Intraoperative GPU-based surgical navigation for needle steering

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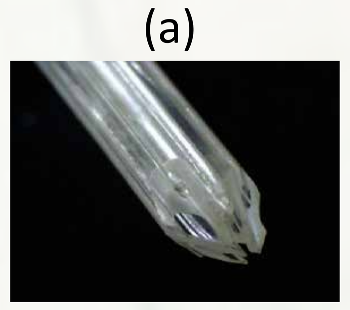
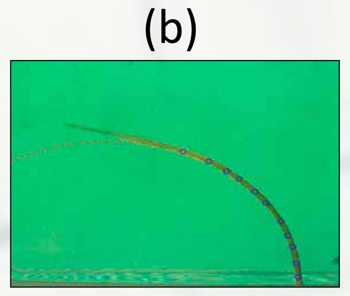
Motivation

Newly developed, robotically steered needles allow minimally invasive access and accurate guidance to deep-seated anatomical targets. They hope to improve efficacy of interventions such as deep brain stimulation and tumour management, whilst reducing patient trauma. By using ultrasound (US) to track both the tissue and needle deformation, the optimal insertion trajectory can be updated intraoperatively. The whole navigation process can be accelerated by using a GPU-implementation, that greatly reduces the navigation latency, making surgery safer and more accurate.

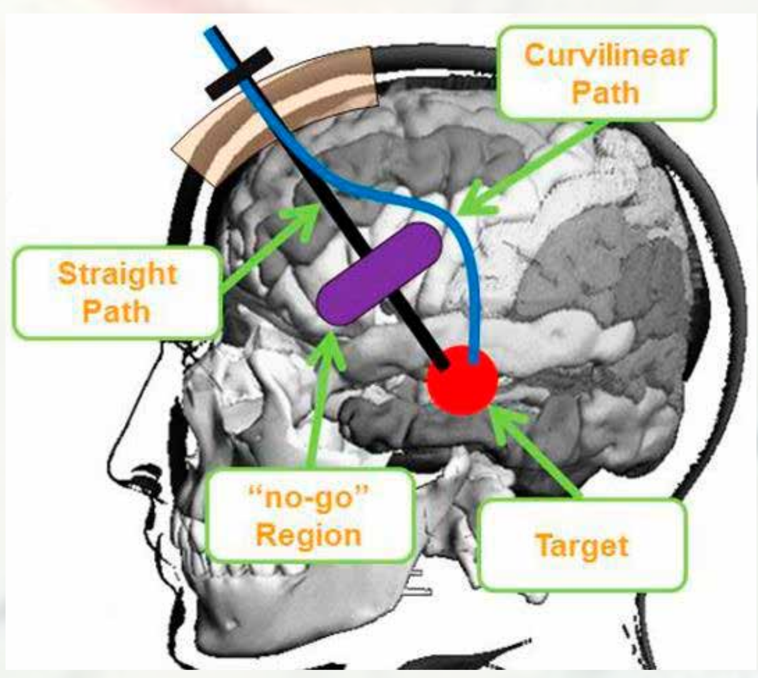
(a)



(b)



(c)

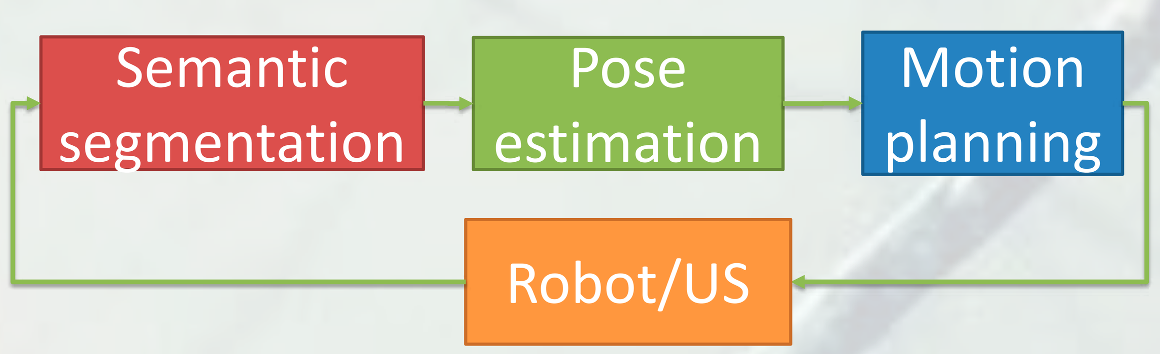


(d)

