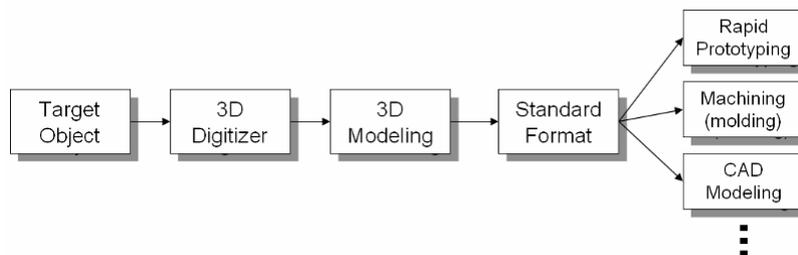# Reverse Engineering (RE)

November 7, 2007

Sung-Hoon Ahn

School of Mechanical and Aerospace Engineering
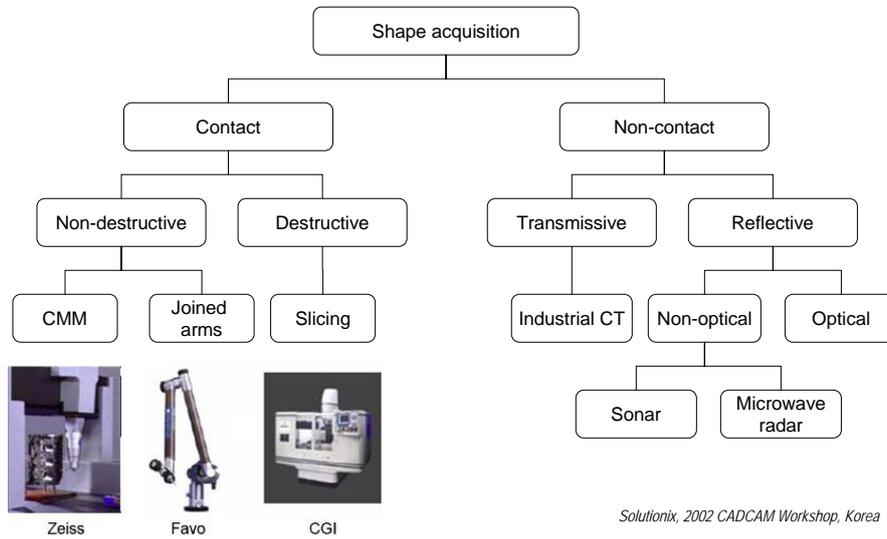Seoul National University

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Introduction of RE

- **Three-dimensional data which is captured in computerized form from physical models or products**

- **Two main phases**
  1. Digitizing or measuring of a part
  2. Three-dimensional modeling of the part from the digitized data

General process of reverse engineering

Digitizing or Measuring Methods

Shape acquisition
- Contact
  - Non-destructive
    - CMM
    - Joined arms
  - Destructive
    - Slicing
- Non-contact
  - Transmissive
    - Industrial CT
  - Reflective
    - Non-optical
      - Sonar
      - Microwave radar
    - Optical

Zeiss   Favo   CGI

Solutionix, 2002 CADCAM Workshop, Korea

Coordinate Measuring Machine (CMM)

- **Move a measuring probe to determine coordinates of points on a work piece surface**

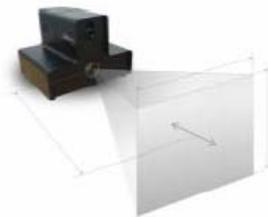*Browne & Sharpe, North Kingstown, Rhode Island*

