Reducing Lower-Back Injuries with a Privacy-Aware Compliance Tracking System

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Outline

- Motivation of the work
- Overview of the privacy-aware compliance tracking system (PACTS)
- Background on human motion tracking with Kinect
- Body mechanics training with PACTS
- Field study with PACTS
- Conclusion and future work
Pain Points

- The total cost of workplace lower back injuries in the US alone exceeds $100 billion per year
- Rates of musculoskeletal injuries for state tested nursing aids (STNAs) were more than seven times as high as the average for all workers
  - 249 per 10,000 compared to 34 per 10,000 (Mohammed, S., Singh, D., Johnson, G. T., Xu, P., McCluskey, J. D., & Harbison, R. D. (2014). Evaluation of occupational risk factors for healthcare workers through analysis of the Florida Workers’ Compensation Claims Database. *Occupational Diseases and Environmental Medicine*, 2(04), 77)
Pain Points

- At the individual employee level
  - Suffering from lower back pains, inconvenience in daily life
  - Reduced satisfaction with job and employer

- At the employer level
  - Workers’ compensation cost
  - Loss of workforce
  - Lower level of patient care
  - Increased staff turn-over
Cause of Lower Back Injuries

- Manual lifting is a main risk factor for lower back injuries
- Not all nursing homes (and not all rooms) are equipped with lifting equipment => Manual lifting of patients
- More Americans are overweight => more weight to carry
- Lifting equipment cannot eliminate all manual lifting and pulling activities, particularly for bedside care
  - Helping patient to scoop up, rolling, putting compression socks, transferring patient from bed to wheelchair, etc.
- Improper body mechanics when doing lifting and pulling tasks due to insufficient training
PACTS Can Help!

- The privacy-aware compliance tracking system (PACTS) is designed to track staff body mechanics and provide realtime feedback when non-compliance activities are detected.

- PACTS can help lower the risk of lower back injuries and therefore promote a healthier workplace by:
  - Training of STNAs on using proper body mechanics while doing bedside care activities.
  - Providing real-time monitoring and feedback while STNAs are taking care of residents at the bedside.
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PACTS System Overview

- Microsoft Kinect sensor
- Computer (to run the Kinect motion tracking application)
- Wearable device, such as smart watch (worn by the consented personnel)
- Smart phone
Demonstration Interface

- No video taping
- No picture taking
- Graphical feedback can be disabled
- Only activities are logged
Privacy-Aware Tracking Mechanism

- Simultaneous detection of a predefined gesture by both the wearable device worn by the consented person and the depth camera: registration mechanism

- If detected: start to track the registered person

- If not, collected data (current frame) is discarded
Activity Tracking

- Activities to track
  - Bending: back flexion angle cannot exceed a predefined amount

```xml
<Session Start="10/03/2016 22:02:02">
  <Activity Start="10/03/2016 22:02:02" Activity="Registered" />
  <Activity Start="10/03/2016 22:02:29" Activity="Wrong Activity Detect"
    Activity Start="10/03/2016 22:02:31" Duration="1.6240929" Activity=""
    Activity Ends" />
  <Activity Start="10/03/2016 22:02:31" Activity="Wrong Activity Detect"
    Activity Start="10/03/2016 22:02:32" Duration="0.3638200" Activity=""
    Activity Ends" />
  <Activity Start="10/03/2016 22:04:28" Activity="Lost User" />
</Session>
```
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The Kinect Technology

- Launched in 2010 as an enhancement device for the Xbox 360 game console
  - “You are the controller”: Game playing using gestures and voices
  - 24 million units sold as of Feb 2013
- Software development kit (SDK) was released by Microsoft in late 2011
  - Third party SDKs were available before that
- Two generations of Kinect sensor
  - Kinect v1: Kinect for Xbox, Kinect for Windows
  - Kinect v2: Kinect for XboxOne
- What Kinect SDK provides
  - 2D color image frames
  - 3D depth image frames
  - 3D skeletal frames with a set of joints in each skeleton
Steps of Motion Tracking and Analysis with Kinect

- Kinect depth frames
- Kinect RGB frames

1. Human subject foreground extraction
2. Pose estimation
3. Skeleton estimation
4. Motion recognition
5. Feedback to user
   - Actions triggered
Kinect Depth Sensing Technology

- The depth-sensing technology used in Kinect v1 was developed by PrimeSense
- It uses structured light with a single infrared (IR) emitter and a single depth sensor for triangulation of depth in each pixel
Human Detection and Tracking

