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Precise Patient Monitoring with Few False Alarms - SuperAlarm

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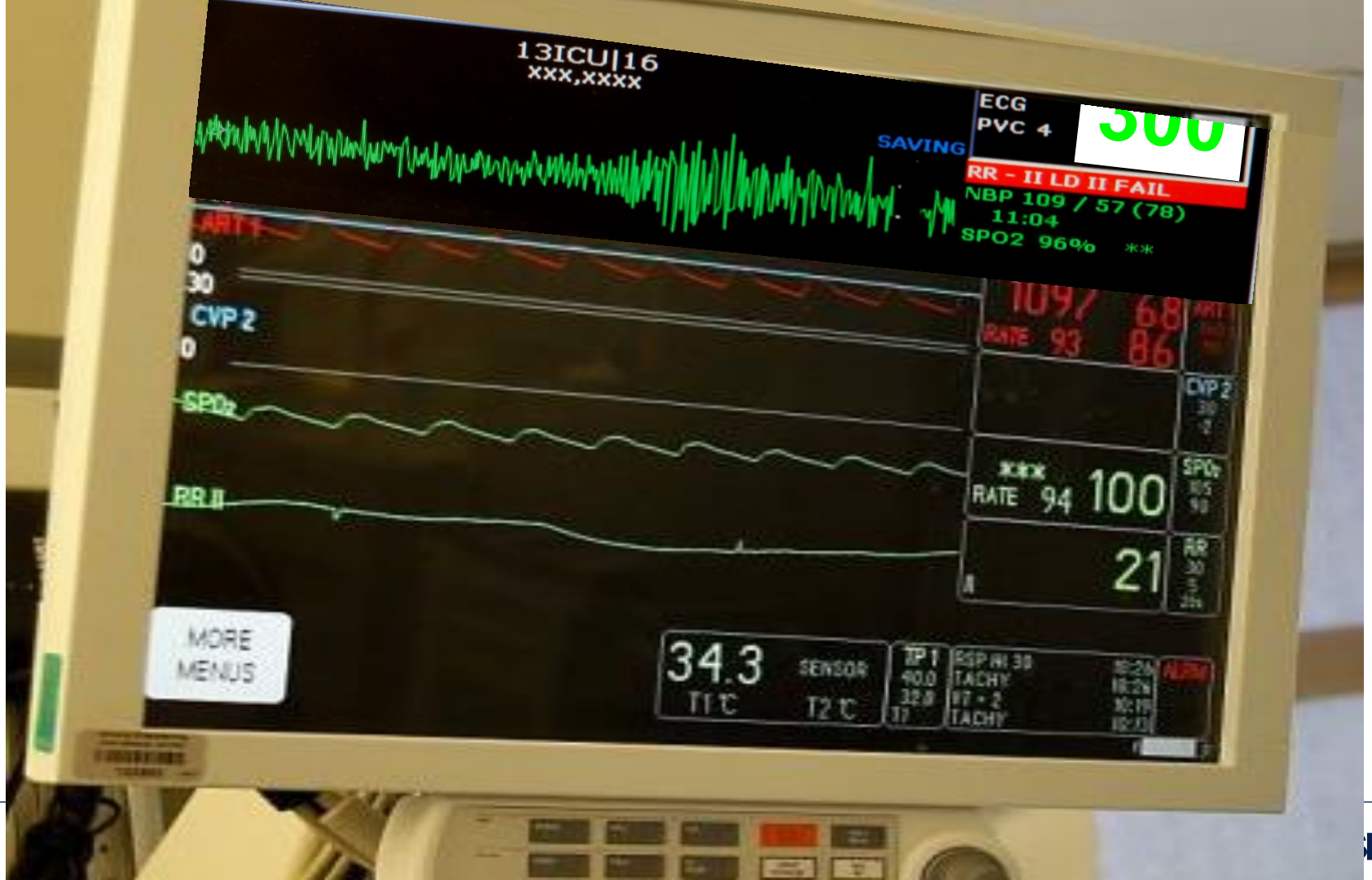
Disclosures

None


13ICU|16
xxx,xxxx
SAVING
ECG
PVC 4
RR - II LD II FAIL
NBP 109 / 57 (78)
11:04
SPO2 96%
CVP 2
SPO2
RR II
RATE 93 86
RATE 94 100
21
MORE MENUS
34.3
SENSOR
T1 ℃
T2 ℃
TACHY
TACHY

