IEEE

Recognition Technology:
A modern perspective of Lofti Zadeh's vision

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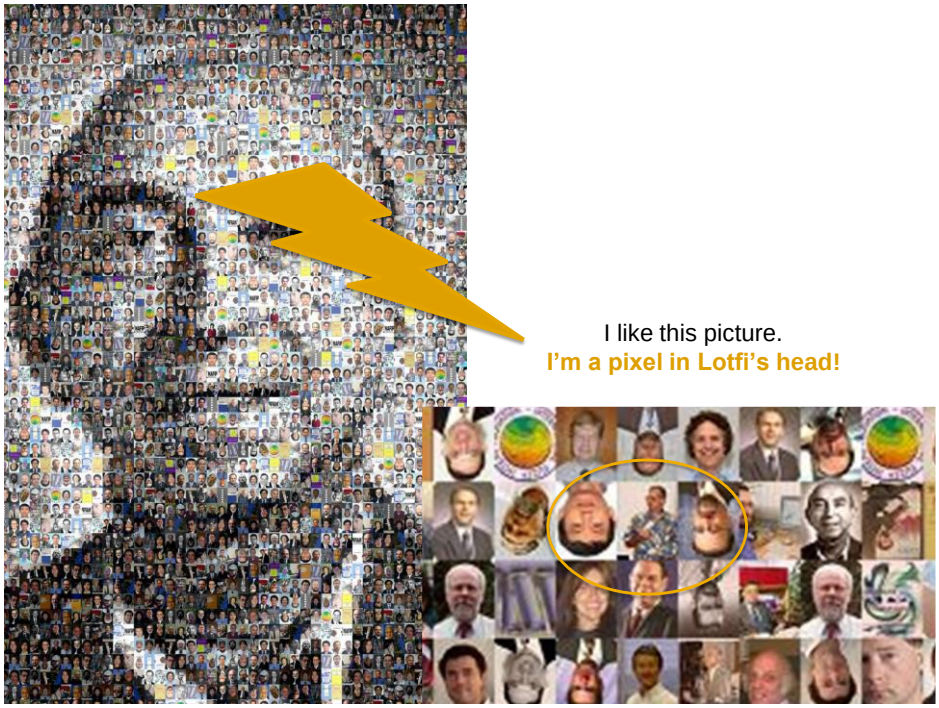
Like Ringo Star, or perhaps Joe Cocker:
I get by with a little help from my friends

Where is The University of Missouri, Anyway?

Missouri's in the Middle of the US - Columbia in the Middle of MO

Where Advanced Sensors Meet Data Science

- My Tribute to Lotfi Zadeh, creator of fuzzy set theory and fuzzy logic
  - 1921-2017



I like this picture.
I'm a pixel in Lotfi's head!

Recognition Technology

As defined by Lotfi

Jims, they are current or future systems that have the potential to provide a "quantum jump in the capabilities of today's recognition systems."

Recognition Technology

- **Result of three converging developments:**
  - **Major advances in sensor technology;**
  - **Major advances in sensor data processing technology; and**
  - **The use of soft computing techniques to infer conclusions from observed data**

L. Zadeh, "Soft Computing, Fuzzy Logic and Recognition Technology" *Proceedings, IEEE International Conference on Fuzzy Systems, Anchorage,* AK, May, 1998, pp. 1678-1679.

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Was Lotfi Right?

- We'll briefly look at two very different recognition areas
  - Explosive Hazard Detection
  - Technology for Eldercare
- And look at the 3 pillars of RT
  - From Research Teams
  - Product deployment

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Outline

- Two personal experiences
  - Explosive hazard Detection
  - Eldercare Technology
- Advances in sensor technology
  - Integrated sensor network
- Advances in sensor data processing
  - Processors, graphics,
  - storage, GPUs
- Soft Computing for
  - Intelligent processing
  - Decision Making
- Conclusions

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Problem Domains

- Explosive Hazard Detection (EHD) vs. Technology for Eldercare
  - Vastly different scales
  - Different purposes
  - Both produce mountains of data
  - Share Recognition Technology pillars

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Technology for Eldercare

TigerPlace

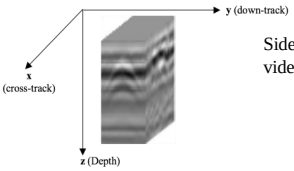
54 apartments
Designed for Aging in Place

- 65 residents, aged from about 70 to 100
- 90% have a chronic illness, e.g., arthritis, heart disease, diabetes
- 60% have multiple chronic illnesses
- Some early stage Alzheimers
- 35% use a walker; some wheelchairs
- Residents tend to be socially active

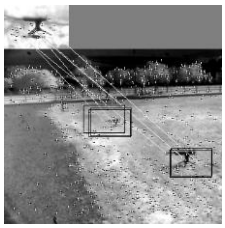
❑ NSF and NIH funded research projects

Explosive Hazard Detection

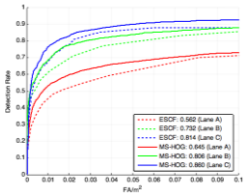
DL GPR research lead to a system ultimately fielded in Theater



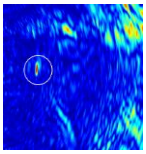
Side attack IED detection from FLIR video



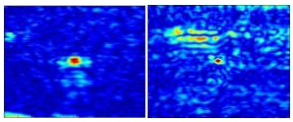
Rigorous comparison of algorithms using ROC curves on US Army test lanes



FL GPR buried hazard detection-harder problem/higher payoff



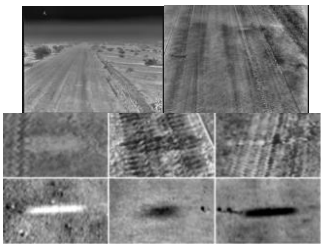
Synthetic aperture acoustic – new low cost sensing for above ground targets



Hard

Easy

FLIR detection – wide variation of cameras, conditions, appearance



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Forward Looking Explosive Hazard Detection Platform

- Various EO/IR Sensors
  - Color
  - Short/Medium/Long Wave Infrared
- Large video streams

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A Forward Looking Ground Penetrating Radar Research System

- **L-band**
  - Multiple-in-multiple-out (MIMO) radar
  - HH, HV, VH, VV
  - Monostatic (HV=VH)
  - Ground Penetration
- **X-Band**
  - VV
  - Surface Object Detection