Jointed Arm

- **Phantom Arm haptic finger device**
  - Pointing tool on a virtual model
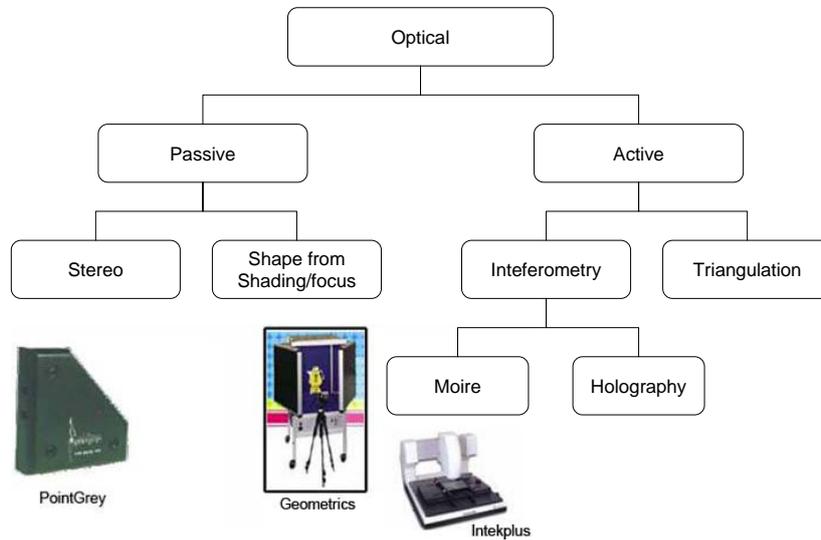 - Allows dynamic 3D modification

Scanners

- **Acquire data by interpreting the interactions of target volumes with various forms of energy**
  - Light
  - Laser beams
  - X-rays

Scanning Methods

```
                    ┌──────────┐
                    │ Optical  │
                    └────┬─────┘
              ┌──────────┴──────────┐
         ┌────┴────┐           ┌────┴────┐
         │ Passive │           │ Active  │
         └────┬────┘           └────┬────┘
       ┌──────┴──────┐       ┌──────┴──────┐
  ┌────┴───┐  ┌──────┴──────┐ ┌──────┴──────┐ ┌────────────┐
  │ Stereo │  │  Shape from │ │Inteferometry│ │Triangulation│
  └────────┘  │Shading/focus│ └──────┬──────┘ └────────────┘
              └─────────────┘   ┌────┴────┐
                            ┌───┴──┐ ┌────┴──────┐
                            │Moire │ │Holography │
                            └──────┘ └───────────┘
```
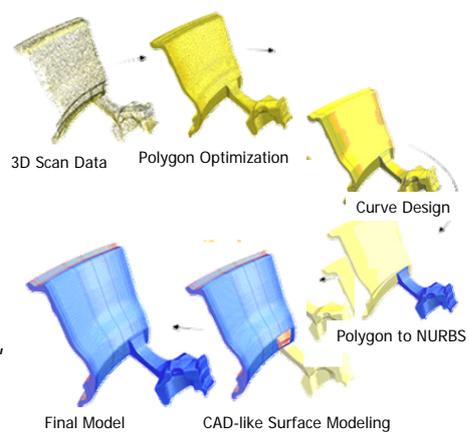
PointGrey   Geometrics   Intekplus

Solutionix, 2002 CADCAM Workshop, Korea

Scanners (cont.)

- **Pros**
  - Non-contact
  - Various profiles can be corrected include free-surface
  - Fast acquisition
  - High resolution

- **Cons**
  - Partial acquisition
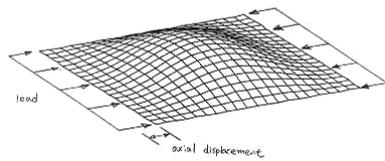 - Sensitive to surface roughness, transparency, shininess, color, variations, darkness, inter-reflections

3D Scan Data   Polygon Optimization

Curve Design

Polygon to NURBS

Final Model   CAD-like Surface Modeling

RapidForm, INUS
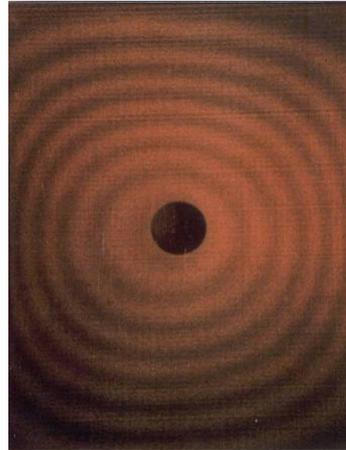
Moire interferometry

- **Example of buckled plate**
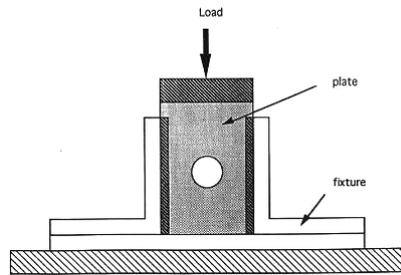
Specimen and fixture