Clinical motivations

OPEN ACCESS Freely available online

PLOS ONE

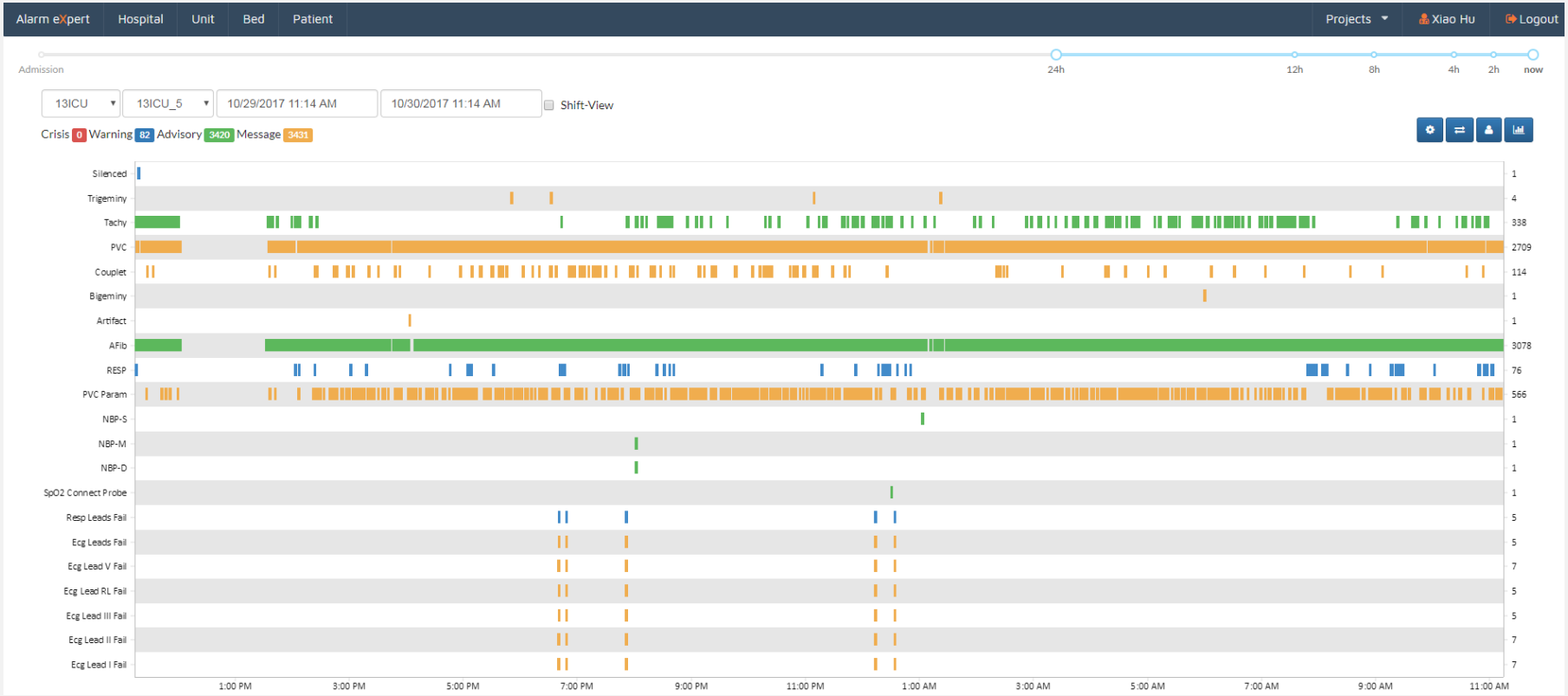
Insights into the Problem of Alarm Fatigue with Physiologic Monitor Devices: A Comprehensive Observational Study of Consecutive Intensive Care Unit Patients

Barbara J. Drew[1]*, Patricia Harris[1], Jessica K. Zègre-Hemsey[2], Tina Mammone[3], Daniel Schindler[1], Rebeca Salas-Boni[1], Yong Bai[1], Adelita Tinoco[1], Quan Ding[1], Xiao Hu[1]

2,500,000+

Bedside patient monitor alarms in March 2013 for only 77 UCSF ICU beds

Alarm Situation at UCSF has not Changed Much!



Alarm Crisis

Little boys who cried wolf

Desensitized Staff

- **375,000**/year unplanned ICU transfers
- **> 200,000** cardiac arrests with **80%** mortality
- **Many potentially predictable events:**
  - **Sepsis**
  - **Bleeding**
  - **Urgent intubation**

❖2015 – 2017 national patient safety goal by Joint Commission:
Reduce the harm associated with clinical alarm systems

❖2013 – 2016 top 10 health technology hazards by ECRI
#1 hazard in 2013, 2014, 2015: Alarm hazard
#2 2016 hazard: Missed alarms can have fatal consequences

