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Distant Speech Recognition in a Smart Home: Comparison of Several Multisource ASRs in Realistic Conditions

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Abstract

While the smart home domain has become a major field of application of ICT to improve support and wellness of people in loss of autonomy, speech technology in smart home has, comparatively to other ICTs, received limited attention. This paper presents the SWEET-HOME project whose aim is to make it possible for frail persons to control their domestic environment through voice interfaces. Several state-of-the-art and novel ASR techniques were evaluated on realistic data acquired in a multiroom smart home. This distant speech French corpus was recorded with 21 speakers playing scenarios including activities of daily living in a smart home equipped with several microphones. Techniques acting at the decoding stage and using a priori knowledge such as DDA give better results (WER=8.8%, Domestic F-measure=96.8%) than the baseline (WER=18.3%, Domestic F-measure=89.2%) and other approaches.

Index Terms: home automation, smart home, distant speech, multisource ASRs, keyword detection

1. Introduction

Since the rise of Ubiquitous Computing, new ways of conceiving our home environment appeared. One of these is the development of smart homes which are habitations equipped with a set of sensors, actuators, automated devices and centralised software which control the increasing amount of household appliances ranging from lights, automatic motorised blinds. .to Hi-Fi systems, PCs, alarms systems, etc. that fit modern homes. These smart homes represent a promising solution to support the elderly and disabled persons in living in their own home as autonomously as possible. Among all the interaction and sensing technologies used in smart home, speech processing technology has a great potential to become one of the major interaction modalities in smart home. Indeed, voice interfaces are much more adapted to disabled people and the ageing population who have difficulties in moving or seeing, than tactile interfaces (e.g., remote control) which require physical and visual interaction [1, 2]. Moreover, voice command is particularly suited to distress situations. A person, who cannot move after a fall but being conscious, may have still the possibility to call for assistance while a remote control may be unreachable. Despite all this, very few smart home projects have seriously considered speech recognition in their design [1, 2]. Part of this can be attributed to the complexity of setting up this technology in a real environment and to important challenges that still need to be overcome [3].

The SWEET-HOME project has started in 2010 to address some of these challenges. One of the major issues that prevents the development of speech technology in real home setting is the poor performance of Automatic Speech Recognition (ASR) in noisy environment [3]. Indeed, ASR systems have reached correct performances with close talking microphones (e.g. head-set), but the performance decreases significantly as soon as the microphone is moved away from the mouth of the speaker. In realistic conditions, this deterioration is due to a broad variety of effects including reverberation and presence of undetermined background noise such as TV, radio and devices [4]. All these problems, related to the so called ‘distant speech’ context, should be taken into account in the home context [5].

This paper presents results of state-of-the-art and novel ASR techniques evaluated on realistic data acquired in a multiroom smart home. Before presenting our experimental framework (Section 3), the proposed techniques are described in Section 2. The experiments and results are then presented in Section 4. This paper concludes with brief remarks about the results and future work.

2. SWEET-HOME project and corpus

The SWEET-HOME project (sweet-home.imag.fr) aims at designing a new smart home system based on audio technology focusing on three main aspects: to provide assistance via natural man-machine interaction (voice and tactile command), to ease social e-inclusion and to provide security reassurance by detecting situations of distress. If these aims are achieved, then the person will be able to pilot, from anywhere in the house, their environment at any time in the most natural way possible. The targeted smart environments in which speech recognition must be performed thus include multi-room homes with one or more microphones per room set near the ceiling. This places the project in a distant-speech context where microphones may be far apart from each other and may thus record similar or very different sources. The most close projects seem to have focused mainly on one-room microphone array [1] or one or unspecified number of microphones [2, 6].

To achieve the project goals, the DOMUS smart home depicted in Figure 1 was adapted to acquire a realistic corpus and to test the developed techniques. This smart home was set up by the Multicom team of the Laboratory of Informatics of Grenoble, partner of the project. It is a thirty square meters suite flat including a bathroom, a kitchen, a bedroom and a study, all equipped with sensors and effectors such as infra-red presence detectors, contact sensors, video cameras (used only for annotation purpose), etc. In addition, seven microphones were set in the ceiling.

An experiment was conducted to acquire a representative speech corpus composed of utterances of domotic order, distress call and casual sentence. This corpus is called the SWEET-
The distance between the speaker and the closest microphone is about 2 meters. Sound data were recorded in real-time thanks to a dedicated PC embedding an 8-channel input audio card [3].

The first phase (Phase 1) consisted in following a scenario of activities without condition on the time spent and the manner of achieving them (having a breakfast, simulate a shower, get some sleep, clean up the flat using the vacuum, etc.). During this first phase, participants uttered 40 predefined casual sentences directing their voice to a particular microphone. The distance between the speaker and the closest microphone is about 2 meters. Sound data were recorded in real-time thanks to a dedicated PC embedding an 8-channel input audio card [3].