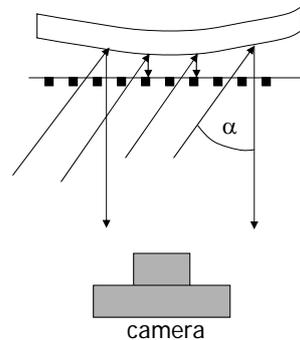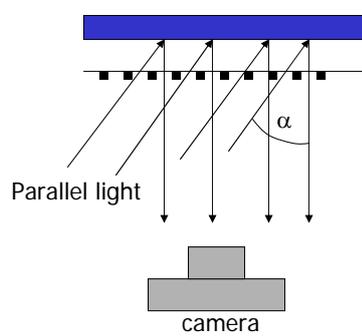
Out-of-plane displacement of buckled plate

D=0.5 in at 900 lb

Shadow Moire interferometer
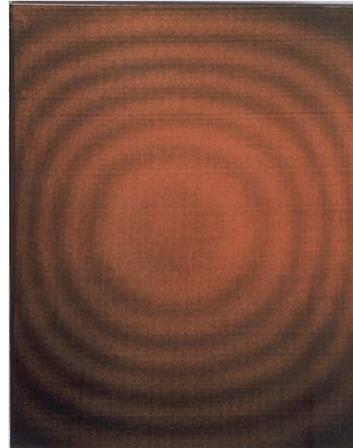
- $\Delta z = d /\tan\alpha$

    where d = grid density eg. 1mm gap

Parallel light

camera

camera

Out-of-plane deformation by fringes
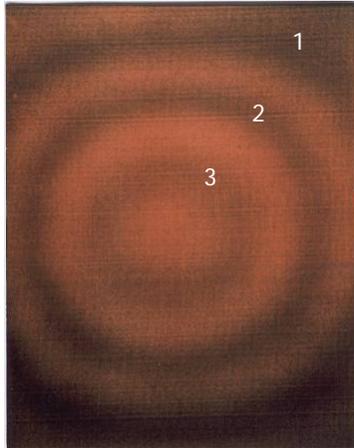
D=0 in at 700 lb

D=0 in at 900 lb

# Moire type 3D scanner

- $\delta z = \delta x / \tan\alpha$

δx

Parallel light

α
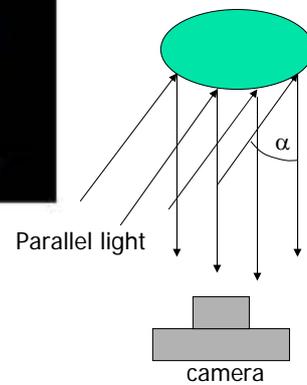
camera

Optical Triangulation Algorithm

- **Z-axis are calculated using Triangulation algorithm after spot light or slit beam shot**

Diagram of triangulation algorithm
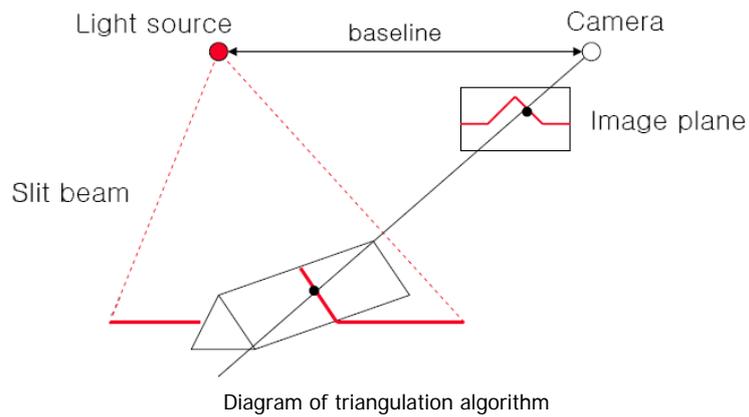
Laser Scan – Area