- Object detection and tracking
  - Main approach: background subtraction => foreground humans
  - RGB-images sensitive to illuminating changes, even if camera is static
  - Depth data helps to establish a more stable background model

- Pose estimation: skeletal tracking
  - Per-pixel body part classification
  - Estimating body joint positions by computing a local centroids of the body part probability mass using mean shift mode detection
Human Motion Recognition

- Human motion recognition aims to understand the semantics of the human gestures and activities

- Gesture
  - Typically involves one or two hands, and possibly body poses
  - Convey some concrete meaning, such as waving a hand to say goodbye

- Activity
  - A sequence of full body movements that a person performs, such as walking, running, brushing teeth, etc.,
  - Not necessarily conveys a meaning to the computer or other person
  - Rehabilitation exercises form a special type of activities
Approaches to Human Motion Recognition

- **Learning based**
  - Classification of an unknown gesture or activity is done by comparing with a pre-recorded template motion automatically via pattern recognition

- **Algorithmic (rule) based**
  - A gesture or an activity is recognized based on a set of manually defined rules
Approaches to Human Motion Recognition

- **Learning-Based Recognition**
  - Direct Matching
    - DTW, etc.
  - Model-Based Matching
    - Various Machine Learning Methods
- **Algorithmic (Rule-Based) Recognition**
  - Non ML-Based Kinematic Modeling
Algorithmic Recognition

- Algorithmic-based recognition is popular in gaming and healthcare applications
  - Gestures and/or activities are usually very well defined, relatively simple, and repetitive in nature
  - Each gesture or activity normally has a predefined starting and ending pose
  - For rehabilitation exercises, rules are primarily defined to assess the correctness of movements rather than to classify them
  - Rules are predominately expressed in terms of joint angles

- Limitations
  - Rules have to be carefully defined by experts and expressed in implementable form
  - Gesture/activity has to be simple enough to be defined in terms of a set of implementable rules
  - Parameters used in the rules for boundary conditions must be manually tuned
Real-Time Rule-Based Assessment for Human Activities

- We recently introduced a set of basic rule elements that can be used to define correctness rules for human activities recognition and assessment
- We also provided a guide on how to develop such rules
- The rules are encoded using eXtensible Markup Language (XML) for extensibility and customizability
- The rules have three different types:
  - Rules for dynamic movement
  - Rules for static poses
  - Rules for movement invariance
Specification of Correctness Rules

- Rules for dynamic movement
  - Each rule is expressed in terms of the sequence of reference configurations of a particular joint or body segment that delineate monotonic segments of each iteration
  - Use finite state machine to track the state of a dynamic rule

- Rules for static poses
  - Some exercises only involve stationary poses
  - It is also possible for some body parts to remain stationary at their desirable positions while other parts are moving in some other exercises

- Rules for movement invariance:
  - Each of which defines the requirement for a moving body segment that must be satisfied during every iteration of the exercise
Encoding of Rules

```xml
<CorrectnessRules>
  <ExerciseName>...<ExerciseName>
  <DynamicRule> ... </DynamicRule>
  <DynamicRule> ... </DynamicRule>
  ...
  <DynamicRule> ... </DynamicRule>
  <StaticRules> ... </StaticRules>
  <InvarianceRules> ... </InvarianceRules>
</CorrectnessRules>

<DynamicRule>
  <Configuration> ... </Configuration>
  <Configuration> ... </Configuration>
  ...
  <Configuration> ... </Configuration>
</DynamicRule>

<Configuration>
  <Type>"JointAngle"</Type>
  <CenterJoint>"JointName"</CenterJoint>
  <DownstreamJoint>"JointName"</DownstreamJoint>
  <UpstreamJoint>"JointName"</UpstreamJoint>
  <Angle>"AngleValue"</Angle>
  <Tolerance> "ToleranceValue"</Tolerance>
  <MaxDuration>... </MaxDuration>
  <MinDuration>... </MinDuration>
</Configuration>
```
Example Rules: Registration & Back-bending

```xml
<RegisterRules>
  <Configuration>
    <Type>BoneOrientation</Type>
    <AlertBody>"Registration"</AlertBody>
    <DownstreamJoint>"WristLeft"</DownstreamJoint>
    <UpstreamJoint>"ElbowLeft"</UpstreamJoint>
    <Plane>"Transverse"</Plane>
    <AlphaAngle>"0"</AlphaAngle>
    <MaxAngleDeviation> "20" </MaxAngleDeviation>
  </Configuration>
</RegisterRules>

<ActivityRules>
  <Configuration>
    <Type>BoneOrientation</Type>
    <AlertBody>"Bend"</AlertBody>
    <DownstreamJoint>"HipCenter"</DownstreamJoint>
    <UpstreamJoint>"ShoulderCenter"</UpstreamJoint>
    <Plane>"Transverse"</Plane>
    <AlphaAngle>"0"</AlphaAngle>
    <MinAngleDeviation> "30" </MinAngleDeviation>
  </Configuration>
</ActivityRules>
```
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Training

