

X-ray Based Craniofacial Visualization and Surgery Simulation

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Outlines

- Research background
- Objectives
- Methodology
- Algorithms
- Experiment and results
- Conclusion and future work

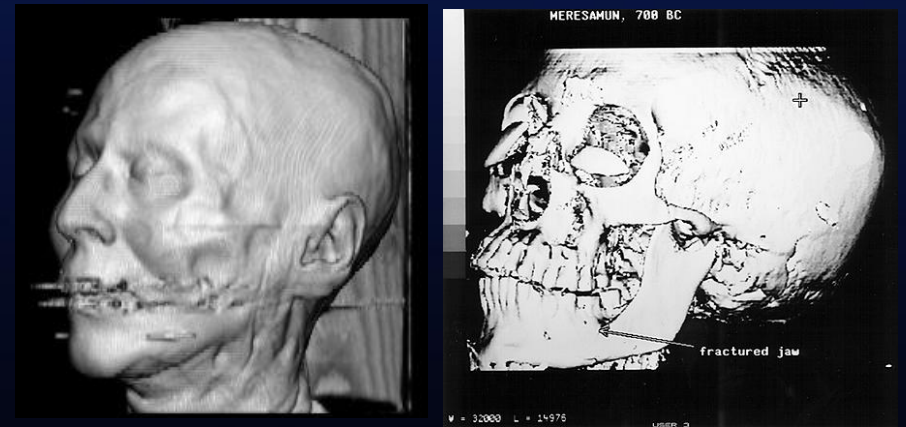
Research background

In orthodontics and plastic surgery, the analysis and measurement of cranium are often needed to diagnose whether there is structure malformation in the mandible or maxilla. At present there are two main kinds of approaches:

- One is the conventional measurement method, which is directly manipulated on the frontal or lateral cephalo X-rays. (2D method, widely used, the accuracy is limited)
- Another is the measurement on the 3D cranium model reconstructed by CT. (3D method, high accuracy)



Frontal and lateral cephalo X-rays



3D face and skull model from CT

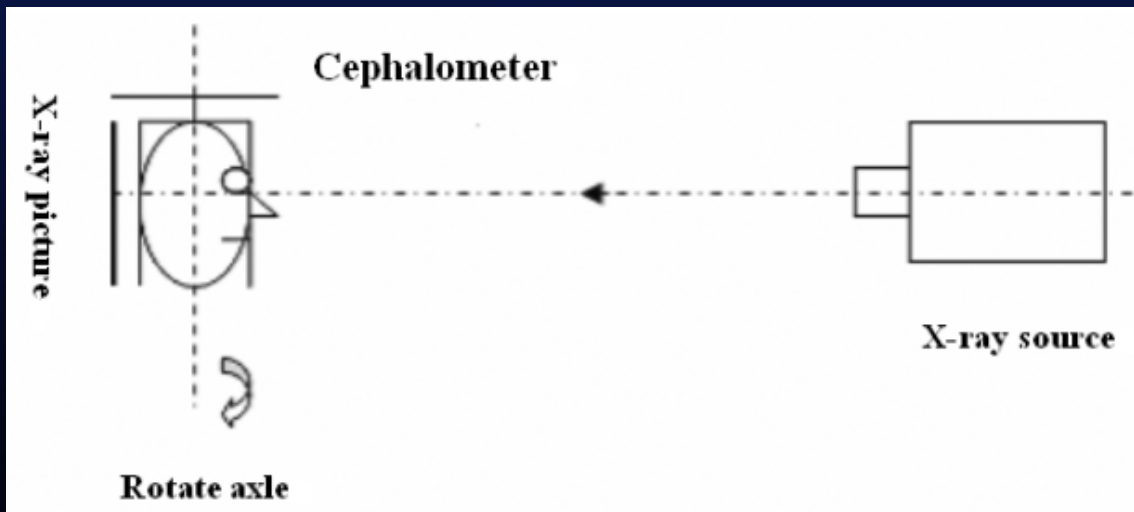
Research objectives

- One disadvantage of CT is that large dose of X-ray radiation could have a serious adverse effect to the human body, especially for the children.
- In addition, compared with ordinary X-rays, CT scan is also more costly, which could be an issue for developing countries and underprivileged regions.
- In this research, instead of the CT based option, we want to design a low radiation, low cost way to reconstruct and visualize the 3D cranium with a small number of X-rays

Methodology

We use the method of computer vision to reconstruct the 3D face of patient from three cephalo X-rays (0° , 60° , 90° projection with lead markers). Then with two of three X-rays and M-ultrasound scan, we can get the thickness of soft tissue and create the 3D skull model by subtracting soft tissue from facial surface. In this process, only X-ray machine, adhesive taps with lead markers and the M-ultrasonograph are needed.

