G-Fall: Device-free and Training-free Fall Detection with Geophones

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Background

60+

>960 M
(9.6亿)

33%

60%

≈190 million(1.9亿) elders
fall at home each year

2.5% World Population

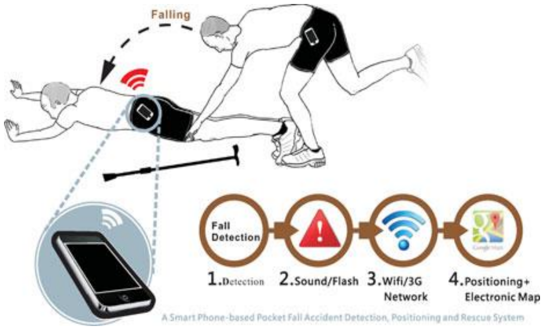
Existing Methods

Vision
- Kinect
- Camera

Darkness ×
NLOS ×
Privacy ×

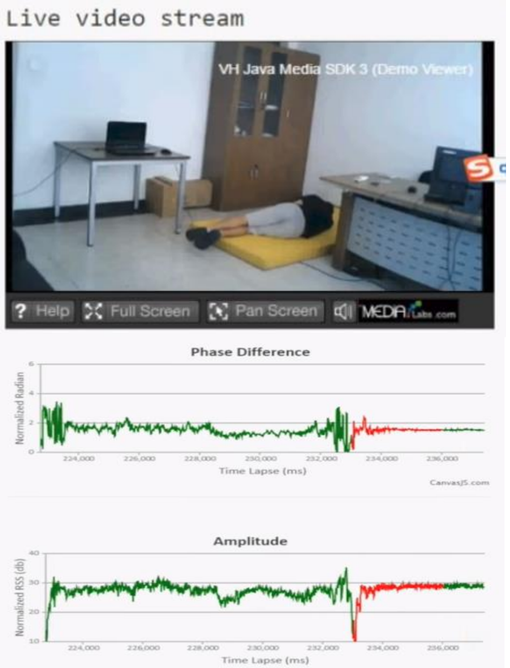
IMUs
- Gyroscope
- Accelerometer

Obtrusive ×
Forgetful ×



RF
- WiFi (CSI)

Training ×
False-alarm ×



Related Work

Accelerometer (SRS) + Microphone (MFCC)

Bayes Classifier

Dataset:

40 drops of human mimicking doll (74 kg)

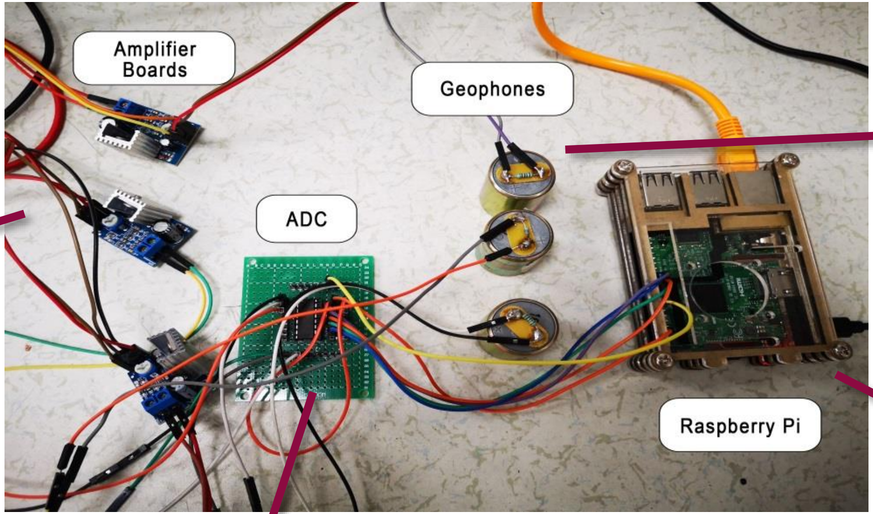
76 drops of objects and other events.

Yaniv Zigel, Dima Livak and Israel Gannot. “A Method for Automatic Fall Detection of Elderly People Using Floor Vibrations and Sound–Proof of Concept on Human Mimicking Doll Falls”, IEEE Transactions on Biomedical Engineering, vol. 56, no. 12, 2009

Prototype

G-Fall Prototype

≈ ¥300 ($45)



TDA2030A Amplifiers

LGT-20D Geophones

MCP-3008
8-channel 10-bit ADC

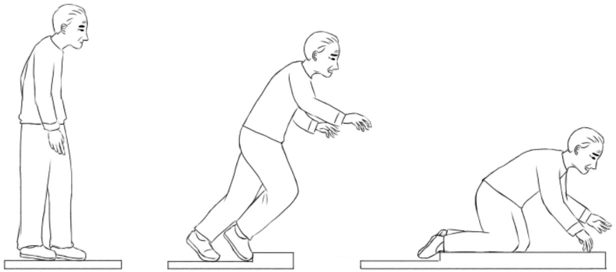
Raspberry Pi 3B

Preliminary study

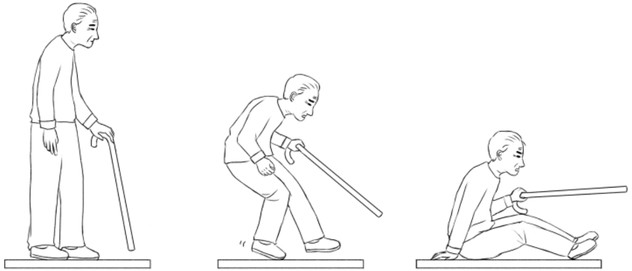
i) Physical lesions incur the uncoordinated walking or faint

