We present a strategy for **markerless, inside-out** registration of 3D imaging to a patient's face, which enables **untethered augmented reality** to aid physicians in the treatment and management of **head and neck cancer**.

Markerless Image-to-Face Registration for Untethered Augmented Reality in Head and Neck Surgery.

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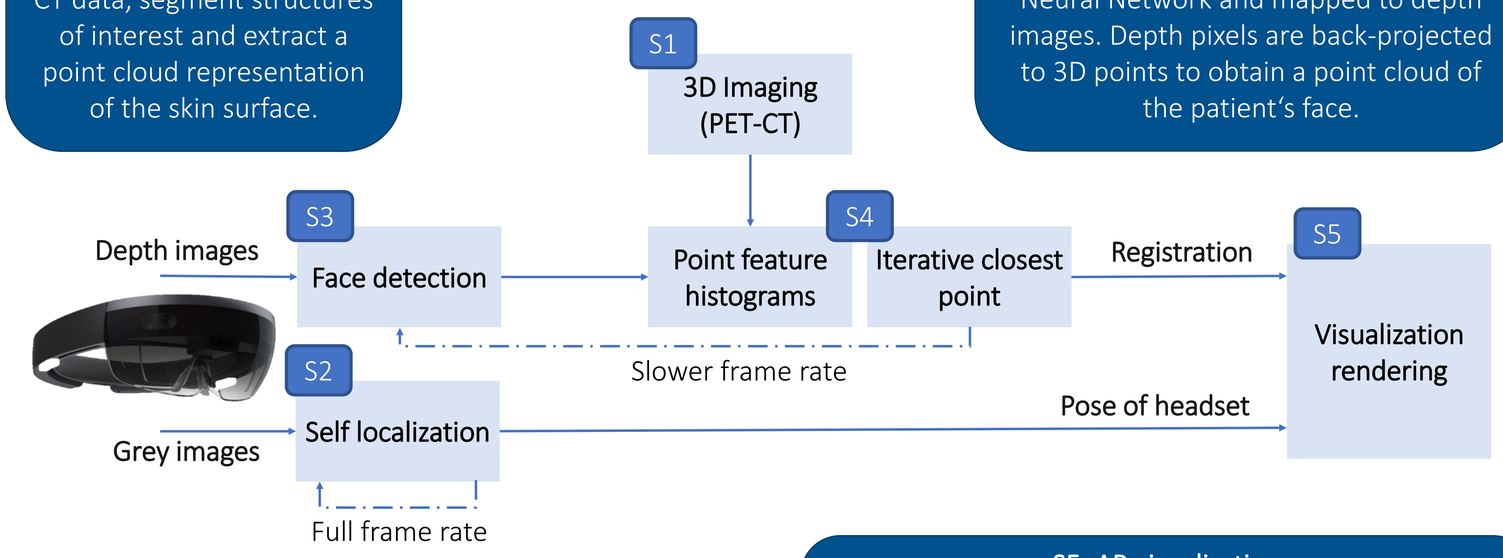
SYSTEM OVERVIEW

We built our system using only the headset hardware, by combining the headset's **self-localization** for tracking and the **depth sensor** for facial localization. Our image-to-face registration pipeline consists of **five steps:**

S1: Medical Imaging & Data Processing
In this pre-interventional, offline step, we acquire PET-CT data, segment structures of interest and extract a point cloud representation of the skin surface.

S2: Self localization
The current pose of the headset is acquired from the headset's SLAM-based self-localization.

S3: Face detection and extraction
A bounding box around the patient's face is regressed in RGB frames using a Single Shot Multibox Detector Convolutional Neural Network and mapped to depth images. Depth pixels are back-projected to 3D points to obtain a point cloud of the patient's face.