(a) Ovipositing wasps provide inspiration for the STING steerable needle. (b) The current STING needle is a 2.5mm OD device extruded from medical grade polymer. (c) The STING needle steering in a gelatine soft tissue phantom. (d) Illustration of application within the brain.

GPU navigation architecture

The whole navigation pipeline is GPU-accelerated. Initially, the US images are semantically segmented, with each pixel classified as either needle, target, obstacle or safe tissue. Once classification is complete, the needle and target configuration is estimated. The path planner identifies the optimal path, which avoids all obstacles, and the surgical plan is updated intraoperatively.



Flow diagram of the system

CNN for robust US image processing

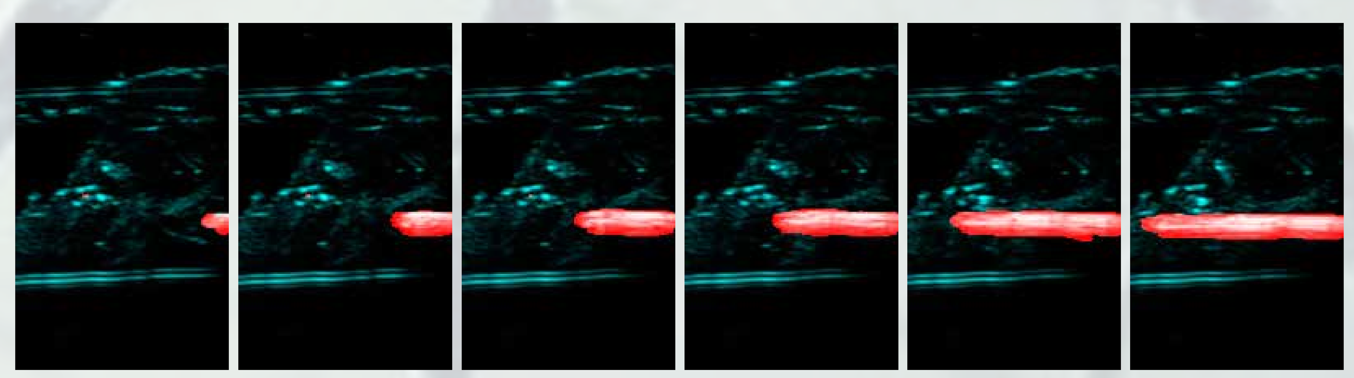
The presence of speckle noise in US makes imaging processing particularly challenging. Convolutional Neural Networks (CNN) provide a robust solution. Initially, a small patch around each pixel is classified via a 7-layered CNN network. Following segmentation, regression is applied on the labelled pixels to estimate the configuration.

Semantic segmentation via 7-layered CNN

US trials with KUKA LDR

The system has been tested in tissue. A steerable needle is inserted into pig's brain, and imaged via an US probe mounted on a KUKA LDR robot.

