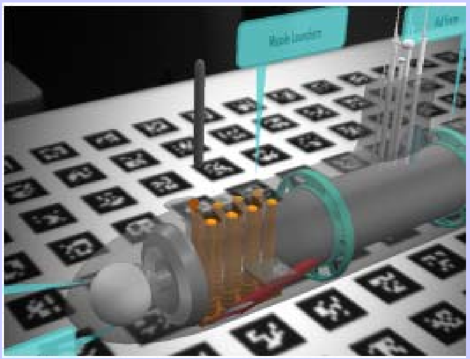
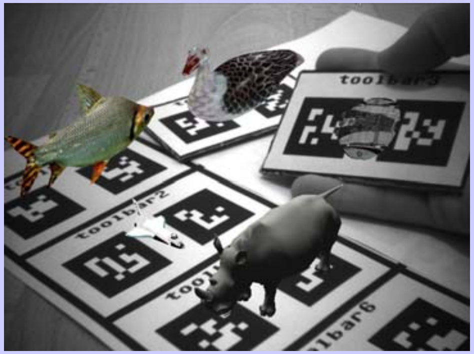
Millennium 3 Engineering

Millennium 3 Engineering
Augmented Reality Product Offerings





www.mill3eng.com www.artag.net

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ISMAR'06
Industrial AR Workshop

Oct 22/2006

Millennium 3 Engineering

- Spin-off of NRC ARTag technology
- Products: AR software system for Windows tablet and desktop PC's
- Market: focusing on AR software for *magic mirror* and *magic lens* visualization systems (eg: public interactive systems such as museum, science center displays)

ARTag technology

- For video see-through AR
- Uses *passive computer vision,* video input is only sensor (low cost, ubiquitous)
- Provides extrinsic calibration per image frame to align virtual and virtual cameras
- Marker based – relies on 2D marker patterns added to object or environment

Solutions for customers

- Complete exhibit: software and 3D content (M3E contracts 3D artists)
- *Magic mirror* and *magic lens* software: client adds content (no programming)
- Stand-alone and networked SDK's for custom AR applications.

Presentation Overview

- Intro demo
- Technology overview
- Description of NRC research (not part of M3E products)
- Solution details – with demos

Presentation Overview

- **Intro demo**

  ***Magic Lens* system**
- **Technology overview**
- **Description of NRC research (not part of M3E products)**
- **Solution (product) details – with demos**
  - **MDEV100, MNDEV100: Stand-alone and networked SDK's**
  - **M100, MN100+MC100, M200: *Magic lens* and *magic mirror***

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NRC · CNRC

Augmented Reality

- New way for people to interact with computers
- Emerging new computer display paradigm

- Today's computer->human interaction

  view content with: computer monitor, TV

- Tomorrow-> AR – view and interact with 3D data by moving around a real space,

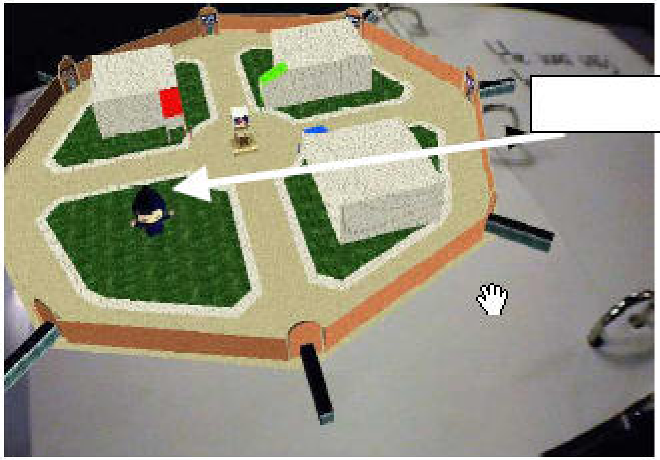
  view content with PDA, cellphone, tablet PC, HMD

- AR– "bring virtual objects into the real world instead of making people go into the virtual world"

Augmented Reality

- *New way for people to interact with computers*
- *Emerging new computer display paradigm*
- *Q: How to make this happen?...*

Fig. 2: A Virtual Object on a Card



FROM: Hedley, Billinghurst, .. *Explorations in the use of Augmented Reality for Geographic Visualization. Presence* 2001