Current Interventions are Inadequate for Alarm Crisis

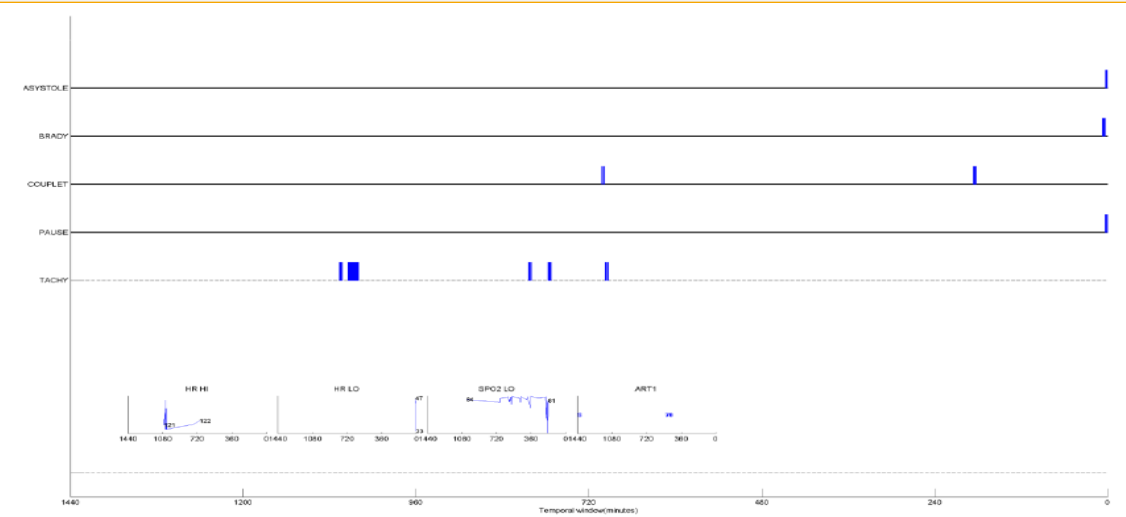
Widening alarm parameters

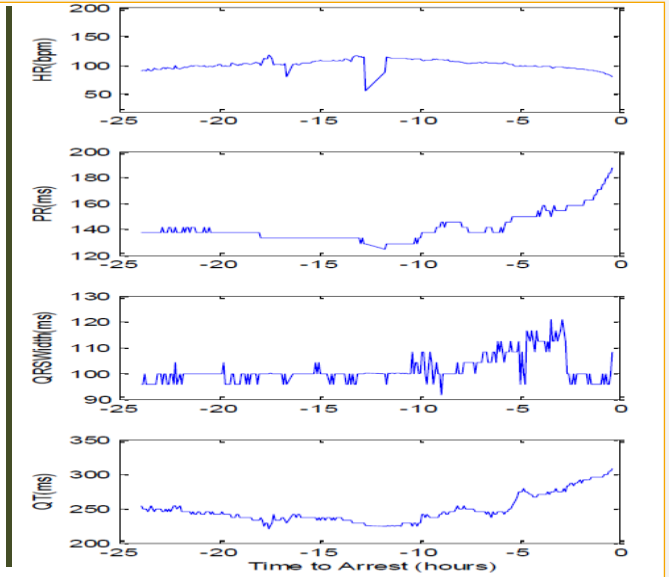
Instituting alarm delays

Frequently changing ECG electrodes

Using disposable ECG wires

Alarm Failure: Too Few Right Alarms





24-Hour Monitor Alarm Profile

Trends of ECG Metrics not Monitored

- Potentially useful metrics not monitored
- Failed to consider patterns such as trending

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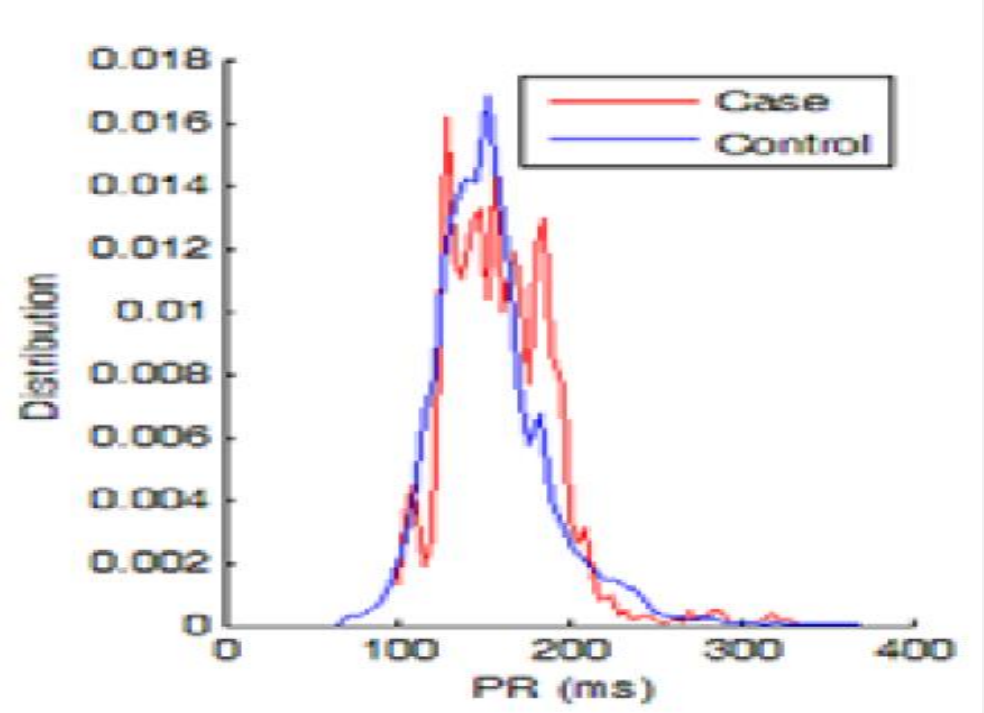
Design Precise Alarm: Trending

Why trending?