ii) falling over the obstacles due to poor vision

iii) losing balance on a slippery floor such as in a bathroom



Fall



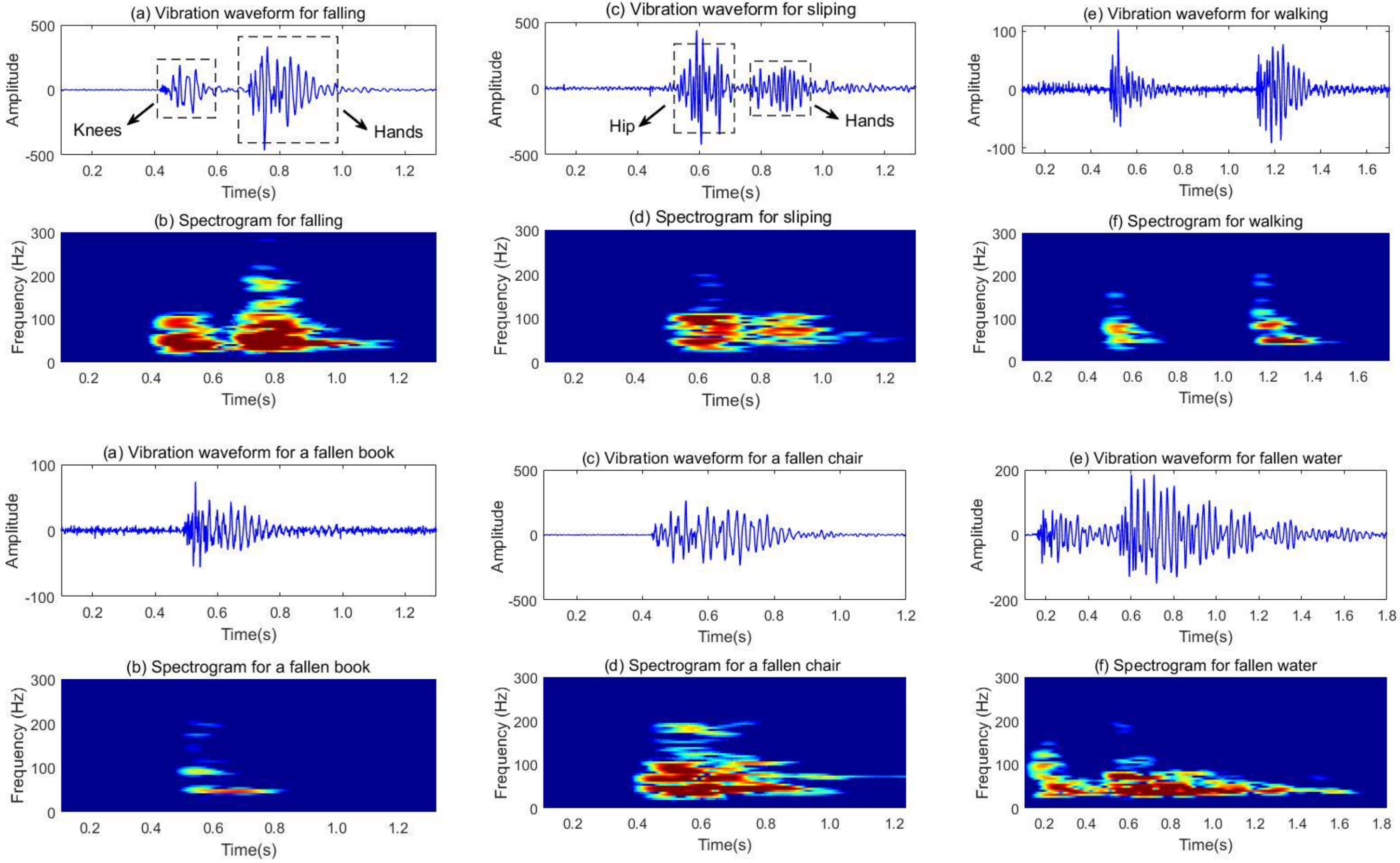
slip

Preliminary study

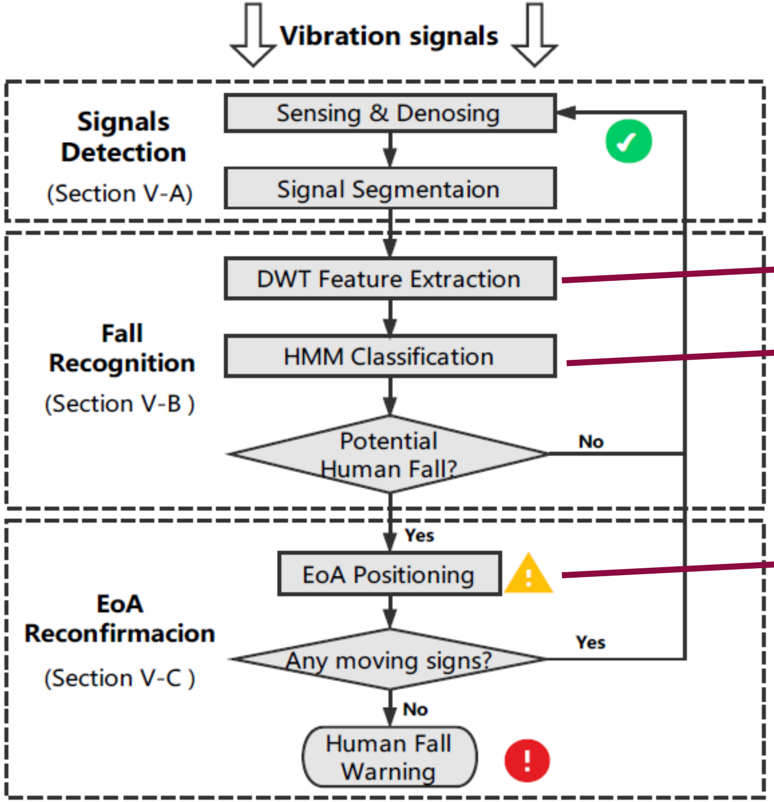
Body-induced