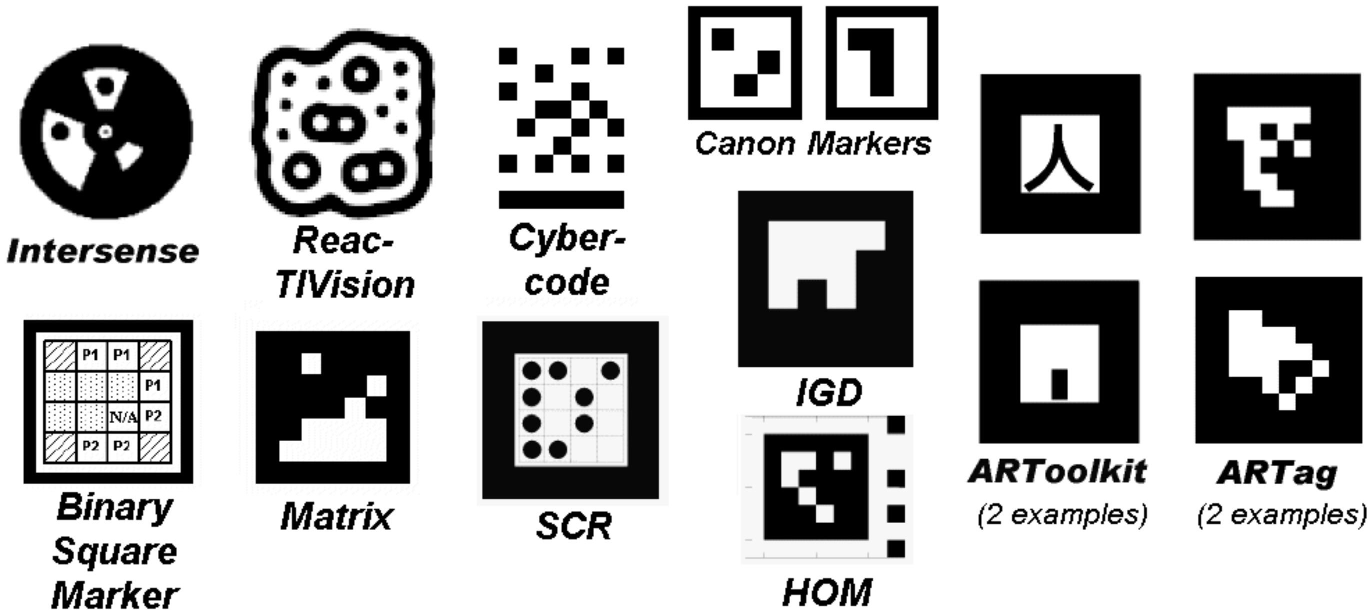
Q: How to make this happen?...
A: (one answer) use computer vision to find correspondences between image and known world, calculate pose, projection matrix, or homography from these correspondences.

Q: What image features?
A1: markerless (interest points: SIFT, PCA-SIFT, ...)
A2: marker-based = **Fiducial Marker Systems**

Fiducial Marker Systems

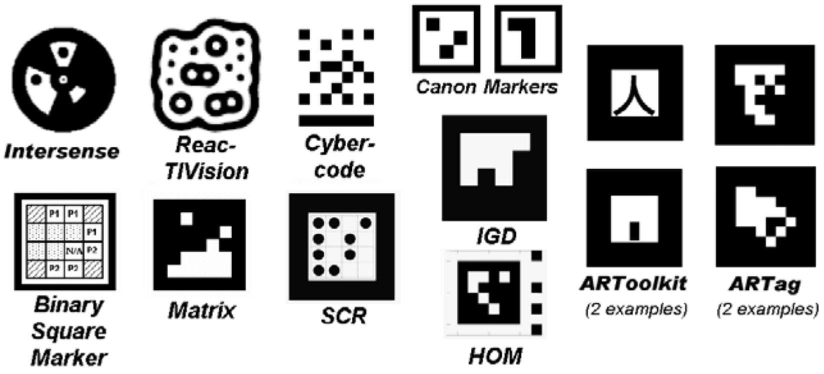
Consist of:

1. **Library of patterned markers to mount in environment (on target)**
2. **Computer vision algorithm to find projection of markers in digital camera image**



Fiducial Marker Performance Criteria/Metrics

- false positive rate: how often is a marker erroneously reported
- false negative rate: how often is a marker missed
- inter-marker confusion rate: how often is one marker mistaken for another
- lighting immunity: performance under harsh uncontrolled lighting
- occlusion immunity: does marker have to be completely visible for detection
- perspective/affine projection support
- planarity restriction: markers on flat or curved/warped surfaces
- library size: how many unique markers can be handled
- minimum & maximum image size -> range of distances for detection
- photometric calibration required
- speed performance: processing requirements



Fiducial Marker Processing Stages

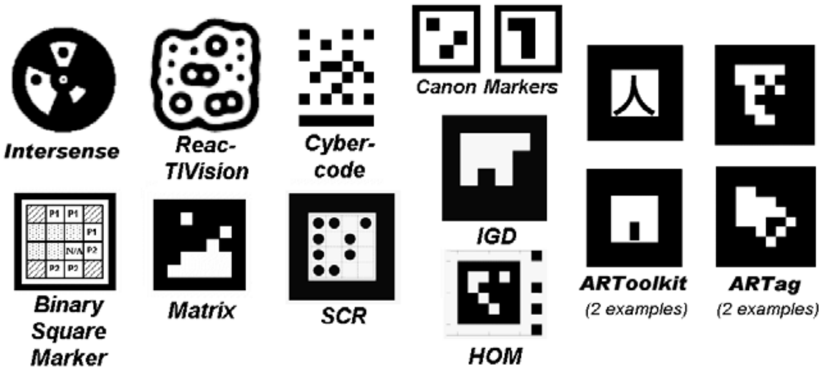
- identifying feature (unique feature)
- verification and identification (is it a marker, if so which one?)

Unique Feature Detection

- binary image -> morphology (ARToolkit, Intersense, Matrix, BSM, Cybercode)
- edge-based: find unique feature from edges (ARTag)