- **Camera is fixed while light source is moving**

- **Simple architecture**

- **Area scanning available**

- **For higher accuracy, accuracy of mechanical device is important**
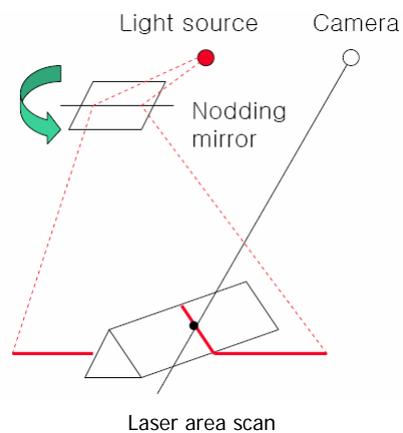
Laser area scan

Laser Scan – Line

- **Camera and light source are moving simultaneously**

- **Uniform resolution can be achieved**

- **Complex hardware configuration**
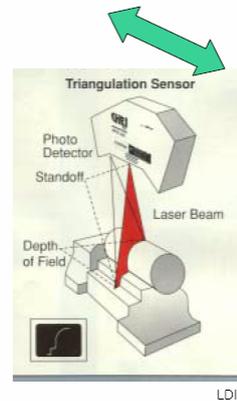
Laser area scan

Laser Scan (cont.)

- **Pros**
  - Good depth to various profile
  - Small energy consumption

- **Cons**
  - Hazardous to human eyes
  - Line scan: long scanning time
  - Area scan: difficult to calibrate
  - Shape edge problem
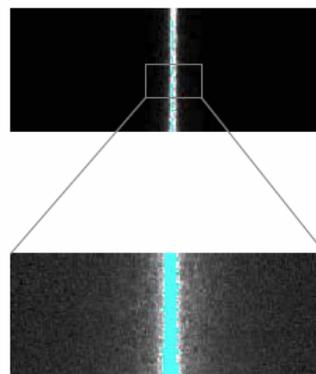
Laser on the object

Shape Edge Problem

- **Slit beam on edges**
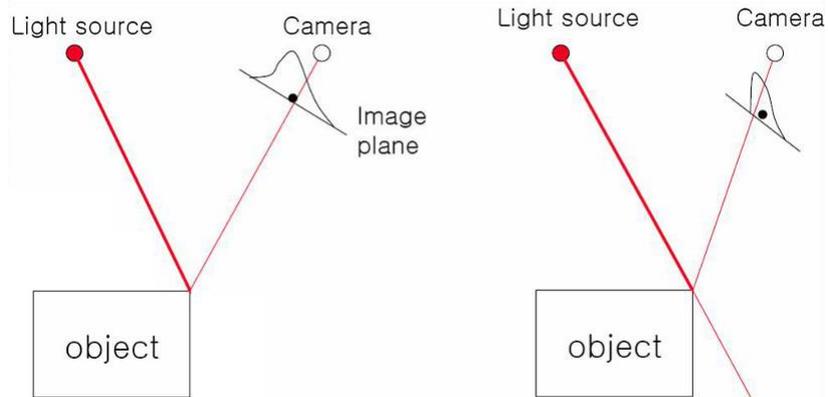
Laser Scan – Example

Spatial Encoding

- **Project encoded patterns on the target object**
- **Using Halogen lamp for light source**

breuckmann

Graycode pattern
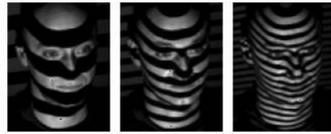
부호화한 패턴이 투영된 모습

측정 결과

Spatial Encoding + Phase shifting

- **For higher resolution, spatial encoding is used with phase shifting**
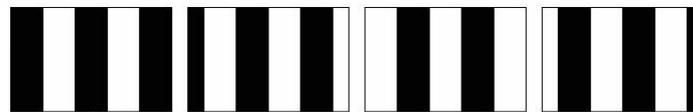
0π $\pi/2$ π $3\pi/2$

Phase shifting pattern

Spatial Encoding (cont.)