Transition state

Object-induced



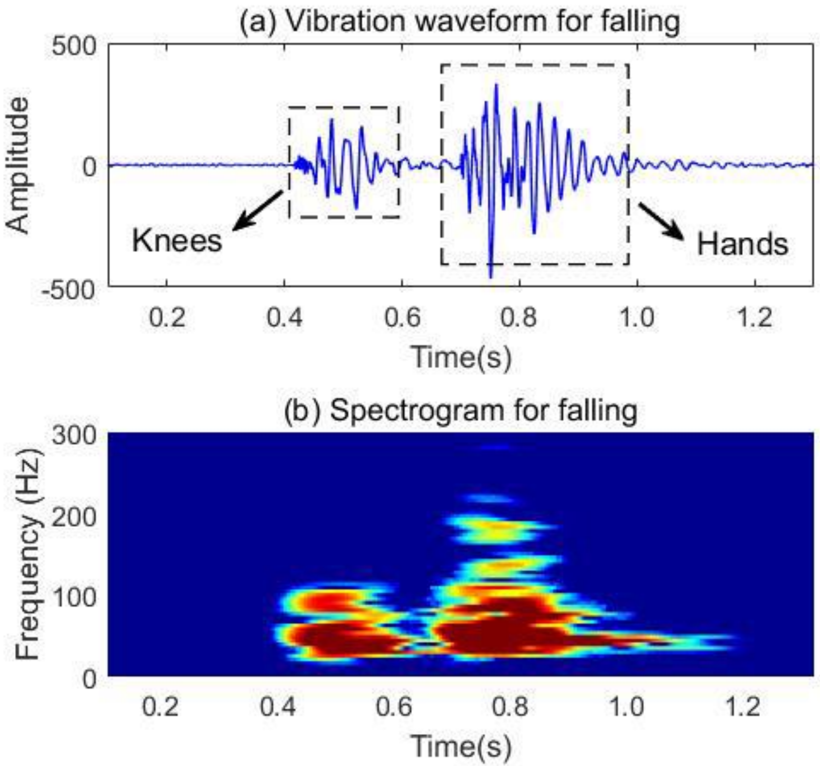
Our approach



Discrete Wavelet Transform (**DWT**)

Hidden Markov Model (**HMM**)

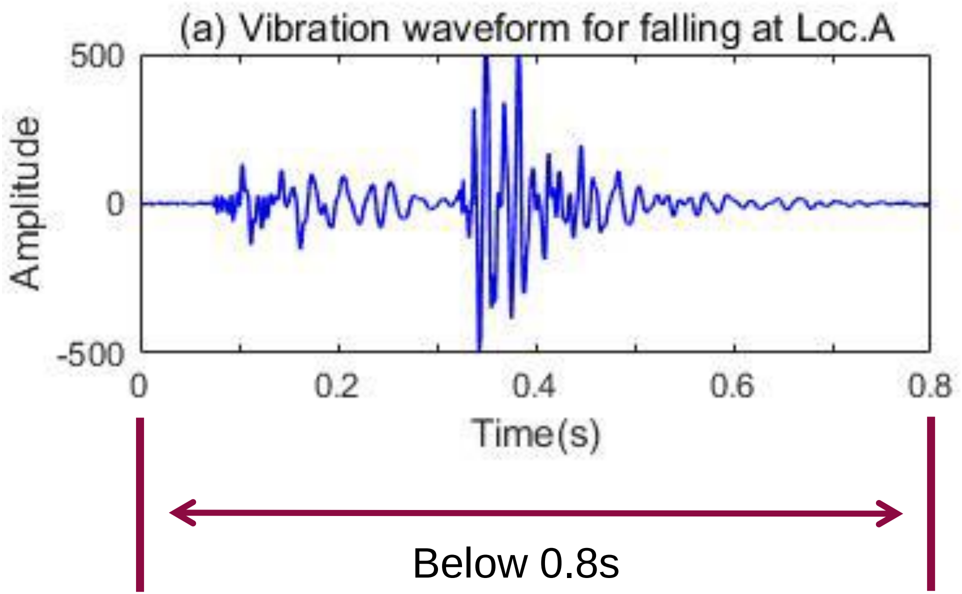
Energy-of-Arrivial Positioning (**EoA**)



