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Conference Theme: "Governing Emerging Intelligent Technologies"

Privacy Governance-Driven Design of AI-Powered Elderly Safety Monitoring for Cambodia

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The Challenge: Elderly Safety Dilemma

Global Aging Crisis

- Southeast Asia: 12.2% elderly (2024) → 22.9% by 2050 (WHO, 2025)
- Falls: 684,000 annual deaths globally, 60% in Western Pacific/Southeast Asia (WHO, 2021)
- Cambodia: 2.1M elderly (60+ years) by 2030 (UN, 2015)

Current Solutions Fall Short

Solution Type	Privacy	Compliance	Cost
Cloud Cameras	❌	✅	❌
Wearables	✅	❌	✅

The Gap: Middle-income Cambodian households ($870-$1,622/month (NIS, 2021)) need affordable, privacy-preserving solutions.

What We're Investigating

The Core Problem Revisited:

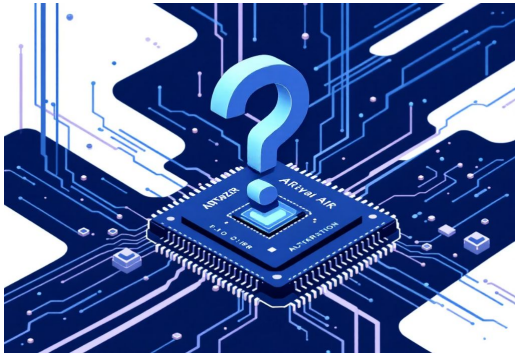
Elderly monitoring cameras today force a choice: send video to cloud companies (privacy risk) OR use wearables that elderly forget to wear (compliance problem).

Can we design a system that:

- ✓ Protects privacy by keeping all data at home?
- ✓ Works 24/7 without wearables?
- ✓ Costs less than cloud alternatives?

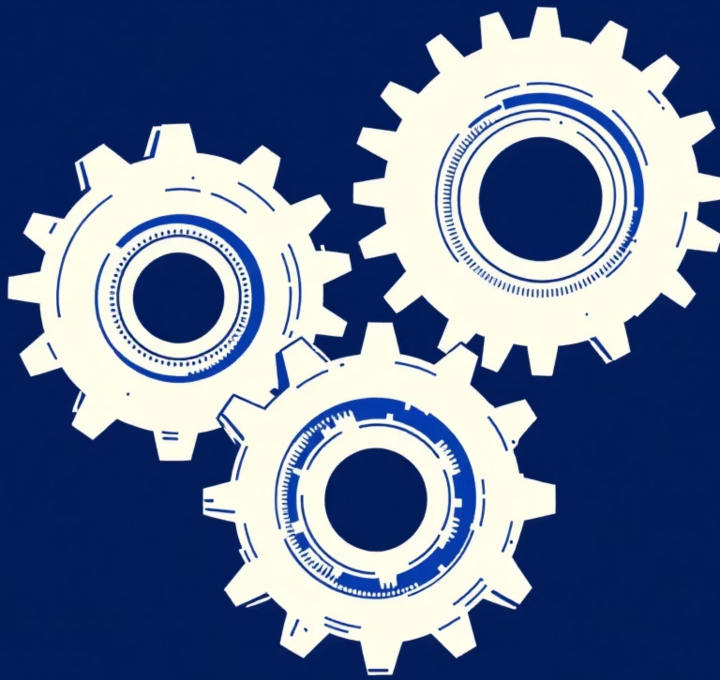
Research Question:

"How can privacy governance principles inform the architectural design of AI-based elderly monitoring systems in resource-constrained contexts?"



Study Type: **Design study** demonstrating governance-driven architecture:

- Validating **NIR camera compatibility**, **cost-effectiveness**, **privacy design**
- NOT Validating fall detection accuracy, real-world deployment.



Three Design Propositions

Privacy governance translate directly into technical architecture?

