Nonintrusive Occupant Identification using Body Shape and Movement

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Energy Efficient And Comfortable Spaces

John likes cold temperature

Sarah likes warm temperature

Different device preferences

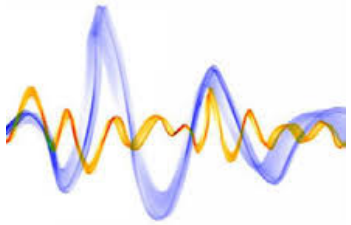
Occupant Identification enables these goals

Related Work

- Require user to carry mobile gadgets
  - RFID, smartphones, iBeacon..

- Require user's active involvement
  - Facial, fingerprint, iris, hand geometry…

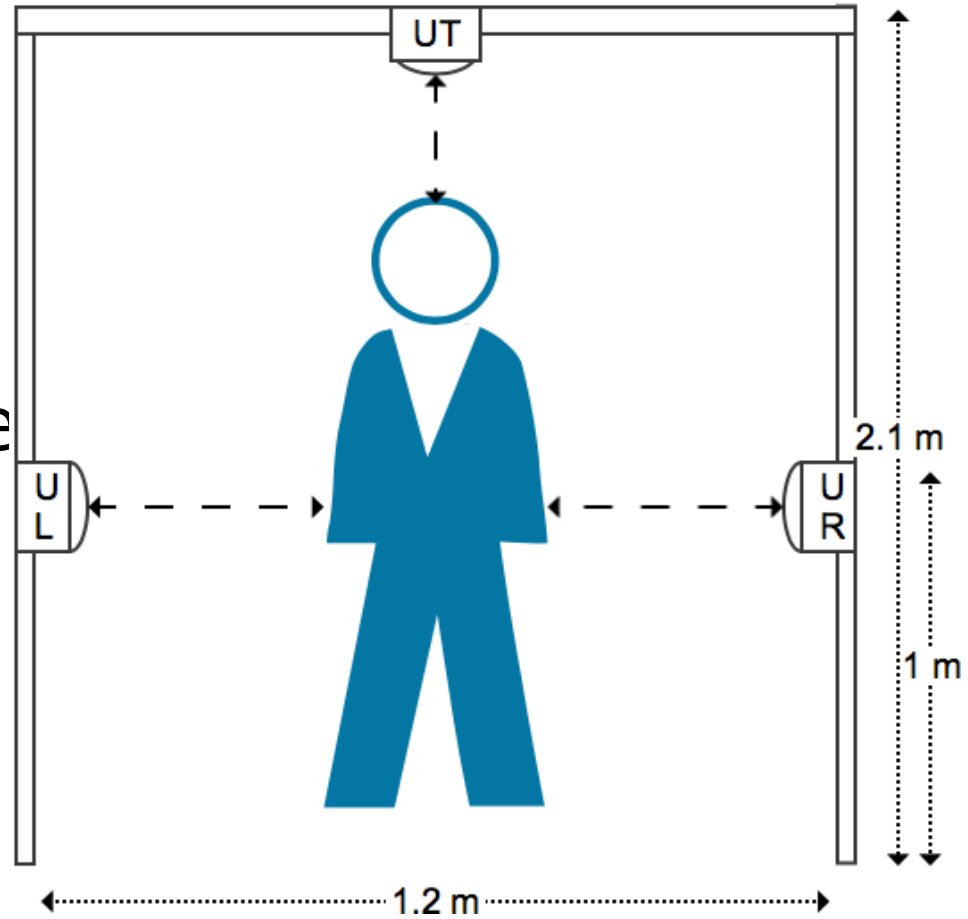
- Nonintrusive and noninvasive
  - Footstep vibration, Wifi RF Signal, Height sensing
  - **Our work improves this approach by factor of 5**



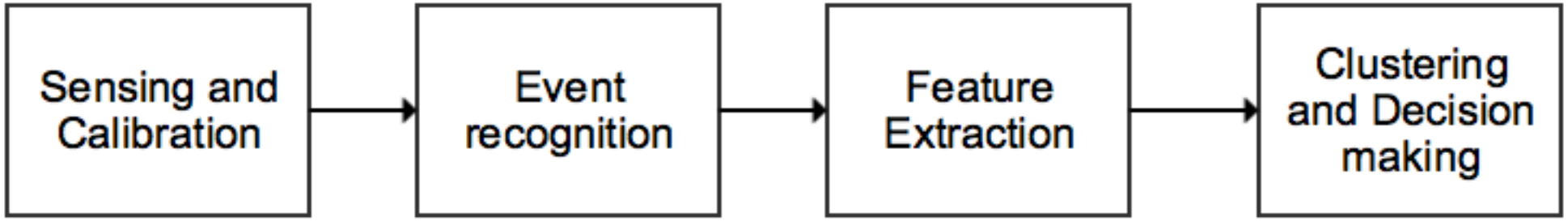
1. Introduction
2. Related Work
3. **System Design**
4. Evaluation
5. Conclusion

System Design

We propose a system that uses ultrasonic sensors attached to a doorframe that senses body shape and movement