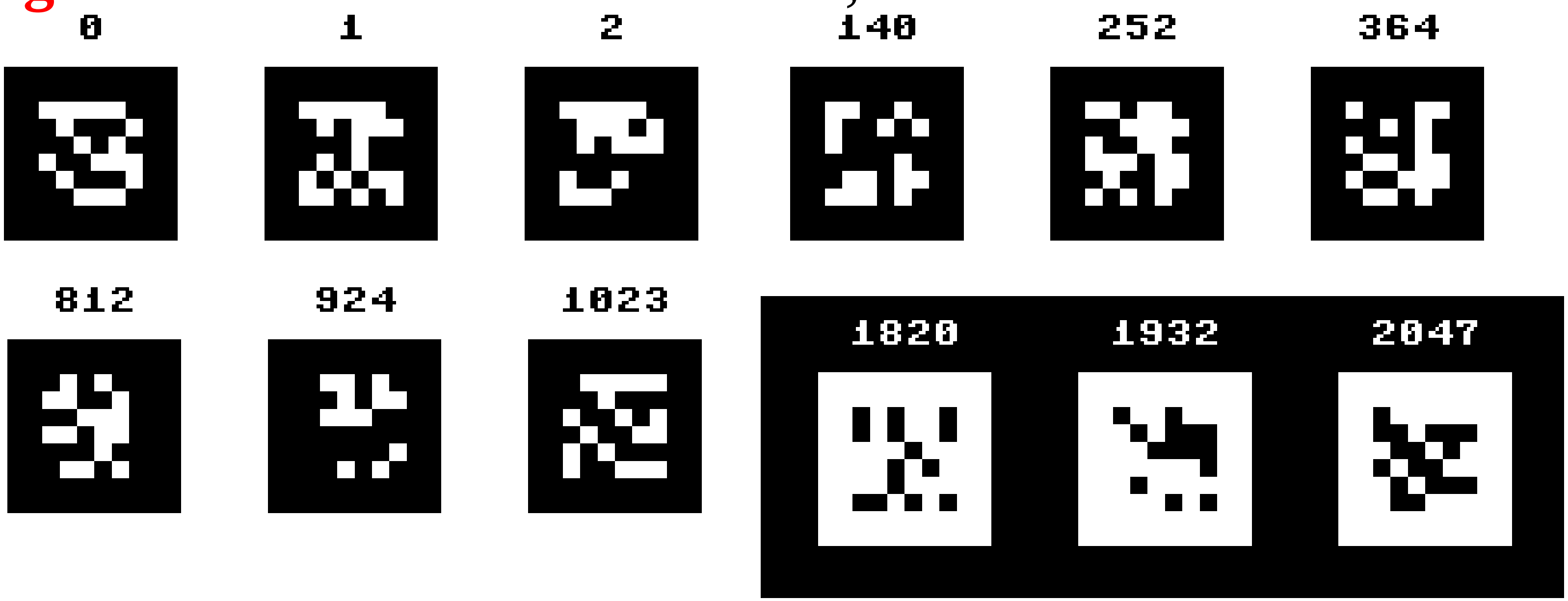
Processing

- correlation (ARToolkit)
- topological (ReacTIVision)
- symbolic digital (Intersense, Cybercode, Canon, BSM, Matrix, SCR, HOM, ARTag)



ARTag Fiducial Marker System

- **Digital (symbol based)**
- **bi-tonal** (only black and white) patterns
- **Edge-based** unique feature detection – no threshold required
- **1001** **(or 2002)** **markers** – no pattern files
- **Digital Methods**: Error Correction, CRC-16 Checksum



ARTag Fiducial Marker System

- **Show artag_coordframes_dragonfly_rev1.exe**

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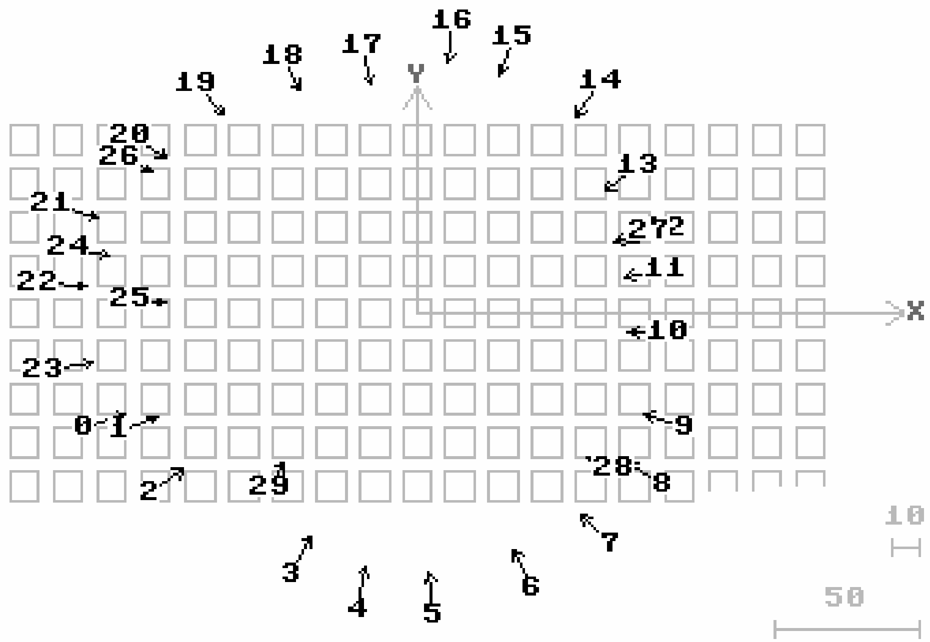
ARTag Research Applications

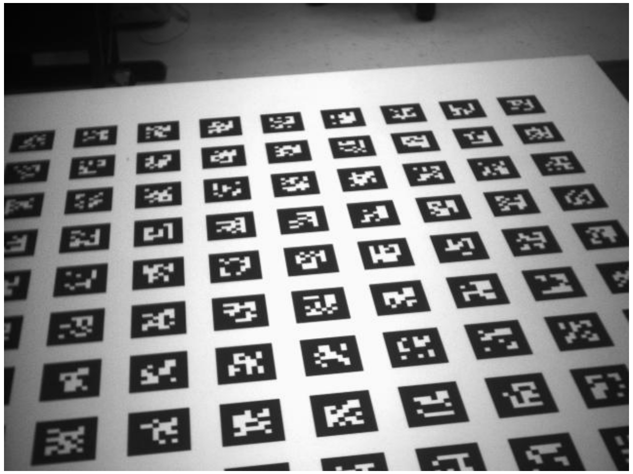
•**Real time find camera position (extrinsic calibration)**

