

Analyzing The Core: Algorithmic Framework for Bone Fracture Detection.

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Abstract: This paper investigates novel algorithmic frameworks for bone fracture detection, emphasizing their feasibility and applicability. Inspired by synthetic aperture radar techniques, the study explores Microwave Imaging (MWI) for non-ionizing diagnosis of superficial bone fractures. This approach is particularly useful in emergency situations where X-rays are either unavailable or not recommended, such as for pregnant women or children. The method employs a single Vivaldi antenna operating within the 8.3-11.1 GHz frequency range to scan bones, collecting scattered fields and reconstructing images using the Kirchhoff migration algorithm. A key advantage is the system's operational simplicity in air, negating the need for immersion liquids. To enhance accuracy, Singular Value Decomposition (SVD) is used to mitigate skin and background artifacts. Testing through simulations and experiments on multilayer phantoms and ex-vivo animal bones demonstrated the technique's efficacy in detecting small bone transverse fractures (as narrow as 1 mm and up to 13 mm deep), even through a 2 mm thick skin layer. This highlights the system's potential to overcome conventional diagnostic limitations.

Keywords: Microwave Imaging, Non-Ionizing Diagnosis, Superficial Bone Fractures, Synthetic Aperture Radar, Singular Value Decomposition (SVD), Bone Morphology

I. Introduction

Bone fractures often require precise detection and monitoring, traditionally achieved through imaging technologies such as X-rays, CT scans, and MRIs. While X-rays provide a quick yet limited view, CT scans and MRIs offer more detailed insights but come with health risks due to ionizing radiation. This is particularly concerning for children and the elderly, who are prone to common fractures like tibia fractures. The need for a non-ionizing, non-invasive, and efficient diagnostic method is evident.

Microwave-based systems present a cost-effective and portable alternative, ideal for first-response screenings in settings where traditional methods might be inaccessible, such as ambulances or low-income environments. While Microwave Imaging (MWI) has been effective in detecting conditions like breast cancer and brain hemorrhage, its application in bone fracture detection remains underexplored. Existing methods often involve immersion-based systems, which are impractical and uncomfortable. Moreover, current techniques typically overlook bone fracture detection or fail to address the challenge of distinguishing fractures from skin and muscle responses.

This research aims to advance the use of microwave imaging for non-contact detection of subtle bone fractures. By leveraging sophisticated signal processing techniques like Singular Value Decomposition (SVD), the study addresses the challenge of weak contrast in bone tissue cracks and aims to improve the accuracy of fracture detection.

II. Algorithm

The study investigates the feasibility of bone fracture detection using a microwave imaging system with a Vivaldi antenna. The antenna is designed to produce linear polarization along the x-axis and operates in close proximity to the bone. The imaging process is treated as a 2D problem, reconstructing images in the plane that includes the antenna's travel path and the z-axis.

Data Acquisition and Processing:

- **Frequency Range:** The system scans multiple frequencies within the 8.3–11.1 GHz range.
- **Signal Measurement:** The S11 parameter is measured at uniformly distributed antenna positions over the bone.
- **Pre-processing:** Initial data contains contributions from internal antenna reflections and external scattered signals. To reduce artifacts, the average signal from all antenna positions is subtracted.
- **Artifact Reduction:** Additional steps address the presence of skin by applying filtering techniques to minimize unwanted contributions.

By refining the algorithm and employing SVD to eliminate artifacts, the study enhances the system's ability to detect minute fractures, thus improving diagnostic accuracy and applicability in real-world scenarios.

- **Pre-Processing**
- The pre-processing stage in the microwave imaging system is crucial for accurate bone fracture detection. Singular Value Decomposition (SVD) is employed to address skin artifacts and other undesired reflections in the collected data. The SVD technique decomposes the signal scattered from the target (bone) into components representing contributions from the skin, fracture, and background.
- **Key Steps:**
- **SVD Application:** The SVD decomposes the collected data into singular values that represent different aspects of the signal. The first and/or second singular values typically correspond to the most significant undesired reflections, such as those from the skin or background.
- **Subregion Analysis:** To manage the non-uniform geometry of the scanned area, the data is divided into smaller subregions. SVD is applied individually to each subregion to accurately capture and filter out artifacts.
- **Concatenation:** After processing each subregion, the filtered responses are concatenated to form a complete image of the scanned area. This approach helps in handling complex geometries and improving the overall accuracy of the image reconstruction.

I. Bone Morphology

- Bone morphology, particularly of the leg, involves a complex combination of tissues including bones, muscles, tendons, veins, arteries, and nerves. Based on the 20th U.S. edition of Gray's Anatomy of the Human Body:
- **Bone Structure:** The primary bones of the leg are the tibia and fibula. The medial side of the tibia is subcutaneous and lacks muscle overlay, which is advantageous for microwave penetration at higher frequencies.
- **Microwave Penetration:** The absence of muscle overlay on the tibia allows for better penetration and resolution, making it possible to detect smaller fractures more effectively. For initial testing, a simplified cylindrical model representing the tibia was used. This model helped to understand fracture detection and identify factors affecting accuracy without confounding geometry-related effects.