❓"Must protect privacy" → "edge computing + pose-only data + delete video frames."?

Privacy-first design → Cost reduction?

🧐 Eliminating cloud infrastructure (for privacy) also eliminates subscription fees (economic benefit).

Body pose alone → Safety monitoring

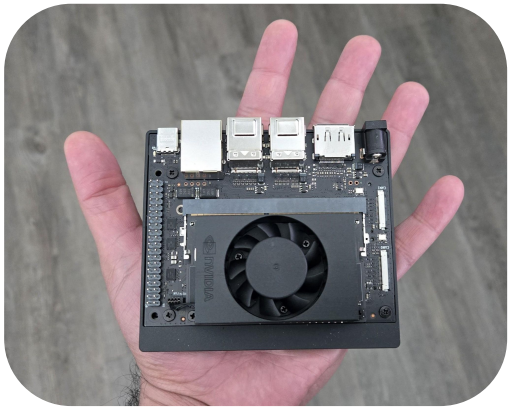
❓Can we detect falls using skeletal keypoints without storing actual video footage?

Testing approach: Validate feasibility through NIR compatibility testing and cost analysis.

Privacy Governance Architecture

Two Design Principles → “Edge-First Processing” and “Post-Only Storage + Immediate Frame Disposal”

1. Edge-First Processing



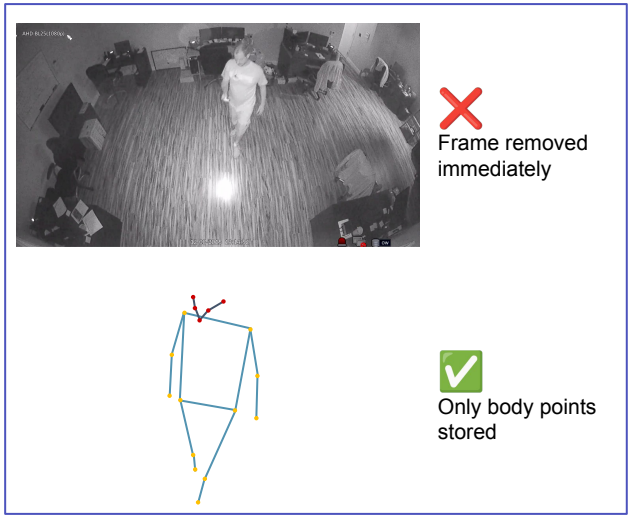
NVIDIA Jetson Orin Nano (https://www.reddit.com/media?url=https%3A%2F%2Fi.redd.it%2Fjust-got-my-jetson-orin-nano-developer-kit-v0-disidevv31we1.jpg%3Fwidth%3D2310%26format%3Dpjpg%26auto%3Dwebp%26s%3D322b76fc914e88c26510f590924f3822527d65b4)

No Cloud Computing (https://images.hanselman.com/blog/Windows-Live-Writer/A-non-Cloud-based-backup-strategy_14D0F/nocloud_thumb.png)

100% on-device computation | Zero cloud transmission | Data sovereignty at home

Privacy Governance Architecture

2. Pose-Only Storage + Immediate Frame Disposal



A studied NIR Video Footage illustrating YOLOv8n Person Detection and MediaPipe Pose Estimation (https://www.youtube.com/watch?v=KvRi6xEspJg)

- Extract 17 body keypoints | Face landmarks explicitly excluded | No facial reconstruction possible
- Raw video frames processed in real-time | Deleted after keypoint extraction | No re-identification risk

Key Message: Privacy by Design, not by Policy.