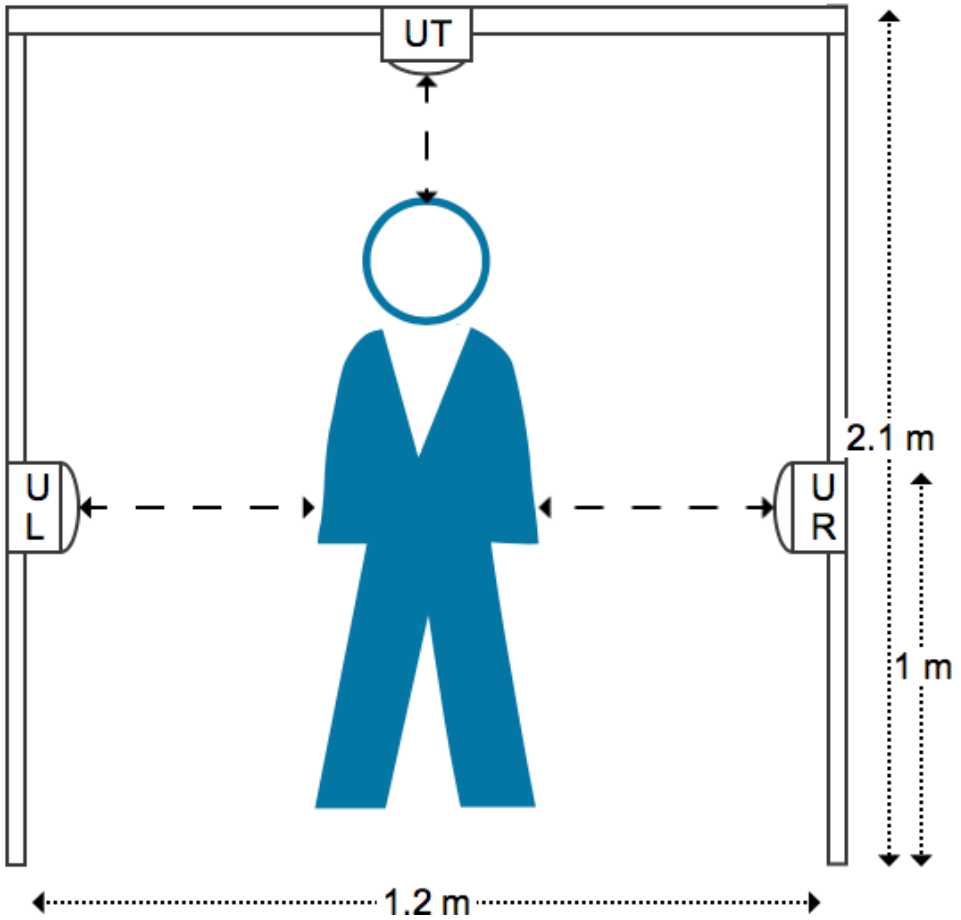


System Design



System Design

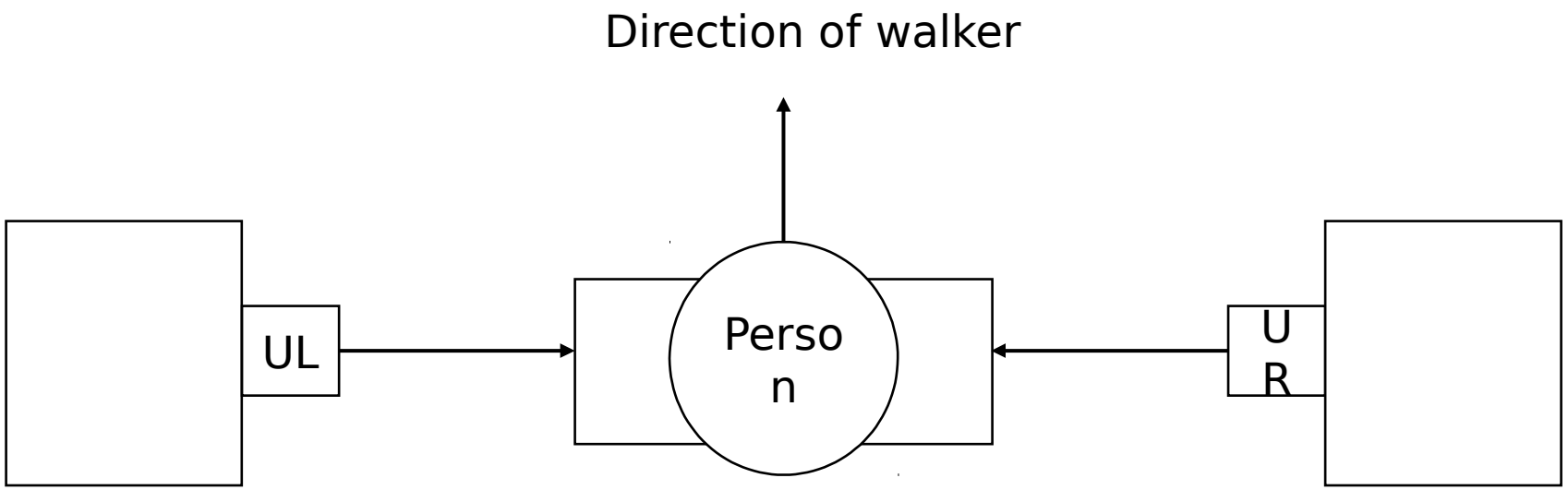
Sensing and Calibration



Sampling rate: 35 Hz
UT measures height
UL and UR measure width

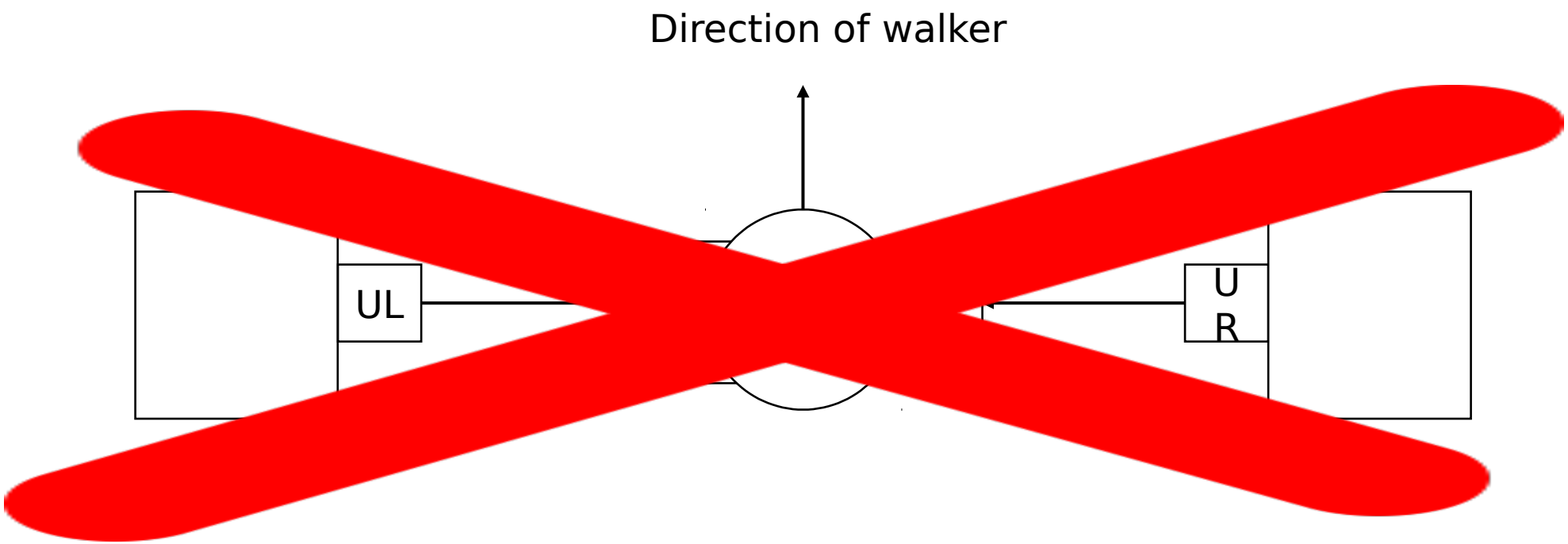
System Design

Sensor Displacement



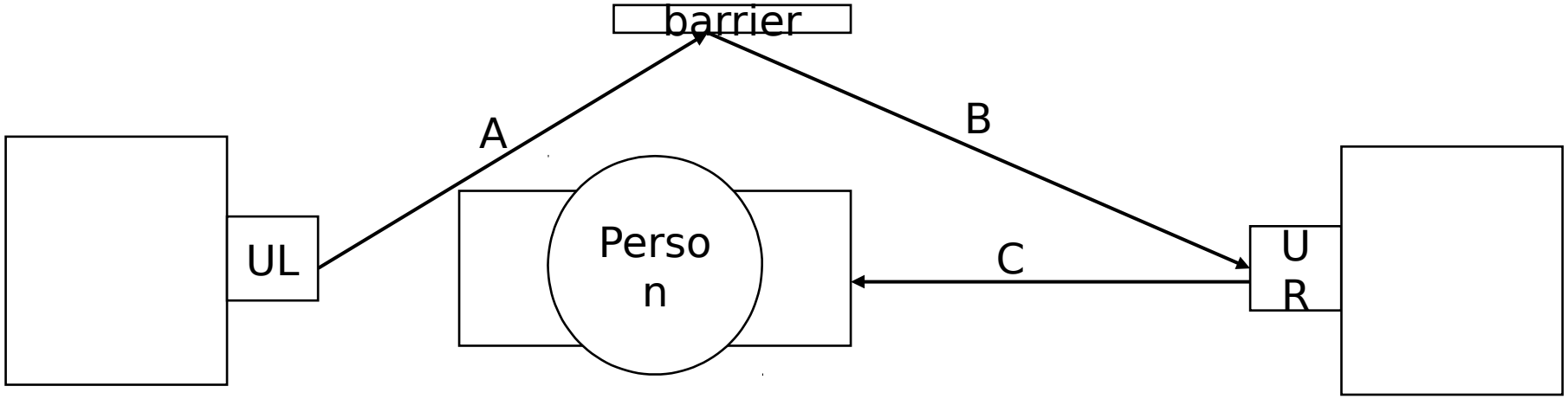
System Design

Sensor Displacement



System Design

Sensor Displacement

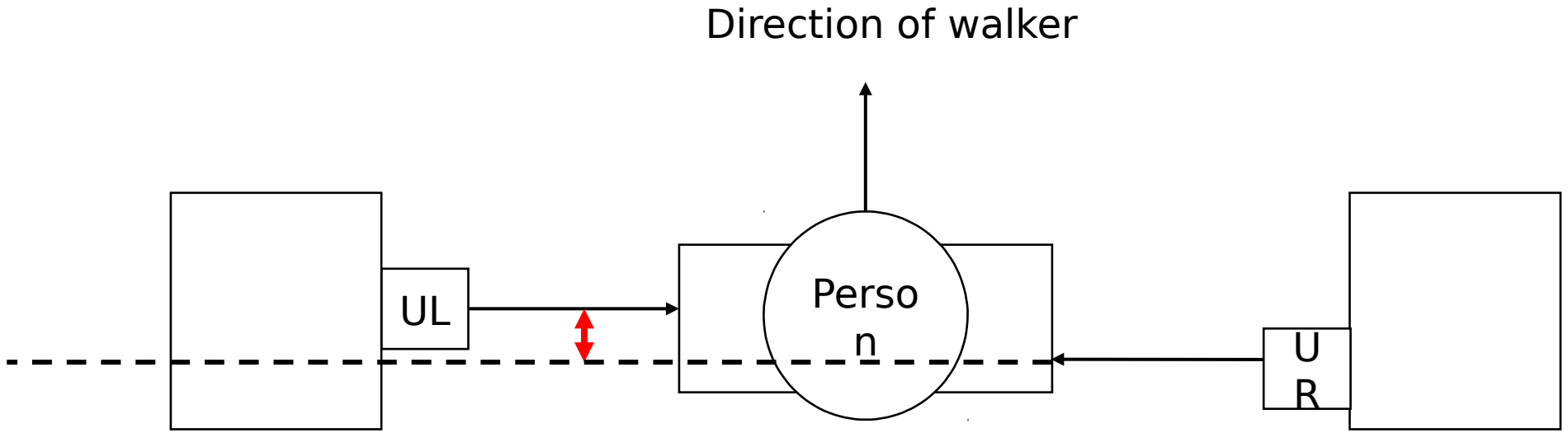


A+B < 2C → Wrong width measurement

UL beam will get to UR before UR's reflected beam

System Design

Sensor Displacement and Sampling in Sequence



System Design
Walking Event Recognition

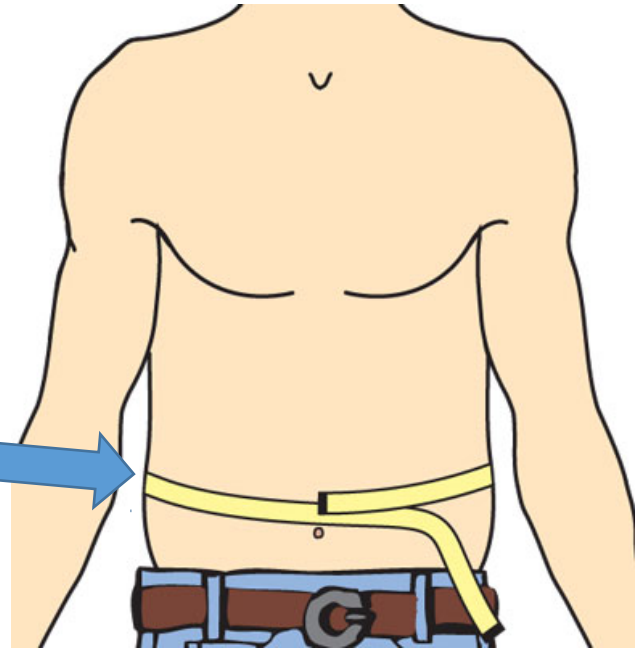