- **Pros**
  - Safe to human eyes
  - Fast scanning
  - High resolution
  - Less shape edge problem than laser scan

- **Cons**
  - Worse depth than laser
  - Large amount of energy consumption

Issues of Using Scanning data

- **Scan data may have some errors such as hole, overlapped area**
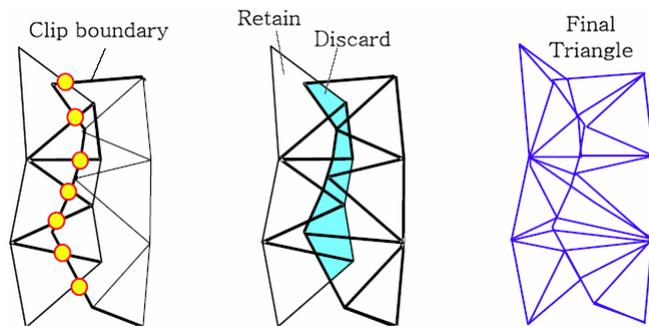
- **Filling holes in polygons**
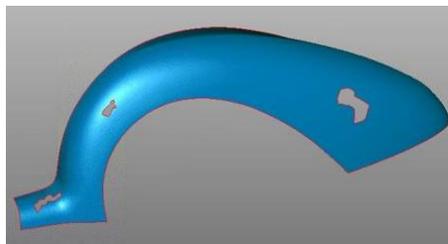
RapidForm, INUS

Holes in generated polygon from scan data
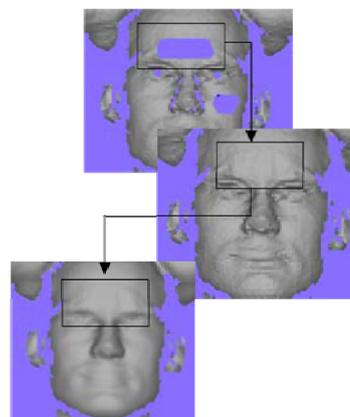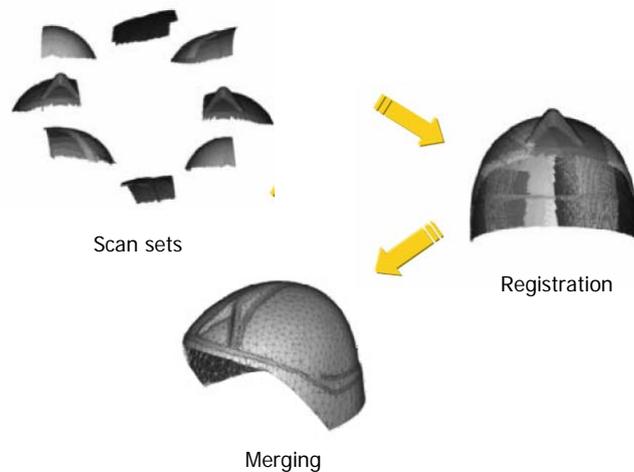
Hole filling process

Issues of Using Scanning data (cont.)

- **Merging overlapped areas**

Clip boundary

Retain
Discard

Final
Triangle

Merging overlapped area in software

Issues of Using Scanning data (cont.)

- **Registration/Merging**

Scan sets

Registration

Merging

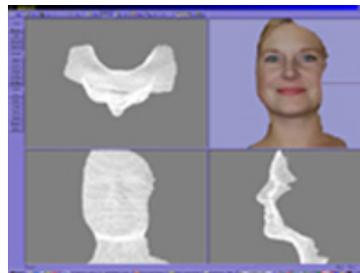# Issues of Using Scanning data (cont.)