Technical Approach Overview

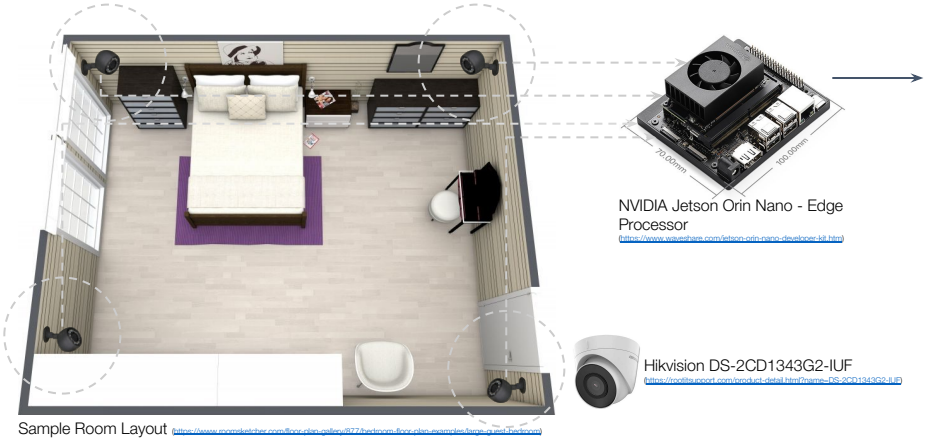
Hardware Configuration

Cameras: 4× RGB with 850nm IR night vision (Hikvision DS-2CD1343G2-IUF)

- 90° spacing for 360° coverage
- 24/7 monitoring capability (IR for complete darkness)

Edge Processor: NVIDIA Jetson Orin Nano 8GB

Total System Cost: $672 (one-time, zero recurring fees)

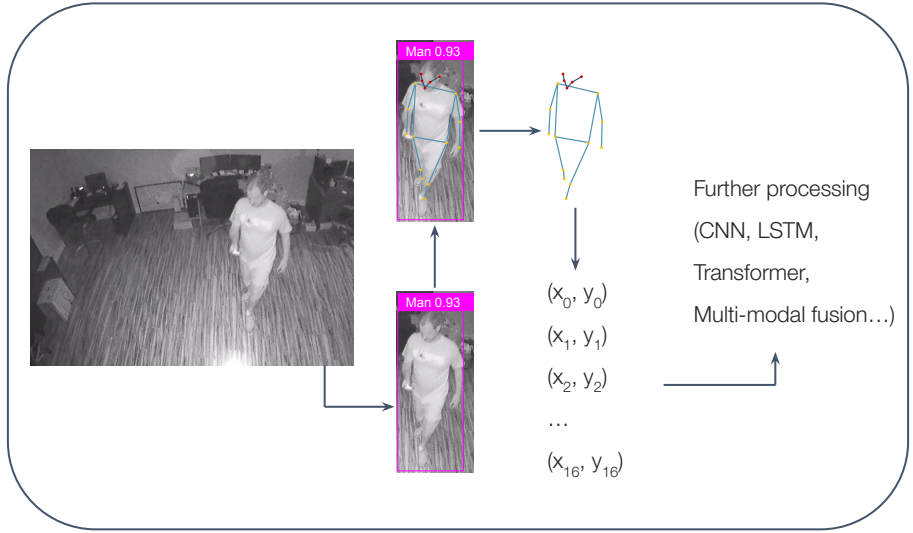


Software Pipeline

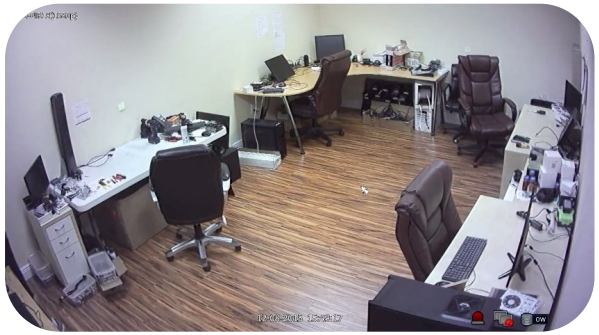
Person Detection: YOLOv8n (Nano - lightweight) identifies bounding box

Pose Estimation: MediaPipe extracts 33 skeletal landmarks → 17 body keypoints stored

