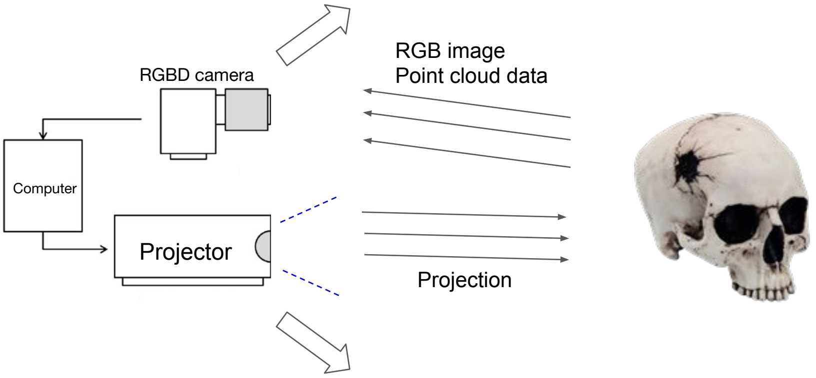
Paper Presentation

Group 10: Austin Shin

Project Statement

The goal of this project is to develop a projection mapping prototype that projects patient data (eg. CT/MRI scan model) onto patient body in realtime.



RGBD camera

RGB image
Point cloud data

Computer

Projector

Projection

Paper Selection

Yi Zhou, Shuangjiu Xiao, Ning Tang, Zhiyong Wei, and Xu Chen. 2016. **Pmomo: Projection Mapping on Movable 3D Object**. *In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). ACM, New York, NY, USA, 781-790.* DOI: https://doi.org/10.1145/2858036.2858329

- Dynamic projection mapping prototype that can handle 6DOF motion
- Accurate projections at an interactive level
- Done in real-time

PMOMO: Problem and Key Result

Problem: low accuracy of projection on target object, restricted range of motion, occlusions

[1] Yi et. al

PMOMO: Background and Previous Work

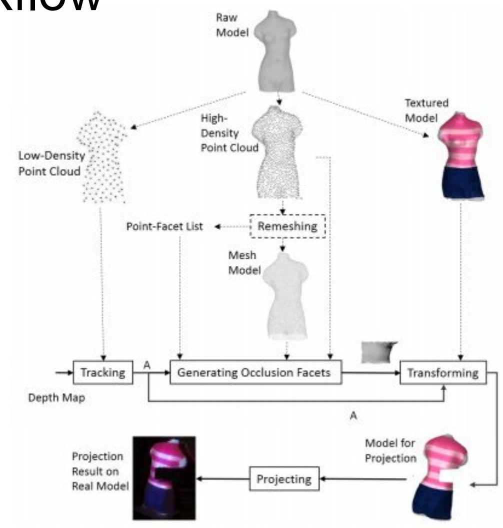
Projection mapping (SAR) - applying visual enhancements (color, texture, geometry) onto real-world objects

Tracking sensors - magnetic trackers, high-speed vision sensor with optical gaze controller, optical markers

Projection features - iteratively minimize distortion in distinct projected features

Registration - ICP

PMOMO: Workflow



[1] Yi et. al

Figure 3. Overall work flow of the Pmomo system. Procedures with solid lines are run in real-time. Procedures with dash lines are done in preparation phase. *A* refers to the transform matrix of the target object.

PMOMO: Setup and Calibration

Hardware

- Kinect 2.0
- AHRS sensor
- PC and projector

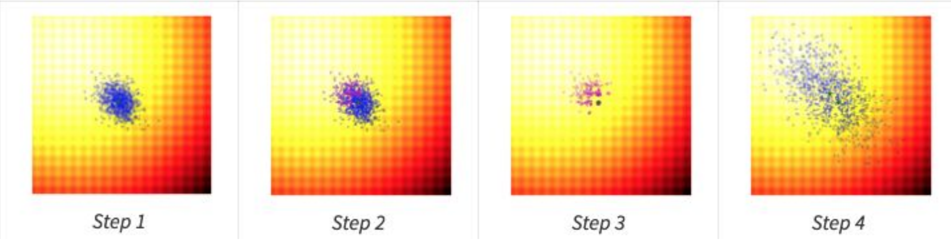
Calibration

- Virtual scene calibrated to real scene
- Calibrate AHRS sensor with Kinect
- Calibrate projector with IR and RGB camera

PMOMO: Tracking

Covariance Matrix Adaptation Evolution Strategy (CMA-ES)

- Process of taking results of each iteration and increasing / decreasing search space of next iteration based on covariance matrix



Step 1 Step 2 Step 3 Step 4

http://blog.otoro.net/2017/10/29/visual-evolution-strategies/

Step 1: calculate fitness score of each candidate solution. Step 2: isolates the best N% of population (purple). Step 3: Calculate covariance matrix of next generation using best solutions and mean. Step 4: Sample new set of candidate solutions using new mean and calculated covariance matrix