- **Smoothing**
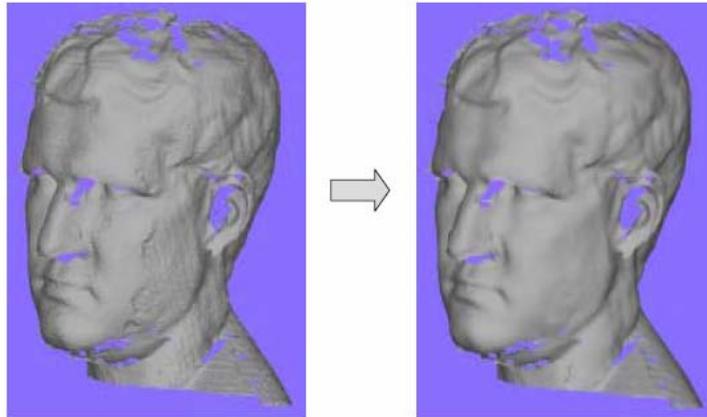
3D Scanner
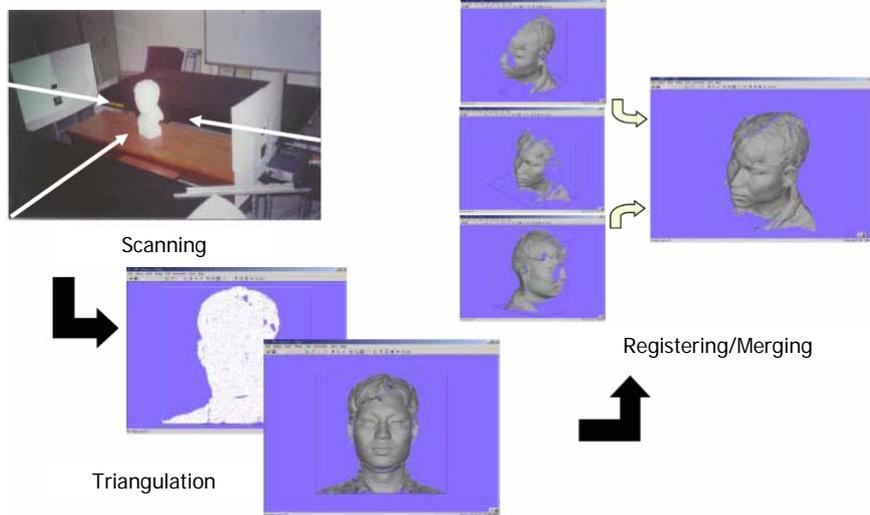
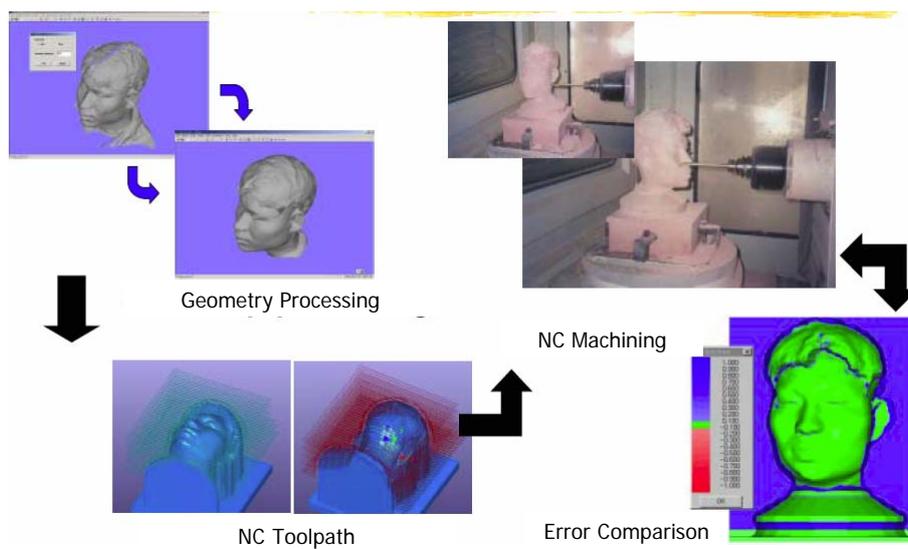- **Input device to read physical geometry into CAD format**