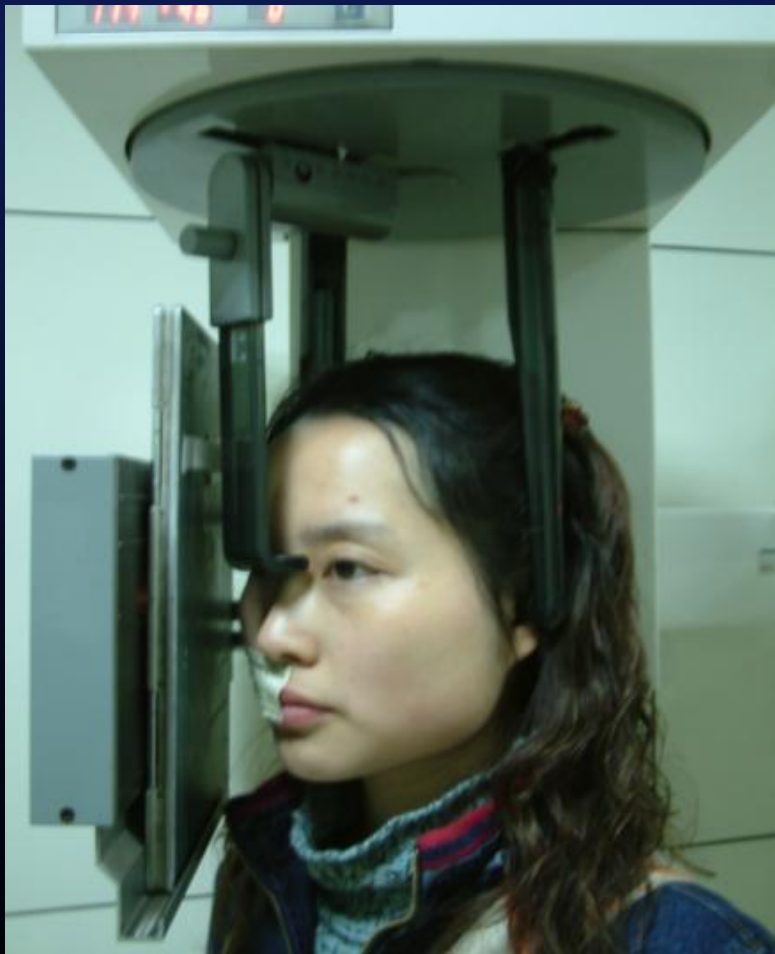
X-ray photographing



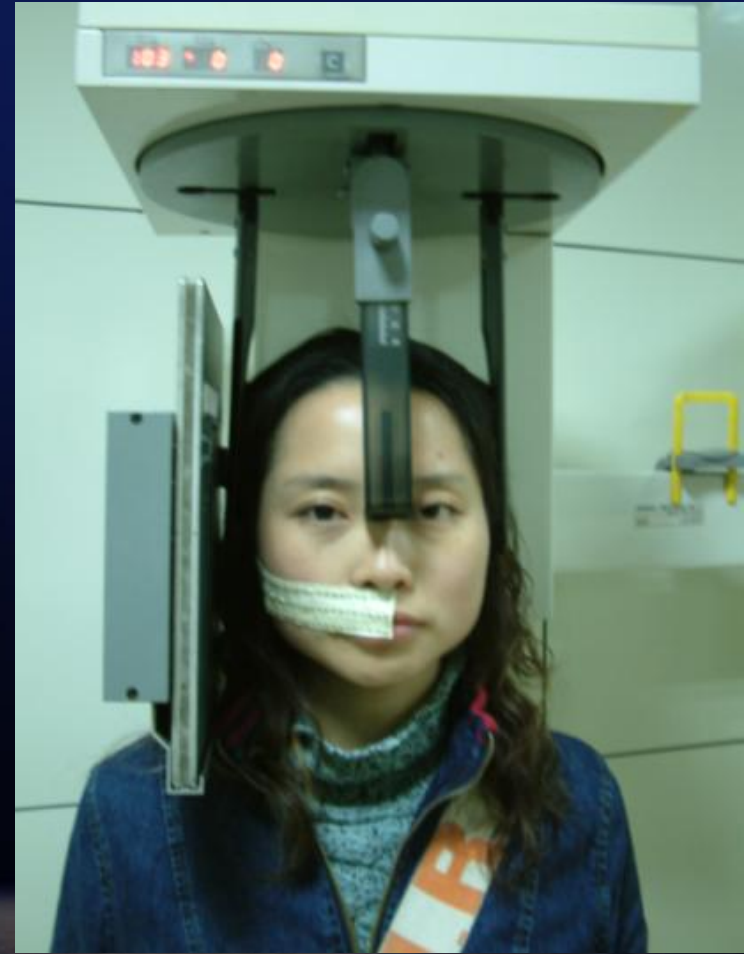
X-ray photographing with cephalometer