- Want data corresponding to walking events

- How do we recognize a walking event?
  - All sensors poll at 35Hz
  - Walking event is assumed when height > 140 cm
    - USA mean height: 169cm
    - Standard deviation: 7.5cm
  - Not perfect but reasonable

System Design

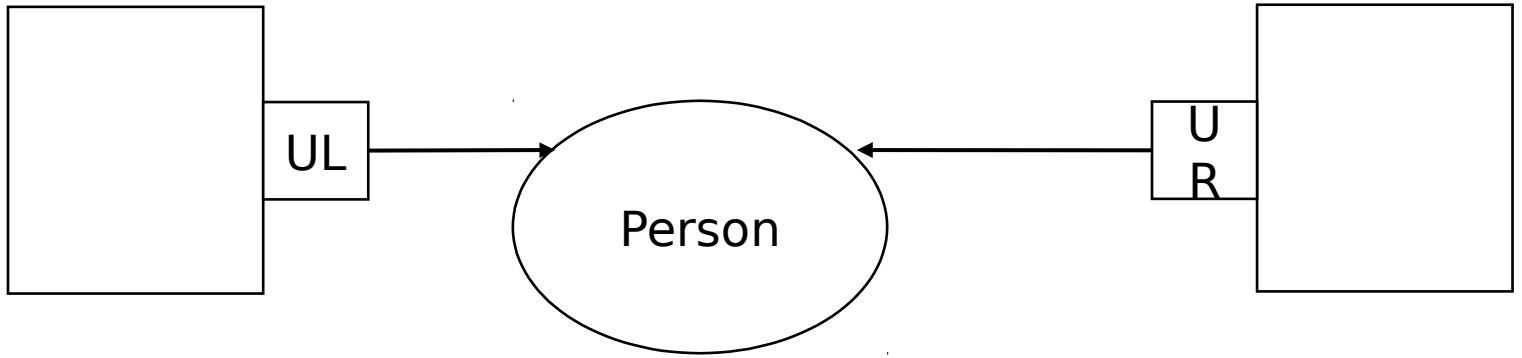
Possible Features

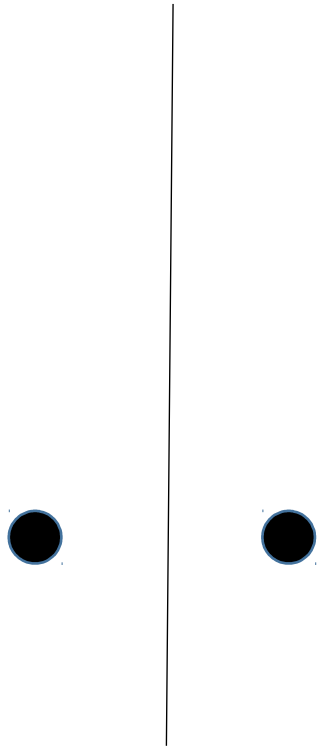
Features Computed
Minimum, Maximum, Mean Height
Minimum, Maximum, Mean Width
Girth = (Waist circumference)
Time under the door
Distance between waist and hand
Bounce = max – min height



System Design

How is Girth Computed?





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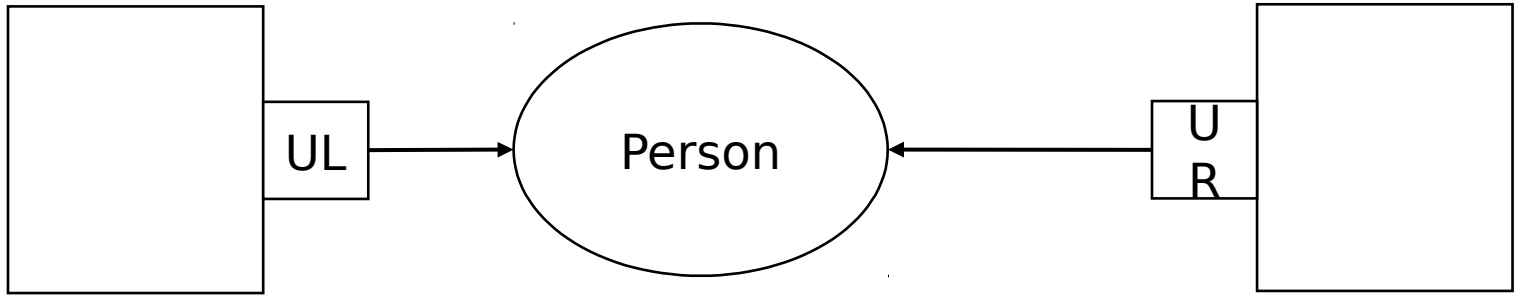