Privacy Layer: Frames immediately deleted



Results: NIR Camera Compatibility



RGB Video footage sample
(https://www.youtube.com/watch?v=8WGdCsQ0G3I)

NIR Video footage sample
(https://www.youtube.com/watch?v=8WGdCsQ0G3I)

Validation Dataset

- 20 commercial NIR CCTV videos (publicly available demo footage)
- Diversity: Hikvision/EZviz/dome/turret/bullet cameras, indoor/outdoor
- Resolution: 1080p and 4K
- Purpose: Validate performance on target camera wavelength (850nm NIR)

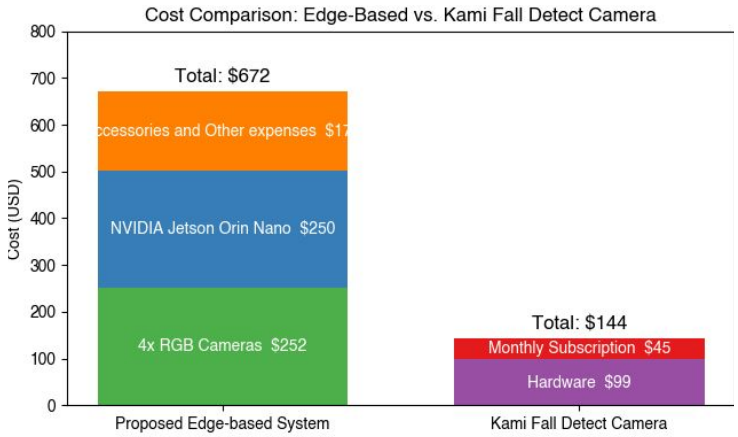
Performance Metrics (Integrated Pipeline)

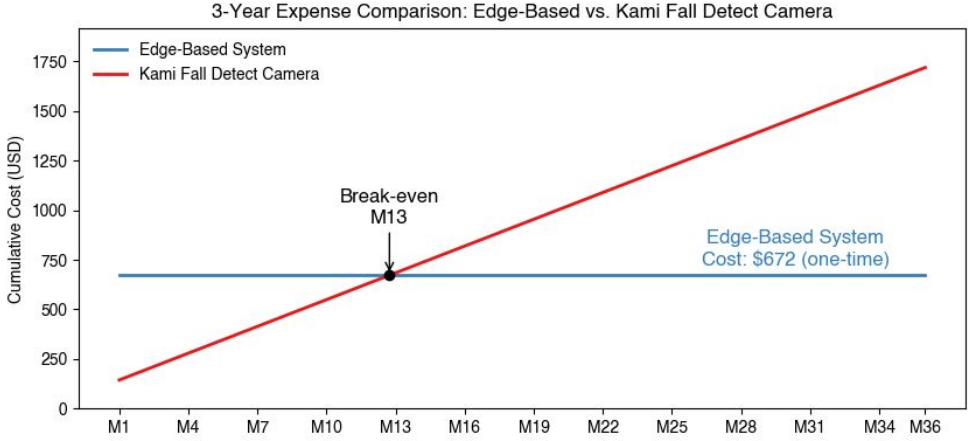
Metric	Result
Keypoint Detection Rate	91.3% (30.1 of 33 landmarks)
Average Confidence	0.868
False Negative Rate	12.3% (person present, pose failed)
Processing Speed	20.53 FPS

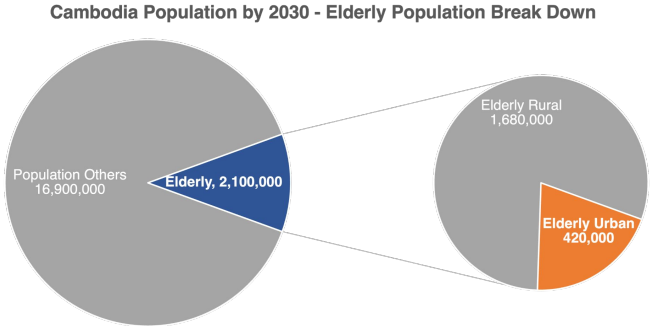
Why it matters?