- Monotonic changes are not physiological
- Single threshold crossing alarm is not adequate to differentiate complex physiological states



Ding Q, Bai Y, Tinoco A, Mortara D, Do D, Boyle NG, Pelter MM, **Hu X**. Developing new predictive alarms based on ECG metrics for bradyasystolic cardiac arrest. Physiol Meas. 2015 Dec; 36(12):2405-22. PMID: 26502065; PMCID: PMC4838570

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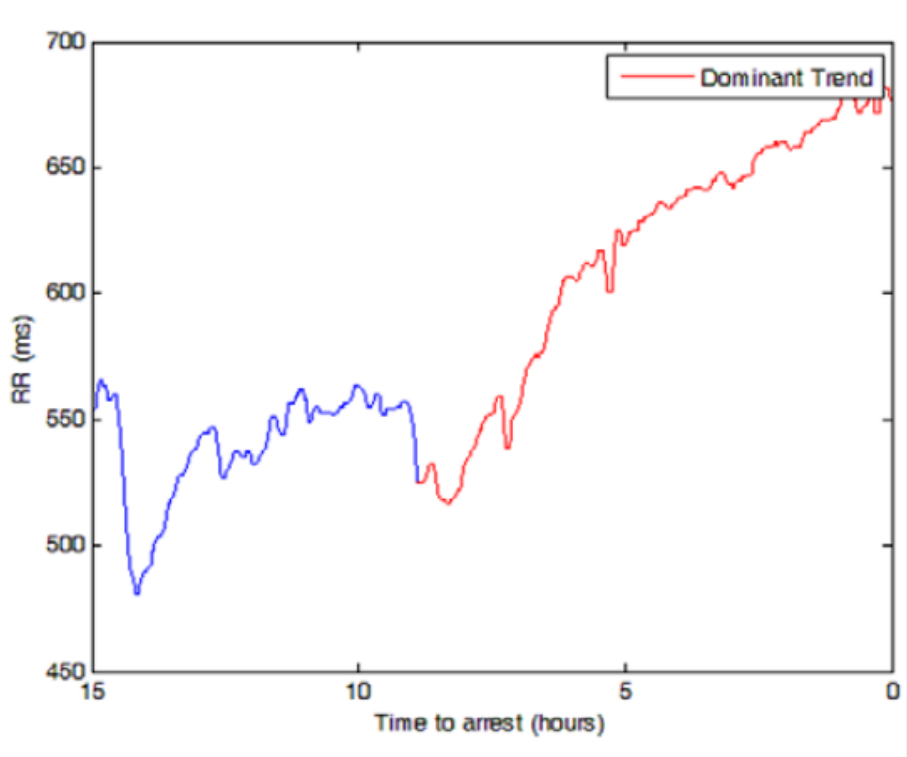
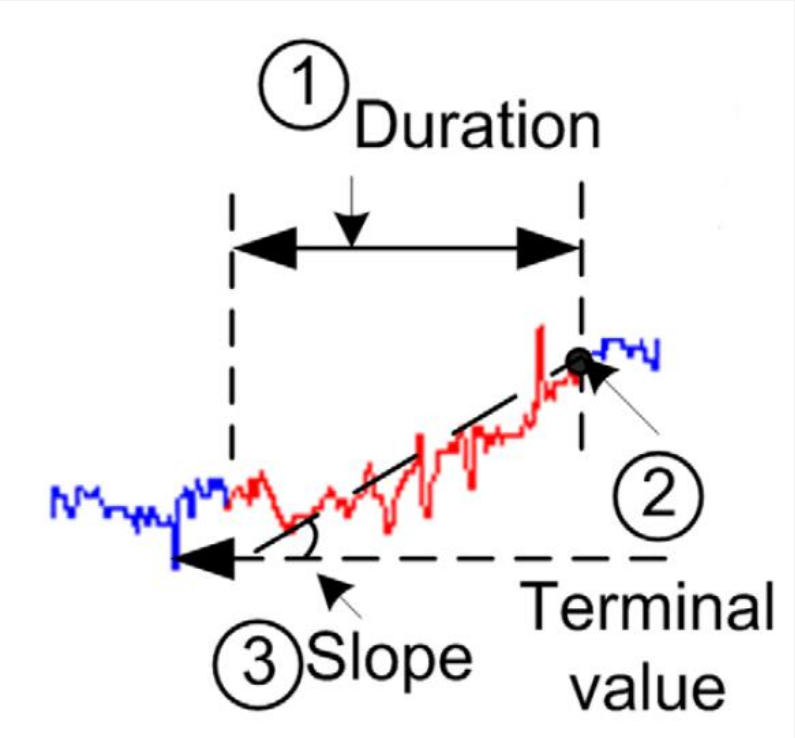
Design Precise Alarm: Dominant Trend & Alarms





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Design Precise Alarm: Case-Control Alarm Screening

- Case patients vs Control patients
- Examine the following factors
  - Which variable?
  - Which kind of alarm: duration/value/slope
  - What is the threshold?
- Criteria: FPR↓ and TPR↑

Ding Q, Bai Y, Tinoco A, Mortara D, Do D, Boyle NG, Pelter MM, **Hu X**. Developing new predictive alarms based on ECG metrics for bradyasystolic cardiac arrest. Physiol Meas. 2015 Dec; 36(12):2405-22. PMID: 26502065; PMCID: PMC4838570

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Design Precise Alarm: a proof of concept study

