Jawbone Quality Assessment Using Co-registered Ultrasound Imaging and CT Scan

Sponsored by Dennis Flanagan, DDS.;
PK Biomedical Engineering Lab; Biomedical Engineering Department
University of Connecticut; Storrs, CT 06269 USA

Abstract – **The goal of this project is to create a method of coregistering Ultrasound (US) and CBCT scan images that is compatible with a custom-designed Ultrasound probe that is able to capture US images invasively. For the imaging process, the design team should begin with ultrasound, as it is easier to manipulate its 2D orientation. After this, the CBCT scan should be performed, and the information from each image should be fused to provide a holistic view of the patient's anatomy. Along with this, a custom probe must be designed to interact with the provided probe allowing for optimal ultrasound images to be obtained to prove out a Proof of Concept that Ultrasound and CBCT scans can be used for providing detailed jawbone quality information beneficial for invasive surgical procedures.**

Keywords: Biomechanics, Ultrasound, CBCT, Co-Registration, Probe, MATLAB, spatial alignment.

1. Introduction

Due to drastic differences in bone compositions from one patient to the next, the importance of analysis within the jawbone with placing implants is imperative for a successful implant design. Jaw bone density analysis, plays an important role in the success and longevity of dental implants. It provides crucial information about the quality and quantity of the patient's bone, aiding dentists in determining the ideal implant size, type, and placement location. Insufficient bone density, meaning bone which is too porous, can lead to implant instability and potential failure over time. [1] While a thorough analysis ensures a secure foundation for the implant to integrate with the jawbone, especially if the implant is incorporated into the surrounding jaw bone, the analysis can result in enhanced implant stability and long-term durability. Therefore, accurate jaw bone density analysis is a fundamental step in the implant placement process, directly influencing the implant's longevity and the overall success of the dental restoration. [2]

2. Software Methods

The methodology to spatially align the two imaging modalities began with exploring available repositories. Options like online bone datasets, in-house imaging, and synthetic ultrasound generation were mainly considered through research and in-house testing. Synthetic ultrasound imaging was the finalized solution for guaranteed Ultrasound image clarity. This approach utilizes specialized software tools to generate artificial ultrasound images, offering a cost-effective and feasible means to achieve our objectives. Subsequently, we embarked on the development of a software prototype capable of producing synthetic ultrasound images based on customizable parameters, such as the emission angles of ultrasound waves. Integrating this synthetic ultrasound capability with existing Cone Beam Computed Tomography (CBCT) scans, we aimed to combine the detailed structural information from X-ray imaging with real-time visualization, enhancing the precision of surgical planning. For preprocessing, applied methods for diffusion filtering, histogram equalization, adaptive histogram equalization with different distributions, and anisotropic diffusion filtering to enhance image quality and edge preservation were tested. Additionally, we evaluated the effectiveness of gamma correction for brightness adjustment and tested edge detection algorithms (Sobel and Canny). Finally, we created a specialized image processing pipeline combining gamma correction, anisotropic filtering, and Wiener filtering to further improve image quality and reduce noise.This process allowed for determining how to customize light and dark exposure settings for patient scans. Validation from industry experts and ongoing feedback loops guided our efforts towards further enhancing the software's functionality and usability. We recognize the significant potential of this technology within the healthcare market, particularly in dental surgery, where precise visualization of bone structures is paramount for optimizing surgical outcomes and improving patient care.

Following thorough assessment, the synthetic ultrasound approach, using the MATLAB Medical Ultrasound Simulation Toolkit (MUST), was the best solution for visualization. Using an .nnrd file of a Cone Beam Computed Tomography (CBCT) scan dataset, a software prototype was developed. An Adafruit LSM303AGR sensor used to relay real time information the angular data coming from a handheld transducer allowed for setting up accurate spatial coordinates for the generated ultrasound image. This prototype could generate synthetic ultrasound images and align them spatially with corresponding CBCT slices, showcasing the feasibility of the proposed solution. Although further optimization is required to improve real-time processing speed, the prototype demonstrated the potential of integrating CT scans and ultrasound for enhanced surgical planning. Future plans include refining the software by incorporating higher-frequency ultrasound probes tailored for dental imaging, aiming to validate ultrasound's efficacy in capturing deep medullary bone density information as well as developing more developed functions to allow for real time rotation across the CBCT 3D plane that will meet the standards for standard operating procedures..

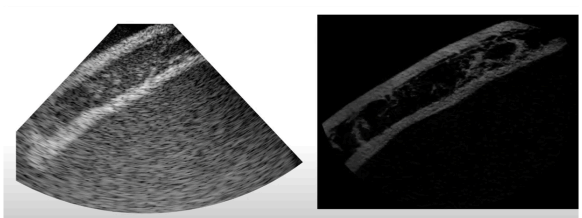

Figure 2 *– Ultrasound image generated (Left) matched by the corresponding CBCT XY-slice (Right)*

3.Current Restraints

Our current POC encountered some constraints that impacted our ability to fully explore the benefits of ultrasound for bone density readings. One limitation was the low frequency of the ultrasound equipment provided by our sponsors. This restricted our preprocessing capabilities and hindered comprehensive validation of the advantages of ultrasound in assessing bone density. Additionally, another constraint arose from the relatively slow rotation speed of the Cone Beam Computed Tomography (CBCT) 3D image that was constructed. However, it's important to note that while challenging, achieving the required views is feasible with the existing technology. It simply requires the refinement of our registration code, a process that has been highlighted as essential in our literature reviews [3]. Through further development and optimization of the registration code, we anticipate overcoming this constraint and obtaining the necessary CBCT views efficiently, thereby enhancing the scope and effectiveness of our study.

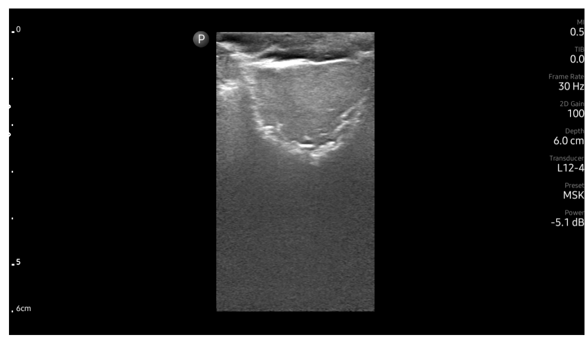

Figure 3 *– Ultrasound Image of Cow Shank*

4. Future Work

The code will be further edited to include inferred labeling and include a more dimensional overlay capability. The ability to repeat this process can also be repeated to see if the software might struggle with overlaying some images compared to others. Although there is a small amount of research on this topic, the ability to both create a probe attachment which will work with the developed software will certainly be a big use when it comes to analysis of the jawbone for dental implants.

5. Acknowledgments

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6. References

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