Main components
below 300Hz

Sample rate
1190Hz

Denoising
20Hz High-pass butterworth filter

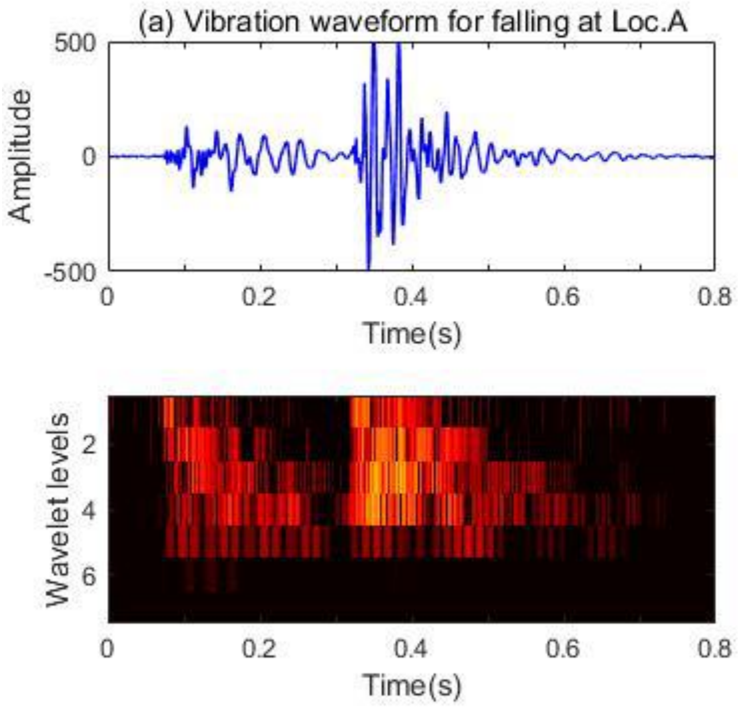


Energy-based detection start point

$$E(t) = \sum_{i=t}^{t+L} s^2(i)$$

L: the length of the sliding time window

s(i): the amplitude of the received vibration signals



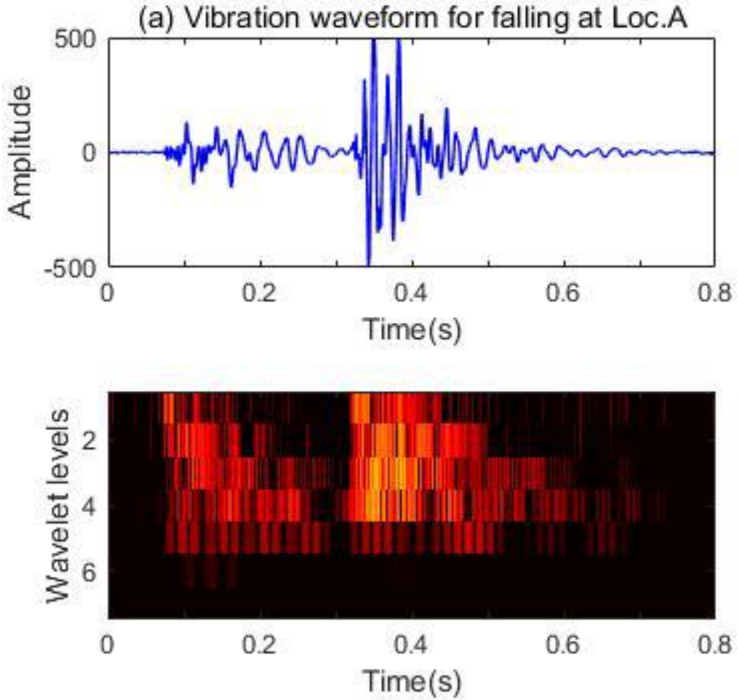
Discrete Wavelet Transform (DWT)

i) DWT performs a nice tradeoff between time and frequency resolution

ii) DWT reduces the size of the input sample

Details:

We calculate the energies for 8 levels using Daubechies wavelet in the order of 6 and extracts a 100-dimensional feature vector.



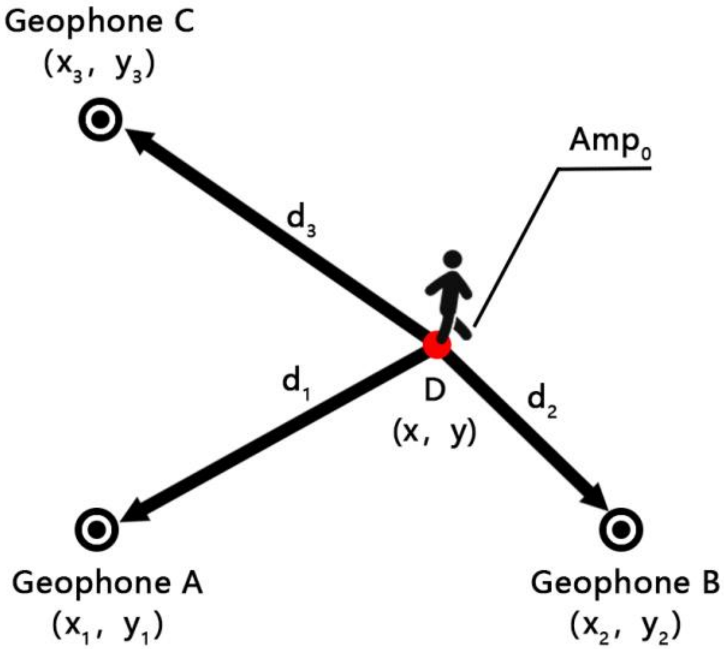
Hidden Markov Model (HMM)

$$\lambda \doteq (A, B, \pi)$$

A: transition probability matrix
B: emission probability matrix
π: initial state vector

