A Bike Parking Management System Based on Object Detection and Tracking

Project Report

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A HKUST ISDN6830B Course Project

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May 23, 2024

1 Introduction

In Hong Kong, bike parking lots often suffer from overcrowding caused by the presence of old and unused bikes. At HKUST's bike parking lot, which is relatively unknown to many school members, the situation is exacerbated as old bikes coexist with new ones, occupying valuable space and posing challenges for identification by the manager. The current approach involves periodic clearing of the parking lot every 2-3 months, during which there is a risk of inadvertently removing new bikes.

To address these issues, this project takes the course opportunity to propose a machine learning and computer vision-based solution that aims to monitor the HKUST bike parking lot, accurately detect and classify bikes, track their parking durations, and provide a user-friendly interface for efficient management. By leveraging advanced technologies, the system intends to optimize space utilization, tackle the problem of old bikes, and minimize the unintended removal of used bikes during clearing operations. The insights provided by the system can contribute to future planning and decision-making processes, including identifying optimal parking durations, determining maintenance requirements, and enhancing overall efficiency in bike parking management at HKUST and potentially other locations in Hong Kong.

The following document will outline the current solution for addressing the issue, the conceptualization of our proposed solution, the introduction of the system and considerations for its design, the choices made during implementation, the suggested user workflow for the system, as well as a discussion on the topic and potential future developments. As a result of limited time and a shortage of personnel, only a proof of concept and a minimally operational prototype will be presented.

2 Related Works

2.1 Datasets

No bike-specific dataset is found, but there are datasets for general vehicles or transportation datasets that can detect bikes. This includes dataset Cityscapes Dataset[1], BikeNet Dataset[2], and KITTI Dataset[3].

2.2 Existing solution

Upon thorough investigation, no specific systems, models, or research pertaining to the management of bike parking lots were discovered. Nevertheless, extensive research has been conducted on methods for managing vehicle parking lots. In a comprehensive review conducted by P. Almeida [4], various car detection and counting techniques were examined, many of which utilized publicly available datasets and custom CNN networks. However, it is essential to note that bike parking presents unique challenges compared to vehicle parking. Bike parking areas tend to be irregular and disorganized, lacking designated lines, which often leads to bikes obstructing one another. Consequently, the majority of methods employed for managing car parking lots are not applicable to bike parking situations.

Airside, a shopping mall in Hong Kong, has implemented a smart bike parking lot by incorporating supplementary hardware [5]. This innovative solution enables the system to park bikes and keep track of the parking status autonomously. However, it is important to consider that such a setup can be costly, requiring additional maintenance fees from bikers. This may not be feasible for many bike parking lots, as they often operate on a free basis and cannot afford substantial expenses.

3 System Overview

Following the introduction and literature review, considering the nature of this course project, the available options for a feasible idea may be somewhat limited but are nevertheless apparent. The proposed concept entails developing a surveillance device specifically designed for bike parking lots capable of detecting the duration of bike parking. Ideally, This device would be an Internet of Things (IoT) device, enabling remote management by the parking lot manager and providing information on which bikes need to be removed after a designated period.

The system comprises three main components: the surveillance device, the server, and the user interface, which will be in the form of a mobile application. The overview of the system is shown in Figure 1.

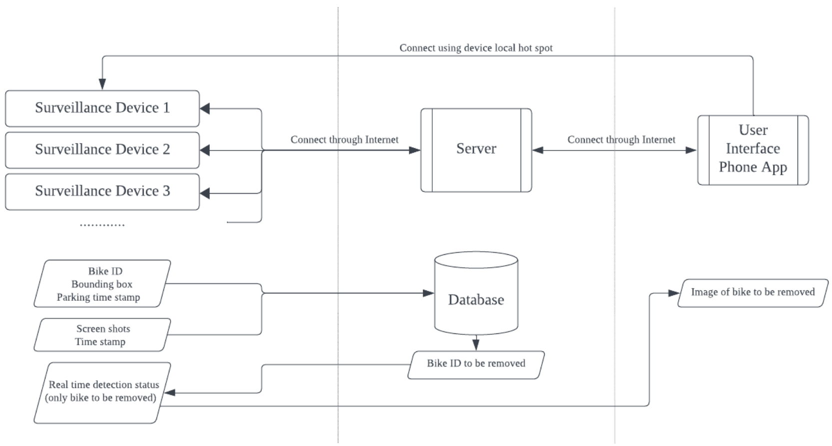


Figure 1: System overview

The surveillance device will execute the bike detection algorithm and store the bike IDs along with their respective parking times. This data can also be transmitted to the servers. Additionally, screenshots of the parking lot situation may be sent to the server to ensure data backup.

