Augmented Reality Patient-Specific Registration for Medical Visualization

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ABSTRACT

In recent years, medical research has made extensive use of Augmented Reality (AR) for visualization. These visualizations provide improved 3D understanding and depth perception for surgeons and medical staff during surgical planning, medical training, and procedures. Often, AR in medicine involves impractical and extensive instrumentation in order to provide the precision needed for clinical use. We propose a mobile AR 3D model registration system for use in a practical, non-instrumented hospital setting. Our registration system takes as input a patient-specific model and overlays it on the patient using an accurate pose registration technique that requires a single marker as a point of reference to initialize a point cloud-based pose refinement technique. Our method is automatic, easy to use, and runs in real-time on a mobile phone. We conduct quantitative and qualitative analysis of the registration. The results confirm that our AR pose registration system produces an accurate and visually correct overlay of the medical data in real-time.

CCS CONCEPTS

• **Computing methodologies → Mixed / augmented reality**.

KEYWORDS

Point Cloud, Visualization, Depth Map, 3D Pose Estimation

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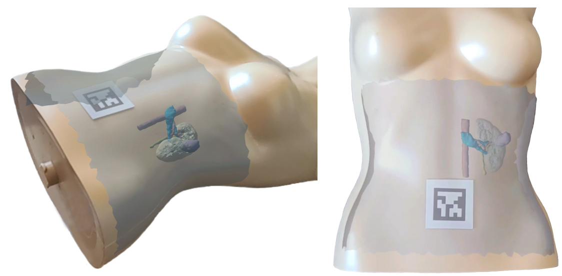

(a) View from the side (b) View from above

Figure 1: Registration Visualization

1 INTRODUCTION

Needle biopsies are complicated medical procedures that can cause significant discomfort to patients and are challenging to perform even for experienced professionals.

Augmented Reality (AR) medical visualization for clinical procedures enhances the 3D understanding of the target mass and surrounding structures. Body pose may be computed with marker-based AR [1, 5], requiring knowledge of the static body pose with respect to the marker. The body is assumed to remain stationary, which is presumed during a needle biopsy. Pose of a body part may also be computed with marker-less AR [6], assuming the body part has features such as texture or contours. For 3D objects lacking in descriptive features, e.g. the abdomen in our case, a depth camera can be utilized for pose estimation and registration [4].

We present an automatic AR 3D model registration system which overlays a patient-specific virtual 3D model onto the patient in a non-instrumented environment. Our technique utilizes a consumer-grade smartphone with a combined RGB and depth (RGB-D) camera and a single fiducial marker to localize the featureless body part and compute an initial pose estimate. Our application achieves accurate registration in real-time $\approx 25 - 30$ fps.

2 SYSTEM

The goal of our system is to register the point cloud of the 3D model, PC_{model}, to the reference point cloud, PC_{ref}, of the real object captured by the depth camera. We achieve this by computing a rigid transformation M such that $PC_{align} = (M \cdot PC_{model})$, where PC_{align} is the transformed model that is aligned with PC_{ref}.

Figure 2 shows an overview of the proposed registration system, which was built in Unity Engine. The system takes in two point clouds as inputs: a reference cloud, computed in real-time of the 3D object, and a model cloud (Figure 2a). We sub-sample the reference

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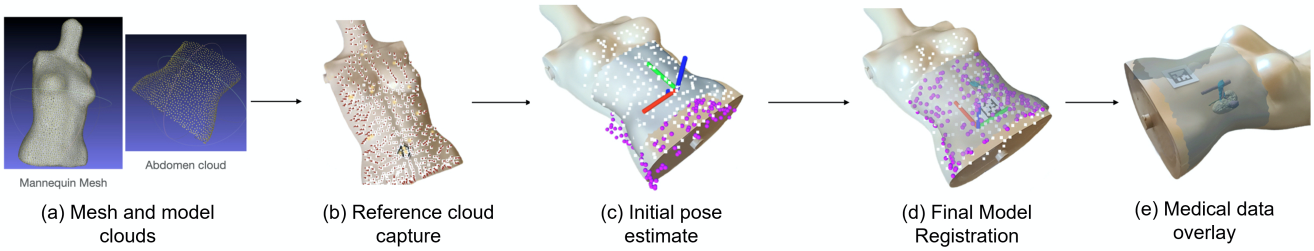