- In October 2016, 38 STNAs used PACTS as part of their annual competence training at Jennings Center for Older Adults

Pictures taken using a smart phone, not the Kinect system!
Training: Experimental Result

- 38 nursing aids tried out our system after they have received lecture-based and hands-on training
- Our system logged a total of 503 wrong activities over the span of 2 hours and 53 minutes
  - The sum of the durations for all sessions when a participant remained registered with our system
- The participants made about 3 wrong activities per minutes while performing the three bedside care tasks
## Survey Result

<table>
<thead>
<tr>
<th>QUESTIONS</th>
<th># Yes</th>
<th># No</th>
<th># NR</th>
<th>Positive Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. Did the vibrating watch help you know when you were using poor body mechanics during bedside care?</td>
<td>36</td>
<td>2</td>
<td>0</td>
<td>95%</td>
</tr>
<tr>
<td>Q2. Do you think this system would be helpful when first learning good body mechanics?</td>
<td>36</td>
<td>1</td>
<td>1</td>
<td>95%</td>
</tr>
<tr>
<td>Q3a. Did you mind wearing the smart watch?</td>
<td>4</td>
<td>32</td>
<td>2</td>
<td>84%</td>
</tr>
<tr>
<td>Q3b. Was the vibrating good way to be notified when you were doing something incorrectly?</td>
<td>29</td>
<td>1</td>
<td>8</td>
<td>76%</td>
</tr>
<tr>
<td>Q4a. Did it ever vibrate when you thought you were moving correctly?</td>
<td>23</td>
<td>14</td>
<td>1</td>
<td>See Explanation</td>
</tr>
<tr>
<td>Q4b. If so, was this a problem for you?</td>
<td>2</td>
<td>18</td>
<td>18</td>
<td>See Explanation</td>
</tr>
<tr>
<td>Q5. Did you mind having our system record your body positions while practicing bedside care activities?</td>
<td>5</td>
<td>33</td>
<td>0</td>
<td>87%</td>
</tr>
<tr>
<td>Q6. Was it hard to start the session by registering (pushing button and then both arms up gesture)?</td>
<td>6</td>
<td>32</td>
<td>0</td>
<td>84%</td>
</tr>
<tr>
<td>Q7. Did using our system make practicing more fun or interesting than when you normally review how to use correct body mechanics?</td>
<td>34</td>
<td>4</td>
<td>0</td>
<td>89%</td>
</tr>
</tbody>
</table>
Survey Result

- Q4a. Did it ever vibrate when you thought you were moving correctly?
  - The reports of false positives are probably due to the fact that some nursing assistants did not even realize that they were bending their back while performing the designated tasks.

- Q4b. If so, was this a problem for you?
  - As many as 18 participants indicated that they wouldn’t mind receiving false alerts (only two expressed that they would be upset).
  - This shows that nursing assistants are quite tolerant to imperfection in technology-based solutions.
Survey Result: Comments Left by Participants

+ Great idea! Thanks for the experience
+ Anything to help prevent injuries. I’m in the know and happy with
+ I think it’s a great invention
+ It is a very great experience, and I would recommend it to be used
+ I think it is very unique, and I would love to wear a watch just to know if my body mechanics are right. It would be great on myself and body. Thanks for the experience
+ Loved it
- Smart watch needs to be updated, I think
- Need instant corrective procedure right after a buzz
Major Findings of the Training Study

- The majority of the nursing assistants engaged in poor body mechanics frequently when performing the designated tasks, which indicated that traditional training is not rigorous and may fail to accomplish its purpose.
- Most participants expressed positive attitude towards using our system for competency training as well as during their jobs to reduce the risk of injuries.
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Field Testing

- An 80-day field test has been done at Jennings Center for Older Adults in early 2017 with 6 rooms and 7 STNAs.

