Retrieving Target Gestures Toward Speech Driven Animation with Meaningful Behaviors

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Motivation

• Creating naturalistic nonverbal behaviors is important for conversation agents (CAs)
  • Animations
  • Entertainment
  • Virtual reality

• More than 90% human gestures occur while speaking

• Complex relationship between gestures and speech
  • Cross modality interplay
  • Synchronization
Previous studies on co-verbal gesture synthesis

- Rule based frameworks [Cassell et al., 1994; S. Kopp 2006]
  - Define rules based on the semantics
  - Synchronization is challenging
  - The variation is limited

- Speech prosody driven systems [Levine et al., 2010; Busso et al. 2007]
  - Learn movements and their synchronization from recordings
  - Capture the variation in the data
  - Disregard the context

- Combination of data driven and rule based methods [Stone et al. 2004, Marsella et al. 2013, and Sadoughi et al. 2014]
  - Utilizing the advantages and overcoming the disadvantages
Previous studies using both approaches

• Stone et al., [2004]
  • Search for combination of speech and motion units with similar meaning to speech and planned behaviors

• Marsella et al., [2013]
  • Create appropriate gestures depending on the communicative goal of the utterance
  • Use speech prosody features to capture the stress and emotional state of the speaker

• Sadoughi et al., [2014]
  • Constrain a speech driven animation model based on semantic labels (e.g., Question and Affirmation)
Our Vision

• Creating a bridge between rule based systems and data driven framework

• SAIBA framework [Kopp et al., 2006]:

  Intent Planning → Behavior Planning → Behavior Realization

• Considering the target gesture for synthesis is known

  • Synthesizing behaviors that are **timely aligned and coordinated with speech**
  
  • Synthesizing behaviors that **convey the right meaning**
Objective of This Study

Annotating few samples of a prototypical gesture

Retrieving similar gestures to the examples

Training the Behavior Realization model

Goal: Retrieve examples of prototypical gestures
Gesture Segmentation and Classification

- Kovar et al. [2004]
  - Find gestures similar to a target gesture using DTW and use retrieved samples to expand the training samples

- Joshi et al. [2015]
  - Train a random forest model using video and depth map of the joints
  - They use a multi-scale window sliding for new data (forward search).

- Zhou et al. [2013]
  - Hierarchical aligned cluster analysis (HACA) to dynamically segment and cluster motion capture data into movement primitives
MSP-AVATAR Corpus

- Multimodal database comprising:
  - Motion capture data
  - Video camera
  - Speech recordings

- Four dyadic interaction between actors
  - We motion captured one of the actors

- Database rich in terms of discourse functions
Discourse Functions in MSP-AVATAR corpus

- Discourse functions that elicit specific gestural behaviors
- Selection guided by previous studies
  - Poggi et al [2005]
  - Marsella et al. [2013]
- 2-5 scenarios per discourse function
- We used the recordings from one of the actors (66 mins)
Prototypical Behaviors

- **So-What**
- **To-Fro**
- **Regress**

**Nods**

**Shakes**

<table>
<thead>
<tr>
<th>So-What</th>
<th>To-Fro</th>
<th>Regress</th>
<th>Nods</th>
<th>Shakes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples_{train}</td>
<td>14</td>
<td>27</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>Samples_{test&amp;developing}</td>
<td>21</td>
<td>29</td>
<td>73</td>
<td>138</td>
</tr>
</tbody>
</table>
Gesture Retrieval Framework
Overview

• Temporal reduction
  • The data is captured by 120 fps, and may have redundant information

• Gesture segmentation
  • Gestures can happen with arbitrary durations

• Gesture detection
  • Binary decision per segment
Temporal Reduction

- Reduce the complexity of the system
  - Inspired by Zhou et al. [2013]
- Non-uniform downsampling
  - Based on Linde-Buzo-Gray vector quantization (LBG-VQ)
  - Discard consecutive frames up to 5 frames if they are in the same cluster
Gesture Segmentation

- Window size ($L_w$)
- Minimum length of search segment ($L_{min}$)
- Maximum length of search segment ($L_{max}$)
- Increment frames between iterations
  - $\Delta = (L_{max} - L_{min})/30$
- One winner per window
Gesture Detection

- One-class SVMs
  - Efficiently reduce the number of candidates
- Dynamic time alignment alignment kernel (DTAK)
  - To increase precision
One-Class SVMs