- Detect explosive subsurface objects
- Range of object composition
  - Metal, low-metal, non-metal
- Range of burial depths
  - Shallow, deep

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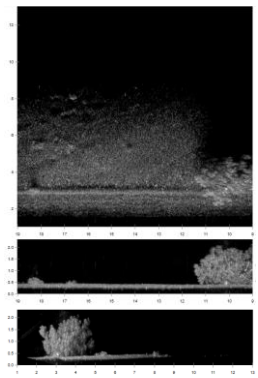
New Sensor: A 3D Radar System

- System is a high-resolution 3D radar imaging system for roadside target detection
- Developed by PNNL
  - Operates in the low Ku-band
  - Creates dense voxel representation
  - Wide dynamic range
  - Advanced motion-compensation
  - Datasets consist of 10m x 10m regions ~2m high



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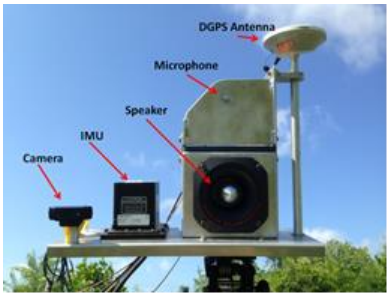
Synthetic Aperture Acoustic (SAA) Sensing

- Low cost and overall weight
- Pyramid speaker
- Pacific ACO microphone

Like Sonar (more later)



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Wave of the future

Take the sensors to the objects

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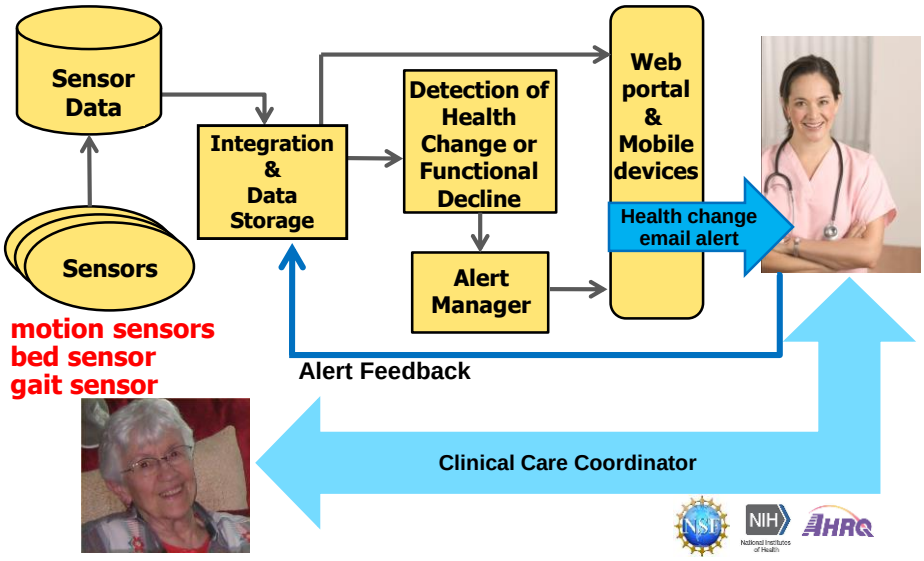
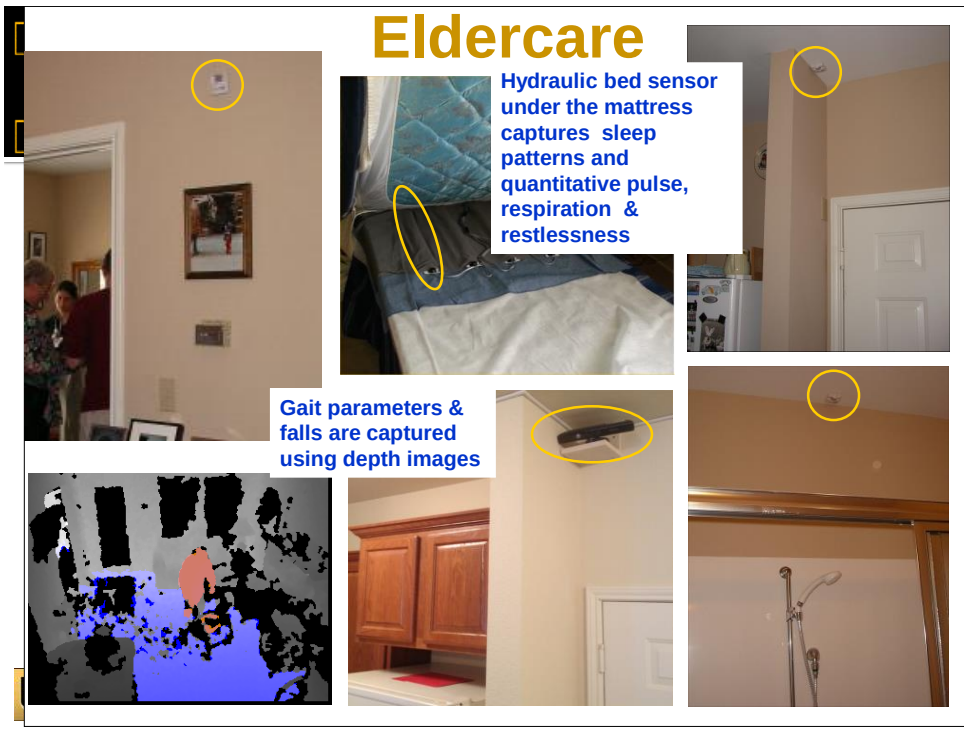
Sensor Network for Health Alerts

