Toward a Participatory Trace-Sensing Framework Using Smartphone LiDAR for Wildlife Habitat Estimation

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Abstract. As damage to agriculture and forestry by wildlife intensifies, wide-area and high-frequency data collection is required to estimate habitats and movement patterns. Although citizen participatory sensing has attracted attention, identifying footprints in natural environments requires high expertise, which is a bottleneck for participation. Furthermore, automatic identification based on RGB images is unstable in real environments due to the influence of lighting and background similarity. This paper presents a conceptual design of a system for exploratory detection of wildlife footprints from imperfect 3D point clouds acquired by non-experts using LiDAR-equipped smartphones. Characteristics of this study lie in the integrated design of data acquisition support and analysis methods, targeting uneven terrain where standard assumptions of existing 3D analysis, such as flat reference planes or high-density measurement, do not hold. Specifically, we design an acquisition application that uses AR real-time feedback to support shooting behavior and ensure a certain quality of photogrammetry point clouds, and a footprint detection method based on local geometric features. By combining appropriate acquisition support and local geometric feature analysis, we present a framework that enables general participants to achieve effective automatic recognition in real environments using only smartphones, providing a technical foundation for wide-area wildlife monitoring based on participatory sensing.

Keywords: Participatory Sensing · Smartphone LiDAR · Wildlife Monitoring · Persuasive Design · Citizen Science

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1 Introduction

In recent years, damage to agriculture and forestry by wildlife has become serious [1], and methods for wide-area monitoring are required [5]. Citizen participatory sensing is promising [9, 3, 6], but identifying traces requires high expertise. This study delegates this judgment to the system to enable non-expert participation, focusing on "footprints," which are critical traces indicating individual presence [2]. However, RGB-based identification is unstable in natural environments due to background similarity and lighting changes [7]. In contrast, 3D information based on geometry is robust against lighting and color. However, point clouds acquired by non-experts inevitably contain imperfections such as low density and occlusion. The purpose of this study is to propose a system that enables exploratory detection of wildlife footprints even from imperfect point clouds acquired by non-experts. We view this as "exploratory detection" where avoiding false negatives is prioritized over suppressing false positives, and aim to support discovery in real environments. The contribution of this paper is proposing a framework for non-expert exploratory wildlife footprint sensing, which integrates participatory data collection, AR-based acquisition support, and geometry-based footprint detection. Specifically, we present the clarification of the problem setting in non-expert participatory sensing, a design rationale for ensuring acquisition quality via AR-based behavioral guidance, and an exploratory detection framework integrating photogrammetry-derived 3D point clouds and geometric analysis.

2 Related Work

2.1 Expert Dependence in Wildlife Footprint Surveys

Track surveys using traces (e.g., footprints) are widely effective for wildlife monitoring because they can cover large areas without special equipment, unlike camera trapping or line census [10]. However, identifying these traces relies heavily on the surveyor's experience and knowledge. This dependence on limited expert personnel creates a structural bottleneck. In other words, traditional methods struggle to achieve wide-area monitoring due to the shortage of experts.

2.2 Data Reliability Issues in Participatory Sensing

To address this "quantitative" shortage of experts, Participatory Sensing [4] has gained attention. The effectiveness of photo-sharing platforms and citizen observation has been reported in various ecological contexts [3, 6]. While scalable, non-expert identification introduces "qualitative" risks. Errors such as false positives or negatives significantly degrade data reliability. Therefore, a system guaranteeing data quality is required to maintain scalability.

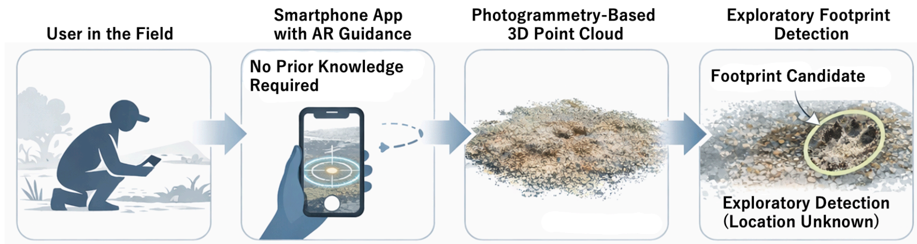

Fig. 1. Proposed system overview. An AR app guides users to ensure photogrammetry quality, followed by geometric analysis for exploratory footprint detection.

2.3 Limitations of Existing Detection Approaches

To support non-expert identification in outdoor environments, automated detection methods are required. Conventional RGB image-based methods are unstable under natural lighting and background variations [7], making them unsuitable for reliable field use. In contrast, 3D shape measurement using LiDAR-equipped smartphones is promising due to its robustness against lighting [8]. However, existing 3D analysis methods typically assume high-density, complete point clouds acquired by skilled operators. They fail when applied to "imperfect" data containing low density, viewpoint bias, or occlusions acquired by non-experts. Existing approaches do not explicitly address footprint detection under the assumption of imperfect 3D data acquired by non-experts in natural environments.

In summary, while footprint-based monitoring, participatory sensing, and 3D analysis have each been studied independently, their integration under the constraints of non-expert data acquisition remains insufficiently explored.

3 Design Concept and System Architecture

In this study, to establish exploratory detection by non-experts, we consistently integrate an AR-based Acquisition Support Design for ensuring point cloud quality and a Design Rationale for analysis based on local geometric features (Fig. 1).

Wildlife footprints, with depths of several mm to 1 cm, are comparable to smartphone LiDAR noise, which is around several cm, making detection difficult on their own. Therefore, in this design, we propose an acquisition interface that spatially guides camera trajectory and distance using AR, allowing users without knowledge to naturally satisfy the conditions for photogrammetry, such as resolution, viewpoint, and coverage.

3.1 Design Rationale: Acquisition Support

When the user taps the ground, AR visually guides ideal camera work, physically inducing user operation. Users only need to move the device along this guide.

This physical constraint enforces the maintenance of optimal distance, elimination of blind spots via all-around views, and blur suppression via constant speed, ensuring high-quality point cloud generation.

3.2 Design Rationale: Exploratory Analysis

Given ensured quality, we propose an integrated workflow: First, diverse footprint data is collected outdoors via the app, where AR ensures consistent quality. Next, experts assign ground truth labels to the acquired 3D point clouds based on shape information rather than RGB images. Finally, a machine learning-based detection model is constructed using the accumulated data and these ground truth labels. We aim to establish non-expert exploratory detection through the integration of this “forced quality assurance” data collection and standard learning process.

4 Design Implications and Future Directions

In this study, we proposed a design for a non-expert exploratory footprint detection system integrating smartphone AR and local geometric analysis as a technical foundation for promoting citizen participation in wildlife monitoring. The core of this proposal lies in the integrated approach of physically ensuring “data quality,” which traditionally relied on user skills, through system-side interface design, and constructing distinct robust analysis algorithms upon that basis.

Future work includes implementing a prototype based on this design and verifying its technical feasibility in actual outdoor environments. Specifically, we plan quantitative evaluations of how much AR behavioral guidance improves actual user shooting behavior, detection accuracy evaluations of the proposed algorithm on acquired point clouds, and user studies on the impact of system-presented information on users’ exploration motivation and discovery rates. We hope the design guidelines presented in this study will serve as a concrete roadmap for realizing future citizen participatory sensing.

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