Finally, the French SWEET-HOME speech corpus is made of 862 sentences (38 minutes 46s per channel in total) for Phase 1, and 917 sentences (40 minutes 27s per channel in total) for Phase 2 all from 21 speakers. Each sentence is available for each channel and has been manually annotated on the best Signal-to-Noise Ratio (SNR) channel. The average SNR for the considered sentences of the best SNR channel is 20.3 dB (SNR is typically around 55 dB in studio record). It must be clear that the data from the 7 microphones was the only data source used in this study.

3. Proposed approaches for robust ASR

To detect domotic commands in the SWEET-HOME context, we propose a three-stage approach. The first one detects audio activity and classifies it as speech or other sound, the second one extracts the utterances using an ASR system and the last one recognizes a vocal command or a distress situation from the decoded utterances. This paper describes the two last stages, for the first stage the reader is referred to [4].

To address the issues of the SWEET-HOME context (noise, distant-speech) and to benefit from it (multiple microphones which are continuously recording) we propose to test the impact of some state-of-the-art and novel techniques that fuse the streams of information at three independent levels of the speech processing: acoustic signal enhancement, decoding enhancement, and ASRs output combination. The remaining of this section presents the implemented techniques for robust ASR and the chosen method for vocal order recognition.

3.1. Beamforming

At the acoustic level, it may be interesting to fuse the different channels in order to enhance the signal. However, a simple sum of signals would result in a worse single channel with echoes. That is why a beam-forming algorithm [8] was used to merge all channels in a single one which fed an ASR system. Beamforming involves low computational cost and combines efficiently acoustic streams to build an enhanced acoustic signal.

The acoustic beamforming algorithm is based on the weighted&sum microphone array theory. Given M microphones, the signal output $y[t]$ is computed by:

$$y[t] = \sum_{m=1}^{M} W_m[t]x_m[t] - D(m,ref)[t]$$

where $W_m[t]$ is the weight for microphone $m$ at time $t$, knowing that $\sum_{m=1}^{M} W_m[t] = 1$, the signal of the $m^{th}$ channel is $x_m[t]$ and $D(m,ref)[t]$ is the delay between the $m^{th}$ channel and the reference channel. In our experiments, the reference channel was the one with the highest SNR overall in Phase 2 and the 7 signals were entirely combined for each speaker rather than doing a sentences based combination (the tested algorithm failed with too short sentences). Once the new signal $y$ is computed, it can feed a monosource ASR stage.

3.2. Driven Decoding Algorithm

At the decoding level, a novel version of the Driven Decoding Algorithm (DDA) was applied. DDA aims to align and correct auxiliary transcripts by using a speech recognition engine [9, 10]. This algorithm improves system performance dramatically by taking advantage of the availability of the auxiliary transcripts.

DDA acts at each new generated assumption of the ASR system. The current ASR assumption is aligned with the auxiliary transcript (from a previous decoding pass). Then a matching score $\alpha$ is computed and integrated with the language model [9]:

$$\hat{P}(w_t|w_{t-1},w_{t-2}) = P^{1-\alpha}(w_t|w_{t-1},w_{t-2})$$

where $\hat{P}(w_t|w_{t-1},w_{t-2})$ is the updated trigram probability of the word $w_t$ knowing the history $w_{t-2}$, $w_{t-3}$, and $\hat{P}(w_t|w_{t-1},w_{t-2})$ is the initial probability of the trigram.

Figure 2: DDA used with two streams: the first stream allows one to drive the second stream.

We propose to use a variant of the Driven Decoding Algorithm where the output of the first microphone is used to drive the output of the second one (cf. Figure 2). This approach presents two main benefits:

- The second ASR system speed is boosted by the approximated transcript (only 0.1xRT),
• DDA merges truly and easily the information from the two streams while voting strategies (such as ROVER) do not merge ASR systems outputs.

The applied strategy is dynamic and used, for each utterance to decode, the best channel for the first pass and the second best channel for the last pass.

Figure 3: **DDA 2-level**: vocal orders are recognized from the first decoded stream which are then used to drive the decoding of the second stream

This approach was extended to take into account *a priori* knowledge about the expected utterances. The ASR system is driven by vocal orders recognized during the first pass. This method is called **DDA 2-level**: speech segments of the first pass are projected into the 3 – best vocal orders by using an edit distance (cf. 3.4) and injected via DDA into the ASR system for the fast second pass as presented in Figure 3.

### 3.3. ROVER

At the ASR combination level, a ROVER [11] was applied. ROVER is expected to improve the recognition results by providing the best agreement between the most reliable sources. It combines systems output into a single word transition network. Then, each branching point is evaluated with a vote providing the best agreement between the most reliable sources. ROVER is expected to improve the recognition results by proposing approaches

At the ASR combination level, a ROVER [11] was applied. ROVER is expected to improve the recognition results by providing the best agreement between the most reliable sources. **Phase 1** corpus. MLR adaptation is a good compromise while only a small amount of annotated data is available.