**Cephalometer
X-ray machine**



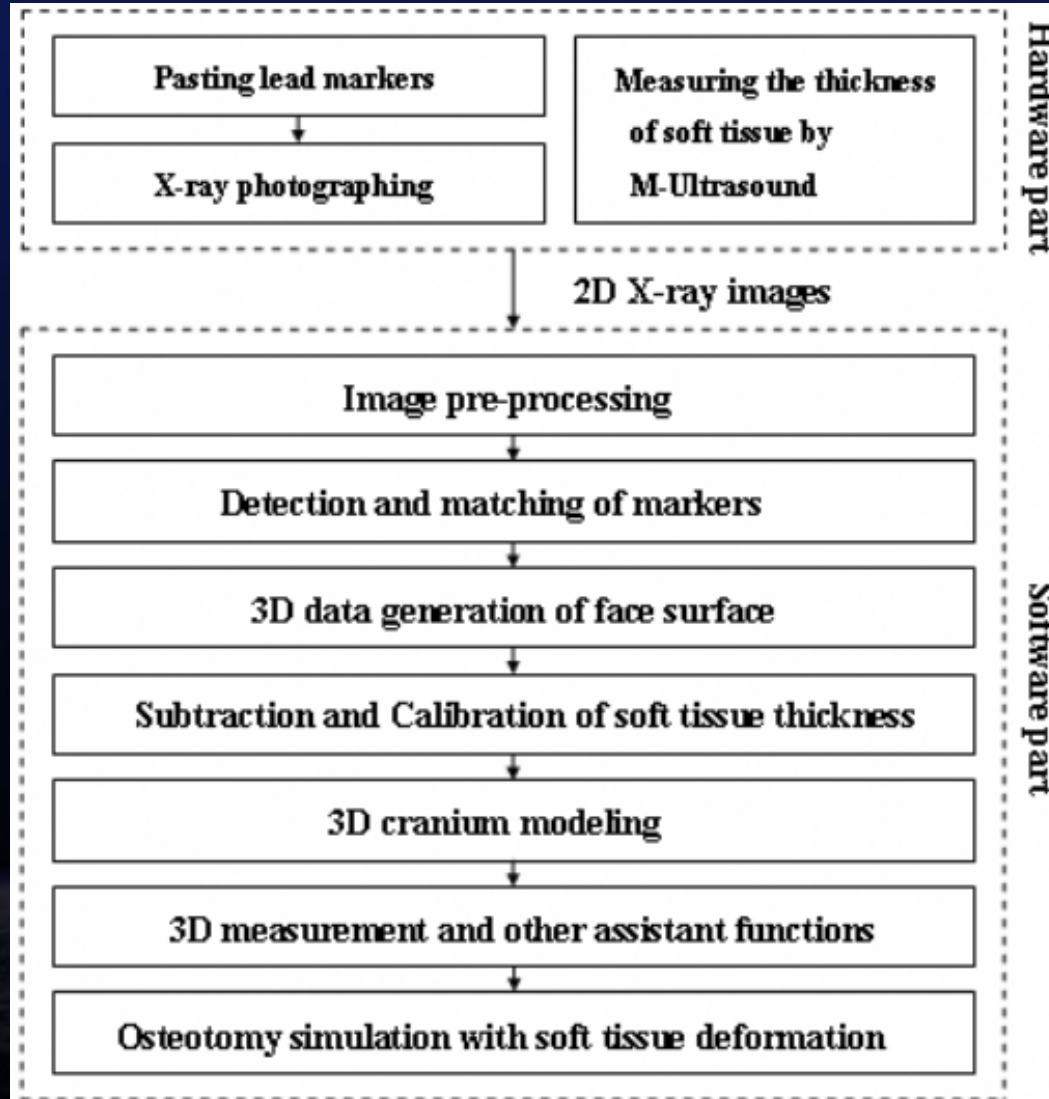
60° Projection

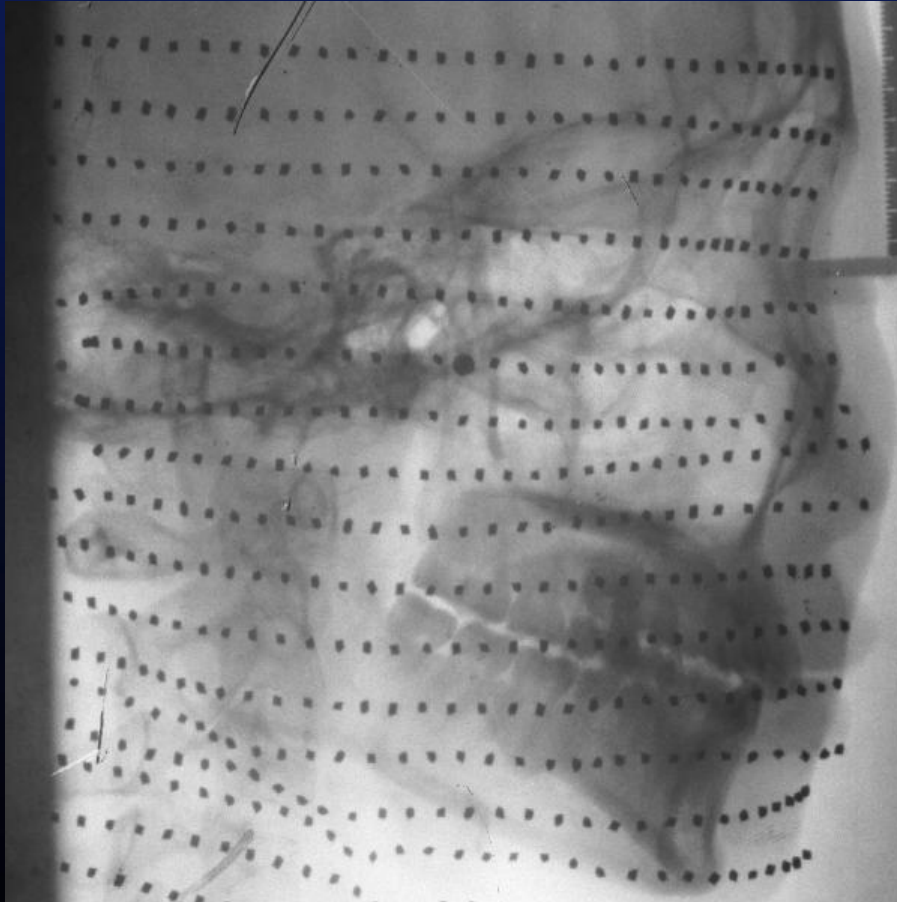