- Only positive samples
- Limited number of training instances
  - Train separately for different features
  - Fuse the classifiers using the AND operator
- Feature selection by cross-validation
  - Sort features according to accuracy
  - Remove one by one to get accuracy $> 0.85$

\[
\text{STD(Joint 1-x)} \rightarrow \text{One-Class SVMs} \\
\text{STD(Joint 1-y)} \rightarrow \text{One-Class SVMs} \\
\text{STD(Joint 1-z)} \rightarrow \text{One-Class SVMs} \\
\text{STD(Joint 2-x)} \rightarrow \text{One-Class SVMs} \\
\text{STD(Joint 2-y)} \rightarrow \text{One-Class SVMs} \\
\text{STD(Joint 2-z)} \rightarrow \text{One-Class SVMs} \\
\vdots \\
\text{STD(Joint n-x)} \rightarrow \text{One-Class SVMs} \\
\text{STD(Joint n-y)} \rightarrow \text{One-Class SVMs} \\
\text{STD(Joint n-z)} \rightarrow \text{One-Class SVMs}
\]
DTAK by Zhou et al. [2013]

- DTAK finds similarity between two segments regardless of their length in term of a kernel (Gaussian)

\[ K_{i,j} = \exp\left(-\frac{\|x_i - y_j\|^2}{2\sigma^2}\right) \]

\[ \tau(X, Y) = \frac{u_{l_x,l_y}}{l_x + l_y}, u_{i,j} = \max\left\{ u_{i-1,j} + K_{i,j}, u_{i-1,j-1} + 2K_{i,j}, u_{i,j-1} + K_{i,j} \right\} \]

- Final score: the median of the similarity measure to the training examples

- Find a threshold by maximizing the F-score on the developing set
Evaluation of Retrieved Gestures

- Precision in head gestures > 0.85
- Precision in hand gestures > 0.59

Head vs. hand gestures:
- Less complex

<table>
<thead>
<tr>
<th>Gesture</th>
<th>19 Sessions</th>
<th>Precision [%]</th>
<th>Test &amp; Developing Sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Shake</td>
<td>91.32</td>
<td></td>
<td>Head Shake 95.65 42.31</td>
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<tr>
<td>Head Nod</td>
<td>85.04</td>
<td></td>
<td>Head Nod 87.10 61.36</td>
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<tr>
<td>To-Fro</td>
<td>59.52</td>
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<td>To-Fro 67.86 67.86</td>
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<tr>
<td>So-What</td>
<td>76.68</td>
<td></td>
<td>So-What 76.92 47.62</td>
</tr>
<tr>
<td>Regress</td>
<td>71.77</td>
<td></td>
<td>Regress 78.85 57.75</td>
</tr>
</tbody>
</table>
The histograms of the discourse functions vs. behaviors

- Different gestures appear with different frequencies across different discourse functions
- Shakes happen in Negation more than in Affirmation
- Nods happen in Affirmation more than in Negation
- So-What happens more in Question than other discourse functions
Modeling the gestures

• Gesture retrieval \(\rightarrow\) more samples to train the models

• Assumptions
  • Target gesture is known
  • Speech prosody features are known

• How to model the gesture?
  • Speech driven models
  • Training: \textit{speech prosody features, motion capture data}, and \textit{prototypical gesture}
  • Testing (synthesis): \textit{speech prosody features}, and \textit{prototypical gesture}

<table>
<thead>
<tr>
<th>Gesture</th>
<th>#Retrieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Shake</td>
<td>287</td>
</tr>
<tr>
<td>Head Nod</td>
<td>535</td>
</tr>
<tr>
<td>To-Fro</td>
<td>223</td>
</tr>
<tr>
<td>So-What</td>
<td>114</td>
</tr>
<tr>
<td>Regress</td>
<td>262</td>
</tr>
</tbody>
</table>
Speech driven animation

• Dynamic Bayesian Network
• Shared hidden variable between speech and head/hand
• Constrained on gestures
• Add the constraint node as parent of the hidden state:
  • More robust to unbalanced data
  • Learns separately:
    • Prior probabilities of the gestures
    • The affect of gestures on transition matrices
HEAD Synthesis

For illustration gesture is always “on”
HAND Synthesis

For illustration gesture is always “on”

To-Fro

So-What

Regress
Conclusions

- This paper proposed a framework to automatically detect target gestures
  - Using few examples in a motion capture database
  - The advantage of this framework is its flexibility to retrieve any gesture
- The approach jointly solved the segmentation and detection of gestures
  - Multi scale windows
  - Two-step detection framework
- We used the retrieved samples to synthesize novel realizations of these gestures
  - Speech-driven animations constrained by these target behaviors
Future Work

• Explore the minimum number of examples per gesture to achieve acceptable detection rates

• Using adaptation to generalize the models to retrieve similar gestures from different subjects
  • With more data, more restrictive threshold can be considered

• Explore the effects of detection errors on the performance of the speech driven models
Multimodal Signal Processing (MSP)

• Questions?

http://msp.utdallas.edu/
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