A deep learning application for Through-the-Wall Radar Imaging

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Introduction

Through-the-Wall Radar Imaging (TWRI) is an application which has received much attention recently due to its large applicability and mathematical challenges. It can be used to assist rescue operations after landslides or earthquakes, in surveillance operations and for monitoring activity inside buildings [1], [2]. In this work, we combine TWRI with data driven methods to identify and localize a person of interest moving inside a building. This represents a non-linear inverse electromagnetic problem which, due to the presence of multiple scattering effects, is generally ill-posed and difficult to solve. We propose to rewrite the localization task as a classification problem which can then be addressed by efficient deep learning strategies.

Mathematical model

The propagation of Transverse-Magnetic fields within the domain is described according to the Helmholtz equation equipped with the Sommerfeld radiation condition as boundary condition at infinity [2], [4]. The 2D example setup here considered is illustrated in the figure below, where the building walls are surrounded by antennas used to collect data.

We split the tracking part into a reconstruction problem for the static background assuming that no moving objects are present, and a tracking problem for the dynamically moving objects once they enter the scenery. The static background is retrieved by performing a standard level set reconstruction [2]. More details about the formulation of the underlying inverse problem, standard iterative reconstruction schemes and level set algorithms can be found in [1]. In order to achieve (almost) real time tracking, we propose in the following a novel localization strategy based on deep learning.

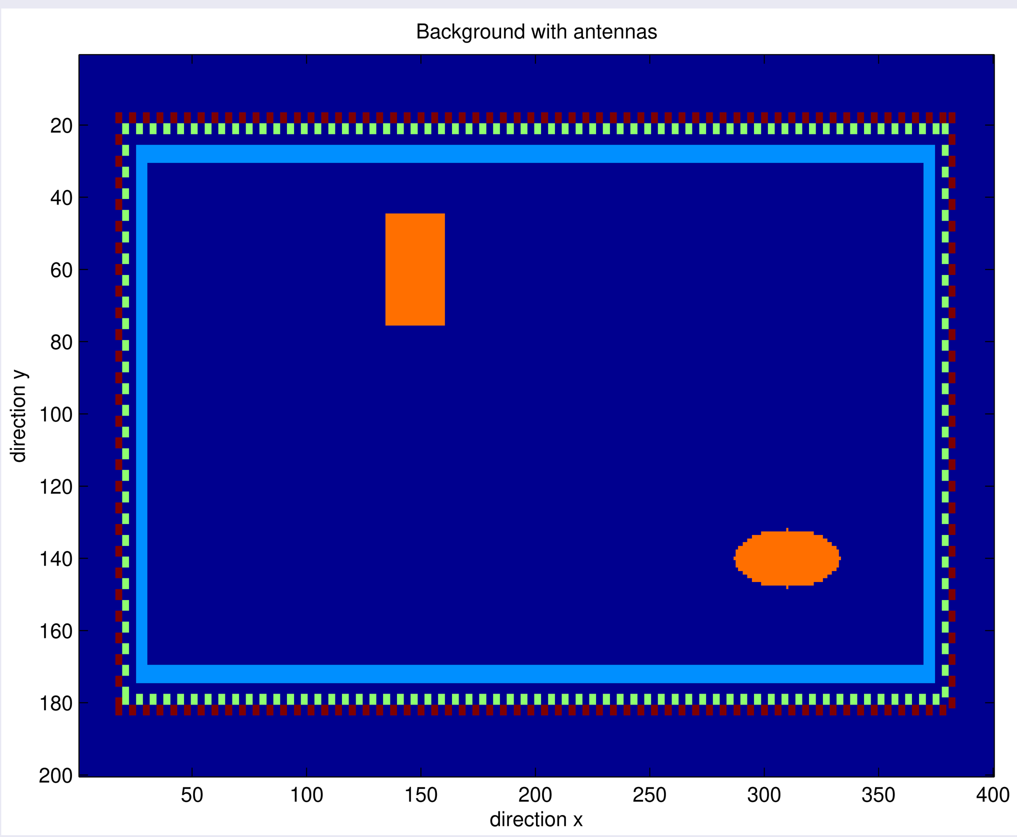

Figure: Background permittivity profile. The antennas (i.e. sources and receivers) are visible around the walls of the building schematized.

Training of the network

In the dynamic tracking part, we divide the domain into cells and rewrite the localization task in terms of a classification problem by identifying the cell where the target is located at each time step. The background profile here considered is the outcome of the level set reconstruction realized before.

The field measurements at the receivers are fed to a deep neural network containing normalization, dense and dropout layers. The popular Adam optimization algorithm [3] is used for training and, in order to improve the performance and prevent overfitting, data augmentation techniques [5] are considered. The training data set is generated by considering, for each measurement, a unique elliptical target with relative permittivity value randomly selected in the interval $\epsilon \in \mathbf{[5, 8]}$. A single frequency $\boldsymbol{f} = \mathbf{100}$MHz is chosen throughout this study.