90° Projection

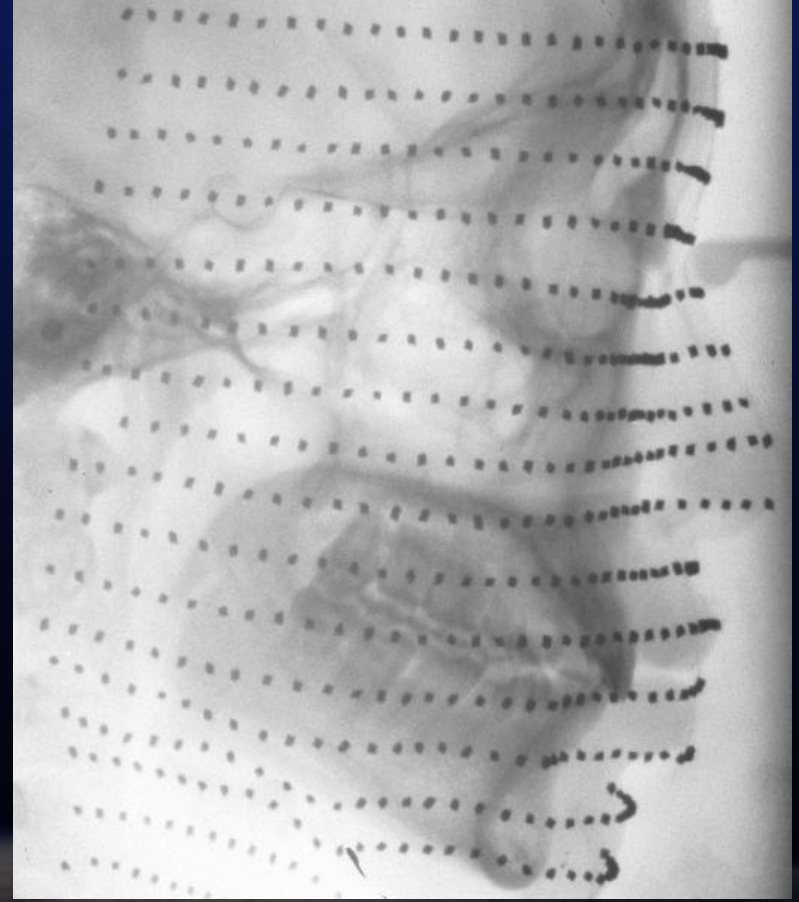
A testee with a tape of lead markers on lips in X-ray photographing