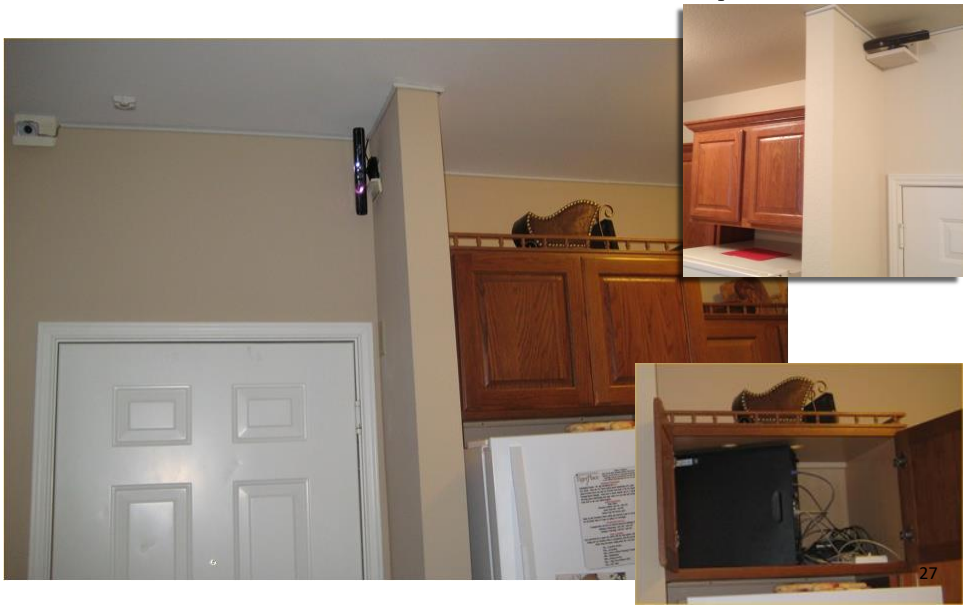
clinical decision support system



Skubic, *et al.*, *IEEE J. of Trans. Eng. in Health & Medicine*, 2015



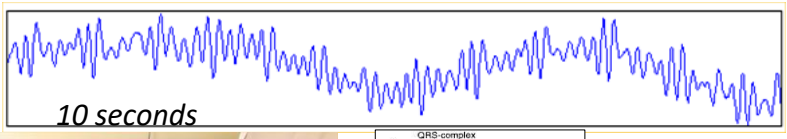
WebCams and Kinect in TP Apartment

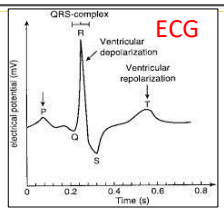


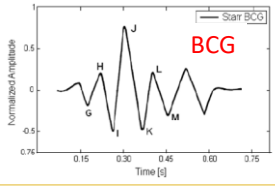
Radar Installed in TP Apartments

MU Hydraulic Bed Sensor

Captures the ballistocardiogram & respiration







Heise et al., 2011, 2013

False Alarms due to stuff thrown on the floor?

Thermal IR too expensive for Eldercare?
Check this out!

Think the Internet of Things!

Ubiquitous sensing now

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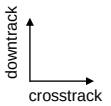
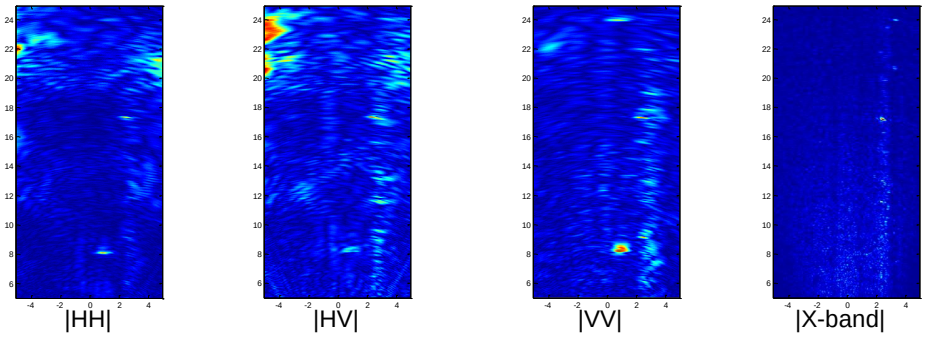
FLGPR Beamforming

Parameter	*Value*
Coherent integration range	5 – 25 meters down-range
Down-range image resolution	2.5 cm
Cross-range image resolution	2.5 cm
Cross-range	-5 to +5 meters
MIMO	
Bandwidth	750 MHz – 3.2 GHz
Polarizations (transmit, receive)	(HH), (HV), (VV)
X-Band	
Bandwidth	8.41 GHz – 10.41 GHz





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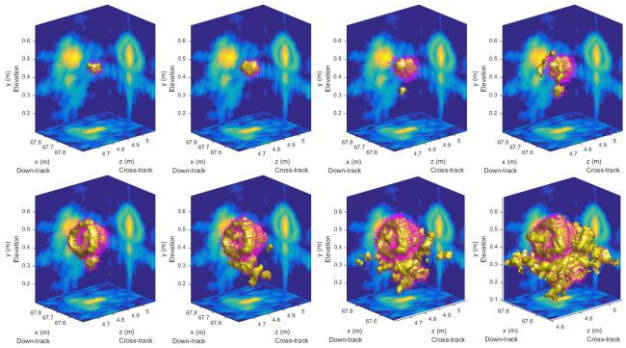
Isosurface Normal Vectors (for 3D Radar)

The gradients are by definition perpendicular to any given isosurface.

The negative gradients give the outward-pointing isosurface normal vectors.

The isosurface morphs into different shapes as the threshold changes.



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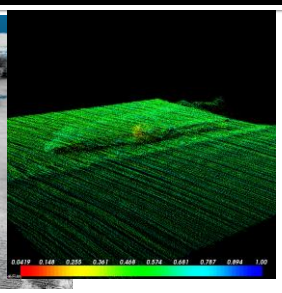
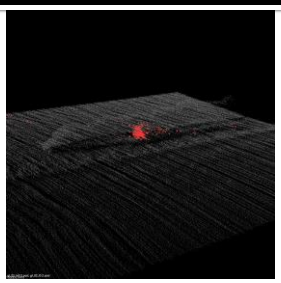
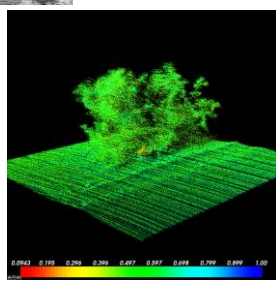
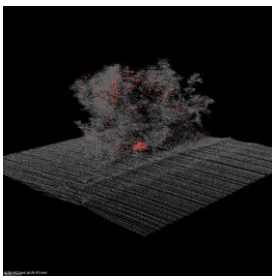
LIDAR for Explosive Hazards









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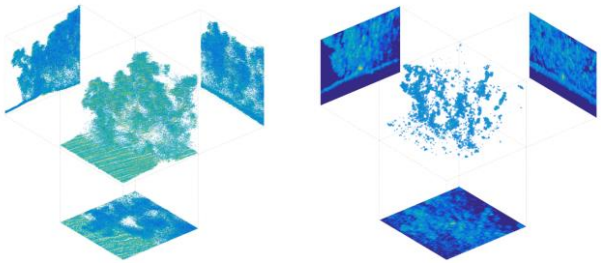
Multisensor data

