Monitoring Building Door Events using Barometer Sensor in Smartphones

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Order

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- Related Work
- Methods
- Observations
- Analysis
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- Discussion
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Introduction

- Typical security systems use installed electrical circuits to detect opening/closing
  - High cost
  - Infrastructure integration
  - Undesirable for simple monitoring
- Application of barometer sensing in existing smart phones
  - Leverage the use of current phone sensors
  - Door events, occupancy, traffic patterns
- Contingent upon the use of HVAC
  - Maintains temperature and building pressure
  - Differences between indoor and outdoor environment
  - Door openings cause sharp change in pressure

Proposed Advantages

- Pressure change can be observed anywhere
  - Insulated buildings allow for even isolated detection
- Pressure variations can be distinguished
  - Door variations produce different patterns
- Barometer readings can detect user mobility
  - Altitude variations, user behaviors

- Provide a low cost ubiquitous building monitoring system
  - Trigger a direct notification
  - Augment existing system robustness

Related Work

- HVAC
  - Pressure sensors with HVAC to detect pressure variations
- Phone sensor
  - Aiding GPS altitude calculations
  - Floor changes with near 100% accuracy
  - Group movements across different floors
  - Better than accelerometer performance for vertical activities
  - Recognize idle, walking or vehicle use with low power consumption
- Improved sensor monitoring solutions
  - Vibration sensors attached to doors
  - Commercial infrasound detection systems

Related Work

- Pressure Tracker
  - 5 min samples
  - 7 day collection
  - PSI measurements
  - CSV output

UMBC Commute

Walk to class

4th floor class

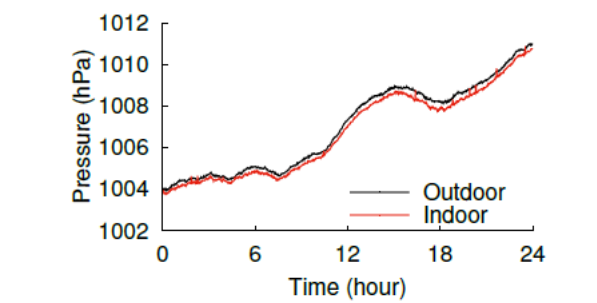
Home pressure

Methods

- Upon door use:
  - Sudden increase in indoor pressure
  - When closed HVAC system restores desired pressure
  - Pressure difference is test for 24 hours
- Smartphone barometers
  - Two Google Nexus 5
  - Bosch BMP280 barometer sensors
  - AndroSensor App used for sampling at 20 Hz
- Machine Learning classifier
  - Weka Naïve Bayes classifier
  - Separate classifier for each building

Observations

- Initial testing of various characteristics of sensor based detection
- Results from one university building
  - 2 floors
  - 4 doors, 1 manual 2-4 automatic
- Two phones recorded pressure for 24 hours
  - Same elevation 1 meter separation by glass wall

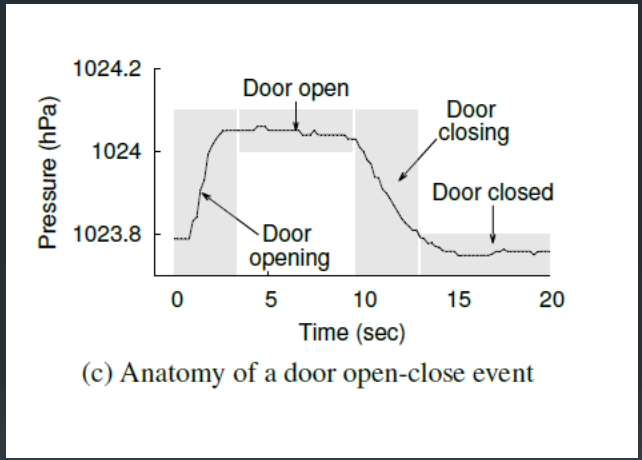


(a) Pressure difference between indoor and outdoor at same altitude

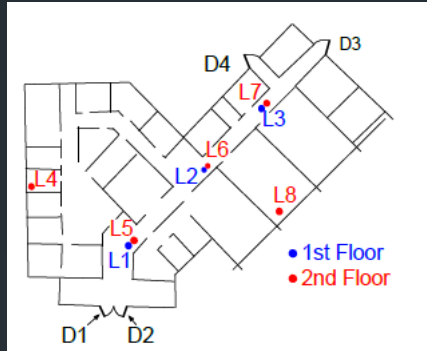
  - Constant 0.25 hPa average difference

Observation 1

- Smartphone barometer sensor can detect door events
  - One phone on the floor at L1
  - Phone accelerometer attached to D2 provides precise timing