For the decoding, a 3-gram language model (LM) with a 10K lexicon was used. It results from the interpolation of a generic LM (weight 10%) and a specialized LM (weight 90%). The generic LM was estimated on about 1000M of words from the French newspapers *Le Monde* and Gigaword. The specialized LM was estimated from the sentences (about 200 words) that the 21 participants had to utter during the experiment (domotic orders, casual phrases, etc.).

### 4.2. Results

Results of the approaches are presented table 1. The ASR stage was evaluated using the Word Error Rate (WER) whereas the vocal order recognition (classification) stage was evaluated using recall/precision/F-measure triplet: the number of domotic orders is about 10. Domotic orders were manually specified by annotating all sentences. During the detection, if a marked do-
motic order is well detected, it is considered as detected. In all other cases, a detected order is considered as false detection. For each approach, the presented results are the average over the 21 speakers (plus standard deviation for the WER). For the sake of comparison, results of a baseline and an oracle baseline systems are provided. The baseline system outputs the best decoding amongst 7 ASR systems according to the highest SNR. The oracle baseline is computed by selecting the best WER for each speaker.

Table 1: WER, Domotic orders detection

<table>
<thead>
<tr>
<th>Method</th>
<th>WER $\pm$ SD</th>
<th>Domotic recall</th>
<th>Domotic precision</th>
<th>F-measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>18.3 $\pm$ 12.1</td>
<td>88.0</td>
<td>90.5</td>
<td>89.2</td>
</tr>
<tr>
<td>Oracle Baseline</td>
<td>17.7 $\pm$ 10.3</td>
<td>88.5</td>
<td>91.3</td>
<td>89.9</td>
</tr>
<tr>
<td>Beam Forming</td>
<td>19.6 $\pm$ 18.3</td>
<td>89.0</td>
<td>92.6</td>
<td>90.8</td>
</tr>
<tr>
<td>DDA +SNR</td>
<td>11.4 $\pm$ 6.5</td>
<td>93.7</td>
<td>97.3</td>
<td>95.3</td>
</tr>
<tr>
<td>DDA 2 levels+SNR</td>
<td>8.8 $\pm$ 3.7</td>
<td>95.6</td>
<td>98.1</td>
<td>96.8</td>
</tr>
<tr>
<td>ROVER</td>
<td>20.6 $\pm$ 5.5</td>
<td>85.0</td>
<td>90.0</td>
<td>87.4</td>
</tr>
<tr>
<td>ROVER 2+SNR</td>
<td>13.0 $\pm$ 6.1</td>
<td>91.3</td>
<td>95.3</td>
<td>93.3</td>
</tr>
<tr>
<td>ROVER +SNR</td>
<td>12.2 $\pm$ 6.1</td>
<td>92.7</td>
<td>97.4</td>
<td>95.0</td>
</tr>
<tr>
<td>ROVER Oracle</td>
<td>7.8 $\pm$ 2.7</td>
<td>99.4</td>
<td>98.9</td>
<td>99.1</td>
</tr>
</tbody>
</table>

5. Conclusion

Several approaches were presented to perform accurate vocal order recognition in multi-room smart-homes where audio information is captured by several microphones in a distant speech context. The proposed approaches were acting at the three main levels of the ASR task: acoustic, decoding and hypothesis selection. Some of them included a priori knowledge either dynamically computed such as the SNR or acquired off line such as the predefined domotic orders.

Results confirmed that the use of the seven microphones improved the ASR accuracy. Beamforming improved the WER (16.8%), however its performance were very close to the baseline one (18.3%). This may be due to the fact that the seven microphones are far apart from each other and might not contain enough redundancy to obtain a really enhanced acoustic signal. The Driven Decoding Algorithm gave the best performance with a 11.4% WER and 95.3% F-measure for vocal order classification. DDA results were only slightly better than the ROVER results, however DDA needs only two channels while ROVER necessitates 7 ASR systems performing concurrently to approach DDA performances. The DDA computational cost is thus very low compared to the ROVER one. Moreover, the 2-level DDA approach makes it possible to include a priori knowledge to increase performances to 8.8% WER and 96.8% F-Measure with much better stability than the baseline (3.7% WER standard deviation vs. 10.3%). However, this amelioration will be achieved only if test data contains domotic orders. This study shows that good recognition rate can be obtained by adapting classical ASR systems mixing multisource and domain knowledge. We plan to adapt these approaches to noisy conditions notably by applying source separation techniques to real daily living records composed of uncontrolled noise.

6. Acknowledgements

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7. References