Small explosive hazard occluded in a bush

FLGPR HH FLGPR HV FLGPR VV SLGPR SAA



LIDAR 3-D SLGPR

Big Data Analytics

- Don't forget Deep Neural Networks and Recurrent (deep) networks, like LSTM
  - Technologies for these new wave classification and approximation engines come from the 1990's
    - Upgraded now because of big data and great increases in computing

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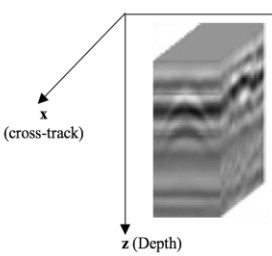
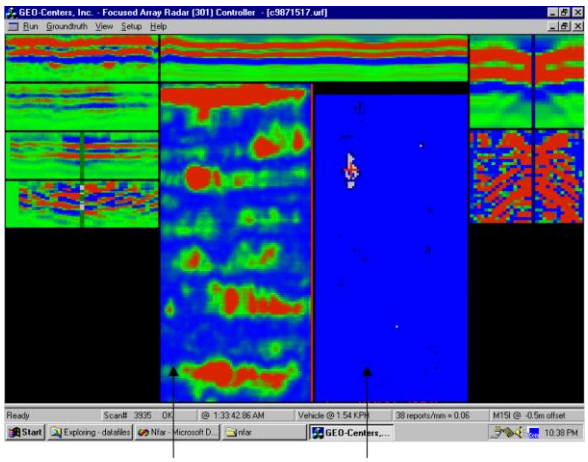
Explosive Hazard Detection



Three dimensional Ground Penetrating Radar

Uses Fuzzy Set based algorithms

DECREASE False Alarms



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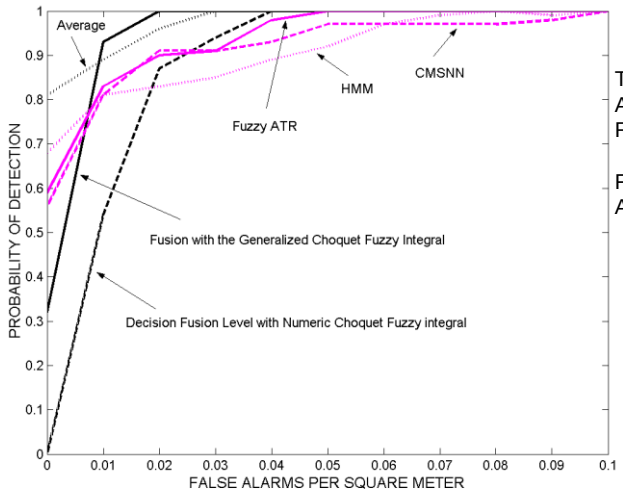
Fusion of Algorithms with fuzzy integrals

- **Run on ten lanes (16 passes) from US Army temperate site**



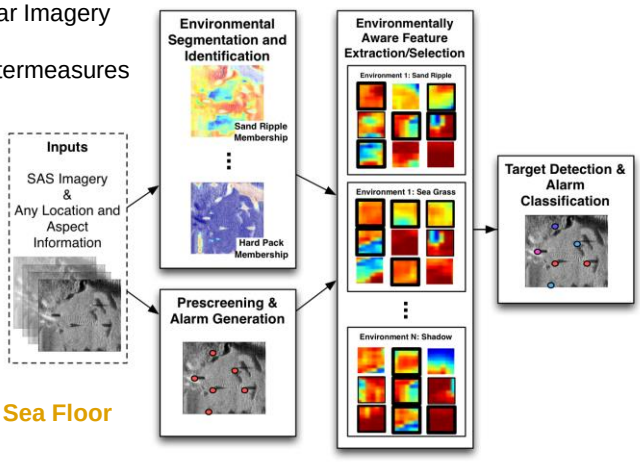
Theoretical Research, Advanced Algorithms, Rigorous Testing

For NVESD though ARO grants

Environmentally aware feature extraction/selection and classification

Synthetic Aperture Sonar Imagery

Underwater Mine Countermeasures



Soft Segmentation of Sea Floor + soft classifiers

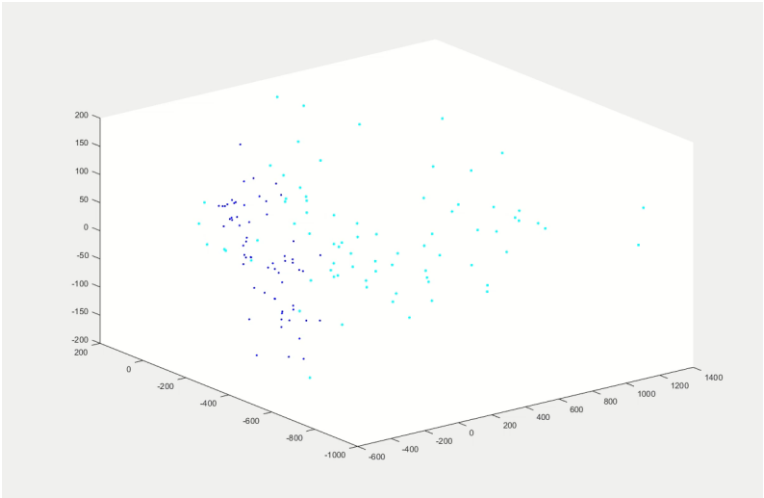
Recently funded by ONR, With Alina Zare, now at UFL

Streaming Clustering for Early Illness Detection

Uses Sequential Possibilistic One Means

For

Initialization & New cluster detection



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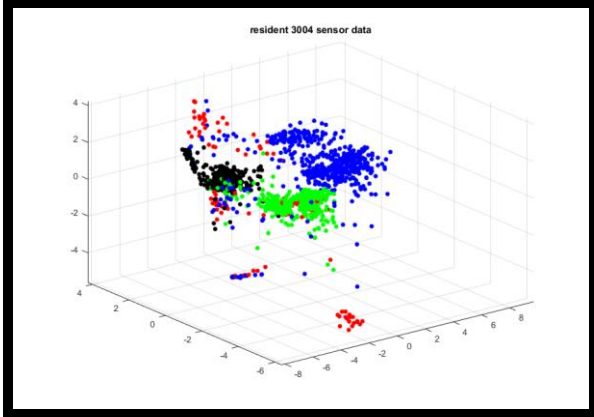
20 features