Pictures taken using a smart phone, not the Kinect system!
System Redesigned for the Field Study

- System requirements
  - A nursing aids might go to two or more rooms. Hence, they must be continuously tracked wherever they go
Improving Usability with a Lease-Based Mechanism

- Manual registration is cumbersome
- Body-geometry based biometrics for automatic registration does not work reliably
  - 10 segments: cervical spine, thoracic spine, left/right arm, left/right forearm, left/right thigh, left/right leg
- Still use manual registration, but each manual registration comes with a 30-minutes lease
  - Within the lease period, a nursing aid would be automatically registered when she leaves the room and comes back
Improving Usability with a Lease-Based Mechanism
Usability Improvement

<table>
<thead>
<tr>
<th>Room Number</th>
<th>Total Registered Duration</th>
<th>Total Wrong Activity Duration</th>
<th>Total Number of Wrong Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.268 hours</td>
<td>0.279 hours</td>
<td>427</td>
</tr>
<tr>
<td>2</td>
<td>3.526 hours</td>
<td>0.034 hours</td>
<td>575</td>
</tr>
<tr>
<td>3</td>
<td>1.486 hours</td>
<td>0.321 hours</td>
<td>345</td>
</tr>
<tr>
<td>4</td>
<td>2.854 hours</td>
<td>0.509 hours</td>
<td>620</td>
</tr>
</tbody>
</table>
Field Study Survey

- Q1: “Did you mind wearing the smartwatch/carrying the smartphone?”
- Q 2: “Did wearing the smartwatch itself interfere with your job duties?”
- Q 3: “Did the manual registration step interfere with your job duties?”
- Q 4: “Did you ever have problems getting the phone to ’wake up’, connect to the internet, and/or getting the watch face activated/to the correct screen?”
- Q 5: “Did the smart watch/phone maintenance (picking it up in the morning, charging, taking on and off, etc.) interfere with your job duties?”
- Q 6: “Did the vibrating watch help you know when you were using poor body mechanics during bedside care?”
- Q 7: “Do you think this system would be helpful when first learning good body mechanics?”
Field Study Survey

- Q 8: “Do you think that using the smart watch/Kinect system resulted in any changes in your using correct body mechanics during your job tasks?”
- Q 9: “Was the vibration a good way to be notified when you were doing something incorrectly?”
- Q 10: “Did the watch ever vibrate when you thought you were moving correctly?”
- Q 11: “If so, was this a problem for you?”
- Q 12: “Did you ever feel like you were doing incorrect movements without any feedback (vibration) from the smartwatch?”
- Q 13: “Did you mind having the Kinect camera record your body positions while doing bedside care activities?”
Field Study Survey Result

![Bar Chart]

The bar chart shows the survey results for different questions (Q1 to Q13) with categories ranging from 'Very Much/Often' to 'No Not At All'. The chart indicates the percentage of responses for each question across the four categories.
Field Study Survey Result

- All seven participants are very supportive in using PACTS to improve their body mechanics
- The survey does confirm our observation during the field test that there are several major areas that need to be improved, particularly
  - the manual registration and
  - the non-compliance activity detection accuracy
Field Study Survey Comment

- “It helps me to realize how I can hurt myself by moving residents wrong to transfer a resident”.
- “I think it would be a good idea”.
- “I think it should be repeated once it’s working properly. It would be a great source for proper body mechanics”.
- “It was a good experience”.
- “It was nice to participate”.
- “I enjoyed the opportunity but it needs a little fixing”.
- “Thanks for thinking of ways to keep us safe”.
- “It was different and I enjoyed it”.

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Further Development of PACTS

- Increase usability of the system: biometric based automatic registration of users
- Increase tracking reliability: incorporate machine learning
- Adding a supporting mobile app with essential services:
  - Mobile app for users to display progress made and performance
  - A private cloud server for data aggregation and analytics
- Extend back-bending detection to a digital analytics platform for objective care performance assessment
Conclusion

- PACTS is the only product on the market that can reliably track body mechanics while an STNA is doing her job
  - Lumo Lift is a competing product that could only track static postures
- PACTS can be used as a vehicle to build an environment of care
  - Healthier and happier STNAs would lead to higher quality of care
  - Higher quality of care would lead to better customer satisfaction, which in turn would lead to potentially more customers (patients)
  - Healthier and happier STNAs would lead to less turn-over (better retention) and increased access to staff hiring