V. Berger, M. Xu, **Mohanad Al-Ibadi**, and others, "**Automated Ice-Bottom Tracking of 2D and 3D Ice Radar Imagery Using Viterbi and TRW-S**," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS), Aug 2019.

Abstract:
Multichannel radar depth sounding systems are able to produce two-dimensional (2D) and three-dimensional (3D) imagery of the internal structure of polar ice sheets. Information such as ice thickness and surface elevation is extracted from these data and applied to research in ice flow modeling and ice mass balance calculations. Due to a large amount of data collected, we seek to automate the ice-bottom layer tracking and allow for efficient manual corrections when errors occur in the automated method. We present improvements made to previous implementations of the Viterbi and sequential tree-reweighted message passing (TRW-S) algorithms for ice-bottom extraction in 2D and 3D radar imagery. These improvements are in the form of novel cost functions that allow for the integration of further domain-specific knowledge into the cost calculations and provide additional evidence of the characteristics of the ice sheets surveyed. Along with an explanation of our modifications, we demonstrate the results obtained by our modified implementations of the two algorithms and by previously proposed solutions to this problem, when compared to manually corrected ground truth data. Furthermore, we perform a self-assessment of tracking results by analyzing differences in the estimated ice-bottom for surveyed locations where flight paths have crossed and, thus, two separate measurements have been made at the same location. Using our modified cost functions and preprocessing routines, we obtain significantly decreased mean error measurements from both algorithms, such as a 47% reduction in average tracking error in the case of 3D imagery between the original and our proposed implementation of TRW-S.

J. Paden, V. Berger, **Mohanad Al-Ibadi**, and others, "**Subglacial bed topography using machine learning and geostatistical analysis applied to 2D and 3D radar sounding**," American Geophysical Union (AGU), 2018 Fall meeting, Washington DC, USA.

Abstract:
Bed topography is an essential boundary condition in the ice sheet numerical models used to predict future ice mass balance relevant to sea level rise and to determine the flux gate in current ice mass balance estimates. Fine resolution measurements from 3D radar sounding are especially relevant to understanding the stability of grounding lines and calving fronts. In order to extract the ice bottom in hard-to-detect regions of the imagery and to handle complex mountainous terrain, we have developed several machine learning algorithms to track the ice bottom. We found that a Hidden Markov Model (HMM) solved via the Viterbi algorithm is very efficient but least accurate. A Markov Random Field (MRF) model solved via Tree Re-Weighted message passing (TRW-S) is most accurate but is also approximately 100 times slower. Since radar data is easily segmented for processing, this computation time is not an issue on a computer cluster. A Deep Neural Network (NN) model offers slightly lower accuracy but, unlike Viterbi and TRW-S, does not require external evidence such as surface elevation and ice mask. Manual picks can be used as ground truth and when operating on small portions of the imagery, even TRWS is fast enough to

run interactively. The best performing TRW-S algorithm achieves a mean tracking error of 5.1 pixels. Using these methods, we present a complete 3D mapping of the Canadian Arctic Archipelagos (CAA) and the first Operation Ice Bridge (OIB) campaign (2018 Arctic) mapped in 3D mode. We also present a geostatistical analysis of these results. The CAA dataset is already publicly released on our website and will soon be released on the National Snow and Ice Data Center OIB data portal. This dataset covers 4500 line-km, much of which is in mountainous terrain. The horizontal posting is 25 m and the vertical RMSE is 38±7 m based on 20 cross overs.

Mohanad Al-Ibadi, and others, "**Crossover analysis and automated layer-tracking assessment of the extracted DEM of the basal topography of the Canadian Arctic Archipelago ice-cap**," 2018 IEEE Radar Conference (RadarConf18), Oklahoma City, OK, USA.

