Constructing Deformable Shapes from Range Scans

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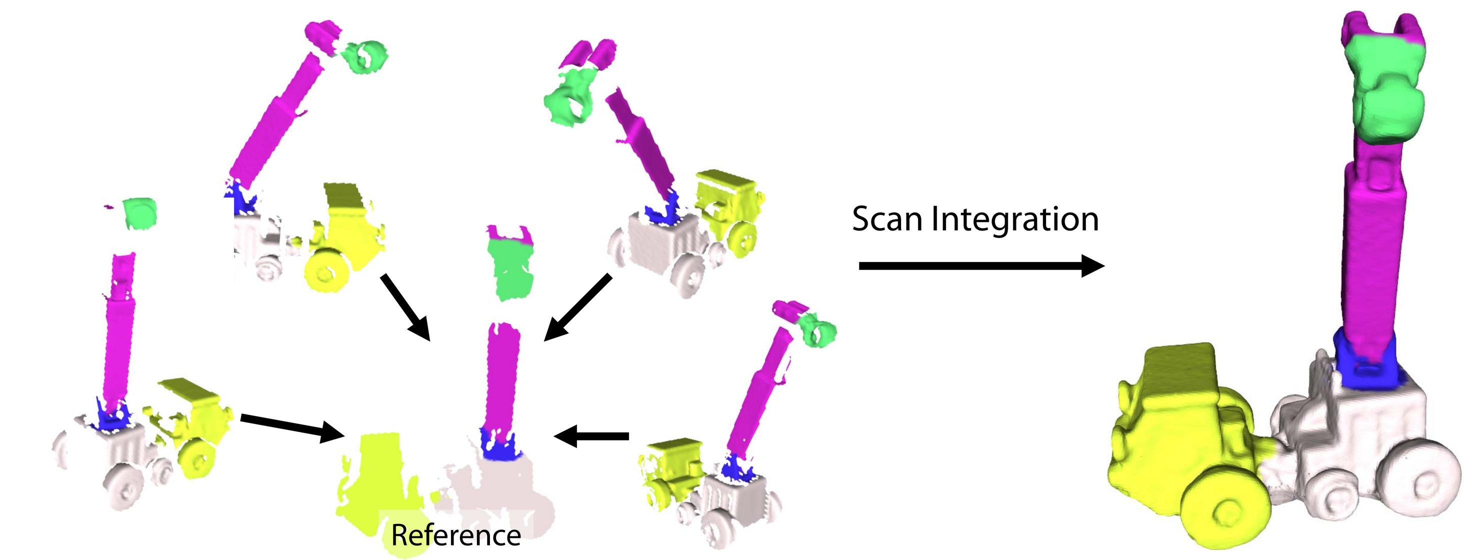
Goal and Problem Statement

Our goal is to capture the full 3D surface geometry of a moving object in the real world, along with a mathematical model describing its movement. We describe a technique to construct such a deformable model by aligning multiple range scans of an articulated moving object.



Registration to a reference scan. Each color represents a separate rigid part, learned based on the motion of the object.

