Disaster Management

• Motivation

• SMART
  – Project overview
  – System
  – Results
  – Lessons learned
Emergency Medical Response

Locate
Rescue
Assess/Triage
Care
Identify
Transport

Resource allocation needs to change according to evolving conditions
How Can We Provide Best Care?

• Monitor patients
  – How are they?
  – Where are they?
  – Who is the primary responder?

• Monitor caregivers
  – Locate nearest available provider
  – Avoid broadcast alerts

• Track
  – Equipment
  – Providers
  – Transport units

• Make decisions
  – Resource allocation
Current Care

• Assessment
• Triage
  – Emergency Severity Index (ESI)
• Prioritization

Paper tags
Vital signs recorded periodically
ESI indicated by detaching colored part
Continuous Remote Monitoring

**e-tags**

Vital signs analyzed continuously

Updatable Emergency Severity Index

Remote transmission
Rationale

• Monitor patients’ vital signs and location in non-traditional contexts:
  – Mass casualty situations
  – While waiting for medical attention
  – In an ambulance
  – At home

• Make technology part of standard of care so it does not have to change in disaster situations
SMART Testbed: Emergency Department at BWH

- Excessive time spent waiting
  - 3 hour wait for medical care
- Difficulty finding patients, personnel and equipment
  - over 50 beds in three different units
  - units expand and contract
- Triage Priority System cannot account for changes
  - Medical conditions can worsen in waiting room
- Uncoordinated alarms
  - sensory overload
Patient PDA
Sensors
Location tag

SpO₂
ECG
Location

Caregiver PDA
Location tag

Equipment
Defibrillator

Location

Signal Processing

Decision Support

Logistic Support
Location System

• Patients, Providers, Vehicles

Indoor
• Ultrasound-based (Sonitor Technology)
• Room and zone-level location

Outdoor
• Commercial GPS
Sonitor Indoor Location: Tags and Detectors
Other Indoor Positioning Systems

- RFID (passive and active)
- Cricket (ultrasound and RF)
- 802.11-based tracking
- …
Patient Monitoring System

One lead EKG
Oximeter
Patient Monitoring
Communication System

SMART Central

HIS
SMART Central

IRB requirement: ACLS-trained professional to monitor the central station (the “SMART Operator”)

Caregiver PDA
Ambulance Bridge
SMART Central with GPS Location
Beat Detection Algorithms

Peak Alg.

SQRS Alg. (FIR filter)

WQRS Alg. (Length transf.)

Comparison
Signal Processing

• Several algorithms were implemented
• Simple SQRS algorithm was selected
• Comparisons with QRS detection from oximeter showed some discrepancies
Decision Support System

• Integration of data from multiple sensors
• Recognition of potentially dangerous conditions
  – Arrhytmia diagnoses

Logistics

• Alerts to specific providers
  – Avoid broadcast alerts
  – Minimize false alarms
  – Escalation strategy
Oximeter Medical Alarms

• High HR
  – Heart rate from oximeter sensor above patient-specific threshold (default threshold is 100bpm)

• Low HR
  – Heart rate from oximeter sensor below patient-specific threshold (default threshold is 60bpm)

• Low SpO2
  – Oxygen saturation below patient-specific threshold (default threshold is 90%)
ECG Medical Alarms

- **Tachycardia, Bradycardia**
- **Irregular**
  - ECG QRS complexes are irregularly spaced
- **Asystole**
  - No beat detected in 3 seconds
- **Ventricular Fibrillation**
  - ECG shows artifacts, abnormal skewness, wide waves or no waves, lacks QRS complexes, and the SpO2 heart rate is missing, below 20bpm, or above 150bpm
- **Ventricular Tachycardia**
  - ECG has wide QRS complexes and heart rate > 100bpm
Technical Alarms

- Leads Off
  - ECG lead is off (signal is saturated)
- No signal
  - No ECG data received
- Technical SpO₂
  - Oximeter sensor removed from finger
- AWOL (away without leave)
  - No communication between PDA and SMART Central
- Battery
  - Low battery (below 20%)
Poseidon Disaster Drill

- 50 federal, state, local agencies
- $750,000
- 150 injured, 25 dead
- threat at LNG (liquid natural gas) facility
- Cambridge Galleria (mall) with a dirty bomb
- (Volunteer) patients processed as usual and delivered to a variety of hospitals
- at BWH, SMART monitored the arrivals (after decontamination)
- system set up quickly ~5 minutes: one laptop, one wireless hub
- 8 patients monitored
Formative Evaluation

• Feasibility of devices
  – Will patients wear the monitor?

• Reliability of devices
  – Are there benefits in dual monitoring?
  – How well do indoor positioning systems work?
Feasibility

• Of first 42 eligible patients approached, 33 signed consent form
  – 1 changed his mind before starting
  – 2 were admitted before having chance to start
• No patient returned the device before end of study
• Duration varied from 26 seconds to 2:24h
• 20 patients answered surveys
Data

• Eligibility: cardiovascular complaint, not too severe, during hours covered by the SMART operator
• Signed informed consent
• Survey languages:
  – English, Spanish, Portuguese

• We collected 129hr 59min of data
Subjects

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approached</td>
<td>215</td>
</tr>
<tr>
<td>Refused</td>
<td>42</td>
</tr>
<tr>
<td>Total</td>
<td>173</td>
</tr>
<tr>
<td>Survey</td>
<td>98</td>
</tr>
</tbody>
</table>

- **Male** Series2: 42
- **Female** Series2: 173
- **No Gender** Series2: 98

- **Series2**
- **Series1**

Survey Total: 215
Patient Survey: Comfort

Was the monitoring system comfortable?

