Kinect Based Motion and Breath Monitoring for Frailty Syndrome Rehabilitation

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Kinect Based Motion and Breath Monitoring for Frailty Syndrome Rehabilitation

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計畫名稱：智慧型叢集式能力回復復健系統之雲端復健驗證與評估系統建構及研究
Outline

1. Introduction

2. Motion monitoring
   - Depth image calibration
   - Joints re-location
   - Experiment results

3. Breath monitoring
   - Experiment results

4. Conclusions & Future work
Introduction – Background

• With the development of the medical technology, the life expectancy of human being is continuously increasing.

• Aging leads the muscle losses in physical strength, causing the Frailty Syndrome.
Introduction – Background

• An effective rehabilitation requires patients to have correct start positions and to do the exercise completely.

• During rehabilitation, the breath condition has to be monitored to make sure the safety of the patient.

• Currently, the rehabilitation monitoring is done by doctors causing less efficiency, and increasing the loading of doctor.
Introduction – Motivation

• To help doctors monitor the motion and breath conditions of patients during the rehabilitation, an automatic rehabilitation monitor system is developed in our project.

• To achieve the goal of rehabilitation monitoring, the RGB-D camera, Kinect V2 released by Microsoft, is used.
Motion monitoring
Motion monitoring

- **Goal**
  - The joints have to be tracked stably
  - The detected angles have to be correct

- **Problem**
  - The depth error caused by the depress angle
  - The detected skeleton will be unstable when the joints of patient are covered or patient holds the equipment

- **Proposed solution**
  - Depth image calibration
  - Ankle re-locate
Motion monitoring – Depth calibration

• Originally, the application of Kinect is focus on the related position of joints, however, in our case, we need the accurate angle of joints.

• Therefore, the calibration need to be conducted the distance between the object and the camera.

• Depth calibration
Motion monitoring – Depth calibration

Depress angle 10 degree

Before calibration

After calibration

Depress angle 30 degree
## Motion monitoring – Depth calibration

<table>
<thead>
<tr>
<th></th>
<th>Maximum error</th>
<th>Average error</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance</strong></td>
<td>1500 mm (1.5m)</td>
<td></td>
</tr>
<tr>
<td><strong>Depress angle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td>396</td>
<td>9</td>
</tr>
<tr>
<td>30°</td>
<td>672</td>
<td>129</td>
</tr>
<tr>
<td><strong>Before calibration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10°</td>
<td>89</td>
<td>9</td>
</tr>
<tr>
<td>30°</td>
<td>215</td>
<td>16</td>
</tr>
<tr>
<td><strong>After calibration</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Caused by floor or corner*
## Motion monitoring – Depth calibration

### Comparison of detected angle

<table>
<thead>
<tr>
<th></th>
<th>Elbow</th>
<th>Knee</th>
<th>Hip</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Set up Depress angle</strong></td>
<td></td>
<td>25°</td>
<td></td>
</tr>
<tr>
<td><strong>Before calibration</strong></td>
<td>65°</td>
<td>92°</td>
<td>93°</td>
</tr>
<tr>
<td><strong>After calibration</strong></td>
<td>75°</td>
<td>103°</td>
<td>99°</td>
</tr>
<tr>
<td><strong>Deviation</strong></td>
<td>10°</td>
<td>11°</td>
<td>6°</td>
</tr>
</tbody>
</table>
Ankle re-location
Motion monitoring – Ankle re-location

• **Anchor point (type 1): the joint is covered**
  – **Find contour**
    • The method is same as hand relocate
  – **Find convex hull**
    • Find the smallest polygon to enclose the contour
  – **Find the defect area**
    • The defect area is bounded by the contour between two continuous convex hull point
  – **Find the defect point**
    • The defect point is the deepest point in the defect area
    • The defect point could locate the y of the ankle
  – **Find anchor point**
    • The x of anchor point is refer to the knee.x
    • The y of anchor point is located by (defect point.y+5)
    • The z of anchor point is finding the corresponding depth value in depth map on position (x,y)
Motion monitoring – Ankle re-location

Defect point
Motion monitoring – Ankle re-location

• Anchor point (type 2): The part of feet are covered
  – The anchor points are the intersection point of feet and machine
Breath monitoring
Breath monitoring – Basic concept

• **Inhalation**
  – Diaphragm contrast
  – Lung expand
  – Chest expand

• **Exhalation**
  – Diaphragm relax
  – Lung contrast
  – Chest contrast
Breath monitoring – Basic concept

- **Breathing frequency detection**
  - To detect the breath, we track the feature points on the chest. According to the movement of feature points, the breathing signal is acquired.
Breath monitoring – Lucas-Kanade algorithm

- **Lucas-Kanade algorithm** is an algorithm that can track the object having tiny movement.