- Motion (11)
  bathroom/bed/bedroom/closet/den/dront_door/litchen/laumdry/living_room/office/shower
- Bed (4)
  pulse_min/pulse_avg/pulse_max/restlessness
- Gait features (5)
  height/walking_speed/stride_time/stride_length/gait_density



2011-10-3 – 2013-4-7 && 2015-6-1 – 2017-9-1

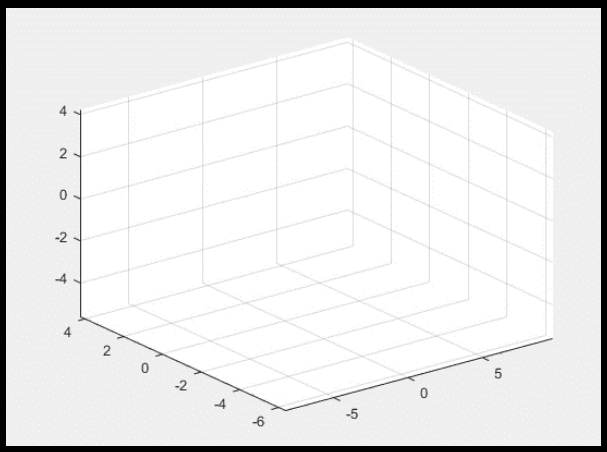
Blue cluster:
early days baseline …

Green cluster:
After mind_cognitive impairment, surgery …

Black cluster:
Neck pain, bed inactivity …

Red cluster:
Big event happening periods

Data stream animation



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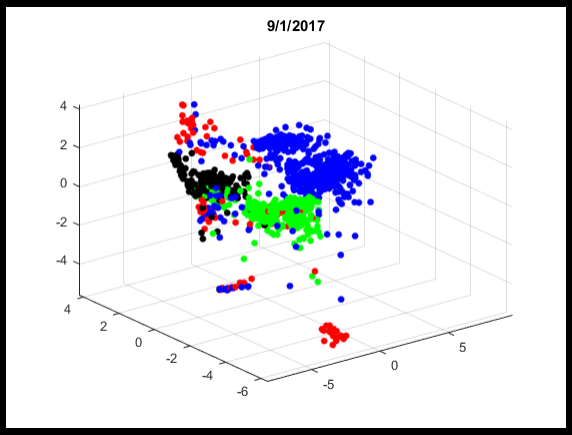

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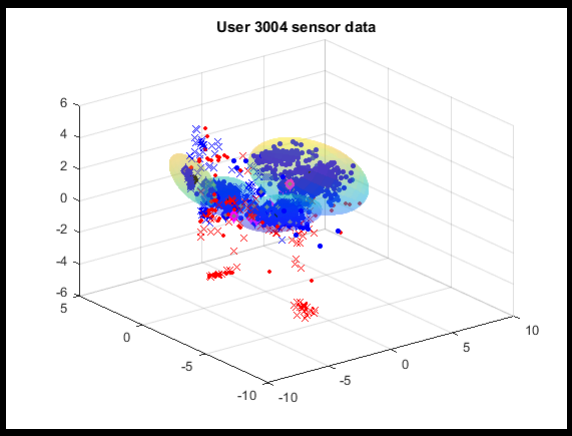
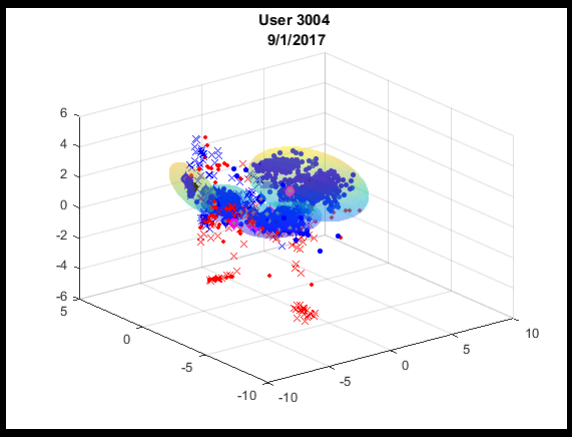
Algorithm result



Strong warning:
2013-3-13, 2017-6-3

Medium warning:
2013-2-10, 2015-11-9, 2016-10-11, 2017-3-8, 2017-6-29, 2017-8-21

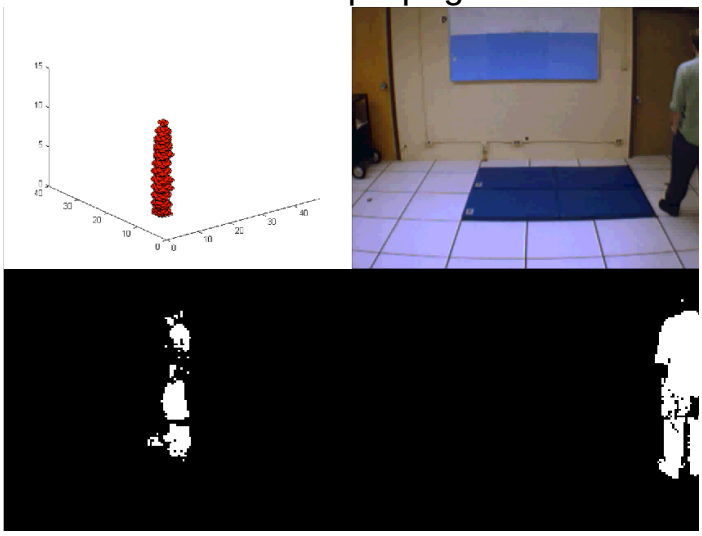
Algorithm animation



Strong warning:
2013-3-13, 2017-6-3

Medium warning:
2013-2-10, 2015-11-9, 2016-10-11, 2017-3-8, 2017-6-29, 2017-8-21

Voxel Person: 2 webcams, silhouette extraction and backpropagation



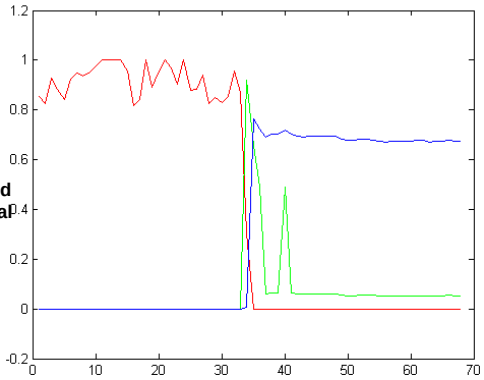
Where did those colors come from?