Training： Baum-Welch Algorithm

Energy-of-Arrivial (EoA) Localization algorithm



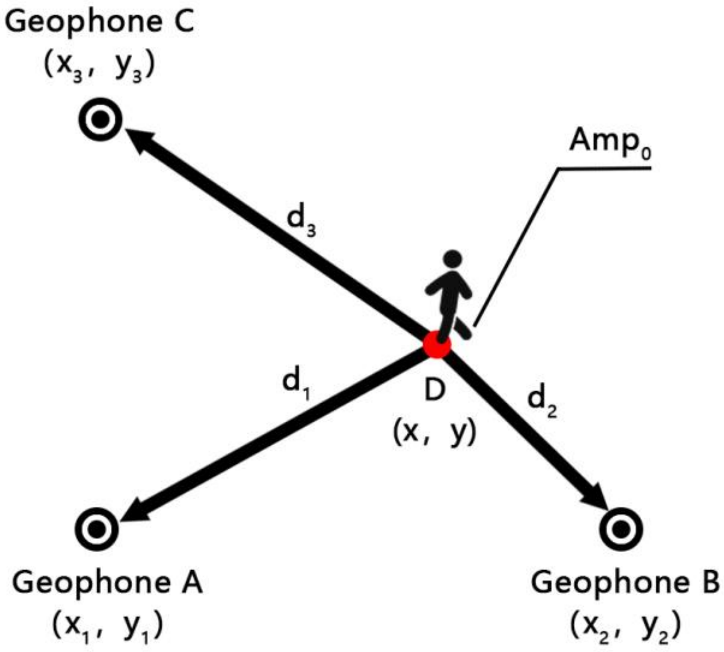
Time Difference of Arrival (TDoA)

- Estimation of accurate time difference
- High sample frequency (65kHz)
- Estimation of signals propagate velocity
- Trouble by Dispersion nature

Energy-of-Arrivial (EoA)

- Estimation of energy of arrival
- Low sample frequency (1190Hz)

Energy-of-Arrivial (EoA) Localization algorithm



Attenuation Model:

$$Amp(d) = Amp_0 e^{-\alpha \times d}$$

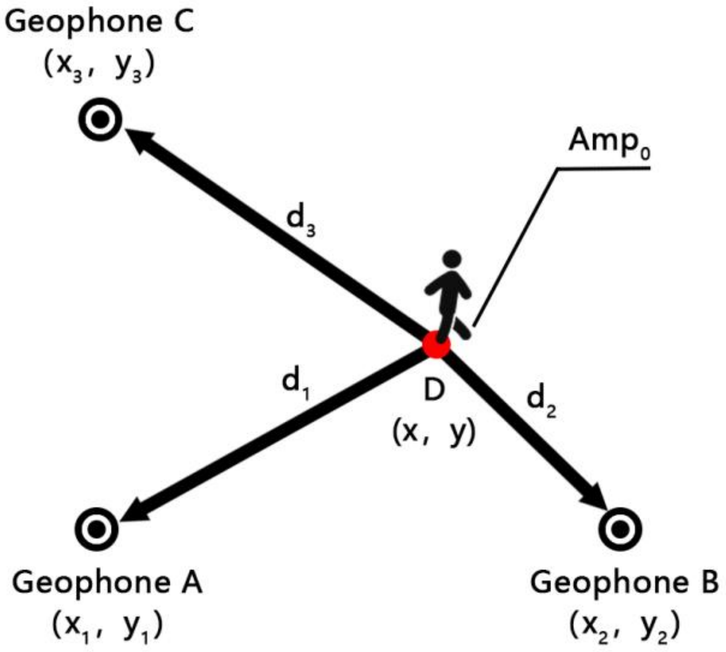
Amp_0 : the initial amplitude
d : the propagation distance
α : the attenuation coefficient
Amp(d) : arrival of amplitude from d

$$A(d_1) = Amp_0 e^{-\alpha \times d_1}$$

$$B(d_2) = Amp_0 e^{-\alpha \times d_2}$$

$$C(d_3) = Amp_0 e^{-\alpha \times d_3}$$

EoA Localization algorithm



$$A(d_1) = Amp_0 e^{-\alpha \times d_1}$$

$$B(d_2) = Amp_0 e^{-\alpha \times d_2}$$

$$C(d_3) = Amp_0 e^{-\alpha \times d_3}$$

Energy ratio:

$$E_{AB} = \frac{A^2(d_1)}{B^2(d_2)} = \left(\frac{Amp_0 e^{-\alpha \times d_1}}{Amp_0 e^{-\alpha \times d_2}}\right)^2 = e^{-2\alpha \times (d_1 - d_2)}$$

$$\left.\begin{aligned} d_1 - d_2 &= \frac{\ln E_{AB}}{-2\alpha} = c_1 \\ d_1 - d_3 &= \frac{\ln E_{AC}}{-2\alpha} = c_2 \end{aligned}\right\} \text{Hyperbola}$$

