**Advanced DSP (2024 Spring) – Quiz Instructions/Questions**

**Beamforming for Ultrasound Imaging**

We will explore the ultrasound imaging (called B-mode, Brightness mode) by processing the original RF (radio frequency) signal to obtain the final B-mode. The technique we will explore is called synthetic transmit aperture. Please read Appendix A for details. These processing includes beamforming using full dataset (i.e., all transmit-receive combinations), envelope detection, log compression and scan conversion. In this quiz, you need to complete coding of beamforming and envelope detection, as well as answer the following questions.

A MATLAB code is provided together with this quiz. Please run and complete the codes according to the instructions in the code. Please deliver BOTH the MATLAB code and your answers for five questions (PDF format) to e3. Make sure that your code is executable showing all results.

**QUESTION 1.1:** Complete the delay-and-sum beamforming code involving image formation of the image pixels in the polar coordinates. (See below)

1. the distance between each transmit (Tx) channel and the target (The variable is called Tx\_dist), and the distance between each receive (Rx) channel and the target (called Rx\_dist).

A diagram of a triangle and a triangle with a triangle and a triangle with a triangle and a triangle with a triangle and a triangle with a triangle and a triangle with a triangle and a triangle with

Description automatically generated

1. Summing up all sub-images (called subbf) corresponding to all Tx-Rx combinations to obtain the final beamformed image (called bf).
2. Envelope detection of the beamformed image (called bf\_env). Envelope detection can be done by one of the following two methods: Hilbert transform and base-band demodulation.
3. Once you complete (a)-(c), the code will generate the final image.

**What is the beamformed image without doing envelope detection (i.e., skipping step (c))? What is the beamformed image after step (d)? Can you tell the difference between the two images? Please explain your findings.**

**QUESTION 1.2:** The image frame rate using full 96 Tx events is slow because it requires 96 emissions. As explained in Appendix A, Tx events are possibly reduced while maintaining similar image quality. Can you design your own Tx event sequence (i.e., specify which Tx channels are emitted) to speed up the frame rate at the expense of slight image quality degradation? **Explore your own Tx sequence and answer how fast your frame rate could be. Justify that the image quality of your design is comparable to that of the full 96 Tx events.**

**Time-frequency analysis (TFA) for music**

TFA is perfect for music analysis. In this question set, we will improve the sound quality acquired by the parametric speaker (Google It!). Two music files, one is the original sound and the other is the parametric sound, are provided. A MATLAB code is also provided to read out these sounds and do the simple display of time waveform and spectrum. What you need to do is to provide STFT (short-time Fourier transform) results associated with the original sound and the parametric sound.

**QUESTION 2.1:** Run the code and you can see two figures. The first figure is the waveform comparison between the original sound and the parametric sound. The second figure is the spectrum comparison. **From these two figures, is there any difference between two sounds? Explain your answer.**

**QUESTION 2.2:** The spectrum shown in Question 2.1 has no timing information. So your job is to provide STFT result for two sounds.Complete the code (you can use MATLAB function “stft” or write by yourself, or other internet/ChatGPT resources), but you need to specify the four parameters: Window size, Windowing function, FFT length, and Overlapping window length between two spectrum calculations. **Show your result in dB within the time range of 0-5 seconds and the frequency range of 0-4000Hz. What is the difference between two STFT results?**

**QUESTION 2.3: Based on the difference you find in Questions 2.1 and 2.2, can you design a filter (may be low-pass, high-pass, or band-pass filter) to improve the parametric sound so that the sound quality is comparable to the original sound? Explain your design and OUTPUT your sound as a mp4 file.**

Appendix A

合成發射孔徑影像

合成發射孔徑影像技術有兩種主要方法，一種是使用全部探頭單元孔徑進行收發的全發射接收資料 (full-data-set)進行成像，另一種是只使用部份探頭單元子孔徑 (subaperture)進行成像。

以全發射接收資料合成發射孔徑方法為例，如圖2- 6所示，Tx和Rx表示同個超音波相控陣列探頭，灰色方格表示用於發射和接收時啟用的探頭單元。本方法會依序使用超音波探頭陣列中的一個單元進行發射，並在每次發射後透過所有探頭單元來接收回聲的訊號，從而擴大了等效孔徑大小[52]。然後，使用延遲與總合 (delay and sum, DAS)的波束成型演算法來形成一次發射的影像。經過發射N次超音波並接收訊號後，最終將不同次發射的成像結果加總起來，便可獲得超音波合成發射孔徑影像。

一張含有 螢幕擷取畫面, 設計 的圖片

自動產生的描述

圖2- 6超音波合成發射孔徑影像方法流程，灰色方格表示用於發射或接收時有啟用的探頭單元。

式- 2中，𝑆是維度 的原始射頻信號資料（RF data），依序代表發射單元、接收單元和訊號的長度，代表一維陣列的孔徑權重函數，則分別是發射和接收對應的探頭單元位置，為得出的合成發射孔徑影像。

|  |  |
| --- | --- |
|  | 式- 2 |

如圖2- 7所示，圖中代表探頭掃描空間中的一成像點，和分別是發射以及接收的探頭單元與成像點𝐏之間的延遲時間，計算如下式- 3, 式- 4：

|  |  |
| --- | --- |
|  | 式- 3 |
|  | 式- 4 |

為超音波傳遞速度，為探頭發射單元之X座標位置, 為探頭接收單元的X座標位置, 𝑖, 𝑘依序代表探頭掃描空間中沿著X軸及Z軸方向的像素。

一張含有 藝術, 設計 的圖片

描述是以中可信度自動產生

圖2- 7超音波合成發射孔徑影像方法探頭與成像點P之間的距離計算路徑。

為了加快影像的幀率，超音波合成發射孔徑影像技術還有一種延伸應用 [37]，不需要按照順序啟用全部探頭單元，而是可以透過稀疏間距單元發射 (例如：Tx=1, 7, 13, ..., 91)，並搭配全部單元接收回波訊號 (Rx=1~96)，從而將發射次數減少若干倍來讓幀數倍增。此方法的影像能保持一定品質的原因可透過等效孔徑 (effective aperture) [53]來說明。根據等效孔徑的定義，如式- 5，系統的等效孔徑 為發射孔徑函數和接收孔徑函數捲積的結果。其中代表單元的位置。

|  |  |
| --- | --- |
|  | 式- 5 |

發射波束圖 (beam pattern) 和接收波束圖的乘積為等效孔徑的傅立葉變換計算之結果，其關係如圖2- 8所示：

|  |  |
| --- | --- |
|  | 式- 6 |

作為本節提及的96單元全發射接收資料和稀疏合成發射孔徑影像方法，其等效孔徑分別如圖2- 9上、下圖所示。由於波束圖為等效孔徑傅立葉變換的結果，代表波束寬度和等效孔徑大小有關。亦可得知兩方法的影像解析度接近，而差異則源自於稀疏發射導致的低信噪比和旁瓣 (peak sidelobe)[37] [53]。

一張含有 寫生, 圖表, 天線, 印刷術 的圖片

自動產生的描述

圖2- 8 圖中為假設有5單元陣列的發射、接收和等效孔徑函數。發射輻射方向圖和接收輻射方向圖的乘積等於等效孔徑的傅立葉變換結果，箭頭表示傅立葉變換[53]。

A blue and white striped square

Description automatically generated with medium confidence

A blue and white striped pattern

Description automatically generated with medium confidence

圖2- 9上為96單元陣列的發射、接收和等效孔徑函數。下為發射稀疏至16次的發射孔徑函數、96單元陣列的接收孔徑函數和等效孔徑函數。