- Very little research validating compatibility between MediaPipe pose estimation and infrared wavelength cameras
- Confirms 24/7 monitoring feasibility without facial recognition technology.

Results: Cost-Effectiveness Analysis







Cambodian Household Income Quintile (NIS, 2021)

252,000 Populations (12%)

168,000 Populations (8%)

Income Quintile	Monthly Income	Affordability
Top 20%	$1,622/month	✔ Highly feasible
Fourth 20%	$870/month	✔ Feasible with savings
Middle 20%	$648/month	⚠️ Requires family pooling
Lower 40%	< $500/month	❗ Cannot afford unless with subsidies

Design Trade-offs: Safety-Critical Priority

Baseline Pipeline

(MediaPipe on Full Frame)

Integrated Pipeline

(YOLOv8n person detection → ROI crop → MediaPipe on ROI)

Metrics	Baseline Pipeline	Integrated Pipeline	Comparison
Processing Speed	**47.37 FPS**	20.53 FPS	Integrated approach is 2.3x slower
Keypoint Detection	85.6%	**91.3%**	Integrated approach detects 5.7% more accurately
Pose Coverage	63.8%	**86.0%**	Integrated approach has 22% more pose coverage

Decision:

Integrated Pipeline

(Prioritize accuracy for safety-critical application)

Rationale:

- Missing fall detection has fatal consequences
- Both configurations exceed real-time requirements (20.53 FPS vs 15 FPS target)
- 5.7% accuracy gain + 22.2% better coverage justified 2.3× slower speed

What This Means for Governance

Privacy by Design Works Technically

91.3% detection on IR cameras. No compromise between privacy and performance.

Privacy Governance Creates Economic Co-benefits

Edge architecture (for privacy) → 61% cost savings. Makes healthcare AI accessible to middle-income markets.

Context-Specific Design Matters

Cambodia's economic constraints shaped our architecture. Scalable model for similar developing countries.

Limitations & Future Directions

Study Limitations

1

Testing Environment

Commercial CCTV footage, not actual elderly subjects. Movement patterns and gait may differ for elderly individuals.

2

Hardware Deployment

Performance measured on standard hardware, not the target edge device. Real-world Jetson Orin Nano validation is needed.

3

Market Accessibility

$672 targets middle-income urban households only. Low-income and rural elderly need alternative deployment models.

What's Next

Immediate Priorities

- Fall detection accuracy testing on benchmark datasets
- Hardware deployment on Jetson Orin Nano edge device
- Custom dataset collection with Cambodian elderly participants

Longer-Term Work

- User acceptance studies with elderly and caregivers
- Development of accessible deployment models for diverse income levels

Conclusion: Key Takeaways

1. **Privacy Governance Principles Drive Design**

   Edge processing, pose-only storage, and immediate frame disposal were architectural decisions driven by privacy-by-design, not policy as an afterthought.

2. **Edge-First Architecture is Feasible & Economic**

   Achieved 91.3% keypoint detection on 850nm NIR, enabling 24/7 monitoring, and delivered a 61% cost reduction over cloud alternatives.

3. **Privacy-by-Design Yields Economic Co-benefits**

   Eliminating cloud costs expands accessibility, potentially reaching 168,000-252,000 Cambodian elderly (8-12% of the elderly population).

4. **Context-Specific Design is Crucial**

   Economic constraints in Cambodia shaped an architecture that can serve as a proof-of-concept for similar developing countries.

So What?

For Researchers

Empirical validation of NIR compatibility highlights performance variability across camera types, crucial for future studies.

For Policymakers

Privacy-first architecture presents a model to expand healthcare AI accessibility in middle-income markets.

For Practitioners

Zero-subscription models offer a pathway to reduce significant cost barriers in developing countries.