(c) Anatomy of a door open-close event

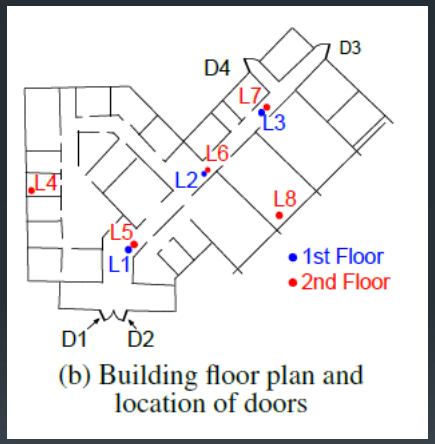


(b) Building floor plan and location of doors

- Pressure changes observed for the duration of door events

Observation 2

- Door events can be detected anywhere within the building
  - Phone placed in 8 different locations
  - Locations on both floors
  - Closed offices and open corridors



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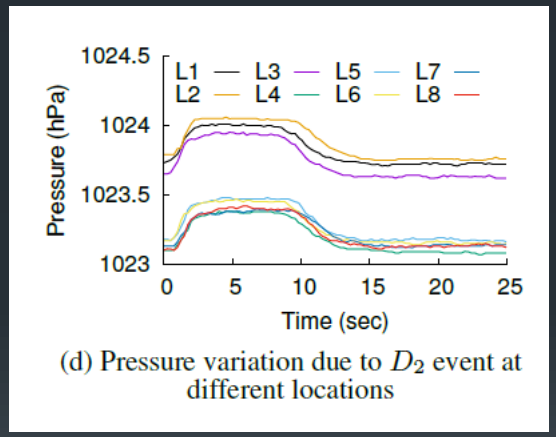
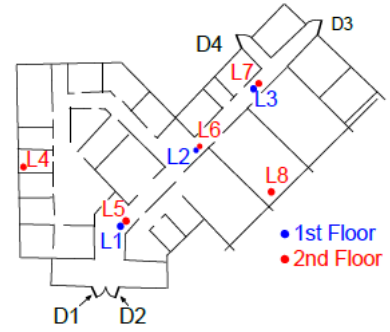


(d) Pressure variation due to D_2 event at different locations

- Observe D2 events at all locations
  - Pressure variation identical for all locations
  - Baseline pressure difference from elevation

Observation 3

- Pressure variations depends on the type of door
  - Pressure readings at L2 for D1-D4
  - D1 manual D2-4 automatic



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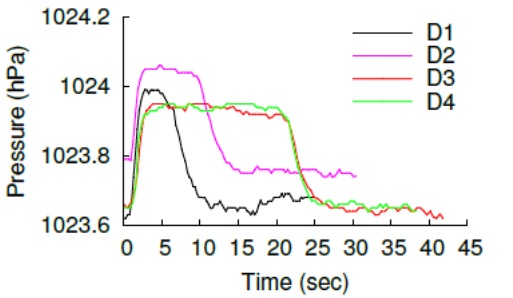
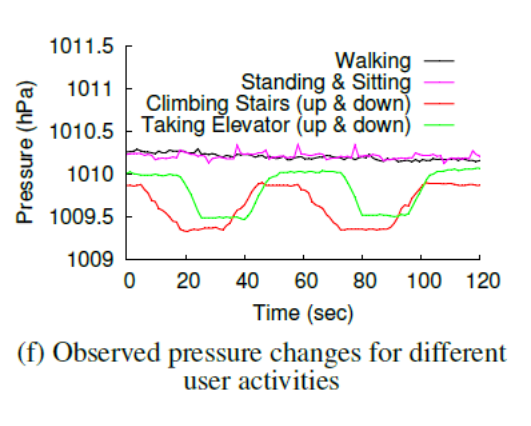


(e) Pressure variation due to opening different doors at location L_2

- Pressure variation patterns allows for door distinction
  - Identical D3 D4 produce identical changes
  - D1 and D2 produce different changes

Observation 4

- User mobility is distinguishable from door events
  - Common indoor activities from users with phone in pocket
- Standing, sitting and walking
  - Minor pressure/ altitude changes



(f) Observed pressure changes for different user activities

- Stairs and Elevator
  - Pressure variation similar to door events
  - Rate of change slower than doors

Analysis

- Data collected from 3 university buildings

	Building-1	Building-2	Building-3
No. of Doors	6	4	4
No. of Floors	3	2	2
No. of Rooms	80	76	23
Area (sq.ft.)	43, 930	47, 823	11, 326