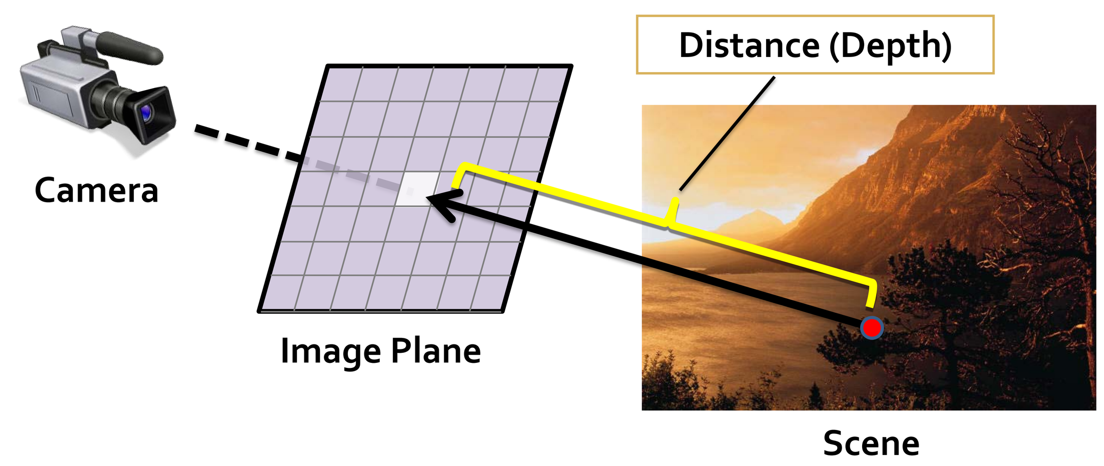
Reconstructed Surface and Segmentation

Our technique demonstrates that 3D models can be reconstructed from moving range scans **without any markers, template, or user-defined segmentation of the model**. The algorithm is an extension of our previous work [CZ09] that aligns a pair of scans. We extend this work by

1. representing a segmentation consistently across multiple scans, and
2. formulating an optimization problem to align scans simultaneously.

Background Information

Range scans are dense measurements of 3D positions on an object's surface. These scans are acquired using a range camera, which measures the distance from the camera to the scene at each pixel.



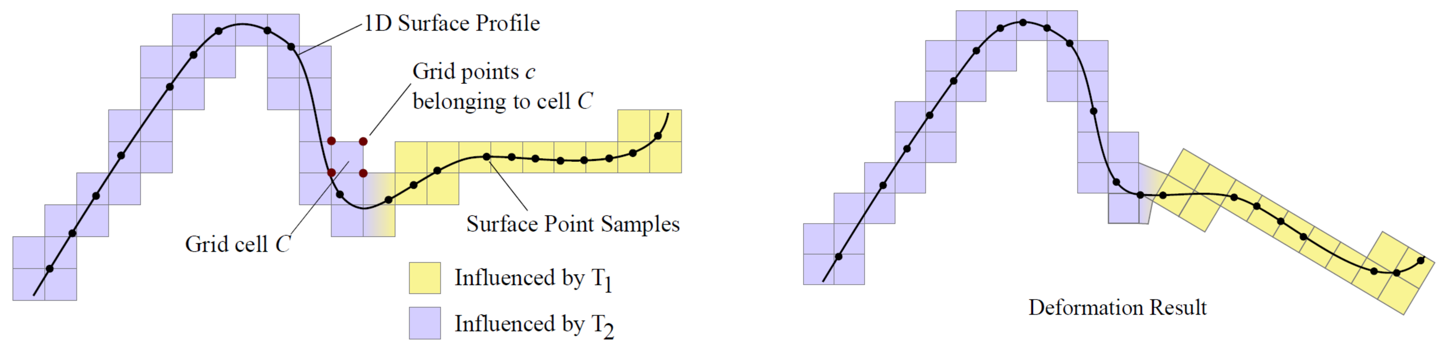
We cannot see the entire surface from a single viewpoint, so we must capture multiple scans from different viewpoints and align them to a common frame of reference. This problem is called scan ***registration***.

While much work has been done to solve the registration problem for rigid objects, researchers are now beginning to tackle this problem for non-rigid, moving objects [CZ09,LSP08,HAWG08,PG08,SAL*08,WAO*09].