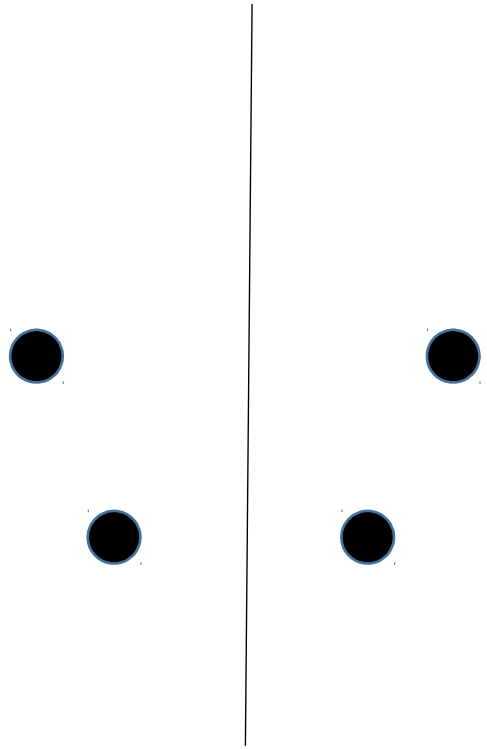

System Design

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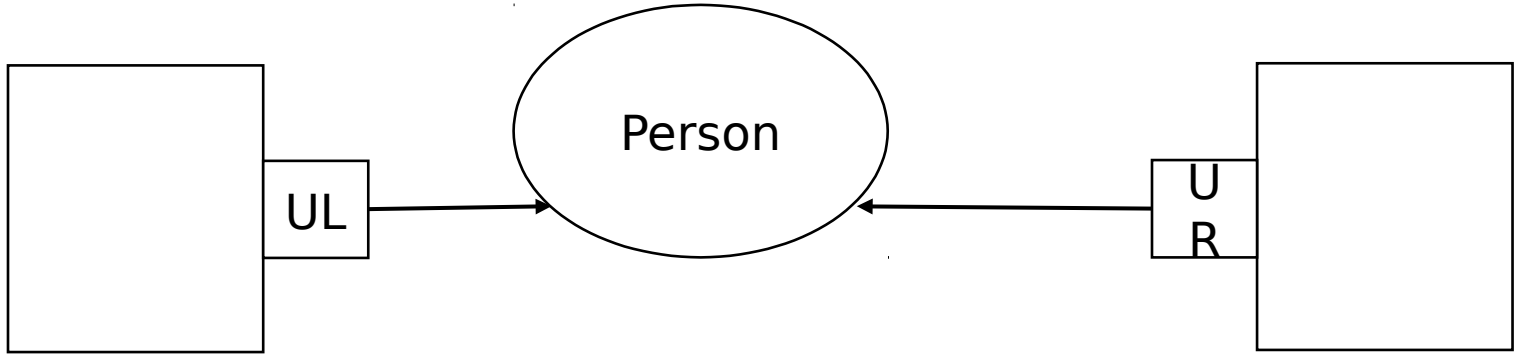
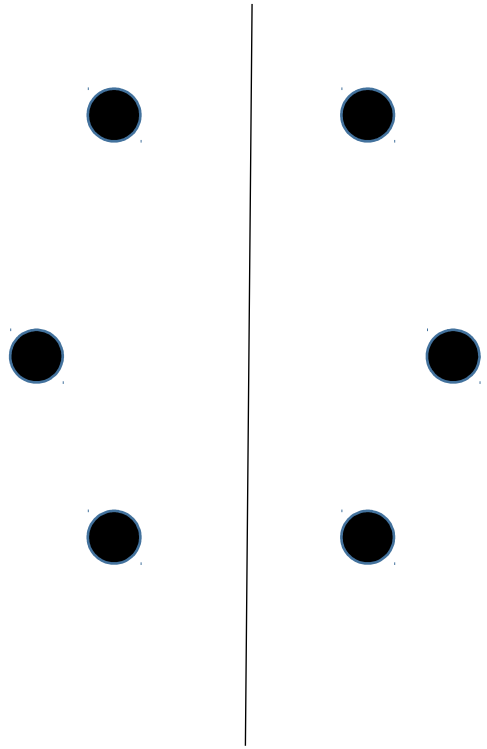
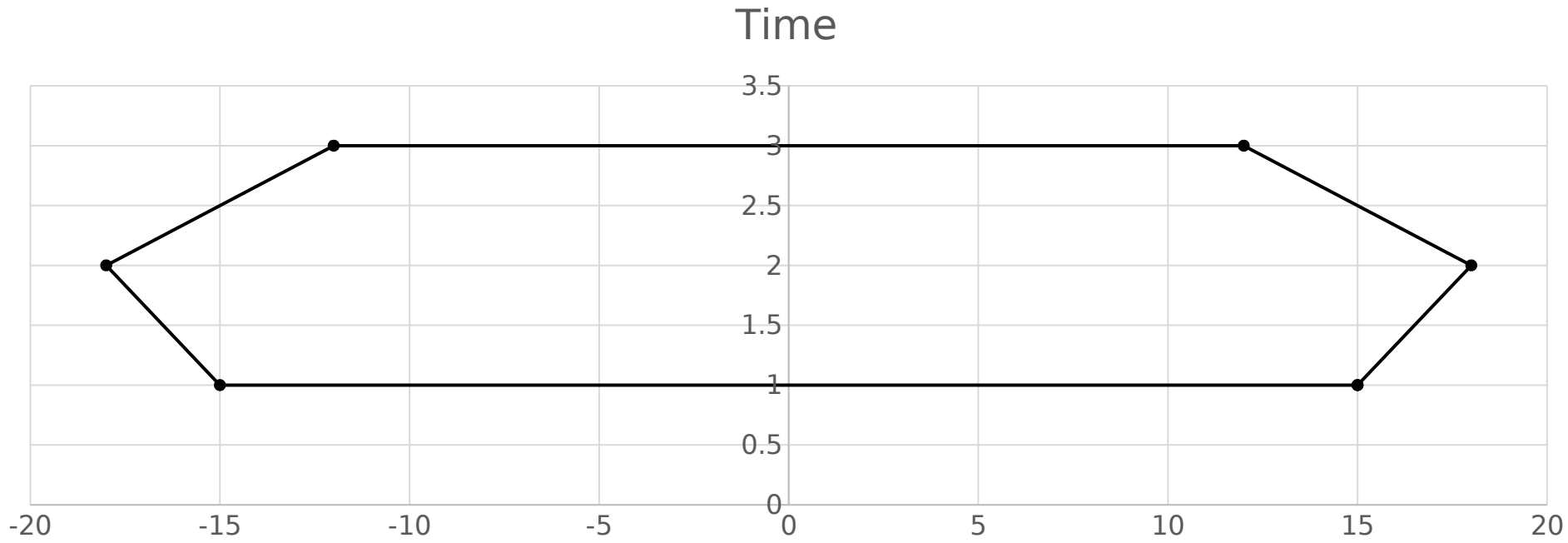




