

Background & Objectives

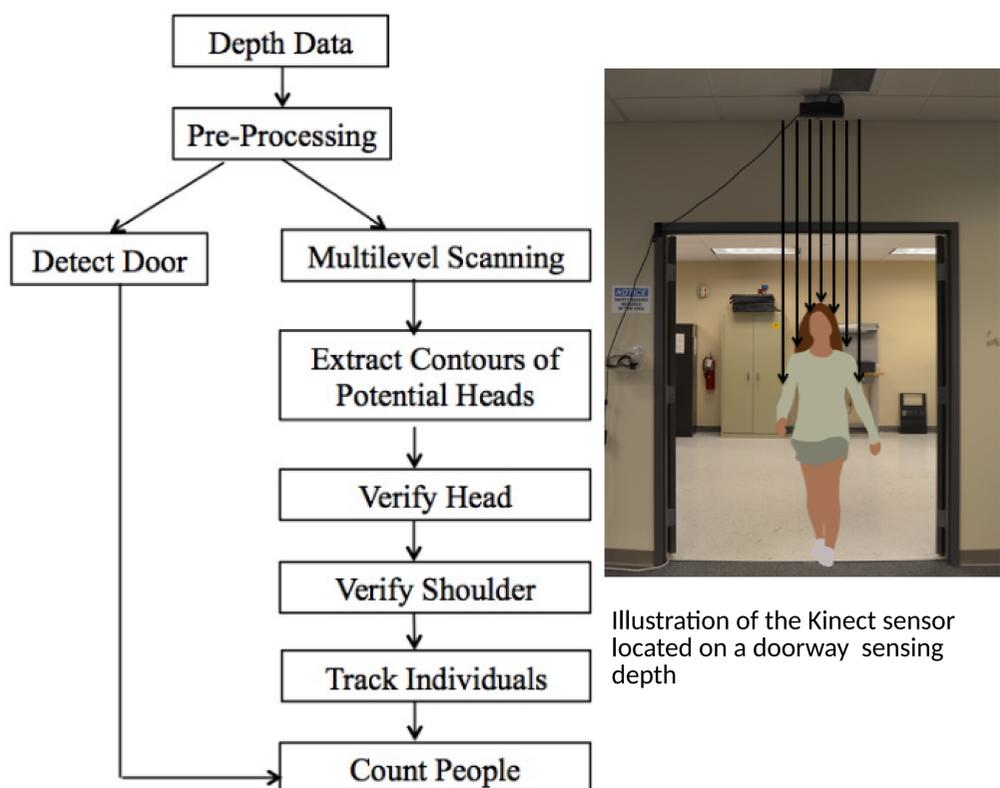
Occupancy estimation is very useful for improving energy efficiency, safety, and security of buildings. Existing solutions rely on motion sensing, thermal or RGB imaging. This demo presents a non-privacy invasive system that uses depth sensing technology, specifically a Microsoft Kinect on an ARM embedded platform, to detect multiple people entering/leaving a room simultaneously. Currently the system is live in 8 classrooms and conference rooms in both Carnegie Mellon University and Bosch Research and Technology Center, Pittsburgh, PA, U.S.

System Architecture



Kinect sensor for XBOX One and Odroid-XU4

We use the depth sensor in Kinect for XBOX One this work. We choose an Odroid-XU4 for processing, as it is one of the few embedded platforms that supports USB 3.0 that is required by this Kinect. FORK does not use the Kinect SDK, so any depth sensor with similar hardware functionality will work.

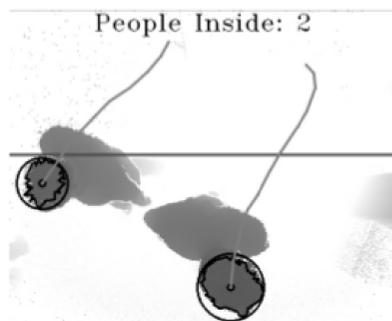


FORK software flow diagram



Illustration of the Kinect sensor located on a doorway sensing depth

Current Status



Sample depth data where FORK is tracking individuals

- Carnegie Mellon University Locations:
 - 3 classrooms
 - 3 master's student lounges
 - 2 conference rooms
- Bosch Research & Technology Center:
 - 2 conference rooms
 - 4 office entrance doors
- Collected ground truth data size: 20 TB
- Deployed systems are running 24/7 since late 2015
- 25 new installations are planned for 2018

Applications & Further Work

- Occupant detection
- Item recognition
- Thermal preference inference based on biometrics

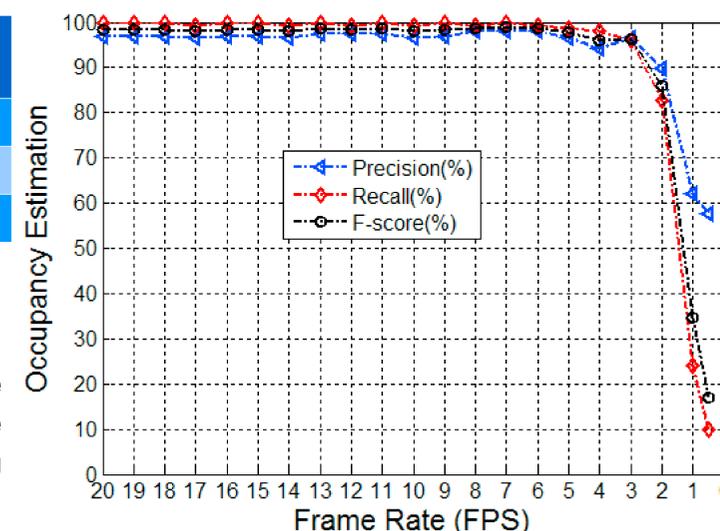


Results & Discussion

Location	Ground Truth (# Events)	FORK (# of events)	True Positive Ratio (TPR)
Classroom 1	292	291	99.67 %
Classroom 2	89	92	98.48 %
Classroom 3	222	217	96.39 %

Performance metrics of FORK based on ground truth data collected at Carnegie Mellon University

Ground truth data was collected from 8:30 AM to 6:30 PM over a one week period in 5 different rooms resulting in 20 TB. Realistic cases were addressed in this experiment: door opening and closing, students coming with backpacks, gym bags, papers, bike helmets, laptops, wearing caps, hoodies, headphones, and sunglasses over their heads. We have evaluate FORK in 3 classrooms so far, the results can be found above, and we achieve a True Positive Ratio (TPR) above 96% in all classrooms. Additionally, an all-tag bi-directional people counter was placed alongside FORK at classroom1, achieving a TPR of 97.26% whereas FORK achieved 99.67%



FORK performance at different frame rates

The occupancy estimation performance varies depending on frame rate. Performance drops significantly when frame rate drops below 3 FPS

Acknowledgement

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Reference

K. S. Liu, S. Munir, J. Francis, C. Shelton, and S. Lin. 2017. Poster Abstract: Long term occupancy estimation in a commercial space: an empirical study. In IPSN.

S. Munir, R. S. Arora, C. Hesling, J. Li, J. Francis, C. Shelton, C. Martin, A. Rowe, and M. Berges. 2017. Real-Time Fine Grained Occupancy Estimation using Depth Sensors on ARM Embedded Platforms. In RTAS.