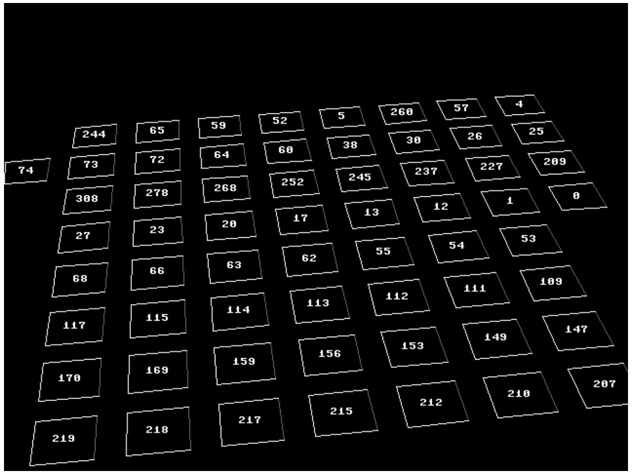
•**Offline find both camera poses and intrinsic parameters (focal length, distortion, etc)**

- **camera calibration – automatically determine zoom factor, image center, and distortion from looking at ARTag marker array**
- **3D model reconstruction – create a 3D model of object placed on ARTag array**



Camera Calibration





a pPriori **model of world points**

```
coordframe
name="table"
   marker
     id=4
     //-list of corners cw from top left
     vtx=-140,-65,0 //upper left
     vtx=-140,-55,0 //upper right
     vtx=-130,-55,0 //lower right
     vtx=-130,-65,0 //lower left
   /marker

   marker
     id=57
     //-list of corners cw from top left
     vtx=-125,-65,0 //upper left
     vtx=-125,-55,0 //upper right
     vtx=-115,-55,0 //lower right
     vtx=-115,-65,0 //lower left
   /marker

   marker
     id=260
     //-list of corners cw from top left
```