PMOMO: Tracking

Modified CMA-ES

- Find transformation matrix that best registers low-density point cloud to depth image
- Fitness score - average RMS distance
- Adaptive step-size control
- Hardware delay management

$$F(A) = \sqrt{\frac{1}{n} \sum_{p_i \in S} \|\phi(\pi(Ap_i)) - Ap_i\|^2}$$

S - set of points, n - number of points in S,
A - transformation at each iteration of CMA-ES,
p_i - ith point, π(p) - returns q, corresponding point in depth image, ϕ(q) - returns associated depth value

$$T_n^{predict} = T_n + f * (D_c + D_k) * (T_n - T_{n-1})$$

$T_n^{predict}$ - predicted translation, T_n - estimated translation of nth frame, T_n - estimated translation of n-1th frame, f - frame rate, D_c - computation delay, D_k - Kinect delay

[1] Yi et. al

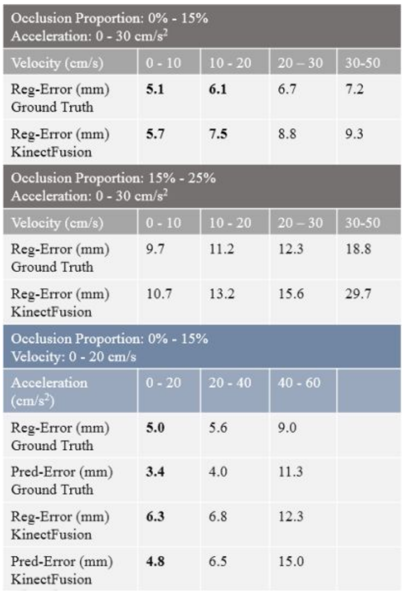
PMOMO: Generating Occlusion Facets

Occlusion Detection

- Determine which points from high-density point cloud are occluded:
  - $Angle(\vec{n}, \vec{pk}) \leq 90^\circ$
  - $(depth_{real}(P) - depth_{virtual}(P)) > thr$
    - $thr = max(F(A_n), minThr)$
- Determine facets associated with occluded points
- Color facets black

PMOMO: Results

- Low registration error at low velocity and low occlusion percentage
- Large registration error at high velocity and high occlusion percentage
- Performs slightly better than Kinect Fusion
- Translation prediction increases accuracy when acceleration is not high



Occlusion Proportion: 0% - 15% Acceleration: 0 - 30 cm/s^2				
Velocity (cm/s)	0 - 10	10 - 20	20 – 30	30-50
Reg-Error (mm) Ground Truth	**5.1**	**6.1**	6.7	7.2
Reg-Error (mm) KinectFusion	**5.7**	**7.5**	8.8	9.3
Occlusion Proportion: 15% - 25% Acceleration: 0 - 30 cm/s^2				
Velocity (cm/s)	0 - 10	10 - 20	20 – 30	30-50
Reg-Error (mm) Ground Truth	9.7	11.2	12.3	18.8
Reg-Error (mm) KinectFusion	10.7	13.2	15.6	29.7
Occlusion Proportion: 0% - 15% Velocity: 0 - 20 cm/s				
Acceleration (cm/s^2)	0 - 20	20 - 40	40 - 60	
Reg-Error (mm) Ground Truth	**5.0**	5.6	9.0	
Pred-Error (mm) Ground Truth	**3.4**	4.0	11.3	
Reg-Error (mm) KinectFusion	**6.3**	6.8	12.3	
Pred-Error (mm) KinectFusion	**4.8**	6.5	15.0	

[1] Yi et. al

Assessing PMOMO Paper

Pros

- Adaptive occlusion threshold and CMA-ES step-size
- Accurate occlusion culling and translation prediction

Cons

- Requires many mesh models and highly accurate virtual scene
- Confusingly tabulated results

Future Steps

- Ways to reduce number of models needed during setup
- Comparison between rotation obtained using CMA-ES and AHRS sensor
- Expanding range of velocity and acceleration

Relevance of PMOMO Paper

- Good survey of previous work, especially tracking sensors
- Great starting point for registration (CMA-ES)
- Gives a baseline of results to compare my results with for tracking error

Conclusions

- Dynamic high-accuracy projection mapping is feasible
- Results depend on high level of model setup
- Modified CMA-ES method is a great enhancement
- Interfacing with projector is still a mystery

Any Questions?

References

1. Yi Zhou, Shuangjiu Xiao, Ning Tang, Zhiyong Wei, and Xu Chen. 2016. **Pmomo: Projection Mapping on Movable 3D Object**. *In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16). ACM, New York, NY, USA, 781-790.* DOI: https://doi.org/10.1145/2858036.2858329