System structure



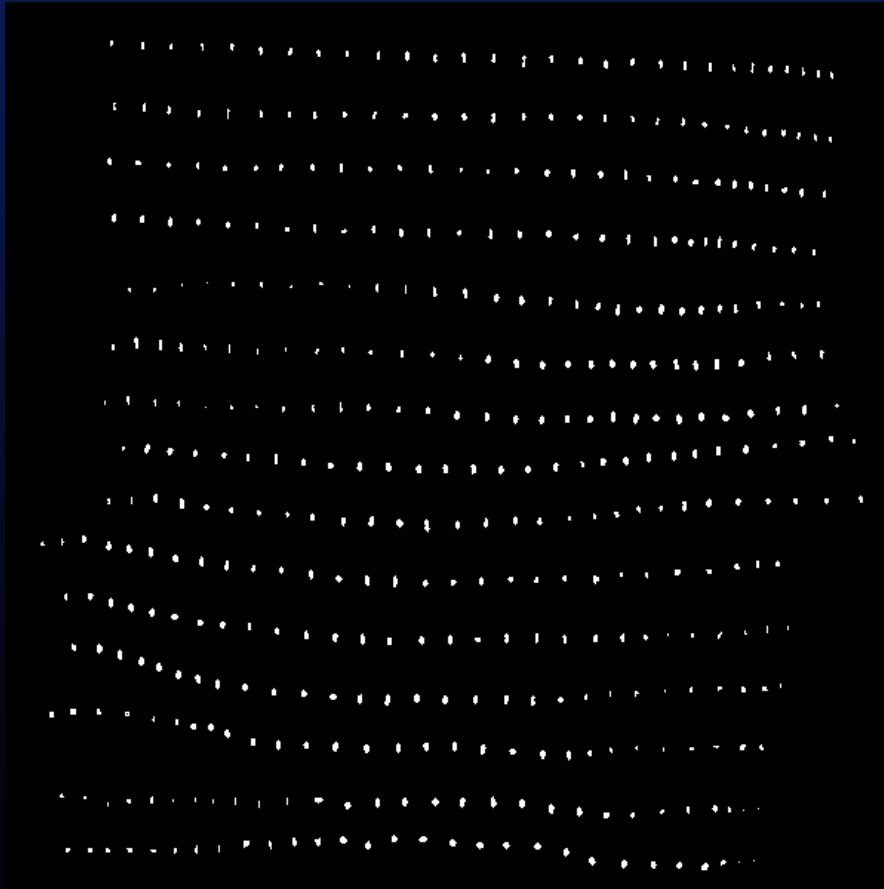


60° Projection



90° Projection

Original X-ray image pair



60° Projection



90° Projection

Binary images detected feature points

Correlated vision

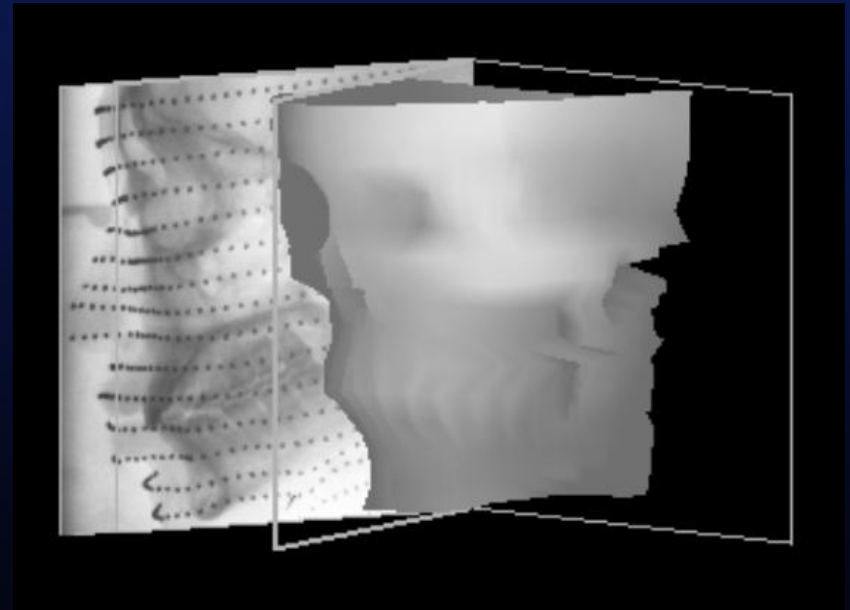
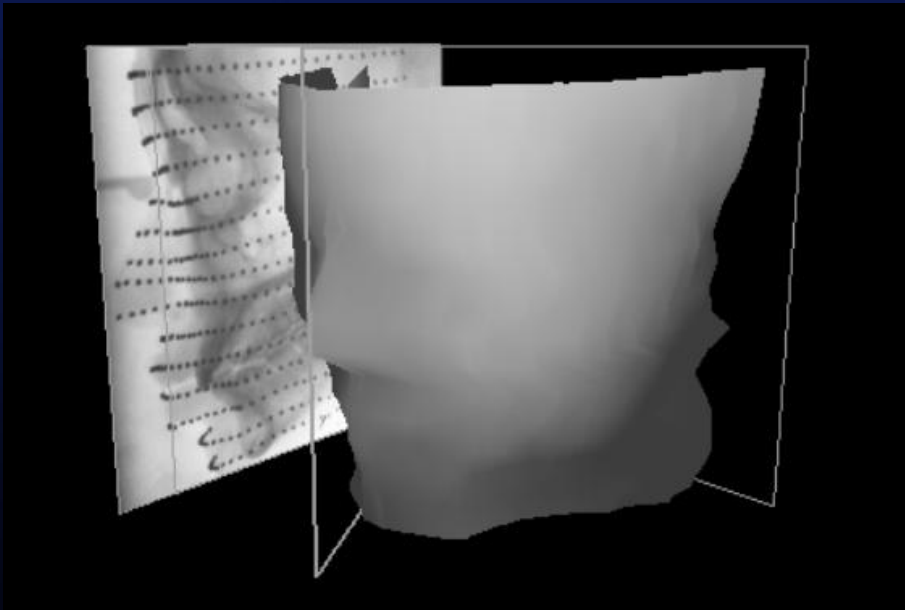
The calculation of 3D coordinates of markers by the correlated vision.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x_l \\ y_l \\ z_l \end{pmatrix} + t_l \mathbf{R}_l \begin{pmatrix} \dot{x}_{l,i} \\ \dot{y}_{l,i} \\ F_l \end{pmatrix} \quad \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x_r \\ y_r \\ z_r \end{pmatrix} + t_r \mathbf{R}_r \begin{pmatrix} \dot{x}_{r,i} \\ \dot{y}_{r,i} \\ F_r \end{pmatrix}$$

$$d^2 = \left[\begin{pmatrix} x_l \\ y_l \\ z_l \end{pmatrix} + t_l \mathbf{R}_l \begin{pmatrix} \dot{x}_{l,i} \\ \dot{y}_{l,i} \\ \dot{z}_{l,i} \end{pmatrix} - \begin{pmatrix} x_r \\ y_r \\ z_r \end{pmatrix} - t_r \mathbf{R}_r \begin{pmatrix} \dot{x}_{r,i} \\ \dot{y}_{r,i} \\ \dot{z}_{r,i} \end{pmatrix} \right]^2$$