Correspondences

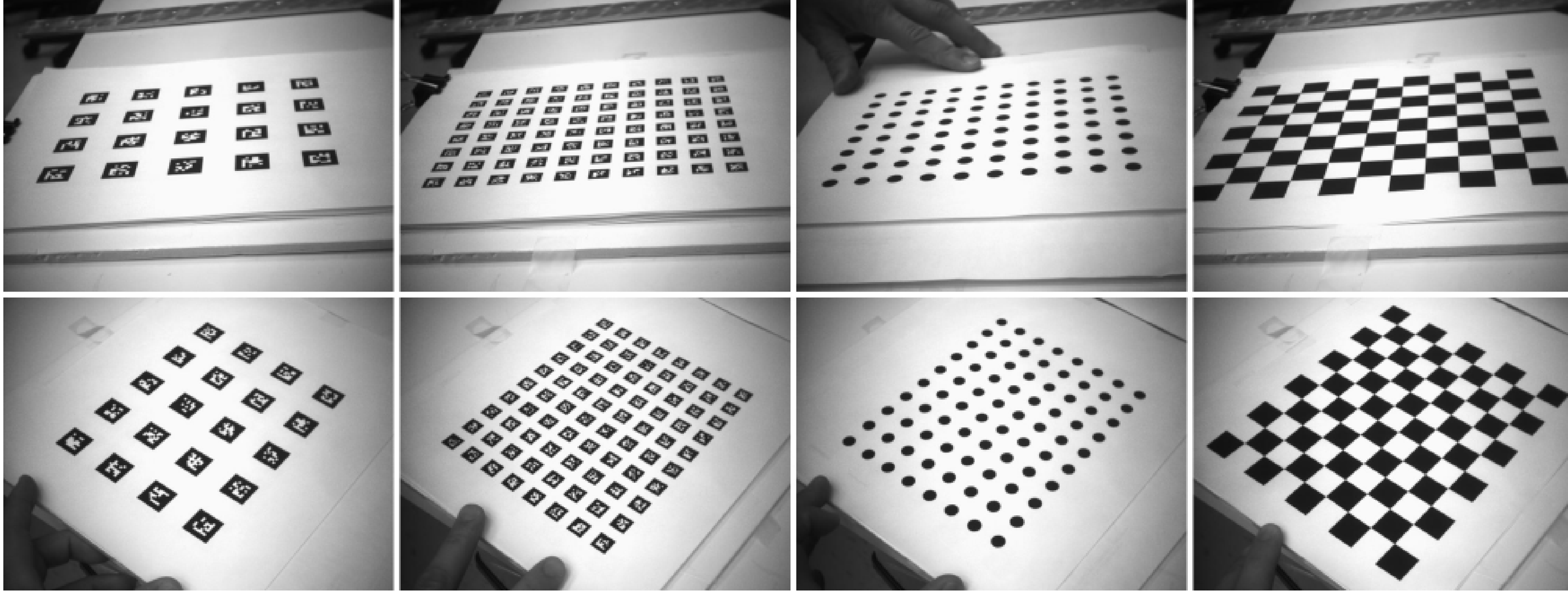
ID **world X,Y** **image U,V**

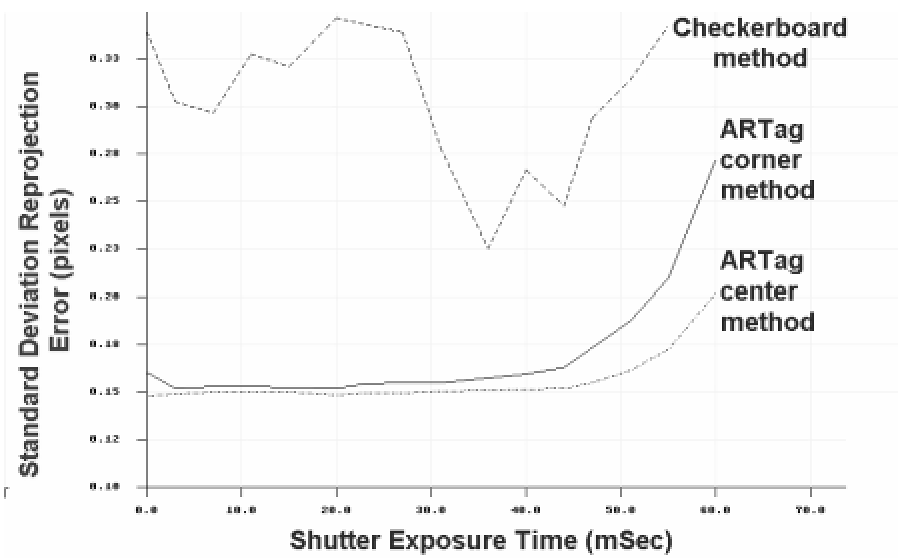
```
296 -0.000000 60.000000 195.898749 378.424467
298 15.000000 60.000000 122.332155 356.161890
299 30.000000 60.000000 53.513503 335.544456
frame 10
2 30.000000 -60.000000 570.538663 109.500841
6 45.000000 -60.000000 516.721182 101.189795
7 60.000000 -60.000000 467.046153 93.603326
9 75.000000 -60.000000 419.478384 86.462512
14 90.000000 -60.000000 374.737823 80.052883
15 105.000000 -60.000000 332.400355 73.759570
24 135.000000 -60.000000 255.083313 62.068971
99 15.000000 -45.000000 599.262130 144.709225
102 30.000000 -45.000000 541.439923 134.435355
```

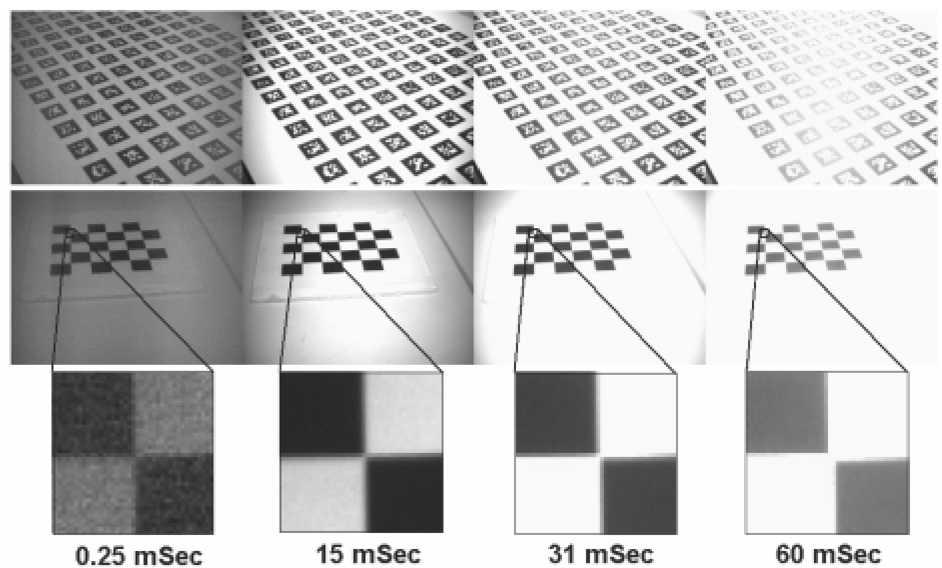
Camera Calibration

Sequence		K matrix				Distortion Parameters				Re-projection Error Std. Dev / Maximum	
# Frms	Avg. Pts/Frm	F_x	F_y	u_o	v_o	k_1	k_2	p_1	p_2	Subset	Full Set Points
Camedia Olympus E20 with 9 - 36 mm zoom lens (640 x 480 pixels) - ARTag center method											
10	64	1331.02	1331.32	315.63	234.32	-0.0745	0.5360	-0.0003	0.0002	0.12/1.19	0.14/1.99
10	58	1323.99	1318.46	324.40	239.69	-0.0375	0.0705	-0.0002	0.0029	0.12/1.19	0.15/1.89
10	46	1319.20	1328.02	316.48	259.98	-0.0822	0.5427	-0.0011	0.0004	0.13/1.68	0.15/1.88
10	60	1324.77	1322.48	322.81	240.47	-0.0543	0.3123	-0.0009	0.0023	0.14/1.85	0.15/1.90
10	70	1334.85	1332.93	315.55	223.41	-0.0474	0.2750	-0.0004	-0.0000	0.16/2.03	0.15/2.04
10	43	1334.30	1321.36	297.01	210.90	-0.0284	-0.2354	-0.0014	-0.0040	0.16/1.00	0.16/2.10
Dragonfly IEEE-1394 camera with 8mm lens #1 (640 x 480 pixels) - ARTag center method											
10	42	1076.85	1117.15	327.68	310.38	-0.0506	-0.1185	-0.0067	-0.0001	0.19/2.88	0.52/5.22
10	54	1094.95	1097.97	330.77	259.02	-0.0733	0.0056	-0.0029	-0.0003	0.16/2.77	0.15/2.77
10	41	1099.22	1098.37	335.90	251.96	-0.0884	0.0630	-0.0017	0.0001	0.11/0.98	0.17/2.71
10	37	1099.71	1098.79	322.86	258.59	-0.0729	0.0912	-0.0004	-0.0027	0.13/1.26	0.16/2.93
10	44	1096.88	1102.26	323.20	260.42	-0.0692	-0.0500	-0.0026	-0.0017	0.15/1.10	0.16/2.88
Intel Pro webcam (640 x 480 pixels) - ARTag center method											
10	30	853.47	856.51	324.55	231.07	0.0005	-0.1876	0.0032	-0.0018	0.18/1.24	0.23/1.23
10	39	847.71	846.36	319.60	228.48	0.0034	-0.2178	0.0022	-0.0024	0.21/1.18	0.22/1.18
10	34	845.40	853.41	323.09	239.31	-0.0058	-0.1064	0.0019	-0.0012	0.22/1.41	0.22/1.41
10	28	838.42	841.23	325.08	241.79	-0.0143	-0.1237	0.0010	-0.0005	0.23/1.65	0.23/1.65
10	35	851.01	848.67	326.89	223.14	-0.0330	0.0075	0.0032	0.0001	0.25/2.13	0.25/2.64
10	26	855.75	848.68	328.14	212.26	-0.0501	0.1393	0.0013	-0.0001	0.29/2.20	0.25/2.39