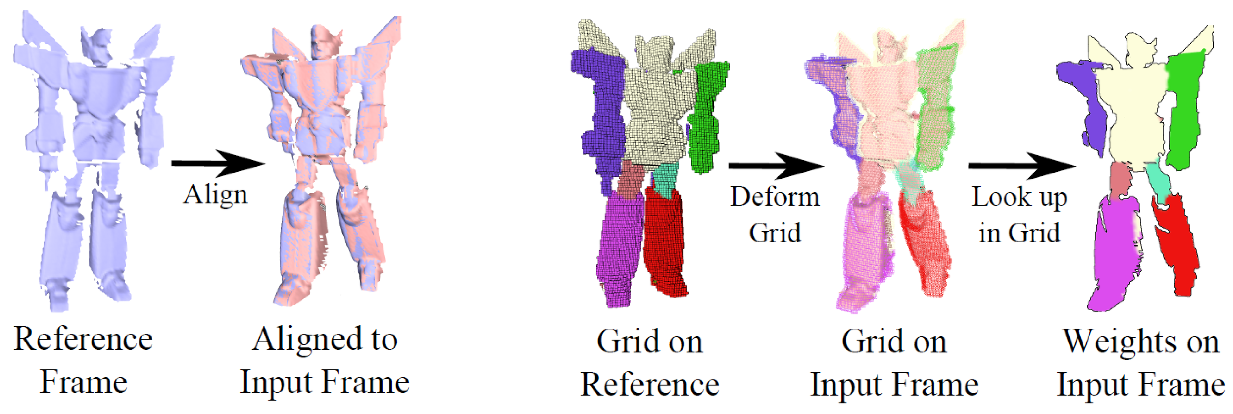
The main challenge of this problem is the lack of any correspondence information between the scans. Thus we must rely on matching the shape of the surface directly in order to align the scans. This task is even more difficult when there is much missing data, limited overlap between scans, and a large motion of the object being scanned.

Our Approach

Our **simplifying assumption** is that the movement of the object can be described by the movement of a few rigid parts. Given a rough guess of the number of parts, we automatically estimate a division of each scan into rigid parts (a segmentation) that best reflects the movement observed in the data.



We define the division into rigid parts by using weights assigned to a regular grid enclosing the scanned geometry.



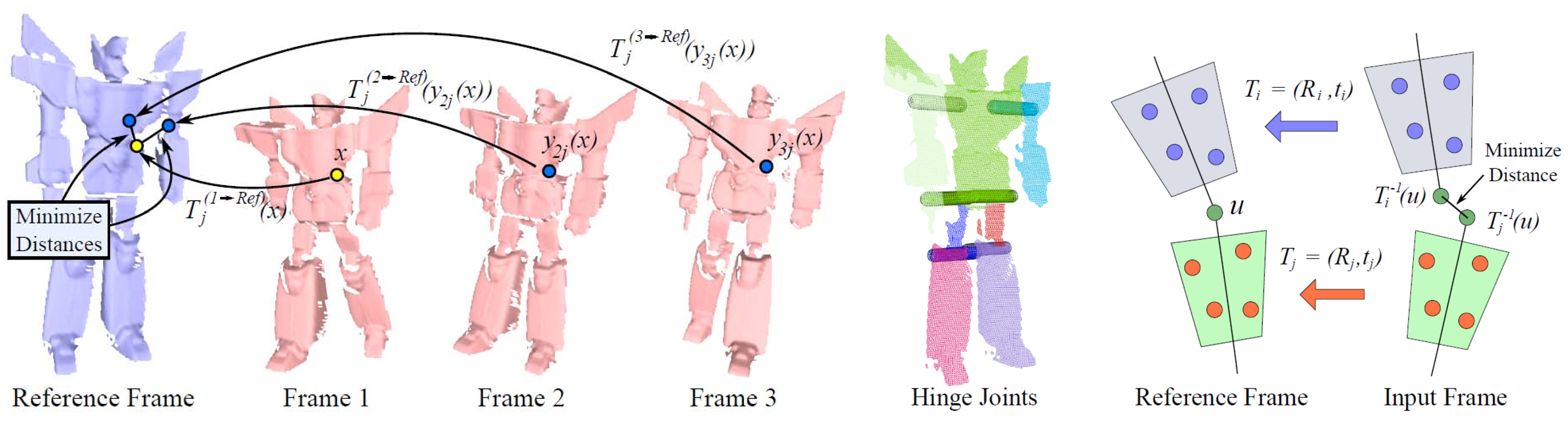
We need weights on all scans. Instead of maintaining a separate grid for each scan, we use a single grid defined on the reference scan. An approximate alignment to the reference is sufficient to look up the weights.