Fuzzy Activity Analysis

Initial Implementation - 24 Fuzzy Rules

INPUTS

1) **Mean**
2) **Eigen based height**
3) **Max eigenvector and ground plane normal similarity**



OUTPUTS

1) **Red = Upright**
2) **Green = Bending**
3) **Blue = On the ground**

LINGUISTIC SUMMARY (Explainable AI)

Derek is **upright** in the living room for a **moderate amount** of time
Derek is **on the ground** in the living room for **a moderate amount** of time.

Fuzzy Logic for Fall Detection

A hierarchical system of smaller fuzzy rule bases
Operates in a continuous fashion (until fall confidence is high)

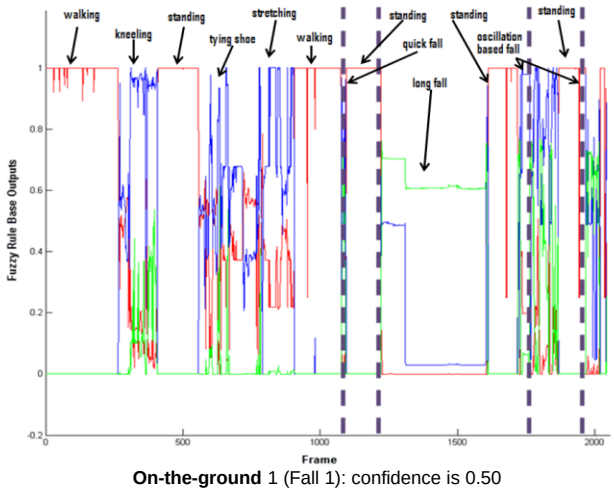
Rule	If	On the Ground	Time Duration	Acceleration	Motion	Oscillating	Then	Fall
1		High	Long					High
2		High	Moderate	High				High
3		High	Moderate		High			High
4		High	Moderate		Low			High
5		High	Moderate			High		High
6		High	Short	High				Medium
7		High	Short			High		Medium
8		High	Short			Medium		Medium
9		Medium	Moderate	High	Low			High
10		Medium	Moderate		Low			High
11		Medium	Short	High				Medium
12		Medium	Short			High		High
13		Medium	Short			Medium		Medium

Validated by Nurses (domain experts)

An 11 minute sequence for fall detection

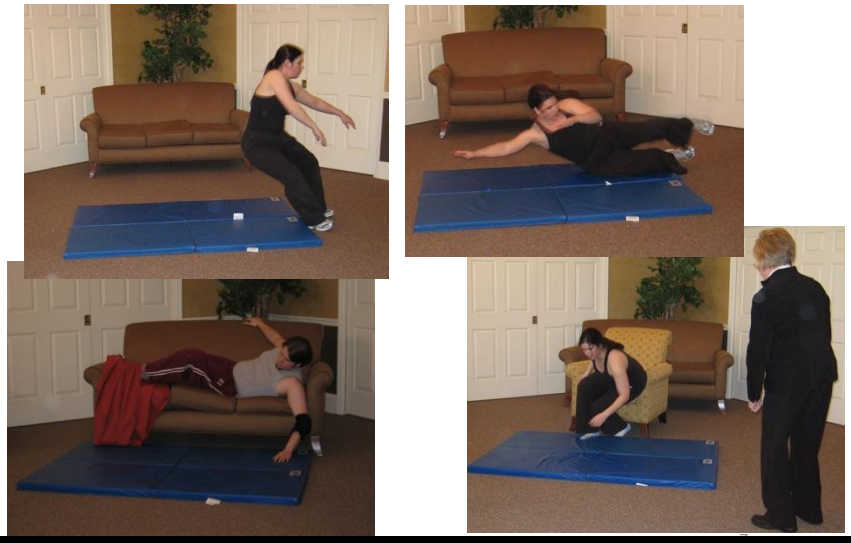
Only one long fall (Fall 2)

Fall 3 is up&down: confidence grows with duration



On-the-ground 1 (Fall 1): confidence is 0.50
On-the-ground 2 (Fall 2): confidence is 1.00
On-the-ground 3 (Fall 3): confidence is 0.50
On-the-ground 4 (Fall 3): confidence is 0.50
On-the-ground 5 (Fall 3): confidence is 0.67
On-the-ground 6 (Fall 3): confidence is 0.81
On-the-ground 7 (Fall 4): confidence is 0.50
On-the-ground 8 (Fall 4): confidence is 0.50.

Acquiring Realistic Data Using Stunt Actors
But first, we had to train them!



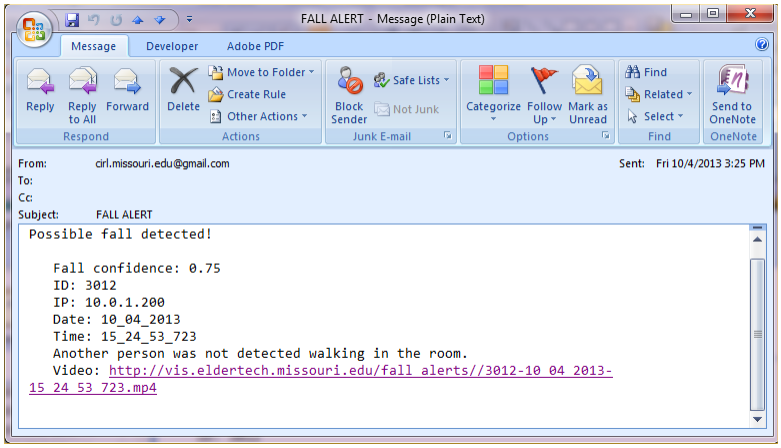
Rantz, Aud, Alexander, Wakefield, Skubic, Luke, Anderson & Keller, Journal of Nursing Care Quality, 2008.