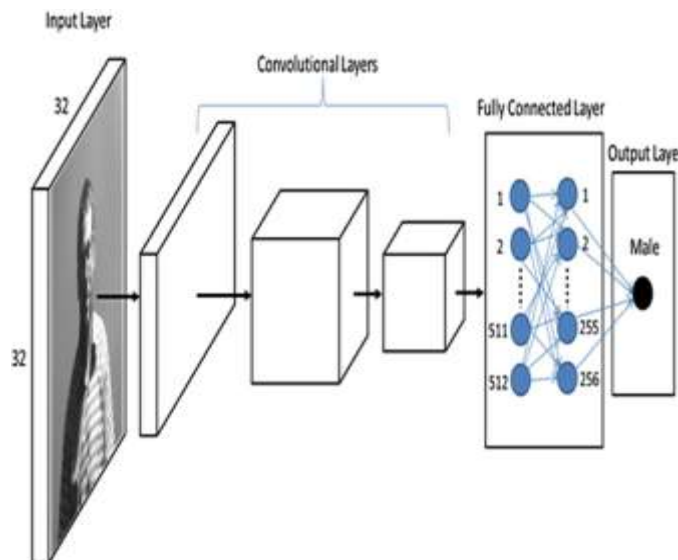
A. Non-Ionizing Diagnosis

- Non-ionizing diagnostic methods use forms of radiation that do not ionize atoms or molecules, thus avoiding potential harmful effects associated with ionizing radiation. These methods include:
- **Magnetic Resonance Imaging (MRI):** Utilizes powerful magnets and radio waves to produce high-resolution images of internal body structures without ionizing radiation.
- **Ultrasound:** Uses sound waves to generate real-time images of internal organs and tissues, providing valuable diagnostic information without radiation exposure.
- **Optical Imaging:** Employs light (e.g., lasers) to visualize tissues at cellular or molecular levels, also avoiding ionizing radiation.
- **Advantages:**
- **Safety:** Non-ionizing methods reduce the risk of long-term health effects and are safer for sensitive populations such as pregnant women and children.
- **Repetitive Use:** These techniques allow for repeated use, which is beneficial for monitoring chronic conditions or during ongoing treatments.
- **Enhanced Precision:** Ongoing advancements in non-ionizing diagnostics continue to improve imaging precision and scope.

B. Microwave Imaging

- Microwave imaging is a promising non-invasive technique that uses microwave frequencies to visualize internal structures. It offers several advantages:
- **Soft Tissue Imaging:** Particularly effective for imaging soft tissues like the breast, where traditional methods like mammography may be limited. It provides a radiation-free alternative, potentially reducing discomfort and risks.

- **Real-Time Monitoring:** Allows for dynamic monitoring of physiological changes, facilitating timely interventions.
- **Potential Expansion:** While currently showing significant promise in breast cancer detection, microwave imaging is being researched for other applications, including brain and abdominal imaging.
- **Challenges:**
 - **Signal Scattering:** Addressing issues related to signal scattering and improving reconstruction algorithms are ongoing research areas.
 - **Resolution and Sensitivity:** Enhancing resolution, sensitivity, and specificity for broader applications remains a focus.
- **Benefits:**
 - **Safety:** Being a non-ionizing technique, microwave imaging minimizes the risk of long-term health effects compared to ionizing methods.
 - **Early Detection:** Provides a potential for early and accurate diagnosis, especially in breast cancer detection.
- Overall, microwave imaging is a developing field with the potential to revolutionize medical diagnostics by offering a safer and efficient alternative to traditional imaging methods.



Review of Research Papers

1. Paper: Bone Stick Image Classification Study Based on C3CA Attention Mechanism Enhanced Deep Cascade Network

Authors: Haoran Liang, Huiqin Wang, Li Mao, Rui Liu, Zhan Wang, and Ke Wang

Abstract: This paper addresses the challenge of classifying bone stick fracture locations and colors from cultural relics. The YOLOv5s-ViT cascade model is enhanced with the C3CA attention module to improve fracture area recognition and reduce background interference. The study also improves training efficiency by increasing the learning rate and introduces Batch Normalization to enhance generalization.

Key Points:

Model: YOLOv5s-ViT cascade model.

- **Enhancement:** C3CA attention module.

Training: Increased learning rate and Batch Normalization.

Focus: Classification of bone stick fractures and colors.

2. Paper: Feasibility of Bone Fracture Detection Using Microwave Imaging

Authors: Kesia C. Santos, Carlos A. Fernandes, and Jorge R. Costa

Abstract: This research explores using Microwave Imaging (MWI) for detecting fractures in superficial bones like the tibia. It employs a single Vivaldi antenna in the 8.3-11.1 GHz range and reconstructs images using Kirchhoff migration. Singular Value Decomposition (SVD) is used to remove skin and background artifacts, with successful detection of small fractures.

Key Points:

Technique: Microwave Imaging using a Vivaldi antenna.

Algorithm: Kirchhoff migration with SVD.

Application: Non-ionizing diagnosis in emergency settings.

Results: Detection of fractures as small as 1 mm wide and 13 mm deep.