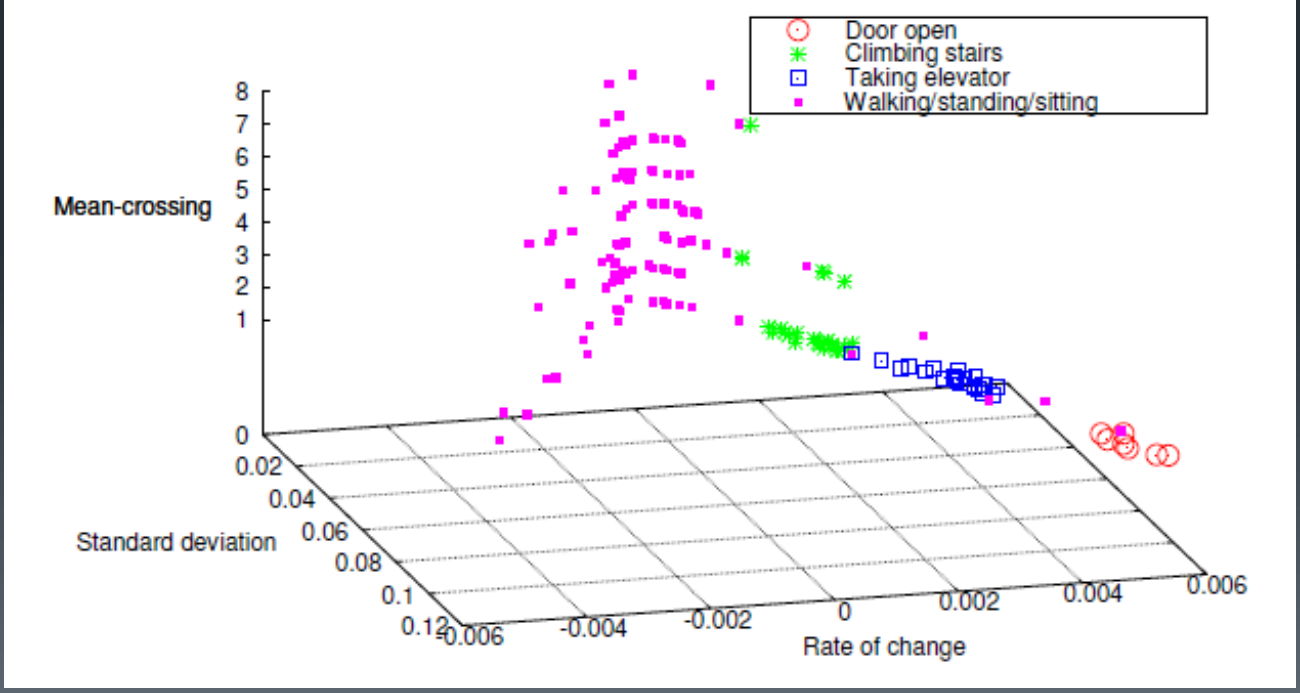
  - Building 1 observed people entering/ exiting
  - Two participants used own phones for building 2 and 3
  - Opening and closing doors
  - Moved freely, taking stairs or elevators
- Manually recorded door events for ground truth
  - 30-50 door events
- Train and evaluate machine learning classifier
  - Sliding window
  - Rate of change, mean crossing, standard-deviation

Evaluation

- Sliding Window approach
  - 3 seconds to accommodate complete door openings
- Rate of change
  - Rate of pressure change within the window
  - Walking/ sitting results in lower changes
- Mean-crossing
  - Counts number of sudden pressure variations
  - Uses mean pressure of window (crossing values close to 1)
  - Distinguish door events from stair/ elevator events
- Standard-Deviation
  - Variation of the mean pressure
  - Detection of same floor activities

Feature Recognition

- Recognition of activities with 3 features
  - Sufficient to classify user activities and events
  - Rate of pressure change distinguishes door events
- Continuous detection calculated every half second for pressure readings of past 3 seconds



Evaluation Accuracy

- Weka Naïve Bayes classifier used
  - Simplicity of feature space
  - Classifier built for each building
- Door event accuracy ranged from 99.34-99.81%
  - Strictly examined door events only

	TP Rate	FP Rate
Building-1	99.81 %	0.19 %
Building-2	99.34 %	0.66 %
Building-3	99.73 %	0.27 %

Table 2: TP and FP rates of binary classification (door opening or not) for 3 buildings

Evaluation Accuracy

- Door event accuracy expanded
  - 4 class classification
  - Door event, stairs, elevator, walking sitting/ standing

Event/activity	TP Rate	FP Rate
Door opening	100 %	0 %
Climbing stairs	93.6 %	1.8 %
Taking evevator	87.0 %	0.3 %
Walking/sitting/standing	97.8 %	3.9 %

Table 3: TP and FP rates of 4-class classification for Building-3

- TP rate for door events reaches 100%
  - Distinct from other events
  - Stairs and elevators easily misclassified
  - Less distinct from door events

Discussion

- Door events can be detected accurately anywhere within the building
  - Pressure difference instead of absolute values
  - Applicable regardless of location
  - Can be classified for individual buildings
- Rates of change in pressure distinguish other events
  - Stair and elevator events produce slower rates of change
  - Can still be misclassified
- Standard deviation improves same floor activities
  - Captures variation around mean pressure

Limitations

- HVAC is required for pressure differentials
  - Detection accuracy depends on HVAC
- Open/Close events depends on pressure recovery
  - Detection can fail during sustained opening
- Building construction variations
  - Room systems, lack of systems, windows

Limitations Cont.

- Stairs and Elevator events easily confused
  - 2-3 stories compared to 10+?
- Only one type of smartphone
  - Sensors have constant difference in readings
  - Half second readings
- Building 1 observations recorded externally
  - People entering/exiting were observed

Future Work

- Expand the testing conditions
  - Various real world settings: windows, timing, HVAC
  - Real world door situations: 300 person lecture ending
  - Double doors used to reduce HVAC recovery

Questions