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

1 INTRODUCTION

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

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ACM Reference Format:

2 SYSTEM

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

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
We assessed the correctness of the registration by computing 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 $T_0 \in \mathbb{R}^{3 \times 1}$ of the body part by projecting a vector away from the marker and into the body. To compute an initial orientation $R_0 \in \mathbb{R}^{3 \times 3}$, 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 $e_{ICP}$ between $PC_{ref}$ and $M_i \cdot PC_{model}$:

$$
\min_{M_i} e_{ICP}^i = \sum_j \sum_k |PC_{ref}^j(i) - M_i \cdot PC_{model}^k(j)|
$$

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 $|R_i - R_{i-1}| < \epsilon_R$ 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 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 viewpoints, 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.

REFERENCES