System Design

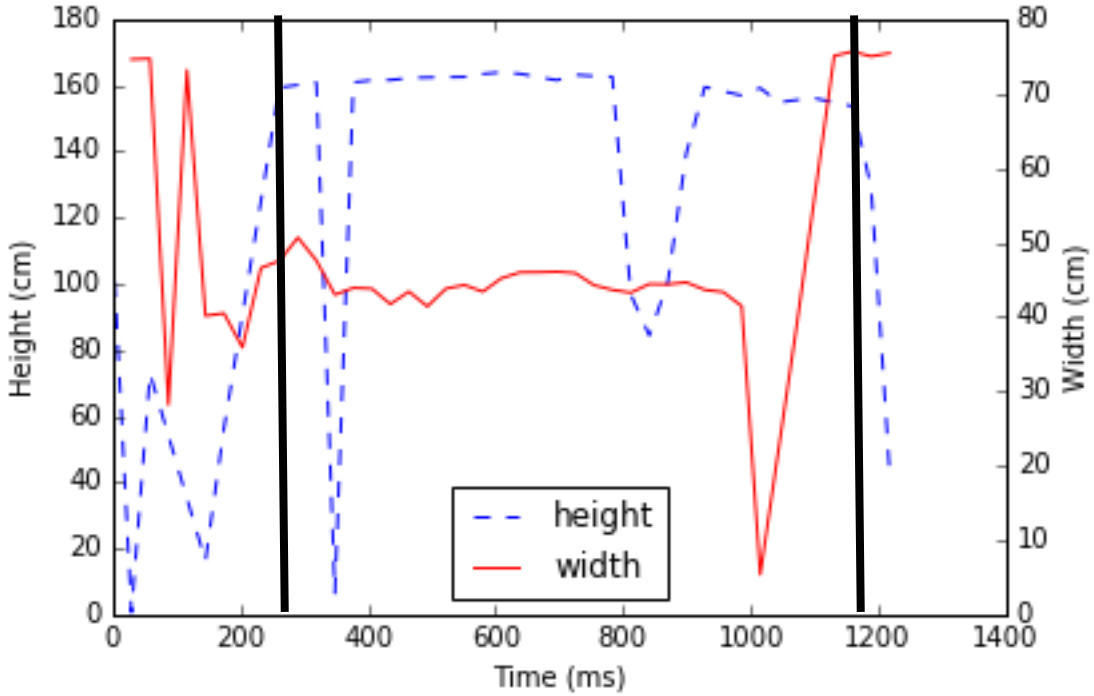
How is Girth Computed?



We calculate perimeter of convex hull

System Design

Feature Extraction



Feature	Value
Mean height	156.1
Maximum Height	163.8
Mean Width	39.5
Maximum Width	42.1
Girth	83.1
Hand-waist Distance	13.2
Bounce	19.7

Example showing sensor data and features computed

System Design
Decision Making

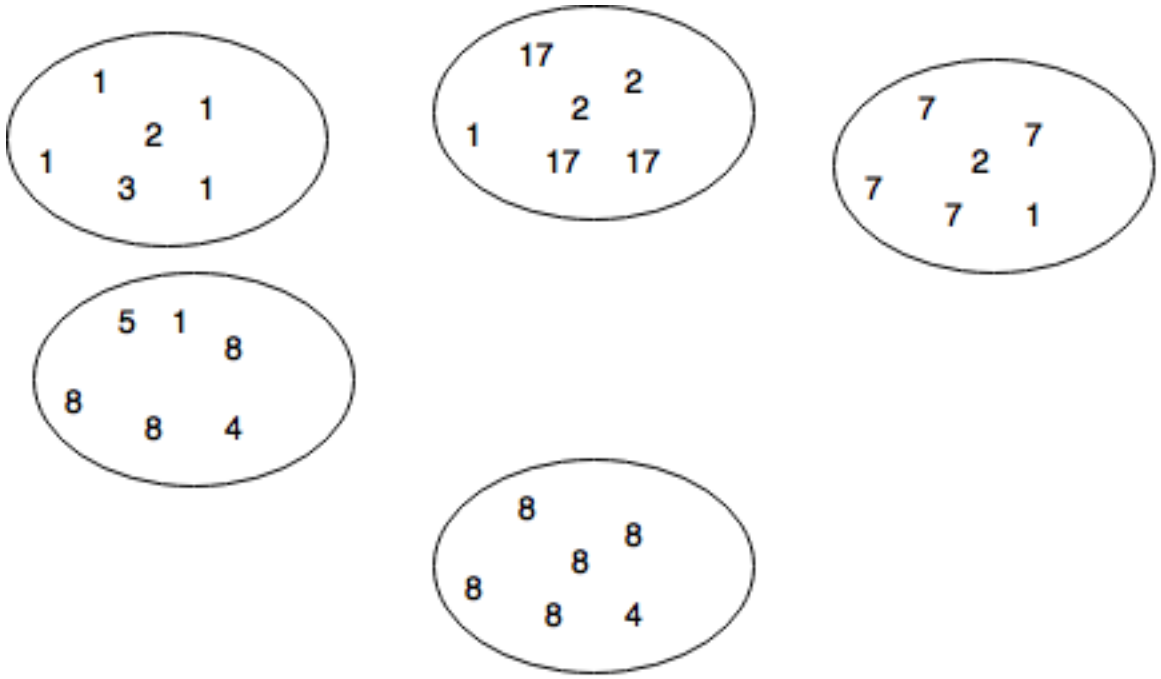
- Anonymous ID => Clustering problem

- Used DBSCAN as clustering algorithm
  - Does not know clusters beforehand
  - Takes into consideration precision of sensors

- We allow multiple clusters per person

System Design

Decision Making



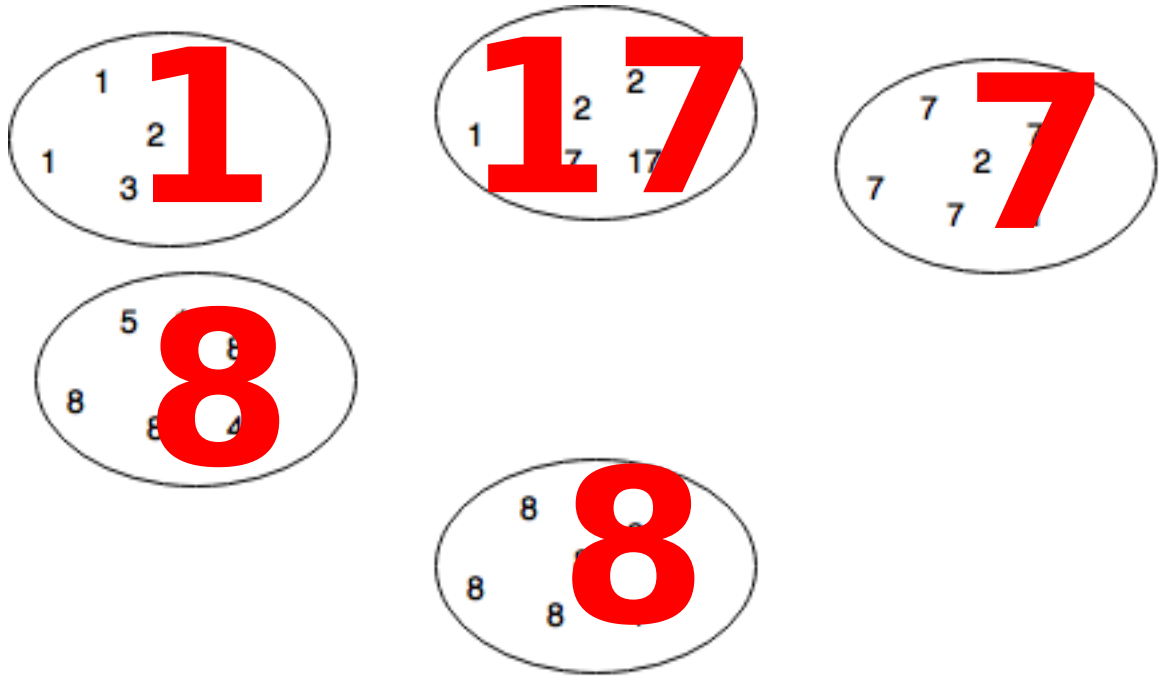
System Design

Decision Making

- We label a cluster with the most frequently occurring person
- Accuracy= $\frac{TP+TN}{TP+FN+FP+TN}$

System Design

Decision Making



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Evaluation
Experiment Design

- Deployed a doorframe for one month
- 20 users participated
  - 53 people participated. We only selected the top 20 that participated most
  - Average of 8 walks per person
  - Users were encouraged to walk naturally and carry bags if they have any
- Used camera for ground truth collection
- IRB approved protocol