Figure 2: Registration System Pipeline.

cloud and remove unwanted points from around the object in the reference cloud (Figure 2b). Next, we estimate the initial pose M_0 (Figure 2c). M_0 initializes the ICP algorithm [2], which computes the transform M that registers PC_{model} to PC_{ref} (Figure 2d). Finally, the transformed model PC_{align} is rendered (Figure 2e).

2.1 Initial Pose Estimation

Providing an initial pose estimate that is close to the true pose improves registration accuracy, speed, and convergence, especially for smooth point clouds like the abdomen. We compute the centroid $T_0 \in \mathbb{R}^{3\times1}$ of the body part by projecting a vector away from the marker and into the body. To compute an initial orientation $R_0 \in \mathbb{R}^{3\times3}$, we use Principal Component Analysis (PCA) on PC_{ref}. Finally, we obtain the initial transformation $M_0 = [R_0|T_0]$.

2.2 Model Registration

The ICP algorithm registers PC_{model} to PC_{ref} by iteratively computing 3D point correspondences and computing and applying a rigid transform M to PC_{model}. The initial pose estimate M_0 initializes the process. ICP computes a transform M_i for each frame i and minimizes the error ϵ^i_{ICP} between PC_{ref} and $M_i \cdot PC_{model}$:

$$\min_{M_i} \epsilon^i_{ICP} = \sum_j \sum_k v^i_{jk} ||PC^i_{ref}(j) - M_i \cdot PC_{model}(k)|| \quad (1)$$

where $PC^i(j)$ is the j-th 3D point in a point cloud PC at frame i, and v_{jk} is a binary variable that is 1 if ICP matches the j-th and k-th 3D points of PC_{ref} and $M_i \cdot PC_{model}$ respectively. ICP continues until convergence. Convergence at frame i is determined when the rotation and translation errors are less than their thresholds i.e. $|R_i - R_{i-1}| < \epsilon_R$ and $|T_i - T_{i-1}| < \epsilon_T$. PC_{align} is the resulting transformation representing the global minimum of ICP.

3 RESULTS

We assessed the correctness of the registration by computing the average distance between points in PC_{model} and their corresponding points in PC_{ref}. Figure 3b shows that the correspondences maintain an average distance of approximately $2.99mm$ following convergence, which is acceptably low for medical visualization.

The combined results from Figure 3 show that starting from the initial pose estimate, ICP computes stable correspondences between the point clouds and converges quickly to the correct pose. PC_{model} registers to PC_{ref} in approximately seven frames, or 0.233 seconds.

We performed qualitative analysis of the registration by inspecting the resulting registration (Figure 1) from many viewpoints. The

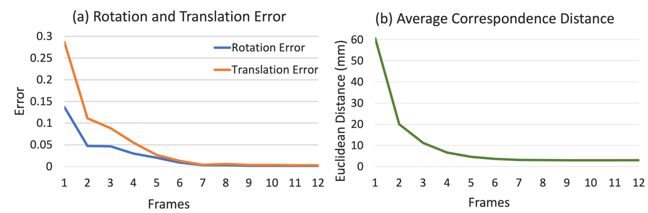

Figure 3: Results

visualization provides a clear view into the torso model, where the user can see the target organ, i.e. a kidney model [3], through the translucent skin of the virtual abdomen model.

4 CONCLUSION AND FUTURE WORK

In this paper, we have proposed an AR registration method that allows for object-specific registration for feature-less objects. Future work includes addressing patient movement, increasing the fidelity of the reference point cloud utilizing depth captures from multiple view points, and developing a marker-less method for detecting the abdomen. This system has the potential for impact in various settings: surgical or medical procedure planning, medical education, and low-cost visualization for humanitarian medical applications.

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