

Privacy-Preserving Elderly Monitoring: Balancing Fall Detection Accuracy and Visual Privacy

Muhammad Ali Fauzi¹, Rakha Apta Pradhana D R², Yudhistira³, Zahra Auliaul Rohman⁴, Yati Sri Hayati⁵, Budi Darma Setiawan⁶, Irawati Nurmala Sari⁷, Bian Yang⁸

^{1,2,3,4,5,6,7,8}Faculty of Computer Science Universitas Brawijaya Malang, Indonesia

⁸Department of Information Security and Communication Technology Norwegian University of Science and Technology (NTNU) Gjøvik, Norway

¹moch.ali.fauzi@ub.ac.id, ²rakhapta@student.ub.ac.id, ³yudhisthereal@student.ub.ac.id

⁴zahrauliaul@student.ub.ac.id, ⁵yshayati.fk@ub.ac.id, ⁶s.budidarma@ub.ac.id

⁷irawati.ns@ub.ac.id, ⁸irawati.ns@ub.ac.id

Abstract—The increasing elderly population has heightened the need for efficient and continuous fall detection systems. Camera-based monitoring solutions, while effective, pose significant privacy concerns. This study addresses these concerns by evaluating video anonymization techniques—stick figures and 3D avatars—that obscure identifiable visual features while preserving essential movement information for accurate fall detection. Simulated scenarios conducted by volunteers wearing elderly simulation suits facilitated realistic data collection. Analysis revealed the advantages and limitations of each anonymization technique, with 3D avatars preferred due to their superior contextual clarity and privacy balance, though stick figures presented notable benefits for resource-constrained environments. The study highlights crucial insights into balancing privacy with fall detection effectiveness, offering guidance for context-specific implementations.

Keywords—Elderly monitoring, Fall detection, Privacy preservation, Video anonymization, Stick figures, 3D avatars

I. INTRODUCTION

Indonesia has officially entered the phase of an aging population, with elderly individuals comprising 12% of the total population in 2024 [1]. This demographic shift brings profound implications for national healthcare systems, social services, and caregiving strategies. Among the key health concerns facing older adults is the heightened risk of falls. Approximately 45.6% of Indonesia's elderly population is considered at high risk of falling—a figure that reflects similar global trends and underscores the urgent need for targeted interventions [2], [3]. Globally, more than 25% of older adults experience at least one fall each year, and those who fall once are significantly more likely to fall again. These incidents are not only physically damaging, often leading to fractures, head injuries, and long-term mobility issues, but also psychologically distressing, contributing to fear of movement, reduced self-confidence, and increasing tendencies toward social isolation [4].

To address these concerns, a range of fall prevention and monitoring technologies has emerged. Traditional methods typically rely on wearable sensors, such as accelerometers or gyroscopes, and manual oversight by caregivers or family members. While these solutions have demonstrated some

effectiveness, they are also accompanied by limitations. Wearable devices can be uncomfortable, require regular charging or maintenance, and are often forgotten or deliberately not worn by the elderly. Manual monitoring, on the other hand, is labor-intensive and prone to human error or delays in response. As an alternative, camera-based monitoring systems offer several advantages. They enable continuous, real-time observation and can facilitate rapid detection and response to fall events. More advanced systems integrate artificial intelligence (AI) to detect abnormal movements or body postures automatically, significantly reducing reliance on human supervision and improving the speed of emergency intervention.

However, the adoption of camera-based monitoring is not without challenges. One of the most critical concerns relates to privacy. Continuous video surveillance, especially in private areas such as bedrooms and bathrooms, can feel intrusive and dehumanizing to older individuals. Privacy concerns are not limited to the subjects themselves; caregivers and family members also express unease about how video data is stored, shared, and protected. The potential for misuse—whether through unauthorized access, data breaches, or surveillance overreach—is a major barrier to widespread adoption [5], [6]. Moreover, many elderly individuals place a high value on their autonomy and personal dignity. Being observed around the clock, particularly without adequate safeguards, can lead to anxiety, stress, and reluctance to accept otherwise beneficial monitoring solutions.

