continuous monitoring of road network conditions**, supporting inspection and maintenance services (e.g., to identify issues such as cracks, defective manholes, pavement detachments, etc.), as well as secondary services, such as inspection of construction and pre-construction works (e.g., checking for violations of construction site areas, monitoring the progress of work and potential violations of safety issues, application of inappropriate practices, etc.) [6].
- **Real-time traffic management** to continuously and promptly assess the impact of traffic load, manage accidents (e.g., vehicle collisions, animals on the roadway, dangerous vehicle movements, etc.), and real-time communication between drones and vehicles.
- **Disaster management**, providing assistance to emergency services and rescue teams, with real-time transmission of information concerning, for example, the location of potential casualties or the evaluation of the overall condition of the road network after an accident.

3 PILOT SITE APPLICATION

All measurements were performed in the Axios bridge area in Egnatia Odos, located in northern Greece. This specific area was selected because it meets the basic safety requirements and specifications without compromising flight planning and data acquisition. It is also a section of the Egnatia road with extensive wear on the pavement due to weather conditions and the continuous passage of vehicles, making it suitable for testing the system developed within the IKAROS framework. Following a strict protocol that ensures the smooth conduct of measurements, minimizing potential risks to personnel as well as unmanned aircraft and their equipment, the following steps were taken: (1) weather conditions were checked, (2) the test location was inspected, (3) potential hazards were identified, (4) safe measurement zones were determined, (5) the flight path was designed, and (6) the expected duration of the measurements was estimated.

Figure 1 depicts the pilot site area with the bridge of Axios river. Figure 2 presents a part of the drone swarm which was used for the field measurements.

Figure 1: Aspect of the bridge at Axios river, which was the pilot site for the integrated IKAROS system.

Figure 2: Unmanned aerial vehicles which were used as part of the drone swarm.

4 CONCLUSIONS

This paper briefly presents an integrated system for the evaluation of the road infrastructure and traffic flow in road networks. The IKAROS system highlighted the usefulness of unmanned aerial vehicles in identifying and managing a multitude of issues related to the condition and traffic flow of the road network. One of the key advantages of the system is that it provides the capability for direct and safe access and inspection of even the most inaccessible points of the road network. In this way, it allows for timely intervention when deemed necessary by the project manager.

It is evident from the pilot tests that control systems based on swarms of unmanned aerial vehicles offer numerous capabilities that can be utilized not only in road networks but also in monitoring a multitude of infrastructures and facilities. This project can serve as a foundation for further research in this particular field, with the expansion of the capabilities of unmanned aerial vehicles and their establishment in the inspection of large-scale engineering projects.

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