- 27 patients with brady-asystole arrests
- 304 age/gender/dx matched control patients
- 17 ECG metrics
  - Heart rate
  - ECG morphological metrics
    - PR interval, p wave duration, QRS width
  - ST (J60)
  - HRV (SDNN, LF, HF…)

Ding Q, Bai Y, Tinoco A, Mortara D, Do D, Boyle NG, Pelter MM, **Hu X**. Developing new predictive alarms based on ECG metrics for bradyasystolic cardiac arrest. Physiol Meas. 2015 Dec; 36(12):2405-22. PMID: 26502065; PMCID: PMC4838570

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		arrests	Control
Number of patients		27	304
Male (%)		18 (66.7%)	220 (72.4%)
Age (mean ± SD)		61.4 ± 20.7	63.2 ± 11.8
Total duration of ECG analyzed (h)		19.4 ± 7.0	22.8 ± 4.1
Causes of arrest (%)	Multi-organ failure	12 (44.4%)	Not applicable
	Respiratory failure	7 (25.9%)	
	Cardiac failure	1 (3.7%)	
	Drug-induced	1 (3.7%)	
	Vagally mediated asystolic event, occurring during the turning of a patient	1 (3.7%)	
	Unknown by documentation	5 (18.5%)	
Arrest subtypes (%)	Sinus arrest	10 (37.0%)	Not applicable
	Complete heart block	7 (25.9%)	
	High-degree AV block	4 (14.8%)	

	TPR	Threshold (h)	Lead time (h)
PR	**11.1%**	**4.4**	**5.0 ± 8.3**
Pdur	0.0%	4.1	NA
QRSdur	**11.1%**	**4.1**	**6.7 ± 6.6**
RR	**11.1%**	**6.5**	**3.6 ± 4.8**
QT	0.0%	5.6	NA
SerumK2	7.4%	4.2	4.6 ± 5.3
T Complex	0.0%	4.3	NA
ST I	**14.8%**	**4.2**	**6.1 ± 5.2**
ST II	0.0%	5.3	NA
ST V	3.7%	5.2	0.4 ± 0.0
SDNN	**11.1%**	**4.7**	**6.3 ± 6.0**

- Duration alarms performed much better across different ECG metrics
- Trend duration of PR interval, QRS width, HR, ST-I, and SDNN are top performers at a FPR = 0
- A sensitivity of 33.3% with zero FPR was achieved by combining four metrics
  - HR, QRS width, ST I and estimated K

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First Study

Contents lists available at SciVerse ScienceDirect

Journal of Biomedical Informatics

journal homepage: www.elsevier.com/locate/yjbin

Predictive combinations of monitor alarms preceding in-hospital code blue events

Xiao Hu [a,b,c,*], Monica Sapo [c], Val Nenov [c], Tod Barry [e], Sunghan Kim [a], Duc H. Do [d], Noel Boyle [d], Neil Martin [c]

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Introducing SuperAlarm patterns…

…”Combinations of alarms that *co-occur **frequently** in a time window preceding code blue calls but co-occur **rarely** among control patients*”

- Key algorithm elements

  - Discretization of parametric alarm values

`Sys ABP Hi 160 > 130 mmHg` **≠** `Sys ABP Hi 200 > 130 mmHg`

  - Using *Apriori* algorithm to find frequent combinations of alarms preceding code blue events

Second Study

Contents lists available at ScienceDirect

Journal of Biomedical Informatics

journal homepage: www.elsevier.com/locate/yjbin

Integrating monitor alarms with laboratory test results to enhance patient deterioration prediction

Yong Bai [a], Duc H. Do [b], Patricia Rae Eileen Harris [c], Daniel Schindler [c], Noel G. Boyle [b], Barbara J. Drew [c], Xiao Hu [c,d,e,f,*]

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[f] UCB/UCSF Graduate Group in Bioengineering, University of California, San Francisco, CA, United States

Extending the definition of SuperAlarm patterns

…"Combination of alarms and abnormal laboratory test results"

- **Key algorithm elements**

- Two approaches to representing abnormal lab test results as events:

- ✓ **Abnormal lab: most recent results with flag [H, HH, L, and LL]**
- ✓ **Delta lab: abnormality flag combinations of two results (e.g., N→H)**

- Use of a more efficient algorithm for mining maximal frequent alarms

Useful Properties

Filter individual false alarms

V TACH & 19.5 < BP MEAN LO < 52.5 & 20.5 < BP DIA LO < 37.5 & 27.5 < BP SYS LO < 75.5

Ventricular Tachycardia alarm unlikely false when co-occurring with Low blood pressure Alarms!

Capture trend of physiologic variables

SpO2 LO < 57.5 & 57.5 < SpO2 LO < 82.5 & 82.5 < SpO2 LO < 93.5

A likely SpO2 trending pattern!

Inherently multivariate

57.5 < SPO2 LO < 82.5 & BNP H→ H & PT H→H & Hematocrit L→ L & Hemoglobin L→ L

Third Study

Proceedings — AMIA Joint Summits on Translational Science

AMIA INFORMATICS PROFESSIONALS. LEADING THE WAY.