$$= [\mathbf{b} + t_l \mathbf{r}_l - t_r \mathbf{r}_r]^2$$

Visualization results



3D face and skull model of a subject in experiment



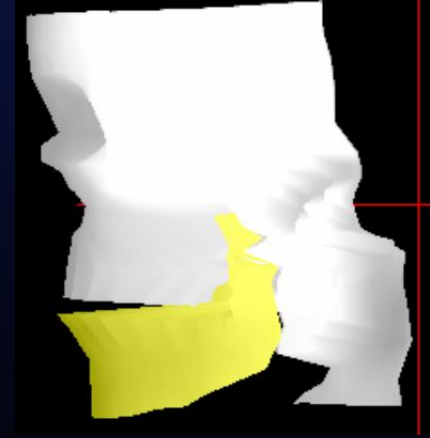
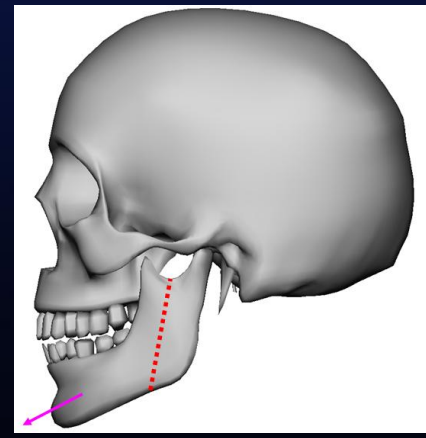
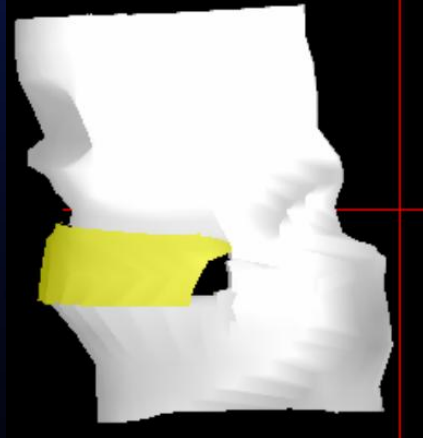
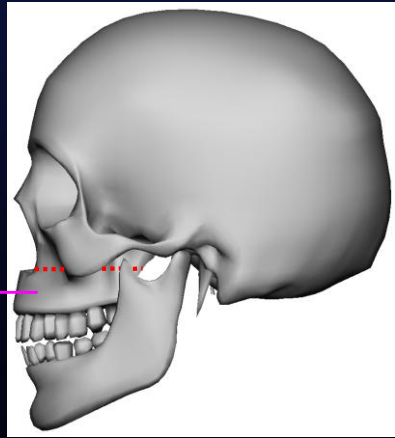
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Demo 1



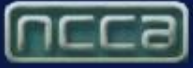
Surgery simulation and soft tissue deformation



LeFort I osteotomy

Mandible vertical osteotomy

Two typical osteotomies and corresponding operation simulations



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Demo 2



New algorithms

1. Corresponding points matching based on position similarity:

When the difference of the projection angles is small for both correlated images and the object. If place both correlated images in the same coordinate system, and let the barycenter of feature points in both images coincide, the summation of the Euclidean distance between pairs of corresponding points is minimum if the correct matching is found.

Corresponding matching by optimization

$$\min \sum_{i,j=1}^n d_{ij} \delta_{ij}$$

$$\text{s. t. } \left\{ \begin{array}{l} \sum_{j=1}^n \delta_{ij} = 1, i = 1, 2, 3, \dots, n, \\ \sum_{i=1}^n \delta_{ij} = 1, j = 1, 2, 3, \dots, n, \\ \delta_{ij} \in \{0, 1\}, i, j = 1, 2, 3, \dots, n, \\ d_{ij} = \sqrt{(x_{li} - x_{rj})^2 + (y_{li} - y_{rj})^2}, i, j = 1, 2, 3, \dots, n, \end{array} \right.$$