University of Houston

Evaluation

Clustering With One Feature

Feature	Accuracy (%)
Girth	89.5
Bounce	88.7
Average Width	87.6
Average Height	84.3
Time	82.6
Body-hand Distance	76.9

Bounce is better than mean height

Evaluation

Clustering With Two Features

	Height	Width	Bounce	Time	Girth	Body-hand
Height	84.3	89.5	89.5	90.5	93.2	86.4
Width		87.6	90.5	91.0	**93.7**	87.2
Bounce			88.1	87.6	**94.7**	89.4
Time				82.6	**95.4**	85.2
Girth					89.5	90.3
Body-hand						76.9

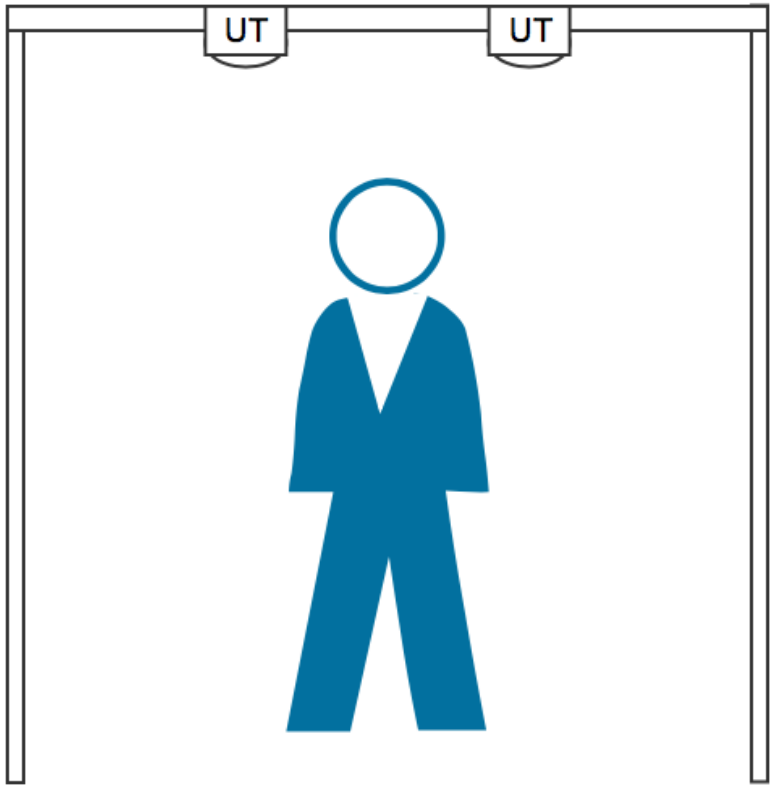
The best clustering result did not use height

Evaluation

Accuracy for Different Numbers of Occupants

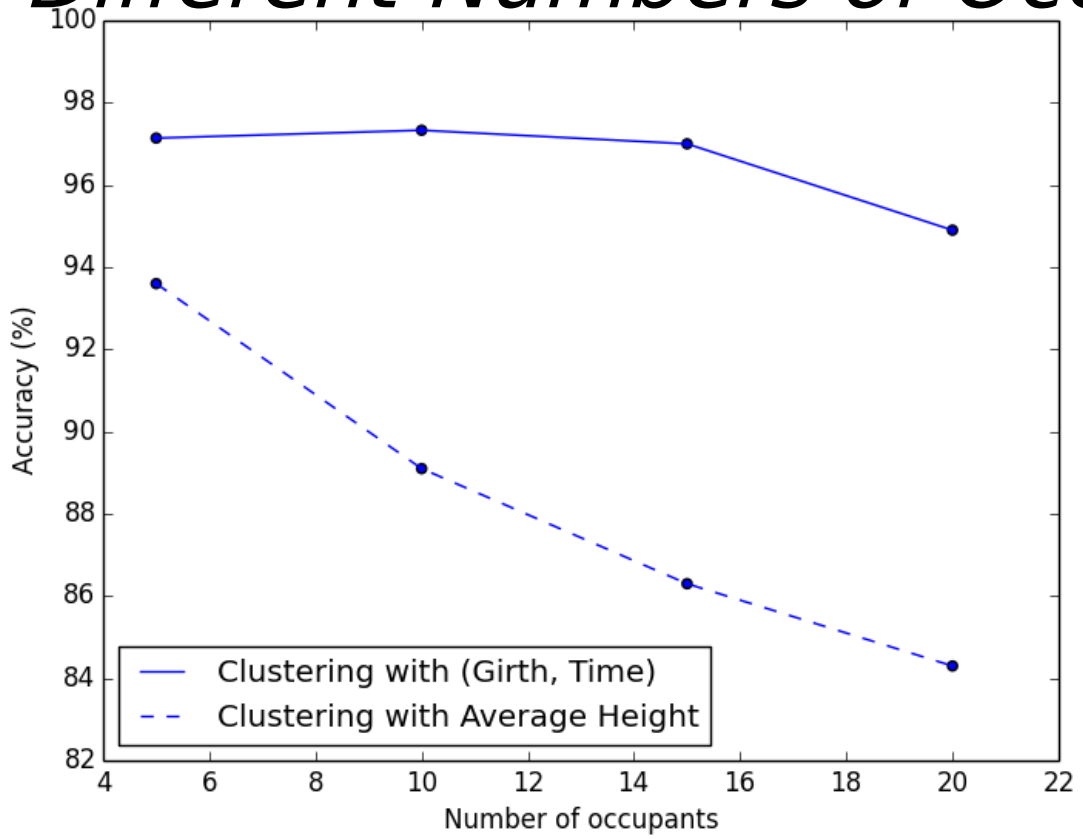
- We compare our method to Doorjamb [Sensys'12]

- Doorjamb
  - Two sensors to sense heig
  - Use height as ID



Evaluation

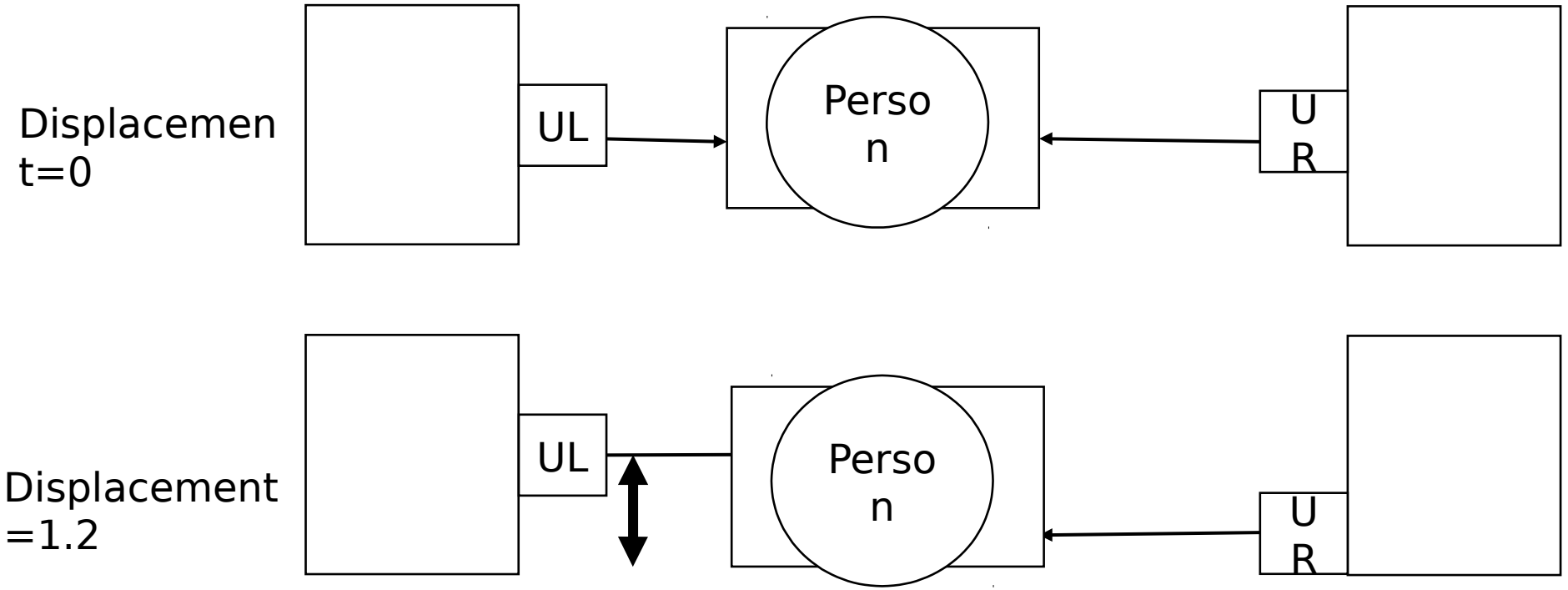
Accuracy for Different Numbers of Occupants