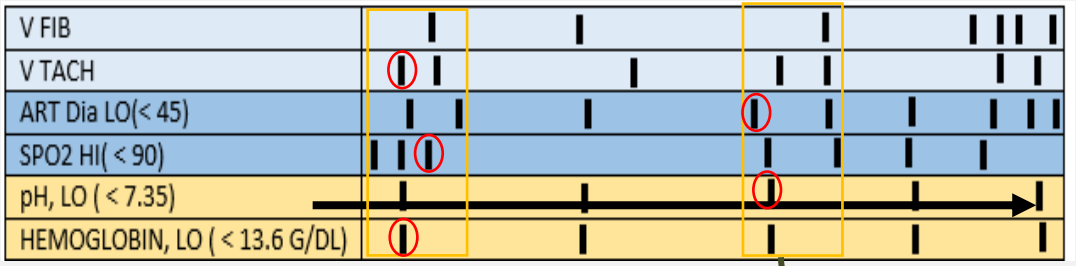
AMIA Jt Summits Transl Sci Proc. 2015; 2015: 162–167.
Published online 2015 Mar 25.

PMCID: PMC4525278

Cumulative Time Series Representation for Code Blue prediction in the Intensive Care Unit.

Rebeca Salas-Boni, PhD,[1] Yong Bai, MS,[2] and Xiao Hu, PhD[1,3,4,5]

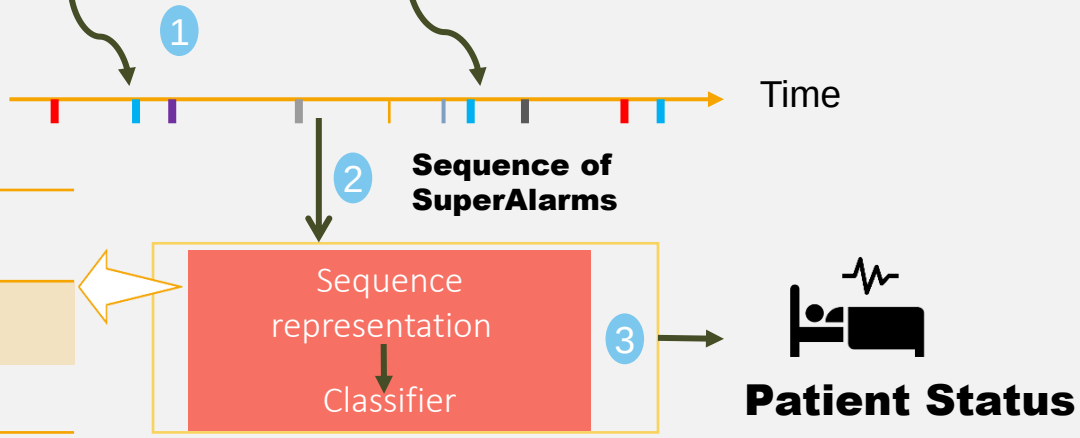
Event Sequence Representation of Heterogeneous Temporal Clinical Data



- Key algorithm elements

A novel sequence representation technique

SuperAlarm Sequence	Fixed-dimensional feature space
$\{a,b,c,c,e,f\}$	[0.1 0.5 0.9 0.8]
$\{e,f,g,c\}$	[0.2 0.05 0.1 0.2]

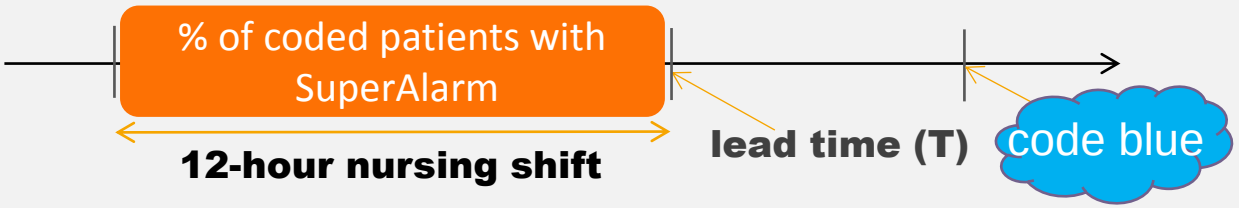


Performance Metrics

- Alarm Frequency Reduction Rate (AFRR)

$$1 - \frac{\text{[hourly \# of SuperAlarms]}}{\text{[hourly \# of Monitor Alarms]}}$$

- Sensitivity^{L}@T



- Work-up to Detection Ratio (WDR)

$$\frac{\text{[patients with SuperAlarm triggers]}}{\text{[coded patients with SuperAlarm triggers]}}$$

Performance Results

Based on SuperAlarm Dataset 1.0

	Sensitivity at Different Lead Time					Alarm Frequency Reduction Rate	Work-up to Detection Ratio
	0.5 Hour	1.0 Hour	2.0 Hour	6.0 Hour	12.0 Hour		
Paper #1	86.7 %	86.7 %	80.0 %	73.3 %	60.0 %	85.3±10.5%	7.8±0.3
Paper #2	93.3 %	90.0 %	90.0 %	86.7 %	80.0 %	85.3±9.8%	6.5±0.2
Paper #3	90.0 %	90.0 %	90.0 %	86.7 %	70.0 %	88.5±21.4%	4.8±0.1