Evaluation——Setup

TABLE I
The height-weight-age table of the participants

No.	H(cm)	W(kg)	Age	No.	H(cm)	W(kg)	Age
1	178	58	19	7	168	58	21
2	179	57	20	8	181	68	22
3	170	60	26	9	168	58	21
4	177	66	27	10	156	48	20
5	165	61	29	11	168	52	20
6	168	55	20	12	182	59	21

Height(cm)	**Weight**(kg)	**Age**
[156， 182]	[48-68]	[19-29]

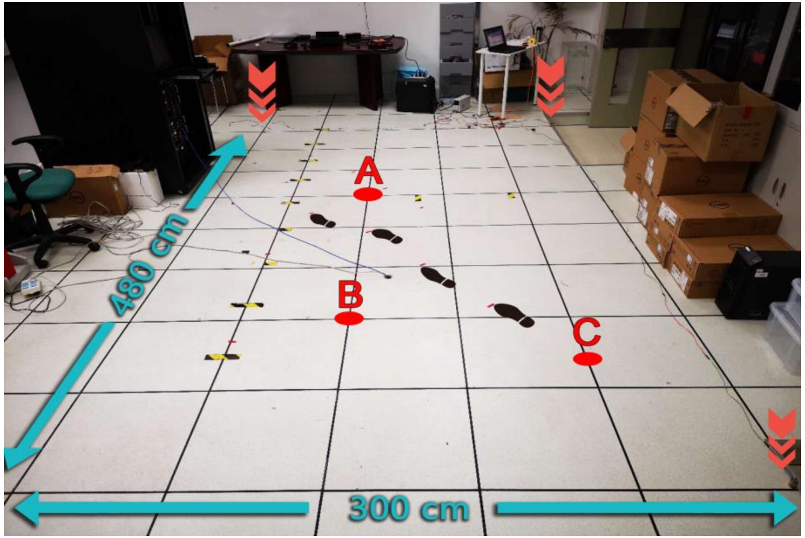


TABLE II
Description of actions for the data collection

Standard Fall	Loc.	Other Actions	Loc.
Trip forward	A	Sit	A
Trip forward	B	Mark time Heavily	A
Trip forward	C	Fall forward from a chair	A
Slip backward	A	Trip forward-Hold on a chair	A
Slip backward	B	Walk normally along the track	Track
Slip backward	C	Walk heavily along the track	Track

$$\text{Precision}=\frac{\#\text{ of truly detected fall}}{\#\text{ of human fall}}$$

$$P_{fls}=\frac{\#\text{ of wrongly detected fall}}{\#\text{ of other events}}$$

Evaluation——Exp1

- Baseline accuracy (one-person training set)

TABLE III
Baseline performance of G-Fall with one person in the training set

Event \ Class. As	Human Fall	Others	Total	Accuracy
Human Fall	495.45	54.55	550	90.08%
Sit	22.68	277.32	300	92.44%
Mark Time	64.05	235.95	300	78.65%
Normal Walk	54.81	1145.19	1200	95.43%
Heavy Walk	227.41	972.59	1200	81.05%
Objects	6.75	68.25	75	91.00%

Training set size enlarge from 5 to 20, the accuracy rise from 80.9% to 94.8%.

Evaluation——Exp1

- Baseline accuracy (one-person training set)

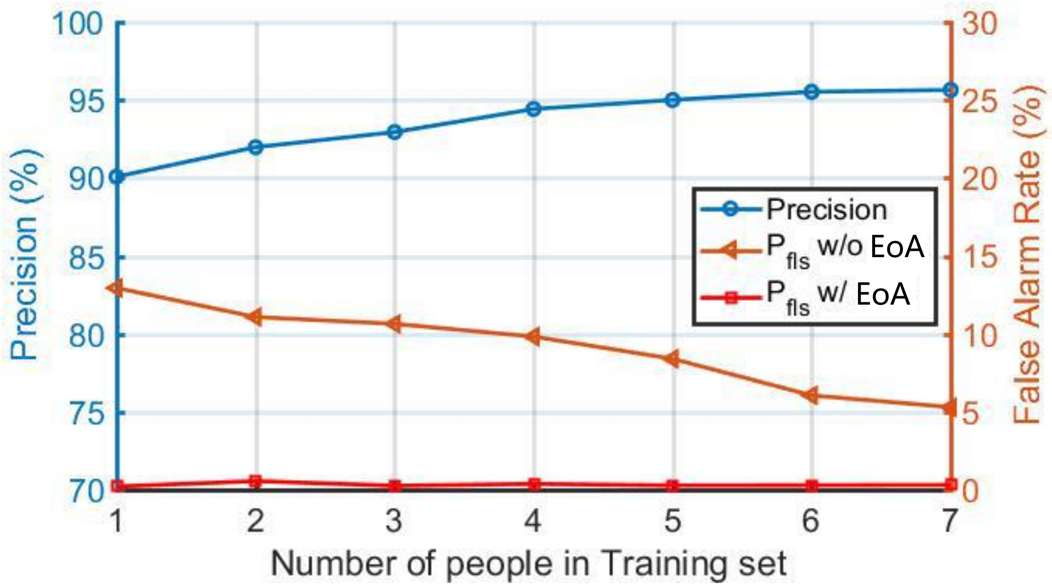
TABLE IV
Comparison of different classifier with one person in the training set

Items	HMM [29]	KNN [35]	SVM [36]	BPNN [37]
$Precision$	90.08%	83.21%	79.73%	82.08%
P_{fls}	12.30%	17.34%	12.55%	15.70%