In light of these challenges, there is a pressing need to develop monitoring systems that balance safety and privacy. Privacy-preserving technologies offer a promising path forward. This study investigates two such anonymization techniques—stick figures and 3D avatars—that aim to obscure the visual identity of monitored individuals while preserving the necessary contextual information required for effective fall detection. Stick figures simplify the visual form of a person to a skeletal structure using keypoint detection algorithms, minimizing personal detail. Meanwhile, 3D avatars offer a more nuanced anonymization by replacing the human subject with a digital model that mirrors movements without revealing facial or bodily identity. By evaluating these approaches in terms of technical performance,

user acceptance, and privacy perception, this research seeks to contribute to the design of ethical, effective, and socially acceptable elderly monitoring systems for real-world application in healthcare, residential, and assisted living settings.

II. METHODOLOGY

A. Data Collection

We collected video data from simulated scenarios performed by volunteers wearing elderly simulation suits, ensuring realism in depicting falls and everyday activities. The collected dataset includes diverse scenarios involving falls and typical daily activities to provide comprehensive training data for fall detection algorithms. Specifically, the dataset encompasses:

- **Falling Forward:** Simulations of participants losing balance and falling face-down from standing or walking positions.
- **Falling Backward:** Instances where volunteers fell backwards from various initial positions, such as standing still or sitting.
- **Sideways Falls:** Scenarios depicting individuals falling sideways, particularly focusing on falls triggered by imbalance or sudden movements.
- **Activities of Daily Living (ADLs):** Including walking, standing up, sitting down, lying down, and performing routine household tasks to differentiate normal actions from fall events.

All activities were conducted under controlled laboratory conditions, and each scenario was repeated multiple times by different volunteers to ensure variability and reliability of the data. Ethical considerations were addressed by obtaining informed consent from all participants, clearly explaining the study objectives and ensuring confidentiality and anonymity throughout the research.

B. Video Anonymization Processes

We utilized two anonymization methods designed to address privacy concerns effectively while retaining critical visual information necessary for accurate fall detection:

- 1) **Stick Figures:** This method involved extracting skeletal representations from video footage using OpenPose [7]. OpenPose employs deep learning-based algorithms to detect and map keypoints corresponding to human joints and limbs, effectively converting detailed human forms into simplified stick-figure representations. This anonymization significantly reduces identifiable personal features while preserving essential movement patterns needed for reliable fall detection.
- 2) **3D Avatars:** We generated detailed 3D avatars using the PyMAF-X algorithm, which reconstructs human

body models from video sequences [8], [9]. PyMAF-X algorithmically infers three-dimensional body poses and shapes from input video frames, creating realistic yet non-identifiable avatars. These avatars preserve critical contextual information about body movements and orientations, necessary for accurate detection of falls and other activities, while significantly obscuring facial features and other identifiable traits.

III. RESULTS AND DISCUSSION

Our analysis revealed distinct strengths and limitations associated with the evaluated anonymization techniques, demonstrated through simulated scenarios including bathroom use, walking through doorways, and sitting on furniture:

- **Stick Figures:** Stick figures provided excellent anonymity by significantly reducing visual identity markers. They effectively illustrated essential movements like walking, sitting, and falling. However, the representation sometimes lacked detailed contextual information. For example, in bathroom scenarios, skeletal mapping was clear but lacked context regarding interaction with environmental elements (e.g., the toilet or furniture), potentially challenging caregiver interpretation.
- **3D Avatars:** The 3D avatar anonymization method using PyMAF-X maintained a high level of visual privacy by replacing human figures with non-identifiable yet realistic avatars. These avatars retained critical information about posture, orientation, and interaction with the environment. For instance, during sitting scenarios and bathroom usage, avatars clearly depicted body posture and interactions with surroundings, aiding caregiver comprehension and intervention accuracy. However, this method demands higher computational resources compared to stick figure anonymization.