- Didn’t bother at all: 80%
- A little uncomfortable: 20%
- Very uncomfortable: 0%
- No response: 0%
Patient Survey: Safety

Did the monitoring system make you feel safer?

Yes, for sure
A little
No Effect
No, less safe
No response

0% 10% 20% 30% 40% 50%
Patient Survey: Value of Monitoring Vital Signs

Value of vital signs monitoring

- Very important
- A little
- Not important
- Not important and actually annoying
- No response
Patient Survey: Value of Location Monitoring

Value of having location known

- Very important
- A little
- Not important
- Not important & actually annoying
- No response
Patient Survey: Effect on Wait

Effect of SMART on length of wait

- Shortened it a lot
- Shortened it a little
- No effect
- Increased it a little
- Increased it a lot
- No response
Patient Survey: Effect on Care

Effect of SMART Monitoring on Care

- Improved it a lot
- Improved it a little
- No effect
- Impaired it a little
- Impaired it a lot
- No response
Patient Survey: Wear Again?

Would you wear a SMART pouch again?

- Yes, for sure: 50%
- Probably: 40%
- No: 10%
- No response: 0%
Reprioritization Due to Bigeminy
Is the Pace Maker Working?
Mismatch

- ECG diagnosis inconsistent with SpO2 heart rate:
  - (a) if ECG indicates asystole and oximeter heart rate is between 20bpm and 150 bpm, or
  - (b) if ECG indicates ventricular fibrillation and oximeter heart rate is between 20bpm and 150 bpm with noisy artifacts and acceptable skewness in ECG signal
Possible Atrial Fibrillation

Database: sensor data 20061030  PDA = #6
Date: 20061030 Start time = 12:59:45 Duration = 20 seconds

[Graph showing ECG HR and SPO2 HR over 20 seconds]
## SpO2 Alarm Results

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Total</th>
<th>True Positive</th>
<th>False Positive</th>
<th>Unclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>High HR (SpO2 sensor)</td>
<td>79</td>
<td>75</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Low HR (SpO2 sensor)</td>
<td>21</td>
<td>15</td>
<td>3</td>
<td>3</td>
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<tr>
<td>Low SpO2</td>
<td>44</td>
<td>35</td>
<td>5</td>
<td>4</td>
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## ECG Alarm Results

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Total</th>
<th>True Positive</th>
<th>False Positive</th>
<th>Unclear</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tachycardia (ECG)</td>
<td>124</td>
<td>61</td>
<td>31</td>
<td>32</td>
<td>Noise often mistaken for tachycardia</td>
</tr>
<tr>
<td>Bradycardia (ECG)</td>
<td>18</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Irregular rhythm</td>
<td>116</td>
<td>43</td>
<td>34</td>
<td>39</td>
<td>Noise often mistaken for irregular</td>
</tr>
</tbody>
</table>
## More ECG Alarm Results

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Total</th>
<th>True Positive</th>
<th>False Positive</th>
<th>Unclear</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Asystole</td>
<td>79</td>
<td>0</td>
<td>79</td>
<td>0</td>
<td>No SpO2 sensor present + noise or no signal</td>
</tr>
<tr>
<td>Ventricular Fibrillation</td>
<td>46</td>
<td>0</td>
<td>46</td>
<td>0</td>
<td>No SpO2 sensor present + noise</td>
</tr>
<tr>
<td>Ventricular Tachycardia</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>
## More ECG Alarm Results

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<tr>
<th>Alarm</th>
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</thead>
<tbody>
<tr>
<td>Irregular rhythm</td>
<td>116</td>
<td>43</td>
<td>34</td>
<td>39</td>
<td>Noise often mistaken for irregular</td>
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<tr>
<td>Mismatch</td>
<td>59</td>
<td>59</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Noisy</td>
<td>59</td>
<td>47</td>
<td>12</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Leads Off</td>
<td>56</td>
<td>49</td>
<td>2</td>
<td>5</td>
<td>Noise sometimes mistaken for leads off</td>
</tr>
<tr>
<td>No Signal</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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</tbody>
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## Technical Alarms

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Total</th>
<th>True Positive</th>
<th>False Positive</th>
<th>Unclear</th>
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</thead>
<tbody>
<tr>
<td>SpO2 Sensor Off</td>
<td>86</td>
<td>85</td>
<td>1</td>
<td>0</td>
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<tr>
<td>AWOL</td>
<td>329</td>
<td>309</td>
<td>16</td>
<td>4</td>
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<tr>
<td>Battery</td>
<td>16</td>
<td>15</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Lessons Learned (1)

• Acceptance of device by patients was high

• Institutional requirements for ACLS trained individual made testing of provider response not feasible

• ED doctors liked it, nurses accepted it, but wanted improvements: documentation of abnormalities in paper form was requested
Lessons Learned (2)

- The number of false positive alerts was still relatively high, but manageable for the SMART operator.
- Location system was somewhat underutilized because of the low volume and limited space that needed coverage.
- Technical solution to disaster management is even more feasible now than when this pilot started: a cost-effective system can be developed from off-the-shelf components.
SMART Collaborators

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