3D SCANNING AND PRACTICAL MACHINE VISION APPLICATIONS

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EMERGING TECHNOLOGY
• Emerging Technology
• $14.85B by 2022
3D SENSORS

- Laser Profile
- Kinect
- TOF
- Structured Light
- Stereoscopic
- Photogrammetry
- Gelsight
3D SENSORS: KINECT

- RGB Camera
- IR Camera
- Structured Light Projector

APPLE – PRIMESENSE
INTRODUCED ON NOV 4, 2010
ORIGINAL DESIGN BY PRIMESENSE
### 3D SENSORS: KINECT

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>640 x 480 (VGA)</td>
</tr>
<tr>
<td></td>
<td>320 x 240 (Depth Camera)</td>
</tr>
<tr>
<td>Working Distance</td>
<td>0.8 m - 3.5 m (10m)</td>
</tr>
<tr>
<td>Depth resolution</td>
<td>1 cm at 2m</td>
</tr>
<tr>
<td>Device connection type</td>
<td>USB (+ external power)</td>
</tr>
</tbody>
</table>
3D Sensors: **Kinect**
3D SENSORS: KINECT
3D SENSORS: KINECT
3D SENSORS: Kinect

**PROS**
- Inexpensive ($200)
- Fast, (30fps)
- Lots of 3rd Party Software Available
- USB2
- Can Track Human Gestures
- Can combine RGB image with Depth Map

**CONS**
- Poor resolution/noisy
- Marginally Robust
- Subject to Ambient Lighting Interference
- Shiny and Dark objects don’t image well
- Most Development is Game Oriented
- Unknown Roadmap
LASER TRIANGULATION
LASER TRIANGULATION

- Laser Light
- Camera
- Trigger Encoder
- Working Distance
- Working Distance
- Laser Light
- Camera
- Working Distance
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- Camera
- Working Distance
- Laser Light
- Camera
- Working Distance

- Power (mW)
- Line Width
- Swath (Angle)
- Color (wavelength)
- Optics
- Frame Rate
- Resolution
- Light Sensitivity
- FOV
- Angle
- Resolution
- Speed
LASER TRIANGULATION
LASER TRIANGULATION
## LASER TRIANGULATION

<table>
<thead>
<tr>
<th>DIY</th>
<th>Packaged Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lots of flexibility: Cameras, lasers, lenses, encoders</td>
<td>• Easy to use</td>
</tr>
<tr>
<td>• Push Limits</td>
<td>• All-In-One</td>
</tr>
<tr>
<td>• Low Cost</td>
<td>• Initial cost higher, but overall cost might be less</td>
</tr>
<tr>
<td>• 3rd party Software</td>
<td>• Locked into limited hardware.</td>
</tr>
<tr>
<td>- AqSense</td>
<td></td>
</tr>
<tr>
<td>- OpenCV</td>
<td></td>
</tr>
<tr>
<td>- Matrox MIL</td>
<td></td>
</tr>
<tr>
<td>- David</td>
<td></td>
</tr>
</tbody>
</table>
LASER TRIANGULATION
Pros
• Very Mature Technology
• Lots of 3rd Party Software
• Ideal for Repetitive Scans
• Prepackaged Cameras or DIY
• Modest Costs

Cons
• Slow
• Active Scanning
• Part needs to be moving
• Limited depth of field
TOF

- Historically
  - Very Expensive
  - Difficult and Complex
  - Mostly used by Military, NASA

- New Technology
- Easy to Deploy
- Very Low Cost
- Limitation on depth range
- Intel, TI, Microsoft, SoftKinetic, Basler
3D SENSORS: TOF

- Softkinetic DS325
- Resolution: 320x240
- Frame Rate: 25-60 fps
- Typically limited to near distances
  DS325 < 1.4cm noise at 1 meter
- Gesture Recognition Algorithms
BASLER TOF
3D SENSORS: KINECT2
<table>
<thead>
<tr>
<th><strong>3D SENSORS: KINECT2</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frame Rate</strong></td>
</tr>
</tbody>
</table>
| **Resolution**          | 1920 x 1080 (Color)  
                          | 512 x 428 (Depth Camera) |
| **Working Distance**    | 0.8 m - 4 m          |
| **Depth resolution**    | ?                   |
| **Device connection type** | USB3               |
| **Microsoft – Windows 8** |                 |
**TOF**

**Pros**
- Low Cost
- Fast (exposure)
- Potential VGR
- Prepackaged Cameras
- Microsoft Software Very Good

**Cons**
- Slow (frame rate)
- Poor Resolution
- Active Scanning
- Limited 3rd party software
- Limited depth of field
3D SENSORS: STRUCTURED LIGHT

DLP Projector

Camera
3D SENSORS: STRUCTURED LIGHT
3D SENSORS: STRUCTURED LIGHT

Pros
• Similar to Laser Triangulation
• No Moving Parts!
• More precise than other methods
• Modest Price
• TI has 3rd Generation DLP projectors
• Modestly Fast

Cons
• Active Lighting
• Software not as well established
• Object must remain still
3D SENSORS: STEREOSCOPIC
3D SENSORS: STEREOSCOPIC