The server will receive and store the data and analyze it to determine which bike needs to be removed under which surveillance device. The server will also facilitate communication with the user's mobile app, providing updates on the status of each surveillance device.

The parking lot manager will utilize the user interface in the form of a mobile app. It will receive messages from the server, including screenshots of the parking lot condition and information on which bike needs to be removed. Furthermore, if the manager is present on-site, the mobile app will be able to connect to the surveillance device using a local hot spot generated by the device. This feature will allow the manager to access a live stream of the device's detection, showcasing the bikes to be removed individually, thereby avoiding a cluttered display.

4 Implementation and Design Consideration

This section will delve into the technical implementation and design considerations of this project. For a more comprehensive demonstration of the system in action, please refer to the demo videos provided in the Appendix section at the end of this document. These videos showcase the practical application and functionality of the developed solution.

4.1 Data collection

To conduct the proof of concept, the HKUST bike parking lot was selected as the designated site, leading to most of the data being collected from this location. However, a few images of other general bike parking lots were also sourced from the internet.

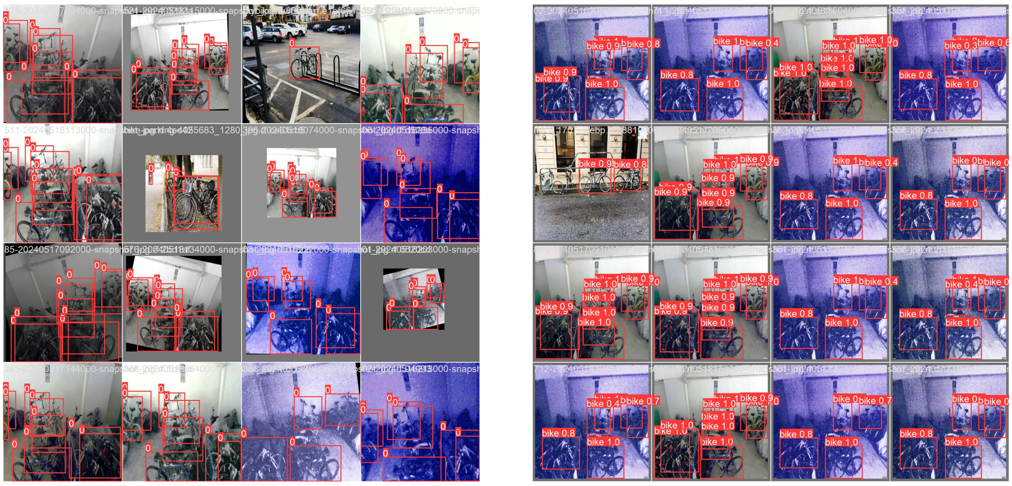
A Raspberry Pi and a standard industrial camera were used for data collection. Fortunately, a readily available power supply was available on-site, simplifying the setup process. As depicted in Figure 2, the system was installed near the rooftop of the bike parking lot. A motion script was implemented on the Raspberry Pi, specifically the one developed by the Motion Project [6]. This script facilitated capturing images every 10 minutes. A video recording was also made featuring a person moving bikes, which would later be used for testing purposes.

Figure 2: Data collection setup

The dataset consists of 243 original images with a total of 1761 bounding boxes. Preprocessing techniques such as auto-orientation, resizing, and automatic contrast adjustment were applied to enhance the quality of the images. Additionally, augmentation was performed to increase the model's robustness. As a result, the dataset was expanded to a total of 620 images.

4.2 Model training

The bike detection model for this project was trained using YOLOv8, the popular You Only Look Once (YOLO) object detection algorithm developed by Ultralytics [7]. YOLOv8 is a state-of-the-art real-time object detection model that stands out for its exceptional performance and efficiency. YOLOv8 boasts improved accuracy, faster inference speeds, and enhanced versatility compared to previous versions. By leveraging the power of YOLOv8, the bike detection model developed for this project can benefit from its cutting-edge performance, enabling accurate and efficient identification of bikes in various environments.



(a) Selected train batch

(b) Validation batch

Figure 3: Training and validation data of the model

4.3 Simple Online and Realtime Tracking (SORT)

As the bounding box predictions in the bike detection model were not entirely stable due to various factors such as occlusions and motion blur, the SORT (Simple Online and Realtime Tracking) algorithm [8] was implemented to enhance the model's robustness. SORT is a widely used algorithm for object tracking in computer vision tasks.

The SORT algorithm operates by associating bounding boxes across consecutive frames to track objects over time. It utilizes a combination of motion and appearance features to match the predicted bounding boxes with the corresponding objects in subsequent frames. By employing this algorithm, the model can effectively track the detected bikes even in scenarios where the bounding boxes may undergo slight variations or temporary occlusions.