Data driven tracking: numerical results

We aim at following the movement of a cross-shaped target by localizing its location in almost real time using the network trained before. The shape is assumed unknown during the tracking part, even though the approximate size of the target is assumed known. This network provides an estimate of the probability of finding the object in each cell of the domain. Therefore, the location with the highest probability value is assumed as the estimation of the target position. By considering measurements at consecutive times, we retrieve the entire trajectory as illustrated by the next figure. This figure also shows that the proposed data driven approach performs well and accurately in the considered experiment.

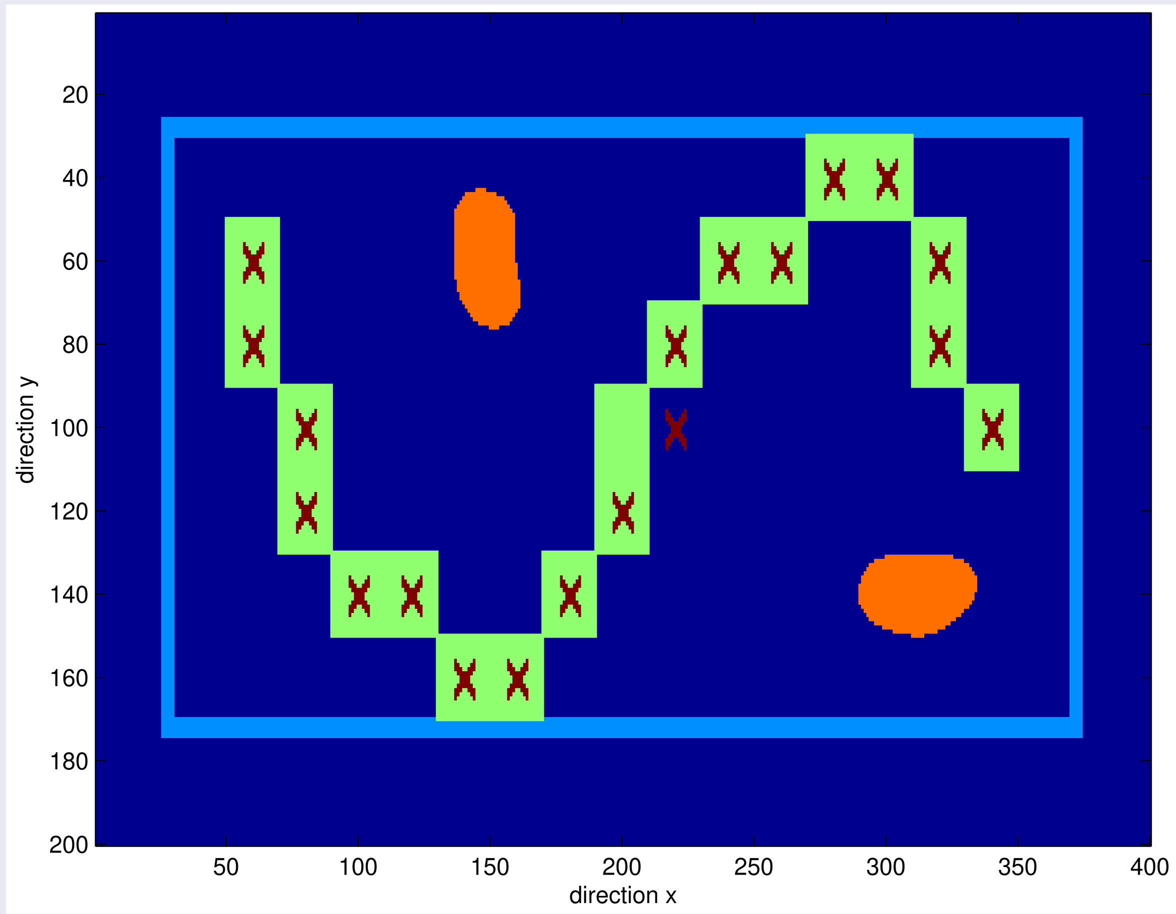

Figure: Estimated vs real trajectory. The true cross-shaped target is illustrated, at each time step, in red. The locations predicted by the network are highlighted in green. As anticipated, the background profile is the result of a level set reconstruction.

Conclusion

We have presented a novel data driven strategy for TWRI tracking applications. It combines typical inverse problem elements and deep learning tools to achieve an almost real time localization of objects hidden behind walls. The proposed method, besides being fast, does not require a model for the expected motion. This represents a great advantage compared to popular statistical tracking techniques (i.e. Kalman filters) since this information is often unavailable in practice.

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