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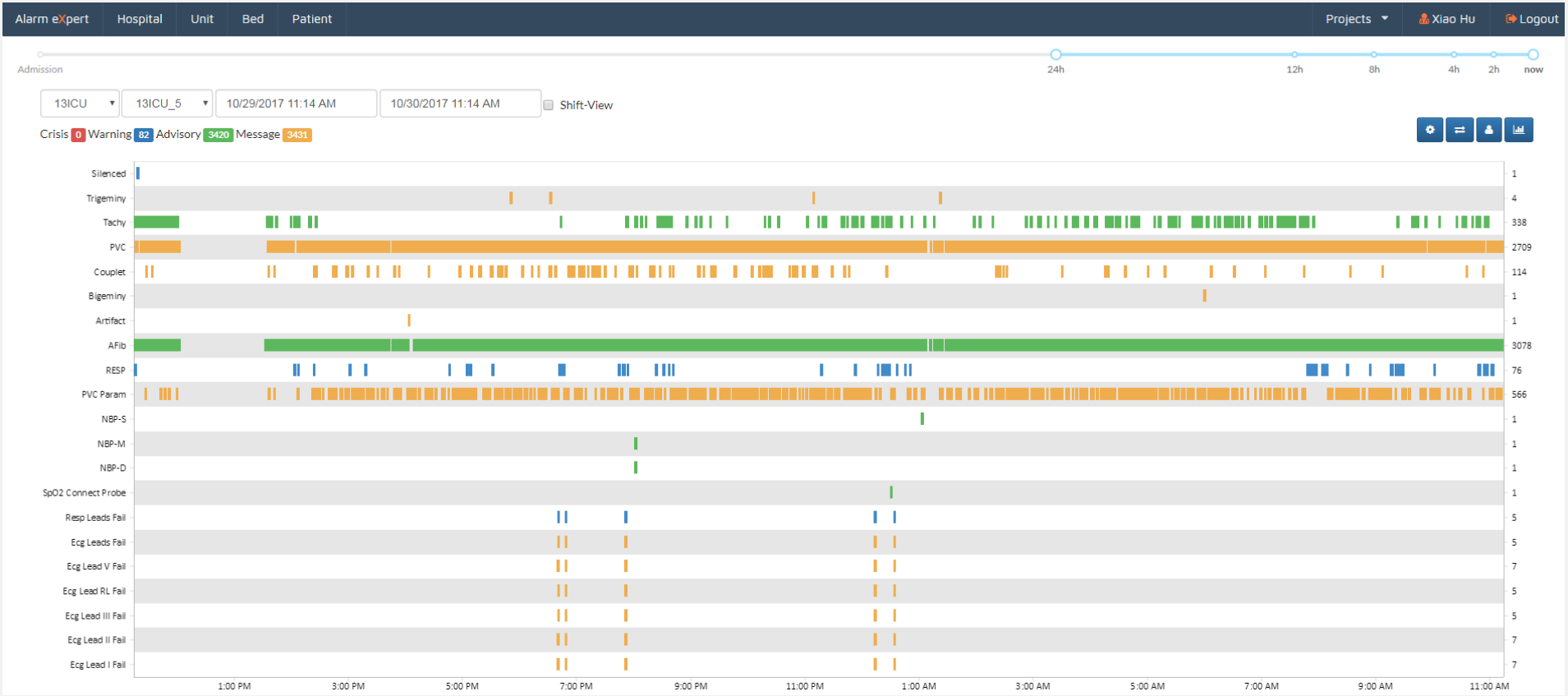
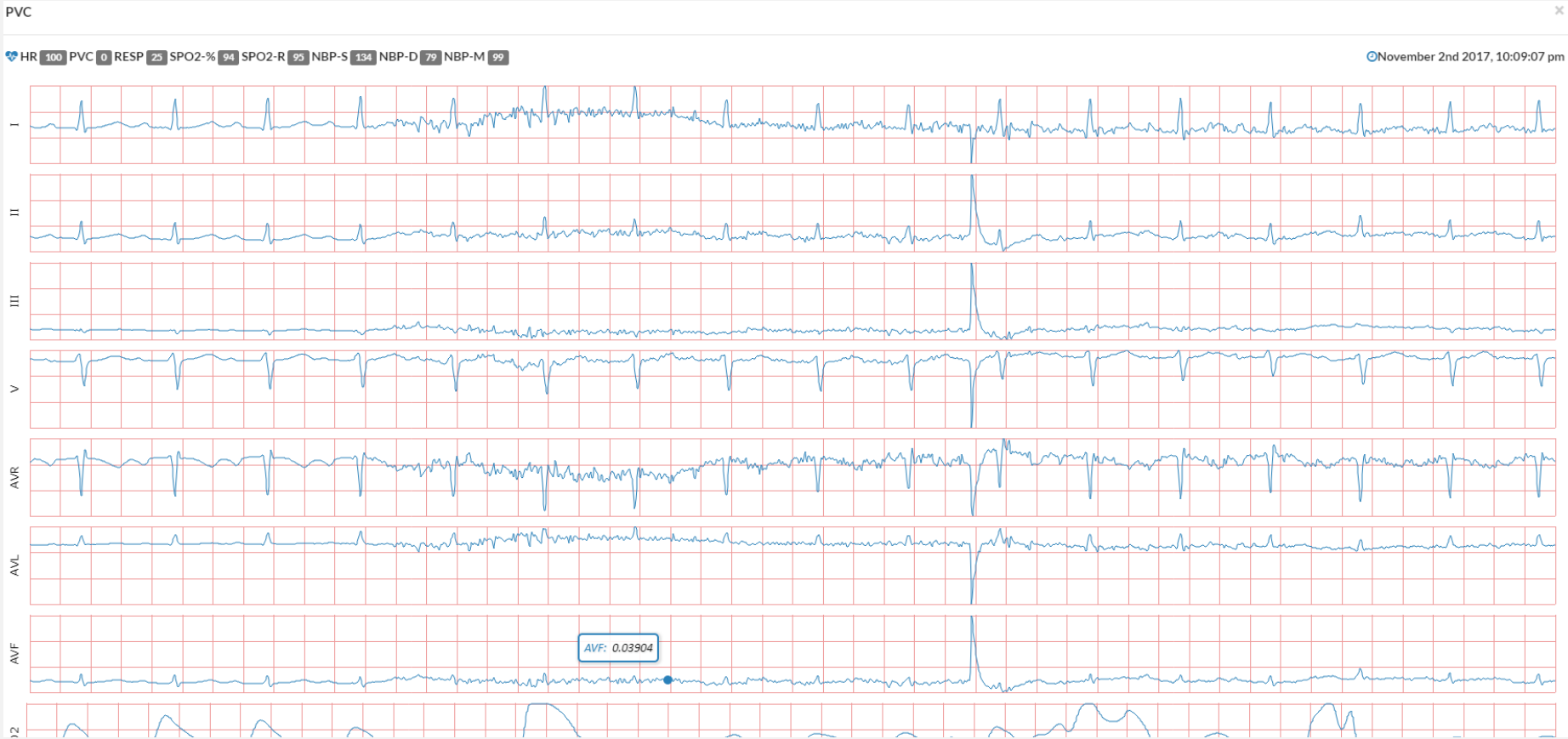
ICU Dashboard of Patient Scores – by SuperAlarm