Table 2: Accuracy of calibration with only 10 frames. The first column of reprojection error is that seen within just those 10 frames, the second column is the reprojection error when the intrinsic parameters were evaluated over the full set of frames. All runs were performed with 10 different frames and used the ARTag marker center method. The consistency of parameters between runs can be seen.

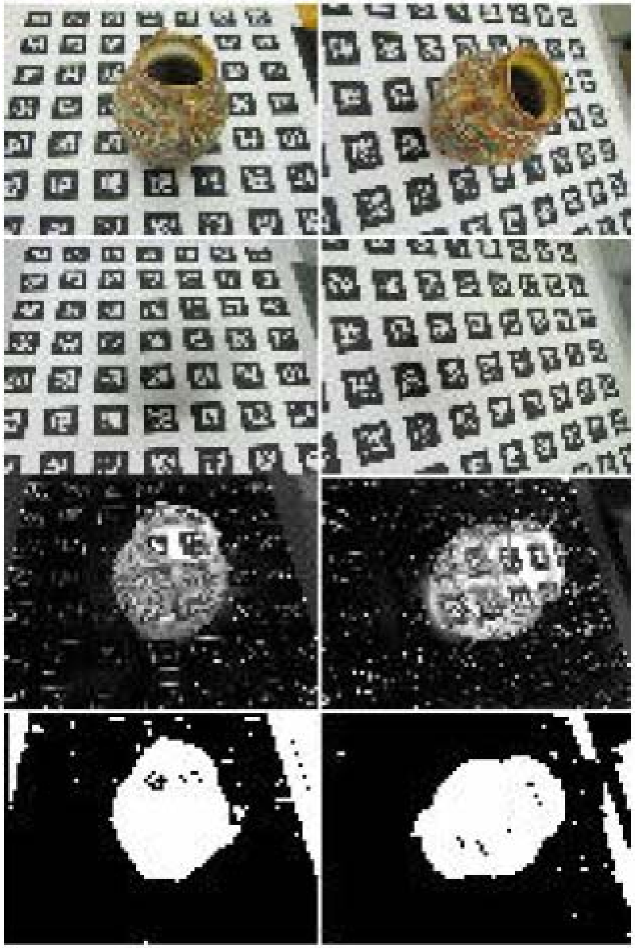



Checkerboard method
ARTag corner method
ARTag center method
Standard Deviation Reprojection Error (pixels)
Shutter Exposure Time (mSec)


0.25 mSec
15 mSec
31 mSec
60 mSec

3D Model Reconstruction

create a 3D model of object placed on ARTag array: voxel carving by outline



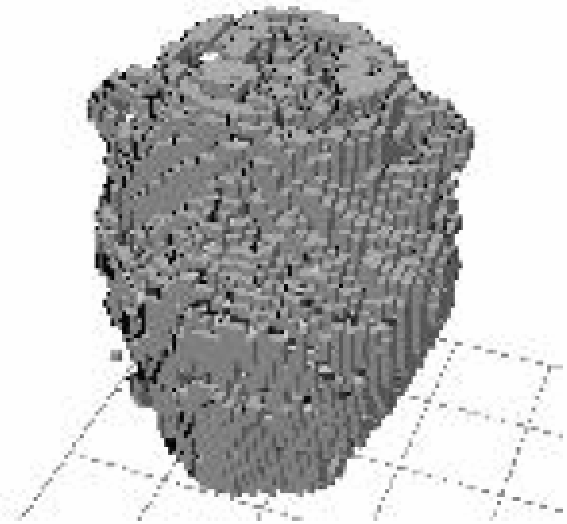


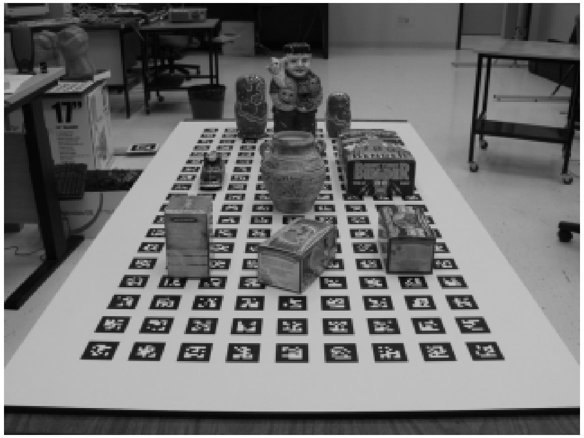
Figure 7: *Stages of 3D model creation. Voxel model (bottom) generated from 14 views, two of these images are shown (left and right columns). The stages are; original image (top), estimated background (2nd down), difference image (3rd down) and the binary mask. The visual hull model is created from space carving of the voxels from binary masks from the 14 image.*

