Camera-based position analysis system for cyclists ordering in bicycle swarms

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ABSTRACT

Cycling in swarms has gained popularity as a social and fitness activity. To offer enhanced digital services for swarm cycling, it is essential to obtain real-time information about the position of each cyclist within the swarm. While GNSS (Global Navigation Satellite Systems) signals such as GPS, Galileo or GLONASS may not provide precise positioning in such scenarios, this paper proposes a novel approach to address this challenge. By equipping each bicycle with a backward-facing camera and leveraging computer vision and deep learning methodologies, we can achieve the absolute ordering of bicyclists in real-time. This position paper outlines a comprehensive framework that utilizes object detection, monocular depth estimation, and object tracking models to process camera information and obtain accurate positioning within the swarm. The proposed solution also enables the detection of overtakes between cyclists, adding an additional layer of information to enhance the overall swarm cycling experience.

KEYWORDS

bicycle swarms, Position detection, camera, Computer Vision, Deep Learning

1 INTRODUCTION

Swarm cycling has emerged as a popular activity that combines fitness, social interaction, and a sense of community. It involves a group of cyclists riding closely together in a coordinated manner that offers various advantages, including enhanced motivation, increased safety through improved visibility, and the opportunity for cyclists to push their limits and achieve collective goals. As swarm cycling gains momentum worldwide, there is a growing need to leverage technology and digital services to enhance the overall experience for participants. One of the key aspects in improving swarm cycling services is obtaining real-time and accurate positioning information for each cyclist within the swarm. This information can provide valuable insights and enable the development of innovative features and services. For instance, knowing the precise position of each cyclist can facilitate personalized guidance, such as navigation assistance or alerts about upcoming hazards.

While GNSS (Global Navigation Satellite Systems) such as GPS, Galileo or GLONASS have been widely used for positioning and navigation purposes, it possesses inherent limitations when applied to swarm cycling. GNSS relies on satellite signals to determine position, and its accuracy is affected by various factors, such as signal multipath, atmospheric interference, and satellite geometry. In the context of swarm cycling, these limitations become more pronounced due to the dense and dynamic nature of the group. As cyclists ride in close proximity, GNSS signals may be blocked or reflected, leading to inaccurate positioning information. Consequently, the precision of GNNS-based swarm positioning is often insufficient for real-time applications that require precise relative and absolute ordering of cyclists.

The objective of this paper is to propose a concept and framework to achieve real-time absolute ordering of bicyclists within a swarm through the use of computer vision and deep learning techniques. By equipping each bicycle with a rear-facing camera and leveraging advanced algorithms, we aim to overcome the limitations of GNNS-based positioning and provide a reliable and accurate solution for obtaining the positional information of each cyclist within the swarm.

2 METHODOLOGY

To overcome the limitations of GNSS for swarm cycling, computer vision and deep learning techniques offer promising solutions. Computer vision leverages the analysis of visual data to extract meaningful information, while deep learning enables the development of sophisticated models capable of learning and recognizing complex patterns from visual inputs. By equipping each bicycle with a rear-facing camera, we can capture visual data that provides rich information about the surrounding environment and the positions of nearby cyclists. Leveraging computer vision and deep learning methodologies, we can process this visual data to accurately determine the relative and absolute ordering of bicyclists within the swarm in real-time. This approach offers the potential to overcome the challenges associated with GNSS-based positioning, providing a more robust and precise solution for swarm cycling applications. The conceptual framework of our solution, as demonstrated in Figure 1 involves a multi-step workflow that addresses the challenges associated with relative and absolute ordering within the swarm.

RGB to Depth Conversion: A crucial step in achieving accurate positioning is estimating the depth information from the RGB images captured by the cameras. Several state-of-the-art methods exist for depth estimation from monocular images, such as MonoDepth [2], LeReS [6], etc. These methods leverage deep learning algorithms to infer depth information based on visual cues in the

