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Research statement

Current developments in wave theory rely on the use of short-pulse ultra-wide band fields. There are numerous medical, geophysical, industrial etc., applications, using electromagnetic, acoustic, elastic, or seismic waves. The propagated fields relate the source and received data through a complex environment. Due to the complexity of the wave problem, it is highly important to understand the wave data, to study propagation and scattering mechanisms. Local wave processing using collimated beams plays an important role in these studies, as complicated events can be explained using simple physical models.

During my PhD and postdoc, I developed mathematical and physical tools, which enable a better understanding of wave propagation models and wave phenomena in complex media. Specifically, I use them for applications of wave propagation, scattering, imaging, and inversion. With the growth of computational power, numerical algorithms for these applications have become more popular. Still, to formulate these problems properly, it is highly important to understand the wave-physics. I use these models to derive physical-based inversion algorithms.

Past research

The inverse problem deals with determining both the shape and the composition of an unknown object. There are numerous medical, geophysical, industrial etc., applications, using electromagnetic, acoustic, elastic, or seismic waves. Typically, reconstruction requires diversity which, depending on the application, may involve several excitation frequencies (or short-pulse response), and/or illumination directions. Ideally, one would like to relate localized data measured to localized scattering event over the unknown object.

We developed a new electromagnetics diffraction tomography theory using beam waves. This work was divided into two main parts. In the first part, we developed the processing tools that have been used in the second part to formulate the tomography problem. We formulated a new mathematical basis for radiation from volume sources, where we used collimated wave propagators (beam propagators) as local basis functions. We also showed a relation between the radiated field to local probing in the source domain. We used these relations to study the inverse problem. We used the new basis to decompose the observed data and to transform it into the beam domain. We showed that the beam domain data is related to a scattering event over a localized region over the target domain, with a specific angle. We used these relations for the application of target-oriented imaging, and also to reduce the amount of data needed to image the target.

Current research

At present, I am working on applications of geophysical migration and inversion. I expended the physical tools I derived during my Ph.D. to geophysical applications. I collaborate with several faculty members to use these methods with inversion algorithms. Our approach is based on the combination of the physical interpretation of the data to reduce the computational complexity of some of the state of the art algorithms such as migration and least-squares migration. We also used these methods with a combination of machine learning algorithms.

Future research

For the next years, I am looking to push forward with studies of local physics-based wave processing and their applications to propagation, imaging, and inversion. Using my previous background, I am looking to apply these methods for electromagnetics, acoustics, and geophysical applications.

- I am planning to use our previous least-squares migration algorithm as an engine for a full-waveform inversion algorithm. This approach has been demonstrated successfully for relatively large inverse problems, such as the geophysical problem. Recently it also has been proposed of medical imaging. This problem is iterative. With the increasing amount of data and complexity of the medium, it is desired to reduce the computational complexity at each iteration. I am planning to use our least-squares migration algorithm to speed up the FWI algorithm. The local wave processing a- priori reduces the computational complexity at each iteration. In addition, for each iteration, it is necessary to solve a full-wave equation. We also showed that a reduced number of wave equations should be solved. I am planning to extend these properties to the FWI problem.
- Recently a new approach for imaging has been proposed, using the Marchenko equation. Beam propagators have been suggested for this problem, as a target-oriented approach. In the Marchenko imaging approach, local waves should be tracked and interpreted. The novelty in our beam-based approach is the data-target relation. Thus our approach may be more efficient than other beam-based approaches.
- We combined the local wave processing with Machine learning algorithms. In this approach, the goal is to select the significant shots that should be selected to image the subsurface. Preliminary results relay on solving a small number of wave equations. The next step is to overcome the wave equation solution and to predict the shots from the data directly. There are several approaches that I would like to use to this purpose: (1) Beam-based mini-batch approach, (2) using a neural network – a collaboration with Dr. XXX. A different approach is to use the SVD decomposition.
- I would also like to extend our migration approach to anisotropic media. The idea is to extend our beam-based approach to such a media, and then to use the advantages of the migration algorithm.

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