Our analysis revealed distinct strengths and limitations associated with the evaluated anonymization techniques, demonstrated through simulated scenarios including bathroom use, walking through doorways, and sitting on furniture.

Both anonymization techniques showed significant potential in balancing effective fall detection with strong visual privacy preservation, suggesting context-specific implementations based on available computational resources, monitoring urgency, and user preferences.

Ultimately, both anonymization techniques showed significant potential in balancing effective fall detection with strong visual privacy preservation, suggesting context-specific implementations based on available computational resources, monitoring urgency, and user preferences. Comparatively, the 3D avatar method offers a balanced combination of privacy protection and contextual clarity. It effectively obscures personal identity while still conveying clear environmental

interactions, enabling accurate interpretation of activities. On the other hand, the simplicity and computational efficiency of stick figures make them more suitable for scenarios that require real-time monitoring with limited processing resources.

REFERENCES

- [1] Badan Pusat Statistik Indonesia, *Statistik Penduduk Lanjut Usia 2024*. Jakarta, Indonesia: Badan Pusat Statistik, December 2024.
- [2] S. Nugraha, S. Prasetyo, I. H. Susilowati, and T. B. W. Rahardjo, "Urban-rural dimension of falls and associated risk factors among community-dwelling older adults in west java, indonesia," *Journal of Aging Research*, vol. 2021, pp. 1–8, August 2021.
- [3] R. Martins, N. Carvalho, S. Batista, and A. Dinis, "Falls in elderly: Study of the prevalence and associated factors," *European Journal of Development Studies*, vol. 2, no. 3, pp. 12–17, May 2022.
- [4] Centers for Disease Control and Prevention (CDC), "Facts about falls," <https://www.cdc.gov/falls/data-research/facts-stats/index.html>, 2024, accessed 2025-07-07.
- [6] L. Sun, P. Yeng, M. A. Fauzi, P. Khatiwada, and B. Yang, "Multi-party privacy policy management in the context of health monitoring: An exploratory study," in *Proceedings of the 8th International Conference on Sustainable Information Engineering and Technology (SIET 2023)*. New York, NY, USA: ACM, 2023, pp. 523–528.
- [7] S. Qiao, Y. Wang, and J. Li, "Real-time human gesture grading based on *openpose*," in *Proceedings of the IEEE International Conference on Intelligent Computing and Control Systems (ICICCS)*. IEEE, 2017, pp. 1–6.
- [8] H. Zhang, Y. Tian, X. Zhou, W. Ouyang, Y. Liu, L. Wang, and Z. Sun, "*Pymaf*: 3d human pose and shape regression with pyramidal mesh alignment feedback loop," in *Proceedings of the IEEE International Conference on Computer Vision*, 2021.
- [9] H. Zhang, Y. Tian, Y. Zhang, M. Li, L. An, Z. Sun, and Y. Liu, "*Pymaf-x*: Towards well-aligned full-body model regression from monocular images," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 2023.



Fig. 1: Bathroom scenario anonymization comparison



Fig. 2: Doorway scenario anonymization comparison



Fig. 3: Sitting scenario anonymization comparison

CONCLUSION AND FUTURE WORK

This study demonstrates the feasibility and effectiveness of using video anonymization techniques—stick figures and 3D avatars—to balance privacy preservation and accurate fall detection in elderly monitoring systems. Through comprehensive scenario simulations and comparative analysis, we found that both methods effectively address privacy concerns while maintaining necessary contextual details for fall detection. Notably, 3D avatars were preferred for their ability to offer detailed contextual interactions, while stick figures showed promise for real-time, resource-constrained environments. Future research should focus on optimizing these anonymization methods to reduce computational demands, enhance real-time processing capabilities, and explore user acceptance in diverse caregiving environments.