Disparity \rightarrow Depth

Disparity
3D SENSORS: **STEREOSCOPIC**

### LEFT IMAGE

### RIGHT IMAGE

Rectify (Find Matches) → Disparity (offset)

Depth Information
### 3D SENSORS: STEREOSCOPIC

#### PROS
- Algorithms are very mature
- Passive Technology
- Can be used with open source code
- Can use any camera/lens sensor pair for wide range of working distances and resolutions
- Many affordable stereo cameras specific to working distances already on the market
- Can be used with structured light to increase accuracy and reduce data dropout
- Great for VGR

#### CONS
- Computationally expensive for higher resolution cameras
- Low feature areas cause data dropout
- Low Light is a Problem
3D SENSORS: NEW

Structured Light & Stereoscopic
2 cameras for Stereo

LED projector for Structured Light

LED as light source for calibration

USB2.0

GPIO
STEREO VISION – WITHOUT PROJECTOR

- Image comparison (‘Stereo matching’) calculates the disparity for each pixel.
- Problem: on unicolored surfaces, the disparity can’t be clearly determined.
STEREO VISION – WITH PROJECTOR

- Shadow
- Full depth image
3D SENSORS: NEW

Line-scan Stereo
3D SENSORS: NEW

Line-scan Stereo
Linear movement

Surface of object

Line-scan camera

Height + image

http://www.chromasens.de/en
3D SENSORS: NEW

Line-scan Stereo

• Single line-scan camera / Dual-lens
• Resolution from 5 µm to 700 µm
• High speeds (up to 60,000 lines/s)
• 120Km/hr
• Flexible in base width
• Optional Color Information
• Utilizes GPU Technology for Fast, Real-Time Processing
PHOTOGRAMMETRY

• Creating 3D images from 2D images
• Potential Low Cost
• Slow Process
PHOTOGRAMETRY

Pros

• Low Cost
• No limit to FOV
• Reverse Engineering
• Consumer Applications
• Good low cost 3rd party software

Cons

• Slow
• Weak Metrology
• Not good for machine vision
• Not good for VGR
3D SENSORS: GEL SIGHT

**simple idea:** convert pressure into images

- Use a slab of clear elastomer
- Add a reflective skin on one side
- The skin deformation yields a shaded image
- Use image processing to learn about touch
3D SENSORS: GELSIGHT
3D SENSORS: GELSIGHT
WHAT DOES GELSIGHT DO?

- MEASUREMENT, VISUALIZATION and 3D RECONSTRUCTION of Micron-scale Surface Features

→ Assess Form, Fit & Finish
GELSIGHT

Pros
• Very Precise
• Very High Resolution

Cons
• Slow
• Expensive
• Only Off-line
NOW WHAT?
• All 3D sensors require some level of calibration
• Data accuracy is only as good as the calibration
• Intrinsic:
• Extrinsic:
Example of Camera Calibration using Chessboard Corners:
3D SENSORS
CALIBRATION
NOISE REDUCTION

[Two images showing the effect of noise reduction on a signal]
DATA REDUCTION

- 3D Files are Huge!
IMAGE FORMATS

- POINT CLOUD
- DEPTH MAP
- POLYGON MESH
- STL
- VOXEL
  - ...

THF

ision SHOW
IMAGE FORMATS: POINT CLOUD

x, y, z
IMAGE FORMATS: DEPTH MAP
• Creates a surface from 3D points
• Properties include: color and transparency, surface normals, texture coordinates and data confidence values.
• STL format is widely used across 3D printing, CAD software and modeling interfaces.
• STL format is ideal for comparing 3D scanned images and 3D CAD drawings.
3D objects represented as set of equal sized boxes. Less accurate but can be simpler/faster to process. Accuracy dependent on box size/number of Voxels. 

Image Formats: Voxels

http://www.bilderzucht.de/blog/3d-pixel-voxel/
IMAGE FORMAT: NORMALS

http://www.blender.org/support/
OCCLUSIONS

http://www.aqsense.com/
NEXT STEP?
APPLICATIONS

- METROLOGY
- CHANGE DETECTION
- DEFECT DETECTION
- SAFETY
- REVERSE ENGINEERING
- AUTOMATED WAREHOUSING/DISTRIBUTION
- VISION GUIDED ROBOTICS
- PACKAGING
- AUTONOMOUS VEHICLES
  - ...

[THF ision SHOW]
STACK/HEIGHT DETECTION
STACK/HEIGHT DETECTION

» Bottle cap

3 tilted

6

7 open

» Can tab

www.matrox.com
PLANE FITTING

www.matrox.com
SURFACE DEFECT DETECTION
PEOPLE TRACKING

http://www.baslerweb.com/en
HUMAN TRACKING
BIN PICKING

https://en.ids-imaging.com/
3D SENSORS: KINECT
CHANGE DETECTION

http://www.aqsense.com/
Printed Circuit Board images with height overlay in pseudo-color
COUNTING
KEY TAKEAWAYS…

• The cost for certain 3D components has drastically fallen. (Disruptive Technology)
• No silver bullet for all cases, different methods have certain strengths and weaknesses.
• 3D solutions can sometimes be simple to deploy while others applications remain complex.
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