

Protecting Privacy in an Era of Pervasive Camera-Based Devices: Challenges and Potential Directions

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Camera-based devices (CBDs) have become a pervasive presence in various contexts such as public transportation hubs, social insurance facilities, infrastructure, business establishments, and private homes, serving as part of the massive Internet of Things (IoT) ecosystem for safety and monitoring purposes [3, 8, 10]. While these devices offer numerous benefits in terms of public safety and security, privacy concerns are often overlooked [21]. Advancements in gaze estimation, especially multiple-person gaze estimation [5, 14, 16, 22, 23] and video-based human activity recognition (HAR) [2, 19] technologies have facilitated the extraction of valuable and sensitive information from such devices. We use a new term to describe the combination of gaze estimation and video-based HAR: *Integrated Human Visual Behaviour Analysis* (IHVBA). However, the privacy implications of data sharing through IHVBA technologies have not been comprehensively addressed [13, 15, 18].

This paper focuses on the application of IHVBA in CBDs of public and smart home contexts. IHVBA is an advanced technology that allows for real-time tracking and analysis of a person's gaze direction, body and social interaction [5, 13]. The ability to understand where people are looking and what they are interested in can provide valuable insights for various stakeholders. However, most recent research has been limited and directed by its particular domain, resulting in insufficient cross-domain dialogue on IHVBA and its applications in academic and industrial settings, as opposed to focusing solely on gaze estimation or HAR.

Privacy is a fundamental human right that is crucial for maintaining personal autonomy, dignity, relationships, and safety in various contexts. The use of IHVBA in public CBDs raises significant privacy concerns for customers, guest users, and specifically vulnerable groups. Previous research has highlighted privacy needs and concerns for these individuals in public CBDs [4, 11] and smart home contexts [12], but few studies have focused on the potential privacy issues and implications of these technologies.

From a legal and regulatory perspective, privacy issues associated with public CBDs and their surveillance systems have the potential to cause serious consequences for society [20]. While public CBDs can provide inherent value to the safety of urban environments through criminal evidence, surveillance, and monitoring, privacy concerns have emerged, causing not only individual customer issues but also society-wide problems, such as excessive personal data collection [7], data leakage [1, 6], data isolation and management by large technology companies [9], and excessive government control [17]. This paper aims to find a balance between

the interests of businesses that can benefit from the insights gained from IHVBA in CBDs, and the privacy and security concerns of customers. To achieve this balance, we pose the following research questions:

- **RQ1:** How can privacy-preserving methods be effectively integrated into IHVBA technologies in CBDs without compromising their functional capabilities in public and smart home contexts?
- **RQ2:** What are the privacy concerns and potential consequences for various stakeholders, when utilising IHVBA in CBDs of public and smart home contexts?
- **RQ3:** How can existing legal and regulatory frameworks be adapted or extended to address the privacy issues arising from the application of IHVBA in CBDs, and what are the best practices for industry stakeholders to ensure compliance and protect user privacy?

To investigate these research questions, we have adopted a hybrid approach by combining qualitative and quantitative research techniques. The first stage of our research involves completing the technical pipeline analysis, which encompasses data collection, preprocessing, and the development of the model architecture for privacy-preserving IHVBA technologies. We aim to understand the state of the art in these domains and identify potential areas for improvement to enhance privacy preservation.

Simultaneously, we have conducted a thorough review of the potential consequences, privacy needs and concerns for various stakeholders. This review consists of examining existing literature, conducting surveys, and engaging in semi-structured interviews with experts in the field of privacy, surveillance, and computer vision. This holistic examination has provided us with valuable insights into the primary privacy concerns and potential consequences arising from the application of multi-person gaze estimation and video-based HAR in public and smart home contexts.

Currently, we are analysing the findings from the technical pipeline analysis and stakeholder review to develop practical recommendations for integrating privacy-preserving methods into IHVBA technologies without compromising their functional capabilities. Additionally, we are identifying gaps in existing legal and regulatory frameworks and proposing future practices for industry stakeholders to ensure compliance and protect user privacy.

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