Confusion Matrix for Falls

		Ground Truth	
		fall	**non-fall**
Systems	**fall**	31/31 29/31	**1/220** 54/220
Fuzzy Rules HMMs	**non-fall**	**0/31** 2/31	**219/220** 166/220

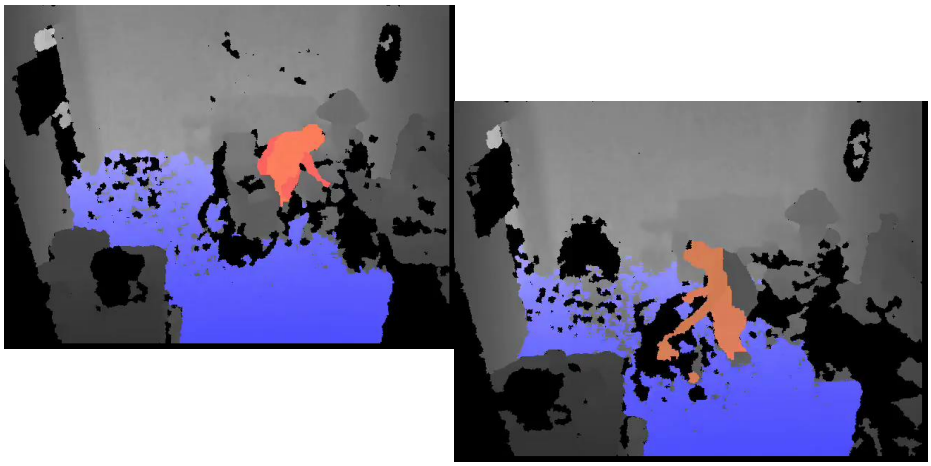
Our webcams: Recognized ALL falls
with 1 false alarm on a floor exercise

Fall Alerts in TigerPlace Apartments using Kinect Depth Images



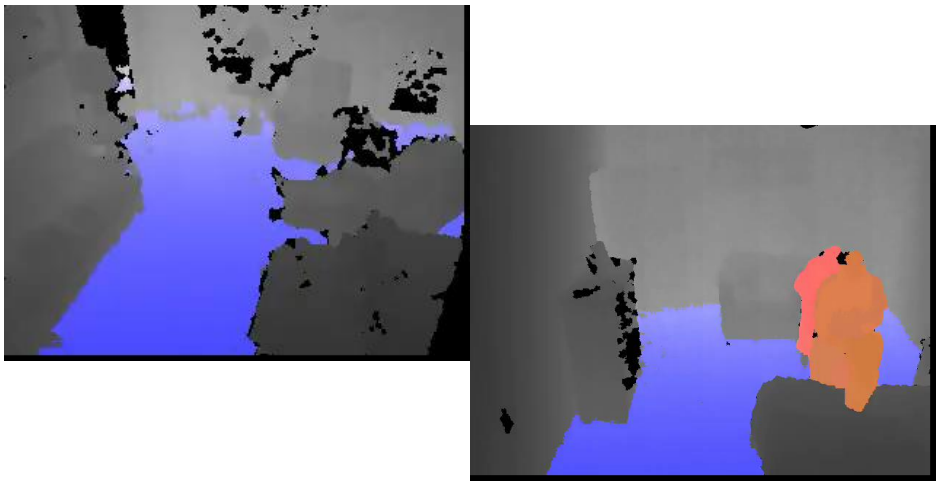
Stone & Skubic, ICOST 2014; *JBHI* 2015.

Capturing Falls in the Home with Depth Sensors

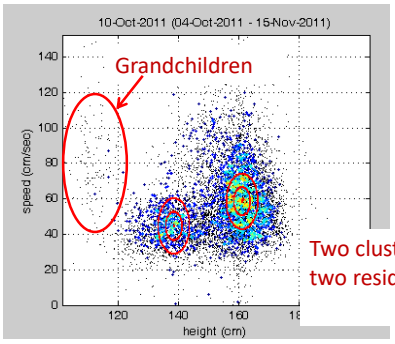


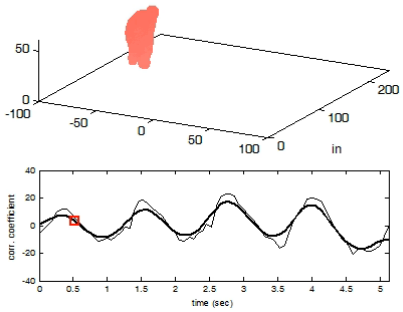
Stone & Skubic, 2014, 2015

False Alarms in the Home



Capturing Gait in the Home with Depth Sensors





Stone & Skubic, 2012, 2013, 2015

Linguistic Summaries
Data2Text – Explainable AI (XAI)

- Anna Wilbik (now at TU/e)
  - Did a lot of work on Linguistic Protoform Summaries
- Carried on with Akshay Jain - trends

Bi-weekly summaries

Day-time Bed Restlessness has been decreasing for the past 12 days.
Day-time in Pulse rate has been decreasing for the past 10 days (from 77 to 69 beats/min).

Summaries with alerts at TP

From: Eldertech Admin <eldertech@missouri.edu>
Sent: Tuesday, August 29, 2017 7:55 AM
To: Jain, Akshay (MU-Student)
Subject: Alert Summary for 54006 in Apt. SK

Alert Summary for 54006 in Sinclair@Home_058 apartment SK on 08/27/2017
Day & Night time Bed Restlessness, Day-time Time in Bed have been increasing for the past 5 days.
Night-time Pulse rate(from 66 to 53 beats/min) has been decreasing for the past 8 days.
View Data on Interface
CERT Alert Manager 1.6

Fielded Systems

- Proof is in the pudding
  - Explosive Hazard Detection
  - Eldercare Technology

Technology Transfer

From: Sherburne, Douglas M Mr CAMBER [mailto:douglas.sherburne@nvl.army.mil]
Sent: Fri 4/23/2004 8:47 AM
To: Ho, Dominic K.; Frank Rotondo (E-mail); Mike Ritondo (E-mail); ....
Cc: Santiago, Angel L Mr RDECOM CERDEC NVESD
Subject: AN/PSS-14 in Afghanistan

All - attached is a very recent photo taken April 04 at Afghanistan using our AN/PSS-14 (HSTAMIDS) in mine detection mission. Thought this might bring back some pleasant memories and serve as a symbol of thanks for all you did to make this happen.
Doug

Computational Intelligence Research Laboratory

Real Win for Soft Computing

- Signal Processing and Soft Computing
  - Vehicle mounted
  - Downward looking Radar
  - Led to fielded system