- The movement of the feature points caused by breath is extremely small, so Lucas-Kanade algorithm is suitable method to be applied.
Breath monitoring – Butterworth filter

• The signal acquired from Lucas-Kanade algorithm includes signal of breath, motion and noise

• To capture the breathing signal, the filter is needed to filter out the signal with certain frequencies

• The Butterworth filter is applied which can use a less order and less computing time to process the signal
Experiment results
Feature point in different region before filtering

- Face
- Neck
- Shoulder
- Chest
Feature point in different region after filtering

- **Face**
- **Neck**
- **Shoulder**
- **Chest**
Different number of feature point before filtering

one

three

ten

cfive
Different number of feature point after filtering

one

five

three

ten
Simulate the patient breathing frequency increasing suddenly

Before filter

After filter

Normal Breath  Increasing Breath

Normal Breath  Increasing Breath
Compare result between breathing detection and reality

<table>
<thead>
<tr>
<th>Name</th>
<th>Gender</th>
<th>Average breath rate</th>
<th>Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eurin</td>
<td>F</td>
<td>14.6</td>
<td>15</td>
</tr>
<tr>
<td>Teresa</td>
<td>F</td>
<td>16.8</td>
<td>16</td>
</tr>
<tr>
<td>Jenny</td>
<td>F</td>
<td>9.3</td>
<td>9</td>
</tr>
<tr>
<td>Wendy</td>
<td>F</td>
<td>11.8</td>
<td>12</td>
</tr>
<tr>
<td>Nancy</td>
<td>F</td>
<td>17.4</td>
<td>17</td>
</tr>
<tr>
<td>Jason</td>
<td>M</td>
<td>9.9</td>
<td>10</td>
</tr>
<tr>
<td>Jaky</td>
<td>M</td>
<td>16.6</td>
<td>16</td>
</tr>
<tr>
<td>Cylor</td>
<td>M</td>
<td>11.7</td>
<td>12</td>
</tr>
<tr>
<td>James</td>
<td>M</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Paul</td>
<td>M</td>
<td>17.2</td>
<td>18</td>
</tr>
</tbody>
</table>
Breath detection on the rehabilitation equipment
Conclusions and Future work
Conclusions

• Reliable
  – The experiment result of motion monitoring shows that the system can track the interesting joints stably even when the occlusion occurs
  – The experiment result of breath monitoring shows that the system can detect the breath rate correctly when the exercise is executing

• Simple
  – The system developed only requires a Kinect to be the input device which is connected to the laptop with a standard configuration
  – With the simple system can be set up or moved easily

• Comfortable
  – Instead of the wearable device, the non-contact method is employed and makes the patients feel more comfortable and convenient
Future work

• For motion monitoring, a new trained skeleton detection system can be created which considers occlusion of skeleton during the rehabilitation

• All the monitoring data can be stored on the cloud which can be a strong reference for analyzing the treatment of Frailty Syndrome

• Build an Augmented Reality rehabilitation system to lead patients to do rehabilitation
Thanks for your listening
Motion monitoring – Depth calibration

- Calibrate the depth data

\[ d_{\text{calibration}} = d \times \frac{\cos(\theta + \beta)}{\cos(\theta)} \]

- \(\beta\) is the depress angle of Kinect

- \(\theta\) is the vision angle of Kinect
Breath monitoring – Lucas-Kanade algorithm

Brightness constancy assumption

\[ I(x, y, t) = I(x + dx, y + dy, t + dt) \]

Taylor Series

\[ I(x, y, t) = I(x, y, t) + \frac{\partial I}{\partial x} dx + \frac{\partial I}{\partial y} dy + \frac{\partial I}{\partial t} dt \]

\[ \Rightarrow \frac{\partial I}{\partial x} dx + \frac{\partial I}{\partial y} dy + \frac{\partial I}{\partial t} dt = 0 \]

\[ \Rightarrow I_x dx + I_y dy + I_t dt = 0 \]

\[ \Rightarrow I_x u + I_y v = -I_t \]  

Optical Flow Equation
Breath monitoring – Lucas-Kanade algorithm

\[ I_x u + I_y v = -I_t \quad \text{Optical Flow Equation} \]

Assumption: the motion is tiny, so the brightness variation of neighborhood is same as (x,y)

\[ I_{x1} u + I_{y1} v = -I_{t1} \]
\[ \vdots \]
\[ I_{x9} u + I_{y9} v = -I_{t9} \]

\[
\begin{bmatrix}
I_{x1} & I_{y1} \\
\vdots & \vdots \\
I_{x9} & I_{y9}
\end{bmatrix}
\begin{bmatrix}
u \\
v
\end{bmatrix}
= 
\begin{bmatrix}
-I_{t1} \\
\vdots \\
-I_{t9}
\end{bmatrix}
\]

\[ AX = b \]
\[ A^T AX = A^T b \]

\[ X = (A^T A)^{-1} A^T b \]

\[ \min \sum_i (I_{xi} u + I_{yi} v + I_t)^2 \quad \text{Least squares Fit} \]
Breath monitoring – Lucas-Kanade algorithm

\[ u = \frac{-\sum I_{yi}^2 \sum I_{xi} I_{yi} + \sum I_{xi} I_{yi} \sum I_{yi} I_{ti}}{\sum I_{xi}^2 \sum I_{yi}^2 - (\sum I_{xi} I_{yi})^2} \]

\[ v = \frac{\sum I_{xi} I_{ti} \sum I_{xi} I_{yi} - \sum I_{xi}^2 \sum I_{yi} I_{ti}}{\sum I_{xi}^2 \sum I_{yi}^2 - (\sum I_{xi} I_{yi})^2} \]