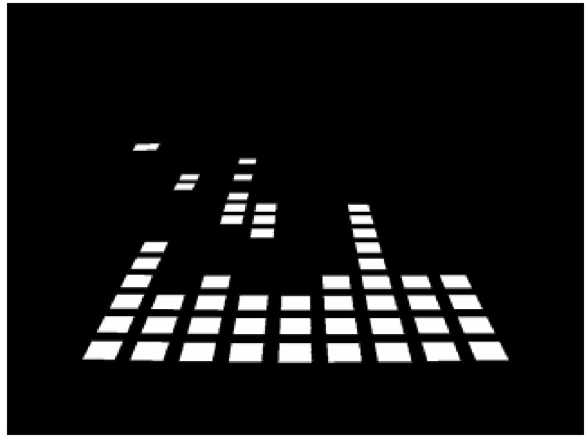
3D Model Reconstruction

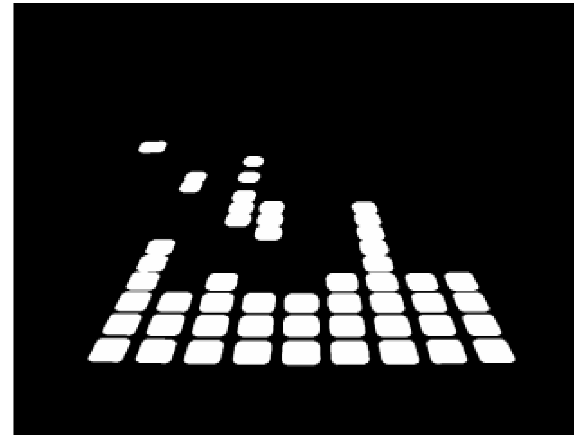
create a 3D model of object placed on ARTag array:
Tetrahedron carving by finding 3D points from SIFT features