SORT also incorporates a Kalman Filter to estimate the position and velocity of the tracked objects, allowing for smoother and more accurate tracking. This filtering technique helps compensate for any noise or inconsistencies present in the bounding box predictions, contributing to the overall stability and reliability of the tracking process.

By integrating the SORT algorithm into the bike detection model, the system becomes more resilient to variations in the bounding box predictions, ensuring robust tracking of the bikes throughout the captured frames. This enables a more reliable and accurate analysis of the bike parking lot, facilitating efficient monitoring and management of the parking spaces.

4.4 The 2.5D bounding box

In the context of computer vision, the vanishing point refers to a point within an image where parallel lines appear to converge. It is a fundamental concept used in creating a sense of depth and perspective in two-dimensional images.

In the case of the bike detection model in this project, the vanishing point is utilized as a reference for creating the depth of the 2.5D bounding box. Using this information, the 2D bounding box is transformed into a 3D-like bounding box by assigning depth coordinates to its corners. By incorporating the vanishing point, the model is able to simulate the perception of depth, resulting in a more visually convincing and immersive experience.

By fine-tuning the depth of the bounding box based on the size of the 2D bounding box, the model can also account for variations in object size and distance from the camera. This adjustment helps ensure that the generated 3D-like bounding box aligns with the proportions and scale of the detected bike, further enhancing the realism of the image.

The thickness of the line is also modify to make the box more three-dimentional like. A demonstration is shown in Figure 4.

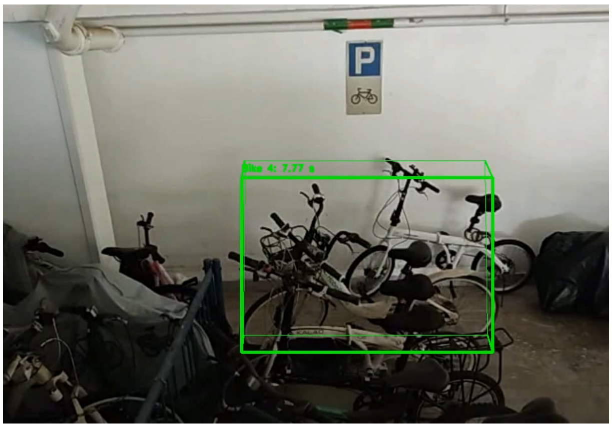


Figure 4: 2.5D bounding box demonstration

5 System User Workflow

Imagine there is a user, which is the bike parking management personnel. The workflow will be as follows:

a) Wait for the system to send him a bike removal message on the phone app.

b) Received the removal message but decided to wait for more.

c) Received several messages and decided to arrange a removal.

d) Check the app for how many bikes need to be removed to arrange the necessary logistics.

e) Check the app for the screenshot to look at the current situation of the parking lot.

f) Arrived at the parking lot and connect the phone app to the surveillance device and start the removal procedure,

g) The phone app will guide the manager to remove the bikes one by one by showing one bounding box one time on the phone app.

h) Finish the removal and go back to step a.

6 Discussion and future works

The bike detection model exhibits commendable performance in low light conditions, thanks to the dataset collected explicitly during nighttime. However, a challenge arises when the bike parking lot becomes completely dark after 1 o'clock in the morning, rendering the camera unable to capture any images. This issue remains a problem that needs to be addressed. One potential solution for future implementation could involve incorporating infrared cameras, which are capable of capturing images in low light or even complete darkness.

Despite the implementation of the SORT algorithm for object tracking, the model may still lose track of bike objects when they are obstructed by humans or unexpected obstacles. To overcome this limitation, a possible approach would be to employ the DeepSORT algorithm [9] that utilizes the Deep Association Metric. This advanced algorithm offers improved object-tracking capabilities, even in challenging scenarios. However, due to constraints in terms of time and manpower, the project was unable to implement DeepSORT in the proof of concept phase.

Despite these challenges, the proof of concept demonstrates the viability and potential of the proposed idea. The performance of the system highlights its effectiveness in monitoring bike parking lots and showcases the value it holds for future development and refinement.

7 Appendix

Github repo link: https://github.com/ooUglyGuyoo/bike-parking-management

Dataset exported from RoboFlow: https://hkustconnect-my.sharepoint.com/:f:/g/personal/yliangbk_connect_ust_hk/EmTeske6n8JAvf2XGmAE2TABjsEKlc_TqBChTAYcs6C7zA?e=weWBUw

Videos: https://hkustconnect-my.sharepoint.com/:f:/g/personal/yliangbk_connect_ust_hk/Eot0pMUadwlMqhi7UeGg_P8BEahYnNis04uAHj5K50Q5NQ?e=UpKL3f

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