Accuracy is consistently higher across the entire range

Evaluation

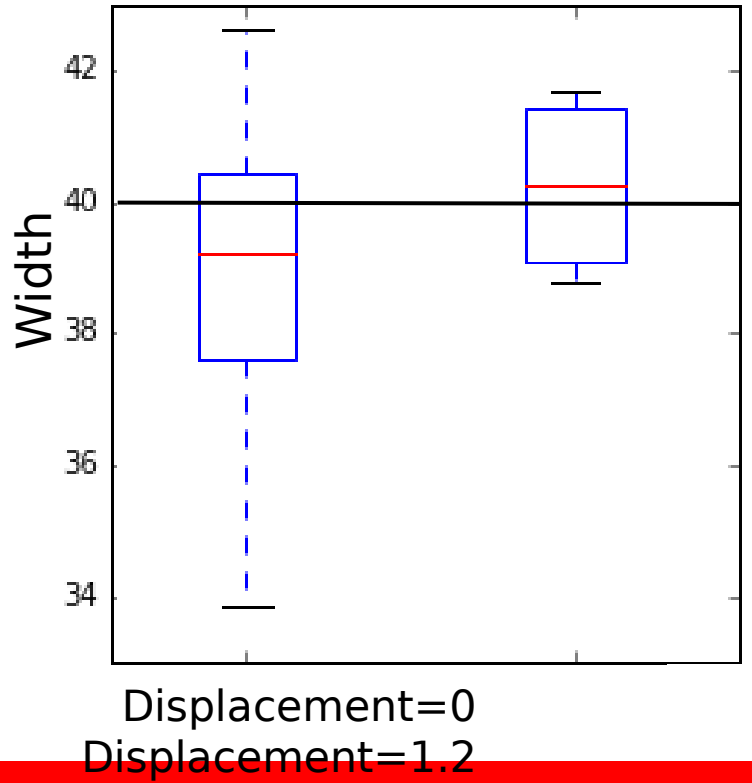
Evaluating Width Measurement Accuracy



Does displacing UL and UR increase accuracy?

Evaluation

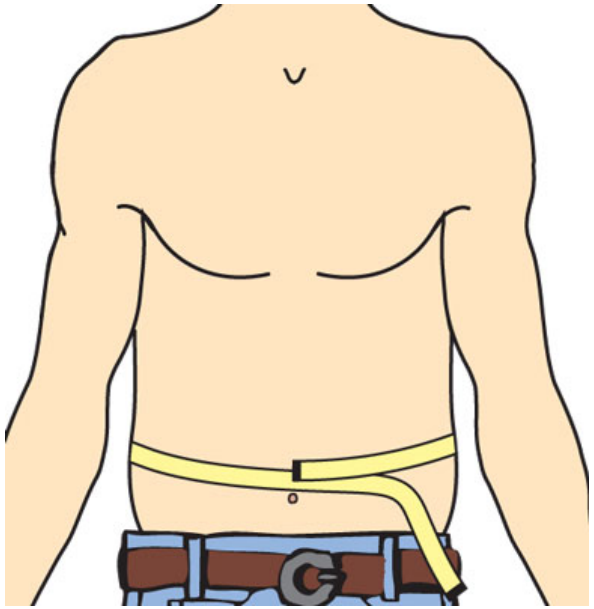
Evaluating Width Measurement Accuracy



For better width measurement, displace UR and UL

Evaluation

Resilience of Girth Measurement Vs. Width



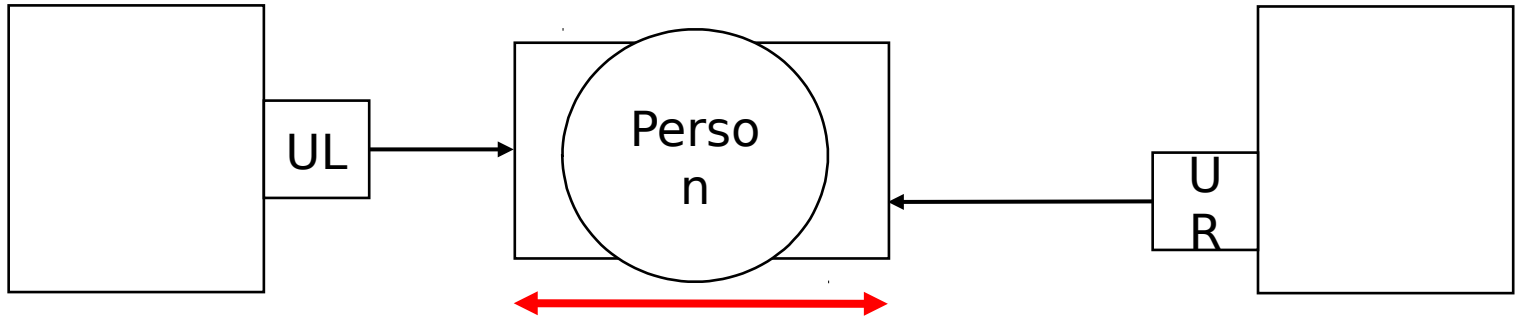
Is girth measurement affected by how one walks?

Source: http://

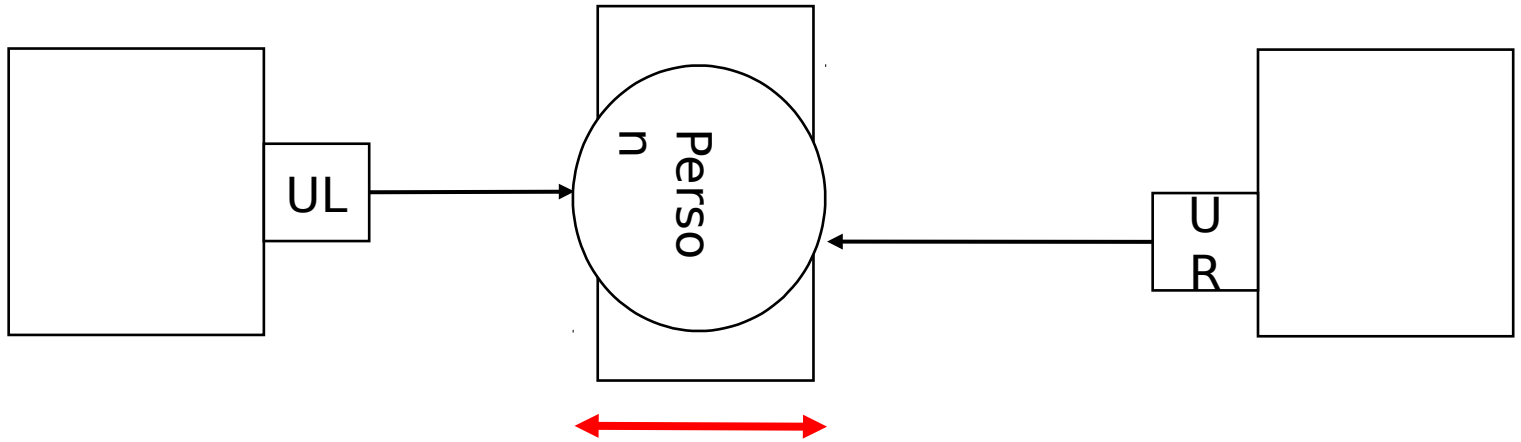
Evaluation

Is Width Resilient to Direction?