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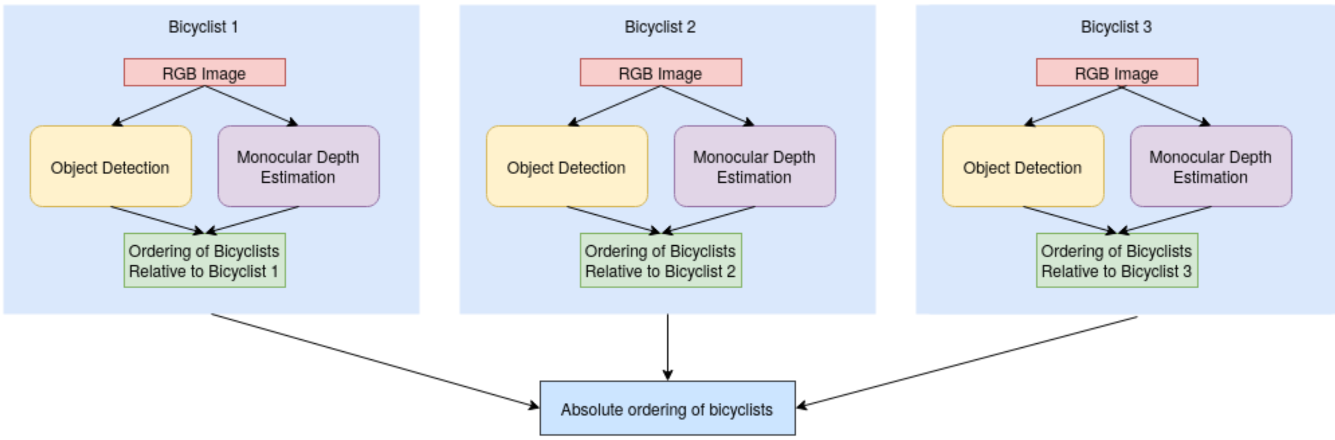

Figure 1: Visual Processing Module for Absolute Ordering of Bicyclists within the Swarm.

images. By applying such techniques to the RGB images captured by the cameras of each bicyclist, we can estimate the relative ordering of the other cyclists in view.

Detection and Tracking of Cyclists: Concurrently, we can proceed with the detection of other bicyclists in view and tracking them between frames. Several state-of-the-art object detection models like YOLOv7 [5], Faster-RCNN [3], DETR [1], etc could directly be used as an off-the-shelf solution. Tracking algorithms can utilize RGB cues, such as color and appearance features, to track the position and movement of each cyclist relative to the camera on their respective bicycles. By employing robust object tracking algorithms, we can maintain the continuity of tracking even in the presence of occlusions or sudden changes in cyclist positions. Real-time tracking capabilities are crucial to ensure the timely and accurate ordering of cyclists within the swarm.

Global Optimizer for Absolute Ordering: The next step involves establishing the absolute ordering of bicyclists within the swarm by fusing the relative positions obtained from the individual cyclist tracking. This requires a global optimizer that can handle the complexities of multiple camera views and varying perspectives. By leveraging optimization techniques, such as graph-based approaches or energy minimization methods, we can resolve ambiguities and inconsistencies in the relative positions to obtain a consistent and accurate absolute ordering of cyclists within the swarm. This global optimization step is essential for achieving the desired real-time absolute positioning information. In practice, the position information obtained from the individual cameras are characterized by a position and a given uncertainty. The global optimizer uses errror propagation methods to compute the final uncertainty on each cyclist position. In addition, we can fuse the results obtained by the image-based method with addition sources of information such as a noisy GNSS signal. If we we can characterize the noise level of the GNSS, we can add the obtained information in the global optimzer in a sensor fusion approach. This can be based for example on Kalman Filters or Extended Kalman Filters [4].

By addressing these subproblems and integrating the proposed solutions, we can obtain the real-time absolute ordering of bicyclists within the swarm. The combination of depth estimation, individual cyclist tracking, and global optimization enables us to leverage the visual data captured by the camera-equipped bicycles to provide precise and reliable positioning information. Furthermore, the use of computer vision and deep learning techniques ensures adaptability to changing swarm dynamics and robust performance in challenging scenarios. We present a system-level concept that combines multiple computer vision and deep learning modules to enhance the accuracy of positioning information in swarm cycling. Our proposed methodology integrates various modules, including a bicyclist detection model based on the YOLOv7 architecture and pixel-wise depth estimation using the LeReS model. Figure 2 showcases the results obtained from our approach, demonstrating the efficacy of the bicyclist detection model and the estimation of pixel-wise depth. Through this system-level concept, we establish a scientific foundation for achieving precise positioning in swarm cycling and lay the groundwork for future research and advancements in the field.

3 CONCLUSION

In conclusion, the proposed solution of equipping each bicycle in a swarm with a rear-facing camera and leveraging computer vision and deep learning techniques offers a promising approach to achieve real-time absolute ordering of bicyclists. By addressing the limitations of GNSS-based positioning and utilizing the rich visual information obtained from the cameras, the framework is intended to provide more accurate positioning information and enables the development of innovative digital services for swarm cycling. This advancement has the potential to enhance the overall swarm cycling experience, improve safety, optimize group dynamics, and pave the way for future advancements in swarm cycling technologies.

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