Abstract:
In 2014, as part of the NASA Operation IceBridge project, the Center for Remote Sensing of Ice Sheets operated a multi-beam synthetic aperture radar depth sounder/imager over the Canadian Arctic Archipelago (CAA) to generate digital elevation models (DEMs) of the glacial basal topography. In this work, we briefly describe the processing steps that led to the generation of these DEMs, algorithm improvements over previously published results, and assess the results from two different perspectives. First, we evaluate the self-consistency of the DEMs where flight paths cross over each other and two measurements are made at the same location. Secondly, we compare the quality of the outputs of the ice-bottom tracker before and after applying manual corrections to the tracker results; the tracker is an algorithm that we implemented to automatically track the ice-bottom. Even though the CAA ice-caps are mountainous areas, where the scenes often have ice and no ice regions, which makes the imaging complicated, the statistical results show good tracking performance and a good match between the overlapped DEMs, where the mean error of the crossover DEMs is 37±9 m.

S. Athinarapu, J. Paden, **Mohanad Al-Ibadi**, and T. Stumpf, " **Model Order Estimators Using Optimal and Suboptimal Methods with Numerical Tuning**," 2018 IEEE Radar Conference (RadarConf18), Oklahoma City, OK, USA.

Abstract:
The performance of several methods to estimate the number of source signals impinging on a sensor array are compared using a traditional simulator and their performance for synthetic aperture radar tomography is discussed. All methods use a penalty term that increases with model order in order to prevent overestimation. We include both separate estimation of model selection and direction of arrival as well as joint estimation. We formulate a new penalty term, numerically tuned so that it gives optimal performance over our operating conditions, and compare this method as well. Simulation results show that the numerically tuned model selection criteria is optimal and that the typical methods do not do well for low snapshots. We also found that there is little sensitivity to SNR greater than 3 dB

when the number of snapshots is high. We discuss some issues to applying the algorithms to data collected by the CReSIS radar depth sounder.

Mohanad Al-Ibadi, and others, "**DEM EXTRACTION OF THE BASAL TOPOGRAPHY OF THE CANADIAN ARCTIC ARCHIPELAGO ICE CAPS VIA 2D AUTOMATED LAYER-TRACKER**," 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS 17), Fort Worth, TX, USA.

Abstract:
The basal topography of most of the glaciers that drain the ice caps of the Canadian Arctic Archipelago is largely unknown. To measure the basal topography, NASA Operation IceBridge flew a radar depth sounder in a wide swath mode with three transmit beams to image the glacier beds during three flights over the archipelago in 2014. We describe the measurement setup of the radar system, the algorithms used to process the data to produce a 3D image of the glacier bed, show digital elevation model (DEM) results of the beds, and provide a basic assessment of the tracking algorithm used to extract the DEM.

Mohanad Al-Ibadi and A. Dutta, "**Predictive analytics for non-stationary V2I channel**," 2017 9th International Conference on Communication Systems and Networks (COMSNETS), Bengaluru, India.

Abstract:
Vehicle to Infrastructure (V2I) channels are particularly difficult to analyze because of high mobility and localized scattering from nearby vehicles and road-side features. The spatio-temporal variation of the scattering environment makes the channel a non-stationary stochastic process, which renders conventional, receiver-side channel conditioning techniques ineffective for this emerging application. Our work takes a radically different approach to introduce predictive analytics at the Road-Side Unit (RSU) to proactively compensate for channel variations over time and frequency while precisely fitting into contemporary protocols like Dedicated Short Range Communication (DSRC) and Wireless Access in Vehicular Environment (WAVE). By assimilating the channel state feedback built into these protocols, we employ an iterative learning algorithm to gather localized knowledge of the channel profile. This acquired knowledge is used to pre-condition the downlink waveform to lower the Bit Error Rate (BER) by ≈ 100 times, when compared to the current vehicular communication standards even at a relatively high Signal to Noise (SNR) of 17 dB. Further, our algorithm is able to predict the non-stationary V2I channel with an average absolute error of 10^{-2} in dense scattering environment.

J. Paden, T. Stumpf, and **Mohanad Al-Ibadi**, "**Wideband DOA Estimation for Ice Sheet Bed Mapping**," 2016 IEEE International Symposium on Phased Array Systems and Technology (PAST), Waltham, MA, USA.