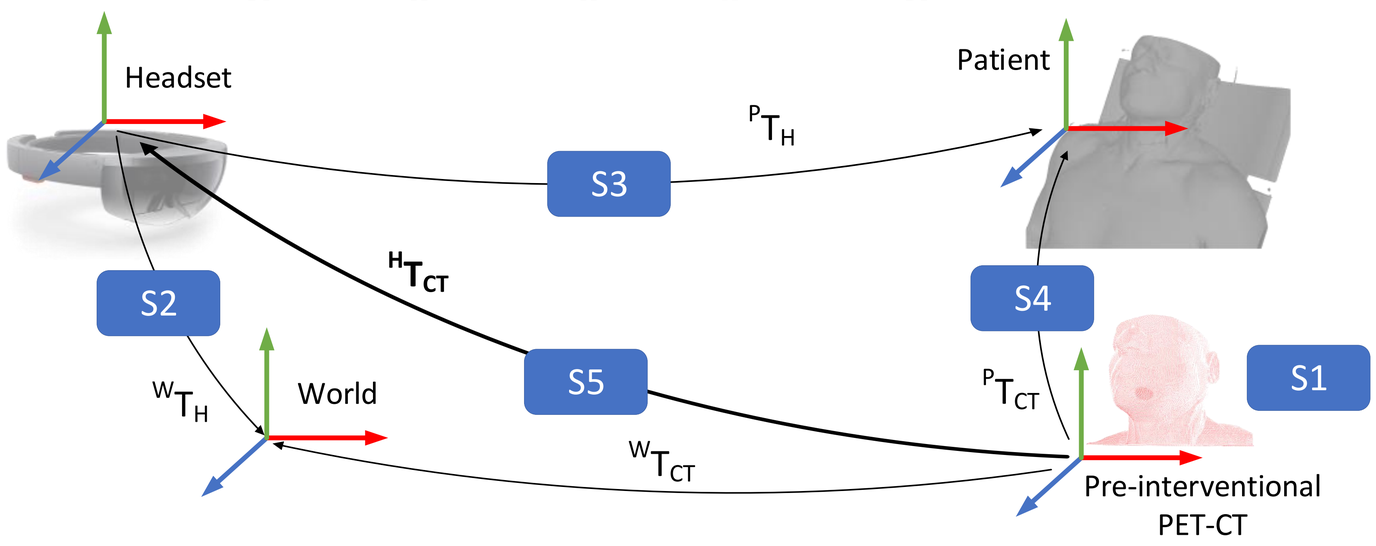
S4: Point cloud registration
The point clouds acquired in S1 and S3 are registered by coarsely aligning them using fast point feature histograms and fast global registration. The registration is refined using iterative closest point.

S5: AR visualization
All steps are combined to render virtual content, overlaid with the patient and anchored to world coordinates. As long as the patient does not move, S3/S4 need to be only run once. If the patient moves, re-detection leads to instant re-registration.

COORDINATE SYSTEMS AND TRANSFORMATIONS

Our system estimates ${}^{H}T_{CT}(t)$, the rigid 3D transformation which correctly positions content in the coordinates of pre-interventional imaging with respect to the physician wearing the headset as

$$ {}^{H}_{CT}T(t) = {}^{W}_{H}T(t)^{-1} \cdot {}^{W}_{H}T(t_0) \cdot {}^{P}_{H}T(t_0)^{-1} \cdot {}^{P}_{CT}T(t_0) $$



MOTIVATION

Medical augmented reality (AR) offers a more intuitive mapping from 3D imaging to the patient, natural 3D interaction and increased perception of 3D structures, to physicians. **Image-to-patient registration** is the key enabling technology for such AR systems. Related works use manual alignment of virtual content, marker-based registration or external tracking systems to establish a correspondence between the real and virtual world. This approaches are **labor-intensive, complicated** and **disruptive** to clinical workflow.

CONTRIBUTION

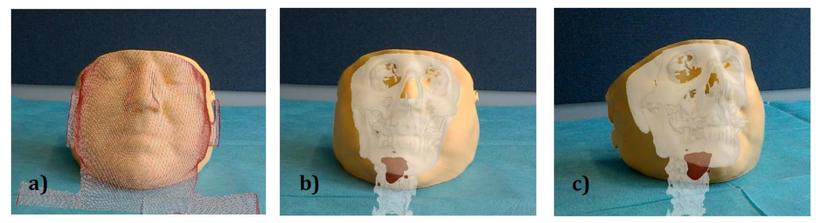
For applications involving the face, the opportunity arises to use **facial features** for both registration and tracking. Thus we present a strategy for **markerless image-to-face registration**, which, in combination with the self-localization of the AR headset, enables untethered real-time AR to aid physicians in the treatment and management of **head and neck cancer.**

EXPERIMENTS AND RESULTS

We evaluated our system using eight phantom heads, 3D printed from real patient data, and a human subject. We report **target registration error** (TRE) as well as **error in translation** E_t **and rotation** E_r by comparing our system with an **external infrared tracking system:**

TRE = 9.2 ±1.5 mm

E_t = 3.9 ±1.8 mm; E_r = 4.9 ±2.4°



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The accuracy our system is subject to several error sources, partly due to hardware restrictions, such as **noisy depth data**, **latency** and virtual content **stability**. We anticipate that future hardware will help us overcome these limitations. While our system does not yet achieve the sub-millimeter precision required for image-guided intervention, it represents a promising **all-in-one tool for immersive treatment and intervention planning** in the management of head and neck cancer.

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