INTRODUCTION

Human gait recognition algorithms are traditionally presented and tested with image sources comparable to those that would be utilized in an operational setting (e.g., 2D surveillance video footage for a system intended to be used in a bank) [1]. Such reports provide an apt depiction of recognition performance for the particular image source and recognition algorithm combination, but it can be difficult to extrapolate and predict the performance of the same recognition approach with varying image fidelity (e.g., different pixel resolutions). Specifically, as in the case of a model-based recognition solution, it would be difficult to determine if the correct classification rate was most greatly affected by image resolution, silhouette extraction, model fitting, or match score selection. However, by utilizing the high-fidelity movement information provided by 3D motion analysis, different environmental conditions can be simulated to evaluate their impact on gait recognition performance. Accordingly, the purpose of this experiment was to study the effect of simulated pixel resolution on gait recognition performance using high-resolution motion capture data.

METHODS

A sample of 50 healthy adult subjects was used in this study (22±1 years, 175±10 cm, 75±15 kg). 3D motion analysis data were collected for each subject using a high-resolution passive optical motion capture system (MAC, Santa Rosa, CA). The marker set was chosen so that the major joint centers were identified and the 3D marker trajectories were temporally normalized to 100% of the gait cycle [2]. Six spatial resolution conditions were simulated by applying uniform noise to the raw motion capture data at magnitudes of 0cm, 2cm, 4cm, 6cm, 8cm, and 10cm. Gait recognition performance was evaluated using a Monte Carlo approach that involved 100 iterations of recognition testing at each level of uniform noise (600 total tests).

Each gait recognition test required the random selection of two different gait cycles from each subject which were then separated into two matching databases (template and unknown). Match scores were calculated between all gait cycles in the template database and all gait cycles in the unknown database to yield 50 true match scores and 2,450 non-match scores (50^2 total comparisons). To validly compare two different gait cycles from either the same or different subjects, 3D marker data were made local to the mid-pelvis, divided by mid-shoulder height, and rotated so that all subjects walked in the positive x-direction. Match scores were determined for each comparison of two gait cycles by calculating the sum Euclidean distance for all 3D landmarks at each percent of the gait cycle.

Gait recognition performance was quantified by using the true match scores and non-match scores from each test to calculate percent correct classification rates (%CCR), the area under the Receiver Operative Characteristic (ROC) curve (AUC), and the Cumulative Match Characteristics (CMC) (Figure 1 and Table 1). Additionally, all data are presented as averages of the 100 recognition tests at each noise level. CMC curves depict the percent of correct matches in the top n rank. Accordingly, the percent of correct matching in the top 1 rank corresponds to the %CCR. For ROC curves, an area of 1.0 indicates perfect discrimination and an area of 0.5 indicates that there is no discrimination power.
RESULTS AND DISCUSSION

The application of 0cm, 2cm, and 4cm magnitude uniform noise had little effect on gait recognition performance with %CCR’s greater than 99.8% and AUC’s greater than 0.998 (Table 1). These results indicate near perfect gait matching for this sample of subjects. Recognition performance began to drop substantially with the addition 6cm, 8cm, and 10cm of uniform noise resulting in %CCR’s of 95.6%, 73.7% and 48.9%, respectively. Similarly, changes in AUC’s indicated considerable reduction in discrimination performance at the higher noise levels.

Figure 1: AVG CMC curves for each uniform noise level (Note: 0cm and 2cm curves start at 100% and follow the top edge of the figure).

The CMC curves for 0cm, 2cm, and 4cm noise levels indicate that the correct matches were in the top 2 rank for 100% of recognition tests (Figure 1). For the these conditions of smaller noise levels, the CMC measures show that the true match scores were always in the top 4% of match scores. 100% of correct matches for the 6cm, 8cm, and 10cm noise levels occurred at the 5, 19, and 30 ranks, respectively. These values correspond to true match scores that are consistently in the top 10%, 38%, and 60% of all match scores for a given recognition test.

Although a %CCR of 48.9% would seem to indicate that there is no minimal discrimination power for correct matching at the 10cm noise level, the associated AUC value of 0.869 demonstrates that the matching is significantly greater than chance (p < 0.001 compared to AUC of 0.5). Further, it should be noted that at noise levels approaching 10cm, there is still the appearance of overall gait motion throughout the gait cycle. Since it cannot be expected that joint centers will continue to align at this noise level, it may be more appropriate to evaluate the overall change in shape of the ‘noisy’ point cloud instead of attempting to identify individual body segments. This type of whole-body shape change analysis is more typical of motion-based gait recognition approaches [3].

CONCLUSIONS

This study demonstrates the utility of simulating different sensor and environmental conditions for gait recognition performance prediction using ground truth motion capture data. Similar analyses could be used to identify limitations associated with sensor viewing perspective, to compare the sensitivity of two competing systems, and to identify the conditions for which model-based or motion-based gait recognition solutions are most appropriate.

REFERENCES


Table 1: Average gait recognition performance for each level of uniform noise simulation

<table>
<thead>
<tr>
<th>Uniform Noise Level (cm)</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>%CCR</td>
<td>100</td>
<td>100</td>
<td>99.8</td>
<td>95.6</td>
<td>73.7</td>
<td>48.9</td>
</tr>
<tr>
<td>AUC</td>
<td>&gt; 0.999</td>
<td>&gt; 0.999</td>
<td>0.998</td>
<td>0.983</td>
<td>0.936</td>
<td>0.869</td>
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