HMM provide the best performance

Evaluation——Exp2

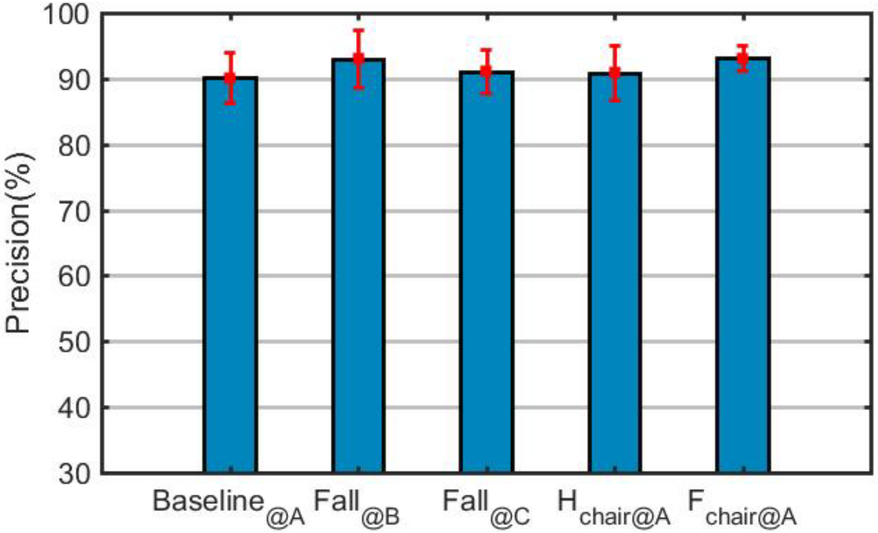
➢ Impact of training set size



Training set size enlarge from one-person to sevem-person,
the accuracy rise from 90.08% to 95.74%.