3. Paper: TimeDistributed-CNN-LSTM: A Hybrid Approach Combining CNN and LSTM to Classify Brain Tumor on 3D MRI Scans Performing Ablation Study

Authors: Sidratul Montaha, Sami Azam, A. K. M. Rakibul Haque Rafid, Md. Zahid Hasan, Asif Karim, and Ashraful Islam

Abstract: This study proposes a hybrid model, TimeDistributed-CNN-LSTM (TD-CNN-LSTM), combining 3D CNN and LSTM to classify brain tumors from 3D MRI scans. The model considers all MRI sequences of a patient as a single data input to improve classification accuracy.

Key Points:

- **Model:** TimeDistributed-CNN-LSTM.
- **Data:** 3D MRI scans.
- **Approach:** Hybrid of CNN and LSTM.
- **Objective:** Improved classification of brain tumors.
- **4. Paper: Detection of Various Dental Conditions on Dental Panoramic Radiography Using Faster R-CNN**
- **Authors:** Shih-Lun Chen, Szu-Yin Lin, Tsung-Yi Chen, Yi-Cheng Mao, Ya-Yun Huang, Chiung-An Chen, Mian-Heng Chuang, Patricia Angela R. Abu, Yuan-Jin Lin
- **Abstract:** This paper introduces a system using Faster R-CNN for detecting seven dental conditions on panoramic radiographs. The inclusion of a Butterworth filter and tailored enhancement technology improved accuracy to over 95%.
- **Key Points:**
 - **Technique:** Faster R-CNN.
 - **Application:** Detection of dental conditions.
 - **Enhancements:** Butterworth filter and tailored technology.
 - **Accuracy:** Over 95%.
- **5. Paper: Validation of a Compact Microwave Imaging System for Bone Fracture Detection**
- **Authors:** Kesia C. Santos, Carlos A. Fernandes, and Jorge R. Costa
- **Abstract:** This study validates a compact microwave imaging system for detecting thin fractures in superficial bones. The system uses a Vivaldi antenna in a monostatic radar mode and employs wave-migration and adaptive SVD algorithms for image reconstruction and artifact removal.
- **Key Points:**

- **System:** Compact microwave imaging with a Vivaldi antenna.
- **Method:** Monostatic radar mode and wave-migration.
- **Algorithm:** Adaptive SVD for artifact removal.
- **Validation:** Tested on ex-vivo animal leg.
- **Conclusion**

The project introduces a CNN-based image segmentation algorithm for detecting bone fractures. This method improves accuracy in detecting fractured areas, even with noise, compared to traditional edge detection techniques. The use of SFCM clustering and DWT edge detection enhances the algorithm's effectiveness.

Key Outcomes:

Accuracy: Improved fracture detection and localization.

Techniques: CNN-based image segmentation, SFCM clustering, DWT edge detection.

Future Vision: Advancements in image processing will significantly impact the development of intelligent digital tools and robots, transforming global management.

Future Scope

1. **Advanced Diagnostic Accuracy:** Development of sophisticated CNN models for precise fracture detection.
2. **Automated Detection and Classification:** More automated systems for detecting and classifying fractures.
3. **Enhanced Data Analysis:** Utilization of larger datasets and improved annotation for robust models.
4. **Adoption in Clinical Practices:** Integration of CNN-based systems into routine clinical practices for faster diagnoses.
5. **Portable and Integrated Solutions:** Creation of user-friendly, portable systems for real-time fracture detection in various settings.

References

- [1] J. Gao, 'Restudy of the name and usage of the bone tallies unearthed from the han period Chang'an city-site,' 'Huaxia Archaeol., no. 3, pp. 109–113, Sep. 2011.
- [2] C. N. Tu, G. Wang, J. Tian, H. J. Li, and T. Li, 'Research on classification algorithm of oracle bone inscriptions based on deep learning,' 'Modern Comput., vol. 27, no. 26, pp. 67–72, Sep. 2021.
- [3] Y. H. Yu, H. B. Zhang, X. Li, J. J. Kou, K. Li, G. H. Geng, and M. Q. Zhou, 'Depth classification model of Qin terracotta fragments based on data augmentation,' 'Laser Optoelectronics Prog., vol. 59, no. 18, pp. 111–120, Aug. 2022..
- [4] J. N. Feng, Q. Zhou, R. R. Zhang, Y. Wang, and H. J. Luo, 'Intelligent chronological study of chinese ancient ceramics based on convolutional neural networks,' 'J. Ceram., vol. 43, no. 1, pp. 145–152, Feb. 2022.
- [5] J. Wang, Y. Gao, and J. Shi, 'Scene classification of optical high-resolution remote sensing images using vision transformer and graph convolutional network,' 'Acta Photon. Sinica, vol. 50, no. 11, 2021, Art. no. 1128002.
- [6] M. Caron, H. Touvron, I. Misra, H. Jegou, J. Mairal, P. Bojanowski, and A. Joulin, 'Emerging properties in self-supervised vision transformers,' 'in Proc. IEEE/CVF Int. Conf. Comput. Vis. (ICCV), Oct. 2021, pp. 9650–9660.