Abstract:

We investigate the performance of several narrow band and wide band direction of arrival (DOA) algorithms for synthetic aperture radar imaging of the basal interface of glaciers and ice sheets. We also introduce a new DOA estimation method based on correlating the measured space-time data covariance matrix (DCM) with its expectation. This new method extends and improves an earlier method based on DCM correlation. In our investigation we use parameters for wideband antenna arrays deployed by the Center for Remote Sensing of Ice Sheets. We define an array to be wideband when the pulse envelope cannot be assumed constant across the array elements. We also look at problems specific to basal imaging of ice sheets. For a variety of reasons such as surface smoothness, imaging is often done at near zero incidence angles. Unlike side looking geometries where pixels usually have localized (in incidence angle) scattering and neighboring pixels are similarly localized and so can be used as independent snapshots, normal-to-surface imaging geometries usually involve multiple localized scattering sources (layover) and the angle of arrival may change rapidly with range so that sample starvation occurs due to neighboring pixels having significantly different angles of arrival.

J. Paden, M. Xu, J. Sprick, S. Athinarapu, **Mohanad Al-Ibadi**, and others, "**3D Imaging and Automated Ice Bottom Tracking of Canadian Arctic Archipelago Ice Sounding Data**," American Geophysical Union (AGU), 2016 Fall Meeting, San Francisco, CA, USA.

Abstract:
The basal topography of the Canadian Arctic Archipelago ice caps is unknown for a number of the glaciers which drain the ice caps. The basal topography is needed for calculating present sea level contribution using the surface mass balance and discharge method and to understand future sea level contributions using ice flow model studies. During the NASA Operation IceBridge 2014 arctic campaign, the Multichannel Coherent Radar Depth Sounder (MCoRDS) used a three transmit beam setting (left beam, nadir beam, right beam) to illuminate a wide swath across the ice glacier in a single pass during three flights over the archipelago. In post processing we have used a combination of 3D imaging methods to produce images for each of the three beams which are then merged to produce a single digitally formed wide swath beam. Because of the high volume of data produced by 3D imaging, manual tracking of the ice bottom is impractical on a large scale. To solve this problem, we propose an automated technique for extracting ice bottom surfaces by viewing the task as an inference problem on a probabilistic graphical model. We first estimate layer boundaries to generate a seed surface, and then incorporate additional sources of evidence, such as ice masks, surface digital elevation models, and feedback from human users, to refine the surface in a discrete energy minimization formulation. We investigate the performance of the imaging and tracking algorithms using flight crossovers since crossing lines should produce consistent maps of the terrain beneath the ice

surface and compare manually tracked "ground truth" to the automated tracking algorithms. We found the swath width at the nominal flight altitude of 1000 m to be approximately 3 km. Since many of the glaciers in the archipelago are narrower than this, the radar imaging, in these instances, was able to measure the full glacier cavity in a single pass.

Mohanad Al-Ibadi, and others, "**DoA estimation and achievable rate analysis for 3D massive MIMO in aeronautical communication systems**," 2015 IEEE Global Conference on Signal and Information Processing (GlobalSIP), Orlando, Fl, USA.

Abstract:
With very high carrier frequencies (such as millimeter-wave (mmW) bands), a very large number of antennas can be packed at the base station (BS). For this kind of high dimensional channel, it is desirable to exploit signal directions to estimate the channel directions. In this paper, we analyze the performance of the direction of arrival (DoA) estimation based on unitary ESPRIT algorithm assuming time division duplex (TDD) wideband system. The mean-squared error (MSE) of the 2D DoA estimation of a multipath signal impinging on a planar antenna array is derived. Accordingly, we propose a power allocation strategy that counts for the DoA estimation error. The achievable rate characterization suggests that our power allocation strategy outperforms the traditional water-filling solution.

R. Talib Hussein and Mohanad Al-Ibadi, "**Cantor Fractal Linear Antenna array with Koch Fractal Elements**," Journal of Computer Communications and Control Engineering/ University of Technology/Baghdad/Iraq, 2009.

Abstract:
In this paper, we investigated the multiband properties of fractal antenna arrays with Koch fractal elements. We used the '101' generator and second stage of growth in the design of the fractal array. MATLAB and NEC software were used in generating our results.