Walking
Parallel
Angle: 0



Walking
Perpendicular
Angle: 90

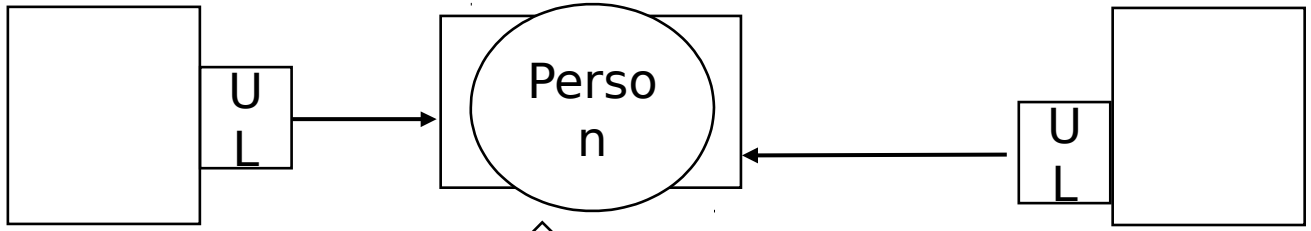


Measured width varies with direction

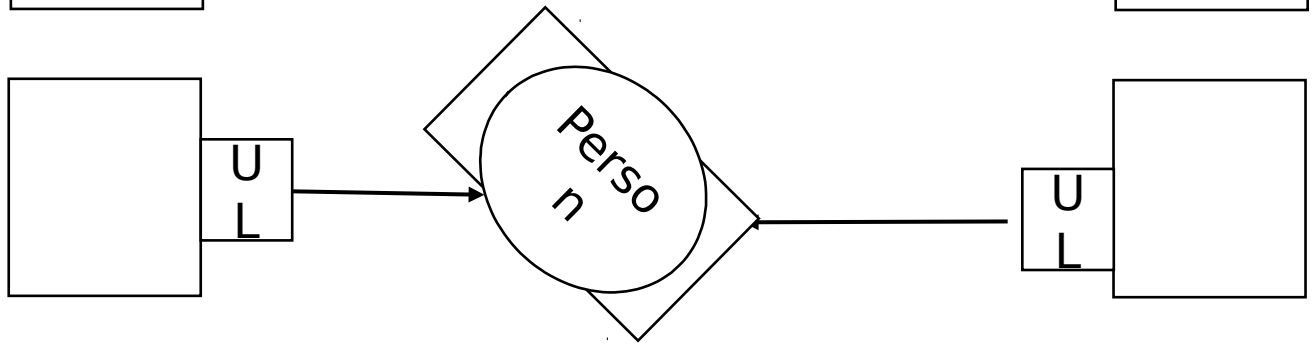
Evaluation

Is Girth Resilient to Direction?

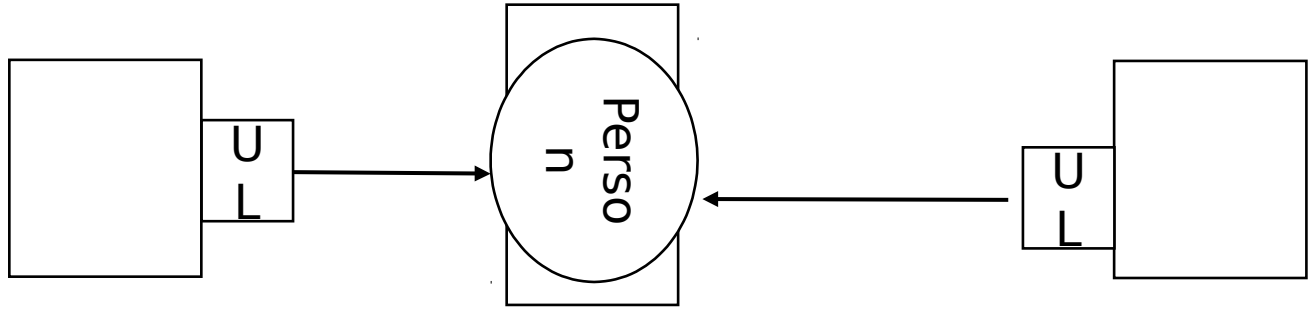
Walking
Parallel
Angle: 0



Walking
Perpendicular
Angle: 45

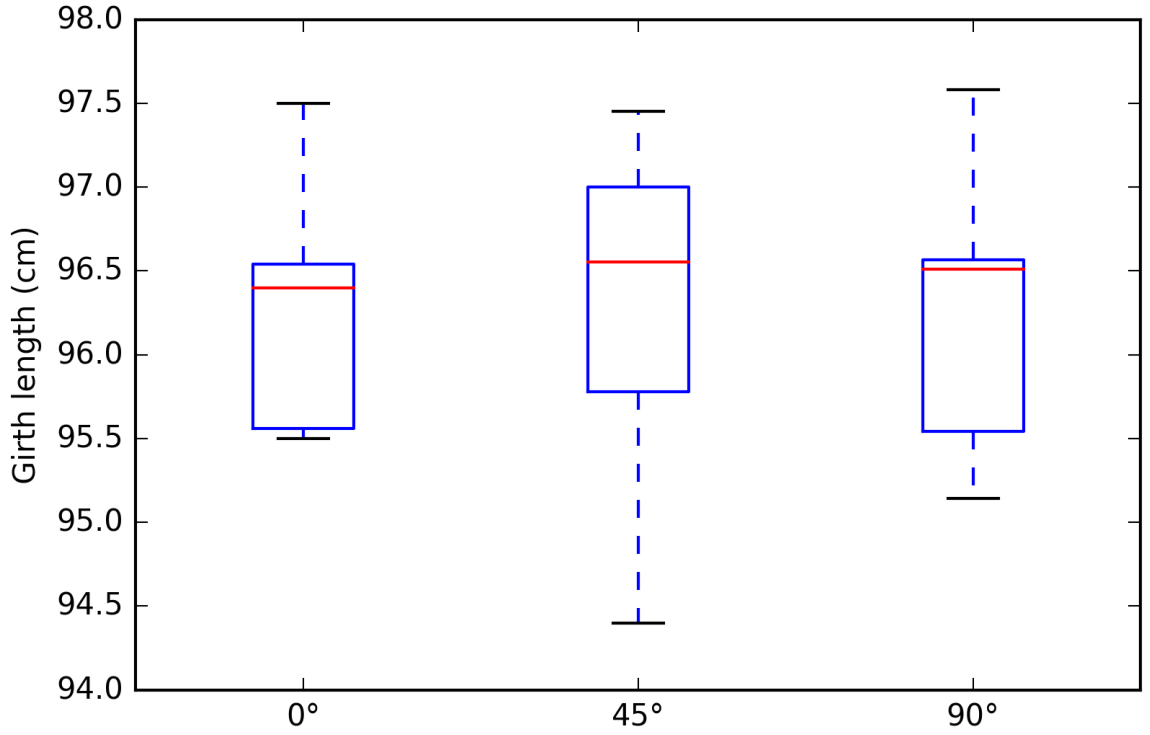


Walking
Perpendicular
Angle: 90



Evaluation

Girth measurement Evaluation



Girth is resilient to walker's direction and stable

Evaluation
Other Results

- For identification, bounce is better than height

- Walking direction detection is 100% accurate at less than 5km/h and 90% at ~10km/h

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Conclusion

- We designed a system that identifies occupants by sensing body shape and movement from height and width measurement

- Our System is able to identify up to 20 occupants with an accuracy of 95%, 5x improvement