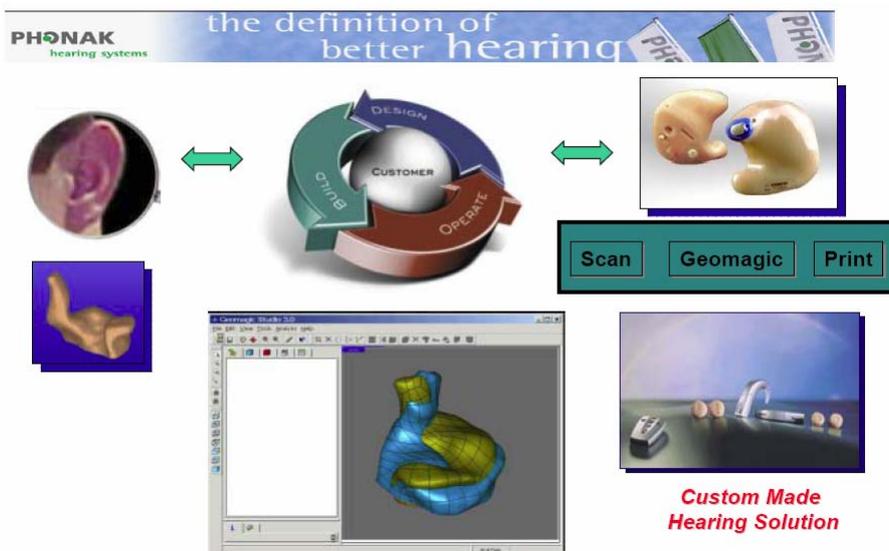3D scanning device   Manipulator software

Replica of Human Face

Scanning

Triangulation

Registering/Merging

Replica of Human Face (cont.)

Geometry Processing

NC Machining

NC Toolpath

Error Comparison

3D Scanner (cont.)

- **Demo**

Applications
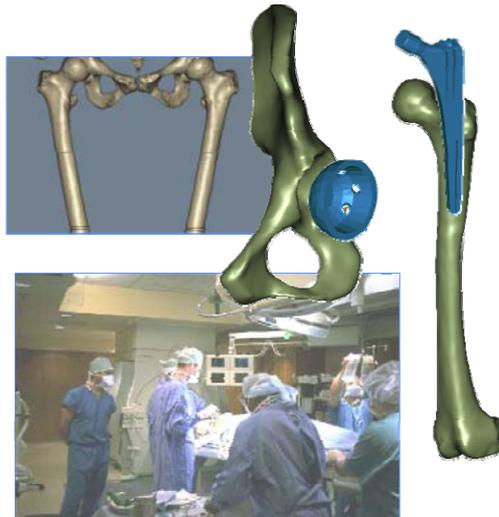

Custom Made Hearing Solution
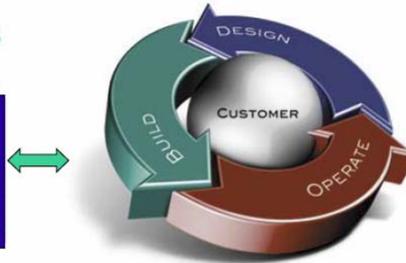
Applications (cont.)

Mass Customization : Orthodontics
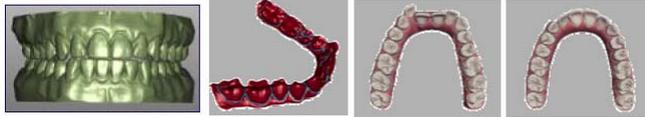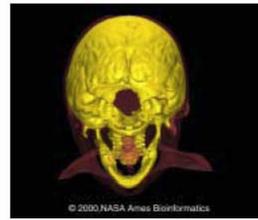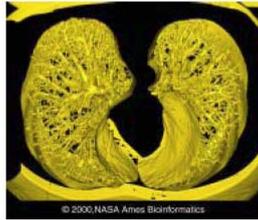

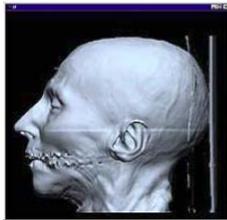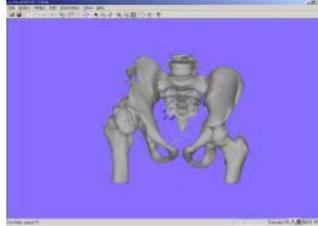# Applications (cont.)

- **Medical**
  - Mechanical Bones
  - Virtual Surgery

Applications (cont.)

- **Medical**

Applications (cont.)

- **3D photography model for e-commerce**

250um (unedited)