Optimization Algorithm

For each scan:

→ Initialize approximate alignment to reference
→ Perform global registration using alternating optimization
  → Non-linear least squares for optimizing transformations
  → Graph cuts for optimizing weights
→ Update reference frame with any new geometry

Objective Function



$$\underset{\mathcal{T},\mathcal{W}}{\operatorname{argmin}}\ \alpha\,\mathcal{E}_{\text{fit}}(\mathcal{T},\mathcal{W}) + \beta\,\mathcal{E}_{\text{joint}}(\mathcal{T}) + \gamma\,\mathcal{E}_{\text{weight}}(\mathcal{W})$$

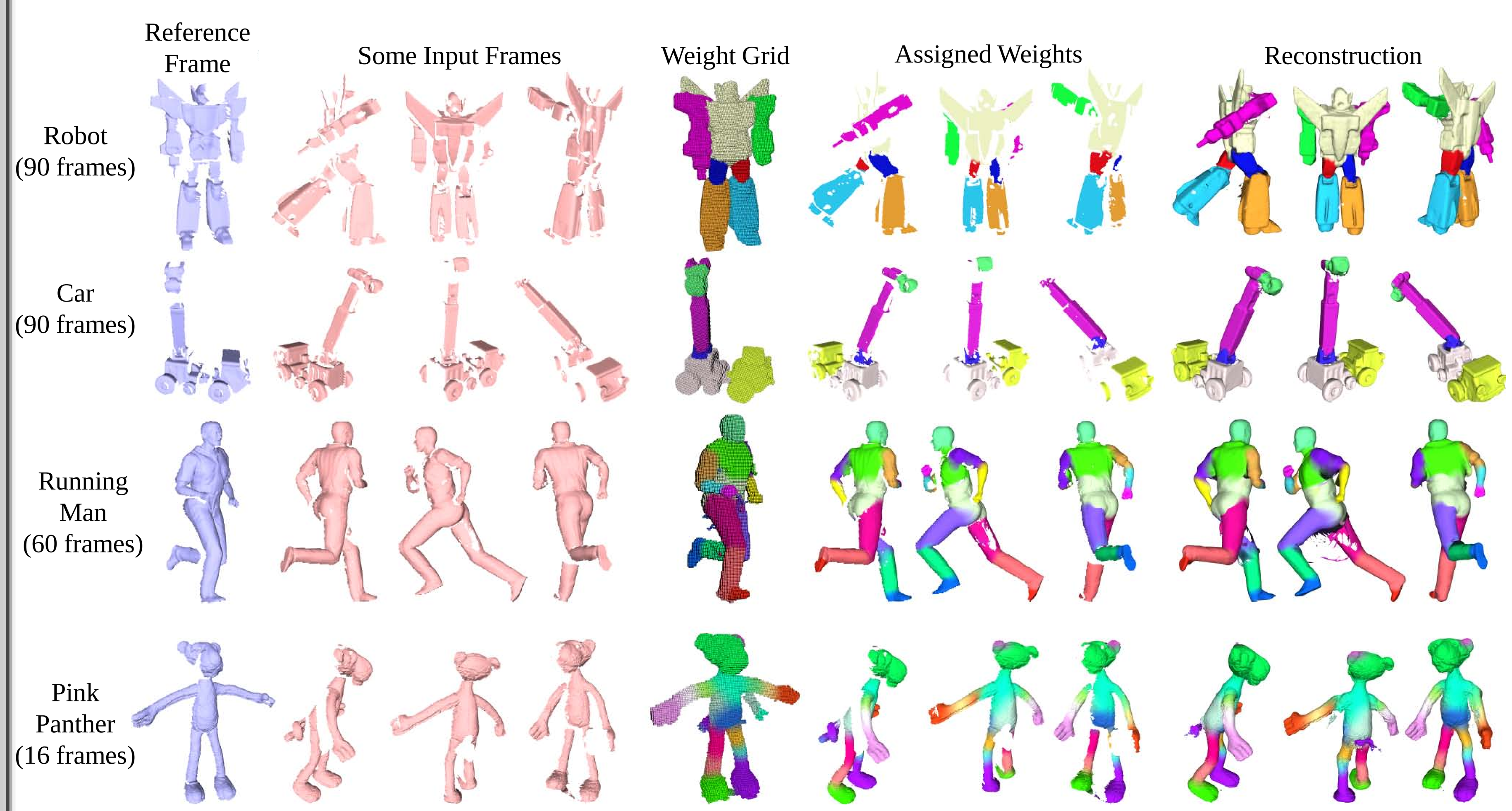
$$\mathcal{E}_{\text{fit}}(\mathcal{T},\mathcal{W}) = \sum_{\mathbf{x}\in S}\ \sum_{\text{Frames } k}\ \sum_{j=1}^{B} w_j(\mathbf{x})\, d\left(T_j^{(f\to\text{Ref})}(\mathbf{x}), T_j^{(k\to\text{Ref})}(\mathbf{y}_{kj}(\mathbf{x}))\right)$$