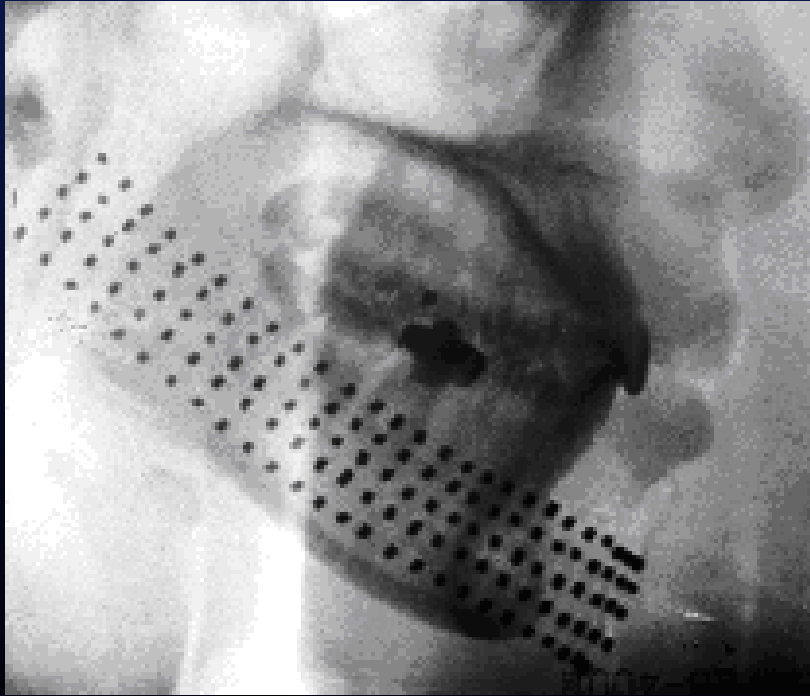
New algorithms

2. An supervised machine learning method to calculate the stiffness parameters in FEM:

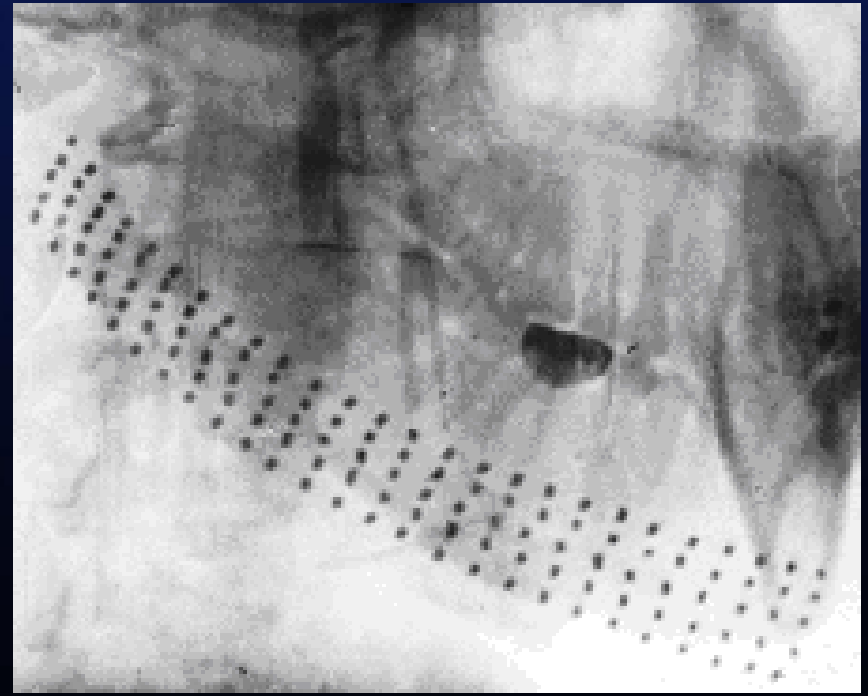
After the computation of the soft tissue deformations using FEM, the results are compared with the measured reference data (training data) taken from the previous operation. The errors are used to adjust the estimated parameters and this training process goes on until a predefined tolerance is satisfied. Then the trained parameters is more accurate and can be used in the following surgeries. The training formula is as follows:

$$\varepsilon_{i+1} = \varepsilon_i + (T - t_i)k$$

Experimental results



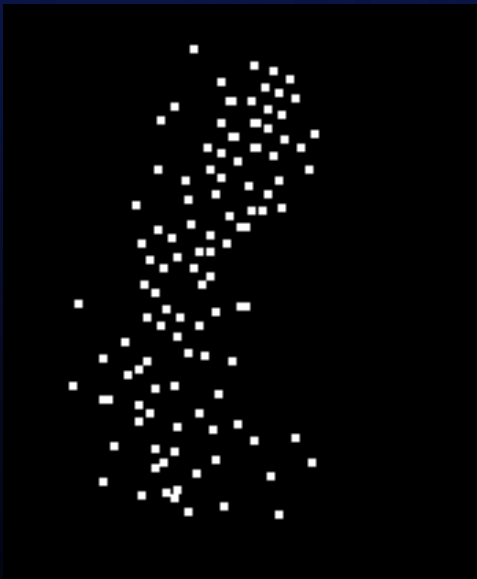
90° Projection



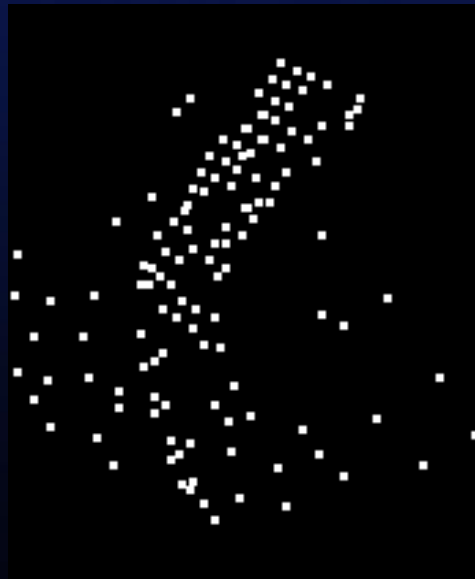
60° Projection

Original X-ray image pair

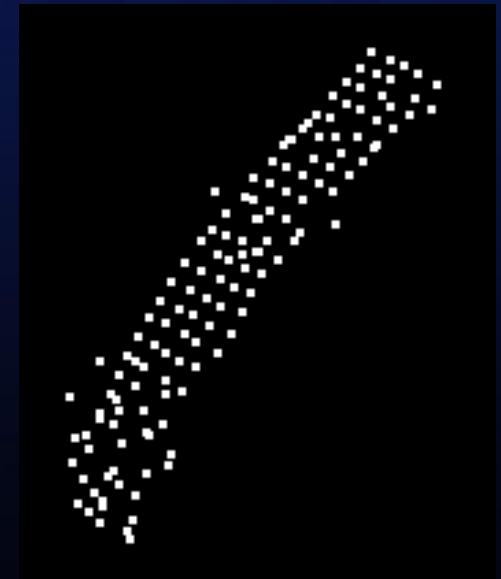
Experiment 1



(a)