Evaluation——Exp3

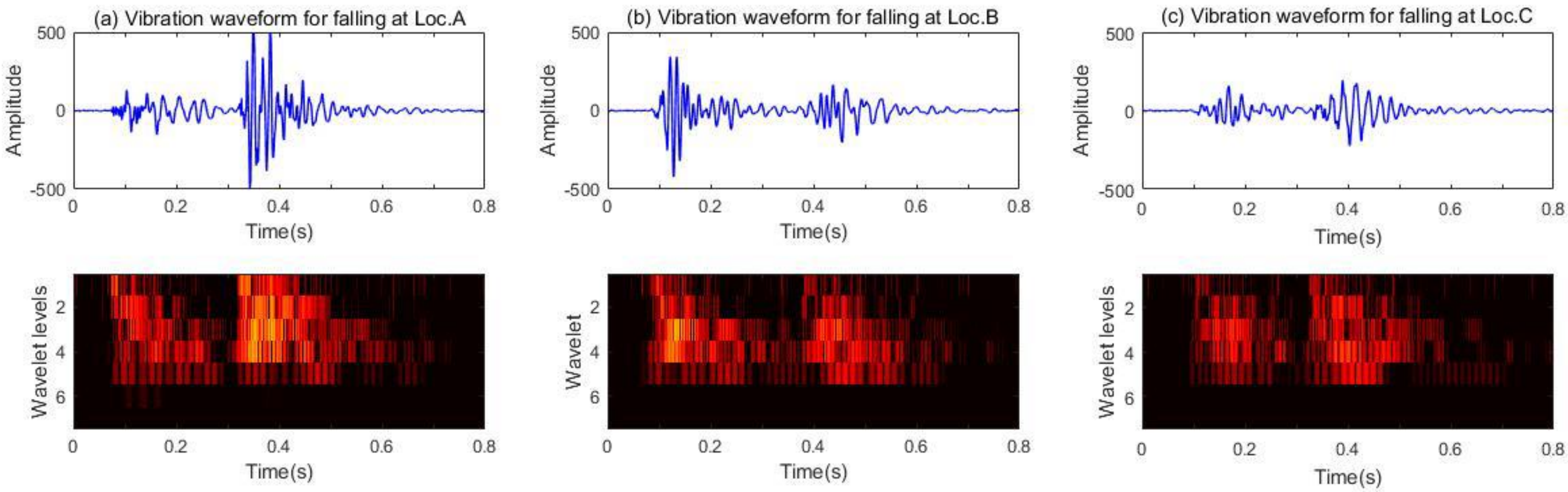
➢ Impact of different locations



Location independent

Evaluation——Exp3

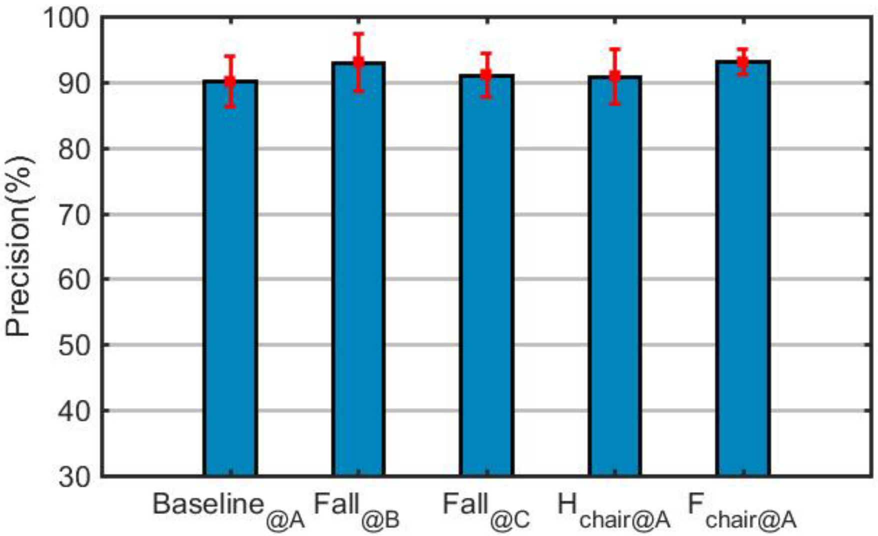
- Impact of different locations



Location independent

Evaluation——Exp4

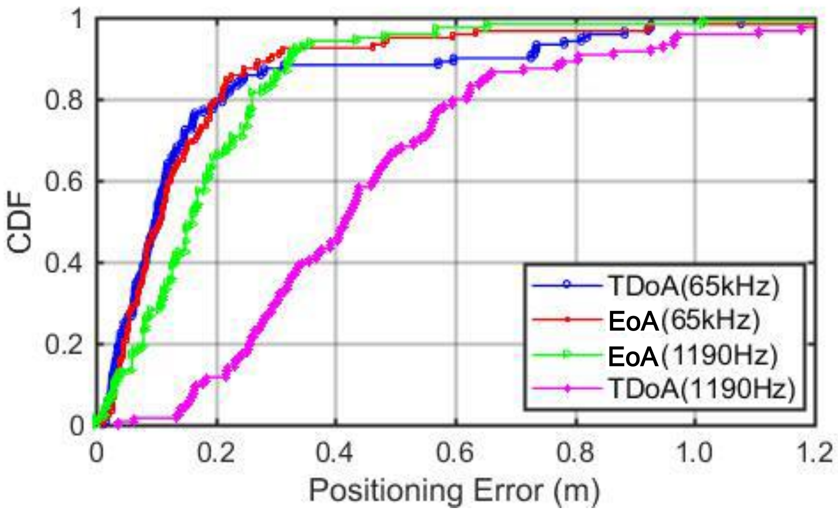
- Impact of non-standard fall

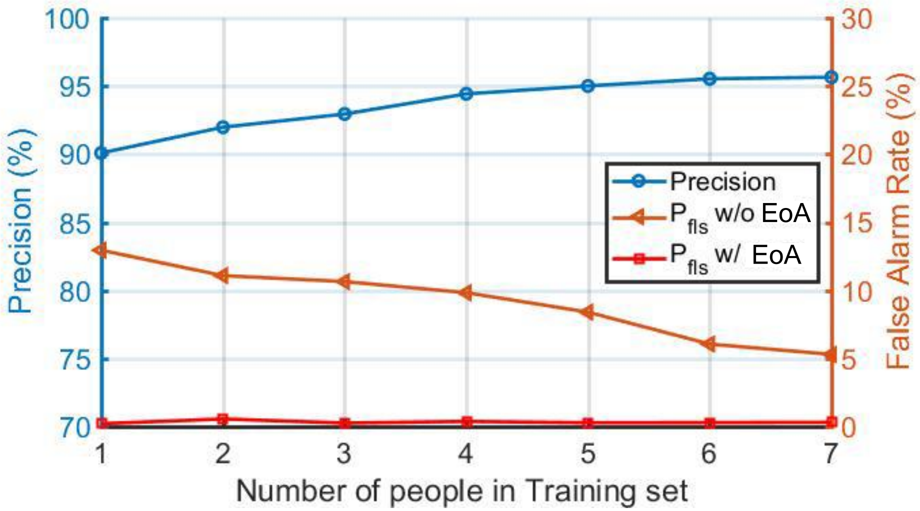


No impact when people perform non-standard fall

Evaluation——Exp5

➢ Effectiveness of EoA





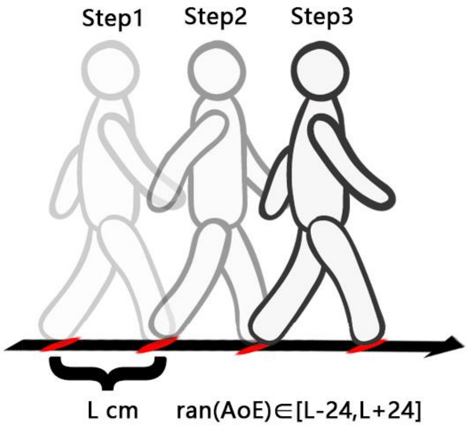
Smaller localization error, and reduce the false alarm to nearly 0%

Conclusion

- G-Fall is the first work to realize a real-time fall detection machine with geophone sensors, achieving a detection precision of 95.74%.
- We propose a reconfirmation mechanism based on Energy-of-Arrival (EoA) localization, the false alarm rate is reduced from 5.30% to nearly 0%.
- G-Fall, is privacy-protected, device-free, training-free, and low false-alarm, which is promising to put into practical use in the future.

Thank you!

Detection of moving signs



$$THR = \sum_{i=1}^{3} \sqrt{(n_i - n_0)^2 + (m_i - m_0)^2}$$

The estimated coordinate of fall position is P0(n_0, m_0) and that of next three steps is P1(n_1, m_1), P2(n_2, m_2), P3(n_3, m_3)