$$\mathcal{E}_{\text{joint}}(\mathcal{T}) = \sum_{\text{Frames } f}\ \sum_{\text{Joints } (i,j)}\ \sum_{\mathbf{u}\in\text{Joint}} \left\| T_i^{(f\to\text{Ref})^{-1}}(\mathbf{u}) - T_j^{(f\to\text{Ref})^{-1}}(\mathbf{u}) \right\|^2$$

$$\mathcal{E}_{\text{weight}}(\mathcal{W}) = V(f_C, f_D) = \begin{cases} 0 & \text{if } f_C = f_D \\ 1 & \text{otherwise.} \end{cases}$$

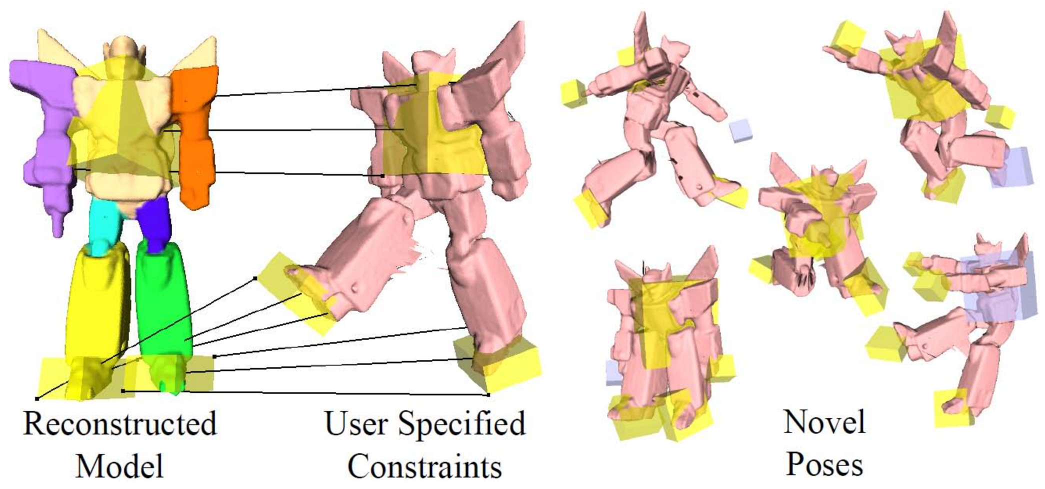
Registration Results

We tested our algorithm on four datasets: robot, car, running man, and pink panther. As shown below, our algorithm is capable of high-quality reconstructions. However, the optimization often converges to undesired local minima, requiring the user to manually adjust the parameters and restart the optimization. The running time is about 4 min/frame, with initialization and global registration being the most time-consuming steps.



Inverse Kinematics Application

Our reconstructed model can be intuitively re-posed and animated interactively, because our algorithm directly provides skinning weights. We implemented a system for a user to interactively pose the robot model by defining positional constraints.



Conclusion and Future Work

We developed a technique to align multiple range scans of a moving articulated object. In the future, we will make the method completely automatic and more robust to topological changes.

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