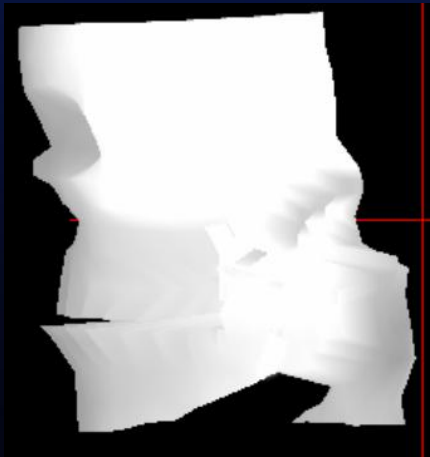
(b)



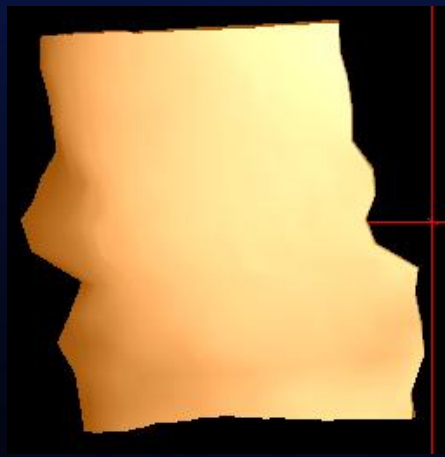
(c)

- (a) 3D points matched by epipolar lines searching
- (b) 3D points matched by sequence matching algorithm
- (c) 3D points matched by the algorithm in our paper

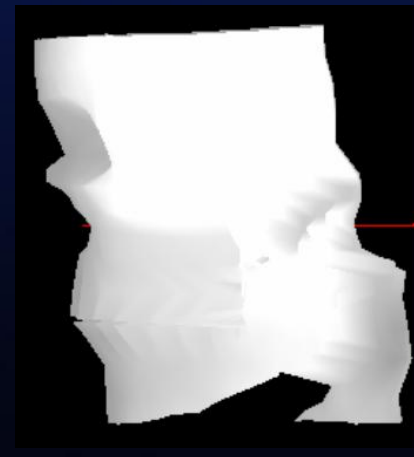
Experiment 2



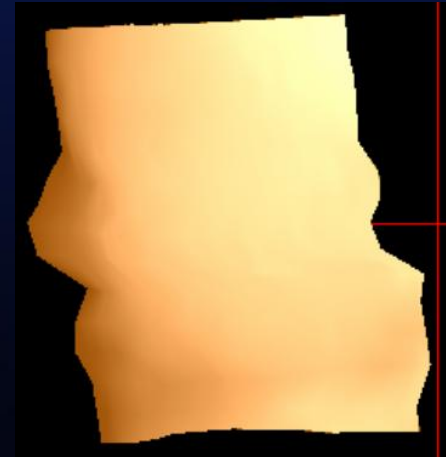
(a)



(b)



(c)



(d)

Mandible vertical osteotomy simulation (the stiffness parameter value are trained in Lefort I osteotomy). (a). bone tissue before surgery, (b). soft tissue before surgery, (c). bone tissue after surgery, (d). soft tissue after surgery

Table 1 3D measurement errors compared with CT (mm)

feature points	our system	CT	difference	permitted error tolerance
N-Gn	120.0	121.3	-1.3	1.6
N-Sto	86.0	83.3	2.7	1.9
Sto-Gn	35.42	38.4	-1.98	2.0
Sn-Go	60.69	60.9	-0.21	2.0
N-Sn	60.14	60.3	-0.16	1.6
Sn-Sto	26.33	24.8	1.58	1.8

Table 2 Deformation prediction in the mandible vertical osteotomy

regions	fang teeth	jawbone
Actual result	1.25:1	1.13:1
Simulation result	1.27:1	1.21:1

Conclusion and discussion

Conclusion

- We present a low radiation, low cost alternative to CT-based method for the visualization of 3D cranium using only three X-rays. We also present a new algorithm to solve the corresponding matching by evolutionary programming and designed a supervised learning method to estimate the soft tissue stiffness parameters.

Discussion

- From the proof of groups medical experiment, our system is easy-to-use and more accurate than the traditional 2D X-rays based measurement.
- Compared with CT, our technique remains deficiency of modeling accuracy in some area where the markers can not be placed.

Future work

- The current method for placing the lead markers is quite awkward and user-unfriendly. We are producing a special face mask to let the markers touch the face automatically, which can also guide the ultrasound scan with accurate placement of the probe.
- Using the developed prototype system, we also plan to investigate the relationship of the stiffness parameter values with human age, race, gender, ethnic origins and some other related factors.



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Thank you!