Runtime Reconfigurable Beamforming Architecture for Real-Time Sound-Source Localization

Bruno da Silva*, Laurent Segers, An Braeken and Abdellah Touhafi
Description and Requirements

- Scalable architecture able to support a variable high number of digital I/O from the external sensor array.
- Real-time (< 100ms) sound source detection.
- Power efficient.

Up to 64 Orientations

Up to 52 MEMS Microphones
Sound-Source location

- Use of Delay-and Sum beamforming to detect sound sources.
- The polar steered response power (P-SRP) is displayed in a polar map.
- The main peak determines the sound-source direction.

Time delay per MIC and orientation:
The total output of the array based on the signal output of each MIC:

\[
O(\kappa, \omega) = \sum_{m=1}^{M} S_m(\omega) e^{-j\omega \Delta_m(\kappa)}
\]

The array’s power output per orientation:

\[
P(\kappa, \phi) = |O(\kappa, \phi)|^2
\]

Polar steered response power:

\[
P-\text{SRP}(\theta, \phi) = \frac{P(\theta, \phi)}{\max_{\theta \in [0,2\pi]} P(\theta, \phi)}
\]
• The PDM signal from the MICs need to be individually filtered.
• The signal also needs to be downsampled to become audio.
A Scalable Design (II)

- The Delay-and-Sum beamforming is decomposed in sub-arrays.
- Scalable solution which allows to deactivate sub-arrays.
Limitations

- Static behavior: Fixed number of orientations.
- "Slow" response: 400 ms per steering loop.
- Internal memory sharing and buffering.
- BRAMs and DSPs become the limiting resources when scaling the design.
How to reach real-time?

- Reduce the number of explored orientations.
- Unfortunately, it leads to inaccurate results.

- Solution: Dynamic angular resolution
  - Behavior based on the acoustic environment.
  - Real-time response (< 100 ms).
Runtime Reconfiguration (I)

- Use of a fast reconfiguration to reach real-time sound-source detection: CFGLUT5
- 5-input loop-up table (LUT).
- Enables the changing of the logical function of the LUT during circuit operation.
Runtime Reconfiguration (II)

- The use of a fast CFGLUT reconfiguration + different steering strategy leads to a real-time sound-source detection.

- Peak

- Increases resolution

8 Orientations → 10 Orientations → 12 Orientations
### Results & Conclusion

- A scalable design allows us to disable not only microphones but also the associated logic.

- The runtime reconfiguration allows to keep accuracy while reaching real-time.

- Only CFLUTs provide runtime reconfiguration in few clock cycles.

<table>
<thead>
<tr>
<th>Array Configurations</th>
<th>One Orientation</th>
<th>64 Orientations</th>
<th>Average Shift Strategy</th>
<th>Average Reconfigurable Shift Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-array 1 Standalone</td>
<td>6.165</td>
<td>394.560</td>
<td>104.805</td>
<td>73.980</td>
</tr>
<tr>
<td>Sub-arrays 1 &amp; 2</td>
<td>6.294</td>
<td>402.753</td>
<td>106.998</td>
<td>75.528</td>
</tr>
<tr>
<td>Sub-arrays 1 &amp; 2 &amp; 3</td>
<td>6.421</td>
<td>410.945</td>
<td>109.157</td>
<td>77.052</td>
</tr>
<tr>
<td>All Sub-arrays</td>
<td>6.550</td>
<td>419.144</td>
<td>111.350</td>
<td>78.600</td>
</tr>
</tbody>
</table>