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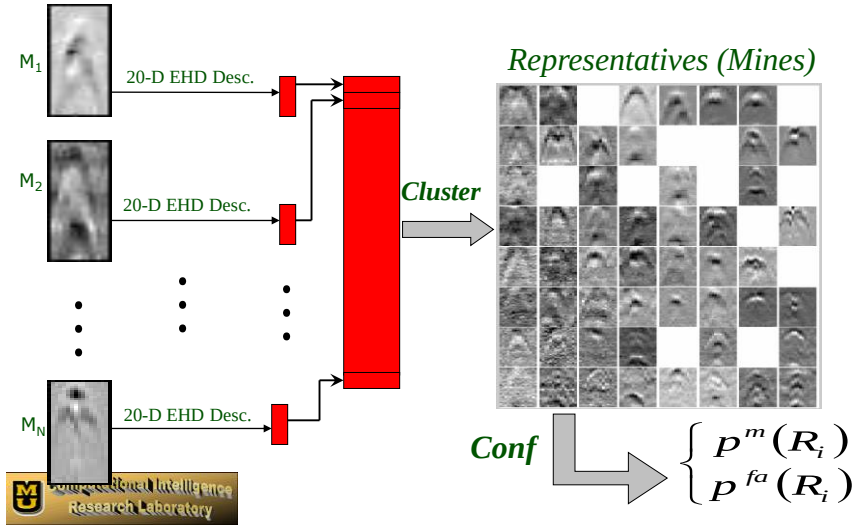
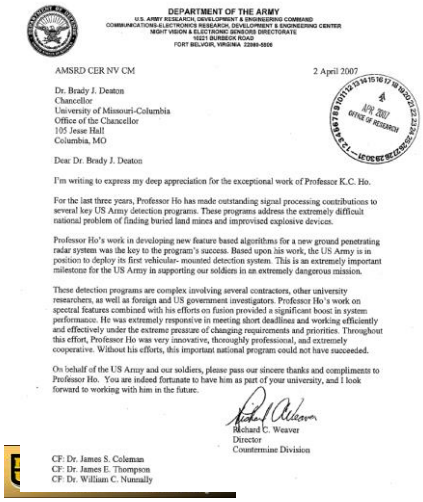
H. Frigui and P. Gader, "Detection and Discrimination of Land Mines in Ground-Penetrating Radar Based on Edge Histogram Descriptors and a Possibilistic *K*-Nearest Neighbor Classifier", IEEE TFS, 2009

The winning strategy turned out to be a possibilistic k-NN



Operational Deployment

Letter to Chancellor 4-2-07



DEPARTMENT OF THE ARMY
U.S. ARMY RESEARCH, DEVELOPMENT & ENGINEERING COMMAND
COMMUNICATIONS-ELECTRONICS RESEARCH, DEVELOPMENT & ENGINEERING CENTER
NIGHT VISION & ELECTRONIC SENSORS DIRECTORATE
10221 BURBECK ROAD
FORT BELVOIR, VIRGINIA 22060-5806

AMSRD CER NV CM

2 April 2007

Dr. Brady J. Deaton
Chancellor
University of Missouri-Columbia
Office of the Chancellor
105 Jesse Hall
Columbia, MO

Dear Dr. Brady J. Deaton

I'm writing to express my deep appreciation for the exceptional work of Professor K.C. Ho.

For the last three years, Professor Ho has made outstanding signal processing contributions to several key US Army detection programs. These programs address the extremely difficult national problem of finding buried land mines and improvised explosive devices.

Professor Ho's work in developing new feature based algorithms for a new ground penetrating radar system was the key to the program's success. Based upon his work, the US Army is in position to deploy its first vehicular- mounted detection system. This is an extremely important milestone for the US Army in supporting our soldiers in an extremely dangerous mission.

These detection programs are complex involving several contractors, other university researchers, as well as foreign and US government investigators. Professor Ho's work on spectral features combined with his efforts on fusion provided a significant boost in system performance. He was extremely responsive in meeting short deadlines and working efficiently and effectively under the extreme pressure of changing requirements and priorities. Throughout this effort, Professor Ho was very innovative, thoroughly professional, and extremely cooperative. Without his efforts, this important national program could not have succeeded.

On behalf of the US Army and our soldiers, please pass our sincere thanks and compliments to Professor Ho. You are indeed fortunate to have him as part of your university, and I look forward to working with him in the future.

Richard C. Weaver
Director
Countermine Division

CF: Dr. James S. Coleman
CF: Dr. James E. Thompson
CF: Dr. William C. Nunnally

" .. outstanding signal processing contributions for U.S. Army's first vehicle mounted system."

"This is an extremely important milestone for the U.S. Army in supporting our soldiers in an extremely dangerous mission."

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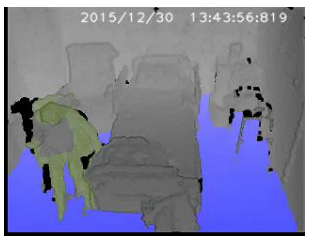
Foresite™ Depth Sensor

- Precisely monitors resident/patient **motion**
- Analyzes environment, **movements** and other features
- Utilizes a continuously updated dataset of millions of hours of motion monitoring
- Continuously assesses **fall risk**
- Detects **falls**
- Issues alerts via text message or email
- No wires, no buttons, completely passive



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foresite HEALTHCARE

Outline

- Two personal experiences
  - Explosive hazard Detection
  - Eldercare Technology
- Advances in sensor technology
  - Integrated sensor network
- Advances in sensor data processing
  - Processors, graphics,
  - storage, GPUs
- Soft Computing for
  - Intelligent processing
  - Decision Making
- Conclusions

Computational Intelligence Research Laboratory

Conclusions

- Lotfi's Vision of Recognition Technology
  - Pretty much spot on (my limited view)
  - Explosion of new and cheap sensors (IoT)
  - Computing power and visualization
    - Enables great advances in signal/image processing and feature extraction
  - Soft Computing for decision making
    - Model and manage the uncertainty

Computational Intelligence Research Laboratory

All for me today

You should always thank your friends:

- **ARO, NVESD, NSF ITR, NSF HCC, the U.S. Administration on Aging, NIH, Alzheimer's Association and grants to help pay for this**
- **And all of you!**

Muito obrigado a
João, João Paulo, and Susana for letting me blab on,
And to
IEEE CIS, and its Distinguished Savapati, Nik, for the travel funds

The Heart of AI is CI

The Best AI is CI

CI: Back to the Future of AI

Questions??