Drilldown of Dashboard: Alarms



Drilldown of Dashboard: Signal Waveforms



Research History Built on Data

SuperAlarm 1.0

Dates
- Start: March 2010
- End: June 2012

Identified Cohorts
- Code Blue patients
- Control patients

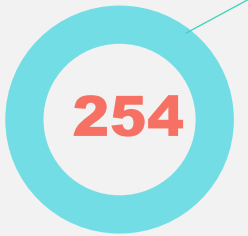
Data Sources
- Monitor Data (BedMaster)
- Electronic Health Records (Epic)

Institutions
- UCLA Medical Center

✓ **EHR**
- Patient Demographics
- ADT
- Labs

✓ **Monitors**
- Alarms
- ECG

Code Blue case patients at UCLA



- 61.6 ± 18.2 average age (year±SD)
- 54% male
- 46% female
- 10.4 ± 16.9 average monitoring duration (days, median±SD)
- 2,213 total control patients

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SuperAlarm Dataset 2.0: Code Blue Patients

Dates
- Start: March 2010
- End: December 2016

Identified Cohorts
- Code Blue patients
- Control patients

Data Sources
- Monitor Data (BedMaster)
- Electronic Health Records (Epic)

Institutions
- UCLA Medical Center
- UCSF Medical Center

UCSF*(325)

From 2013

- Average age (year) 61 ± 15
- Male 54.61%
- Female 45.39%
- Average monitoring duration (days, median ± SD)
  7.56 ± 15.37
- Control patients
  2,234

UCLA(777)

From 2010

- Average age (year) 62 ± 17
- Male 57.82%
- Female 42.18%
- Average monitoring duration (days, median ± SD)
  12.96 ± 39.21
- Control patients
  3,734

* *Data collection started in 2013*

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Conclusions

- Current patient monitoring practice is imprecise
  - ✓Alarm fatigue – too many false and nuisance alarms
  - ✓Alarm failure – too few right alarms, patient deterioration missed

- Precise patient monitoring is the future
  - ✓Systematic design of precise single alarm
  - ✓Multimodality data integration (monitor + EHR)
  - ✓Pattern recognition across modalities and temporal dimension

Team Members

Hu Lab

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Algorithm Researchers

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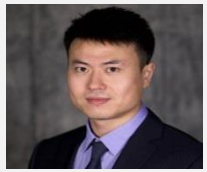
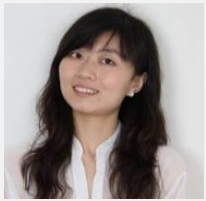
Peter Li, MS

Software engineers

Del Bold, MS
Jacob Abba, BS

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Catalyst

UC CAI
University of California Center for Accelerated Innovation
Enhancing health, lengthening life, and reducing illness and disability

NIH National Heart, Lung, and Blood Institute

cdhi Center for Digital Health Innovation at UCSF

THANKS !