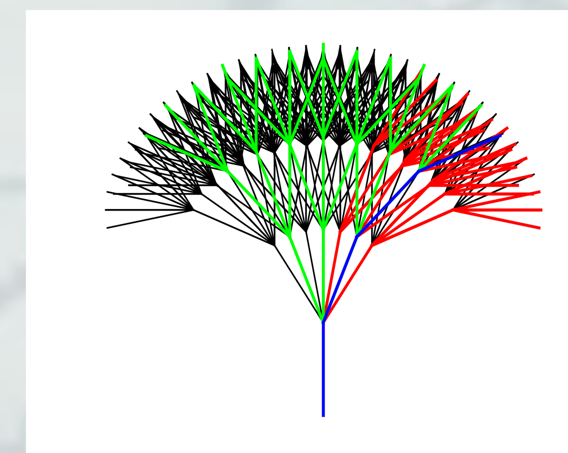
In a preliminary trial, 300 frames are collected and 10 frames manually segmented. The US images are down sampled to 200X158 pixels. For each pixel, a patch of 28x28 is classified via the CNN network. Our code is implemented in Matlab with GPU acceleration, and run on Nvidia's GTX780. Classification was achieved at a rate of approximately 5000 patches/sec.



Needle (marked red) segmentation in sequential frames

Parallel surgical planning

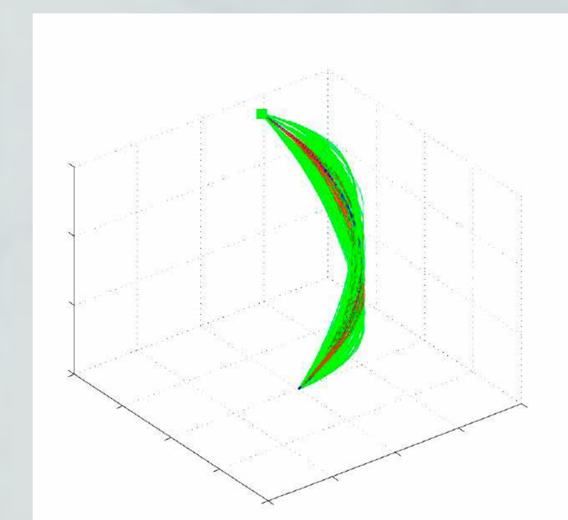
We developed two parallel path planning algorithm that perform exhaustive search of all the possible insertion trajectories and find the best surgery plan. Exhaustive search are more robust, it can over handle complex anatomy structure and guarantee path quality.



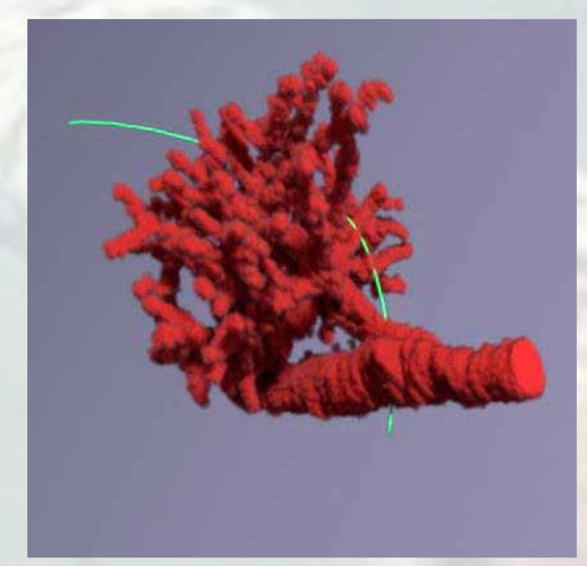
Parallel tree growing

The first path planner performs a global search in the path space. Motion planning is performed by forming a fractal tree of all possible paths, with each branch mapped to a GPU thread for cost evaluation and collision detection

The second path planner parameterizes the null space of all paths that connect the start point and target. Particle swarm optimization is performed on the GPU to identify the best path.



Null space exploration



Planned needle trajectory avoiding vessels

Path planning has been tested separately with manually segmented CT and MRI data. The GPU-based path planner can assess 100 million paths/sec. For our application, this translated to approximately 100 frames/sec for a HD 3D volume.

Conclusions and future work

This work takes a step towards realising intraoperative GPU-based surgical navigation. The architecture is fully parallelized and in theory, real-time intraoperative surgical navigation can be achieved with a sufficiently powerful GPU. In future work, we will utilise GPU clusters to further accelerate navigation. In-vivo animal trials will be completed with the fully integrated system.

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