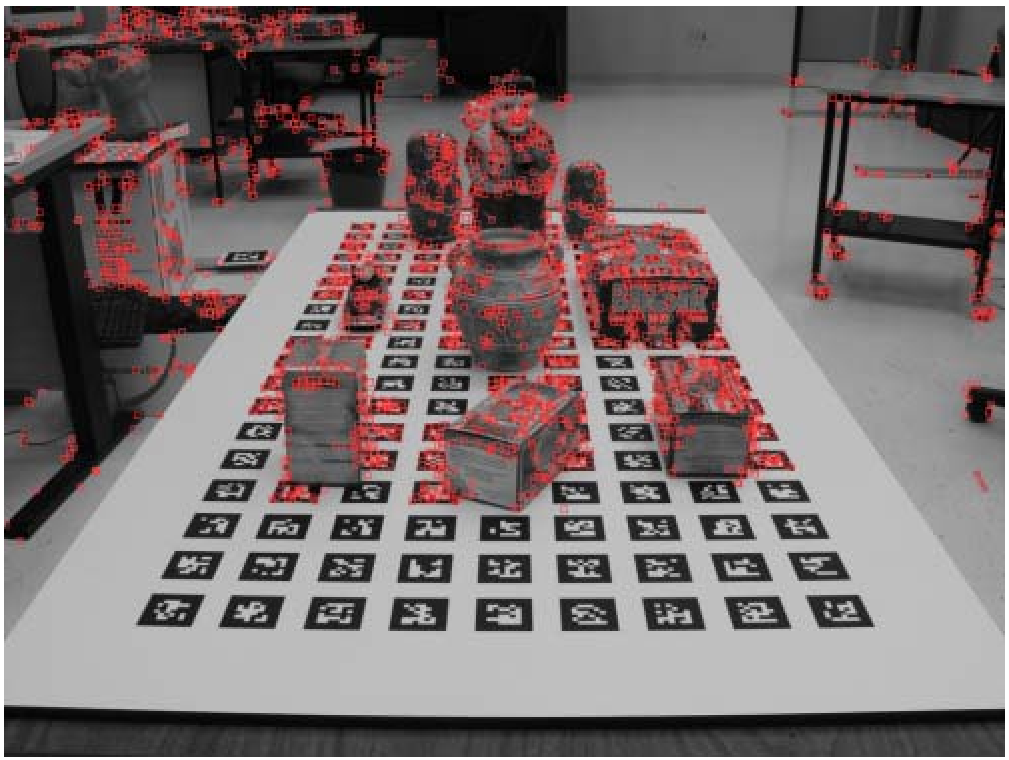
3D Model Reconstruction

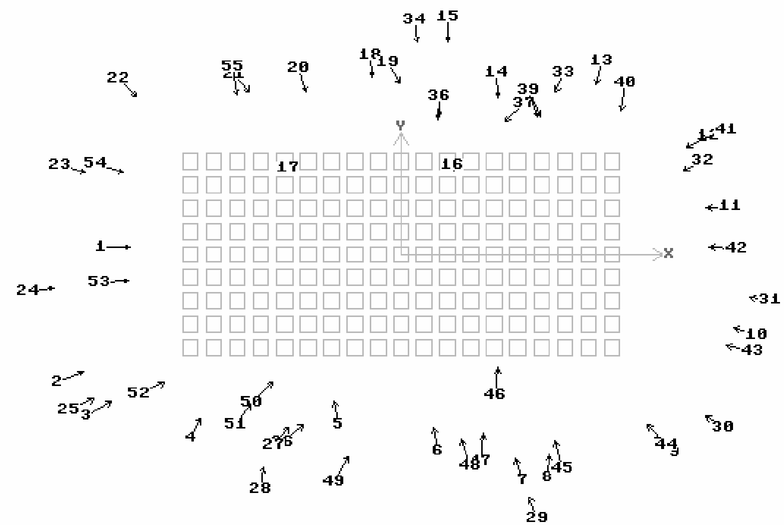
create a 3D model of object placed on ARTag array: Tetrahedron carving by finding 3D points from SIFT features











Show scene_model.wrl

NRC · CNRC

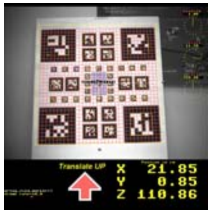
Computer Vision for AR, HCI, and Smart Cameras

Applications of Smart Technology for Industry and Human Interface Devices

Use ARTag markers in arrays to find camera-object relative pose (pose=position+orientation)

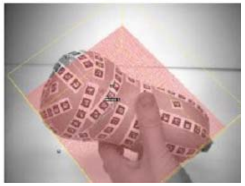
3D positioning with planar ARTag marker arrays

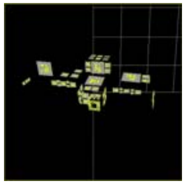
- **Augmented Reality (AR)**
- **industrial 3D positioning**



3D positioning with non-planar ARTag marker arrays

- **industrial 3D positioning**
- **spacecraft docking (industry)**
- **3D user interface device (HCI)**
- **"Magic Mirror"**





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Millennium 3 Engineering

AR Solutions from M3E

- **Stand-Alone AR Windows software – available mid-Nov 06**
  - **M100:** ***Magic lens*** **software – planar arrays with portable devices (tablets, etc)**
  - **M200:** ***Magic mirror*** **software – for moveable 3D arrays and stationary camera**

- **Networked AR Windows software – available Q1 07**
  - **MN100: Server-side of networked portable devices**
    - **-on main machine, hosts and controls session**
  - **MC100: Client-side of networked portable devices**
    - **-runs on tablet PC's (Q1 2007) and PDA, cell phones (tentative)**
    - **-content is delivered from server, client doesn't restart**

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  - **MDEV100: Use to make custom stand-alone** ***Magic Lens*** **apps. –for use with OPENGL**
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- ***Magic mirror*** **and** ***magic lens*** **software: client adds content (no programming)**
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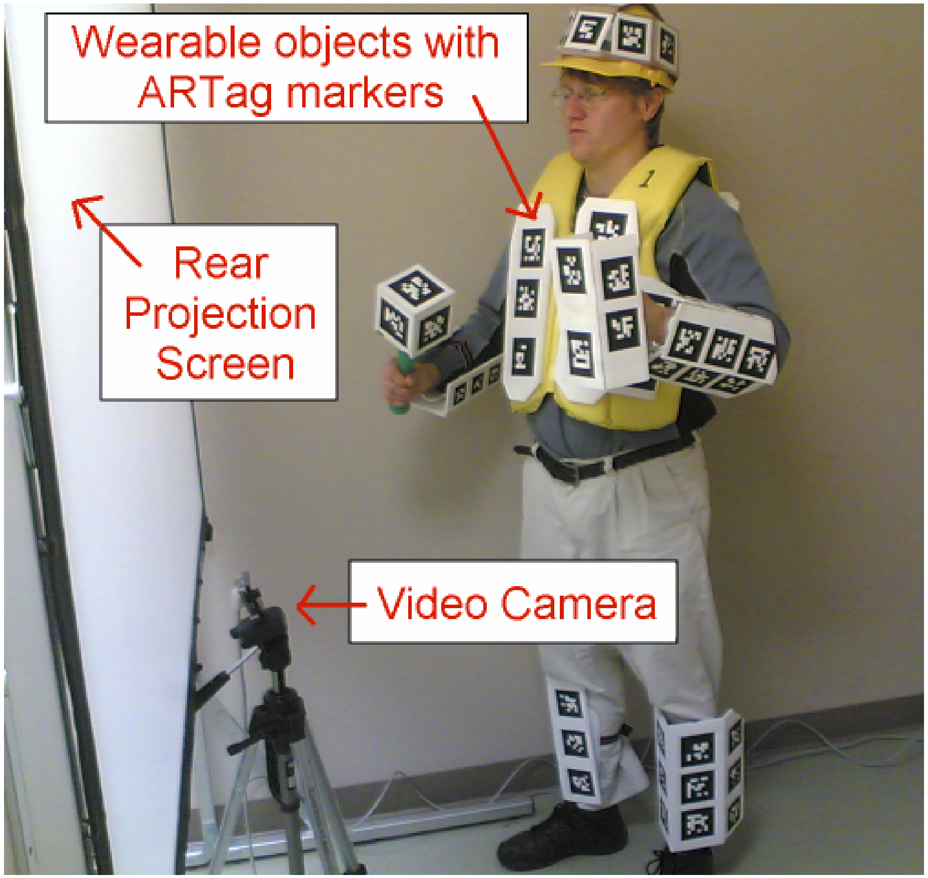
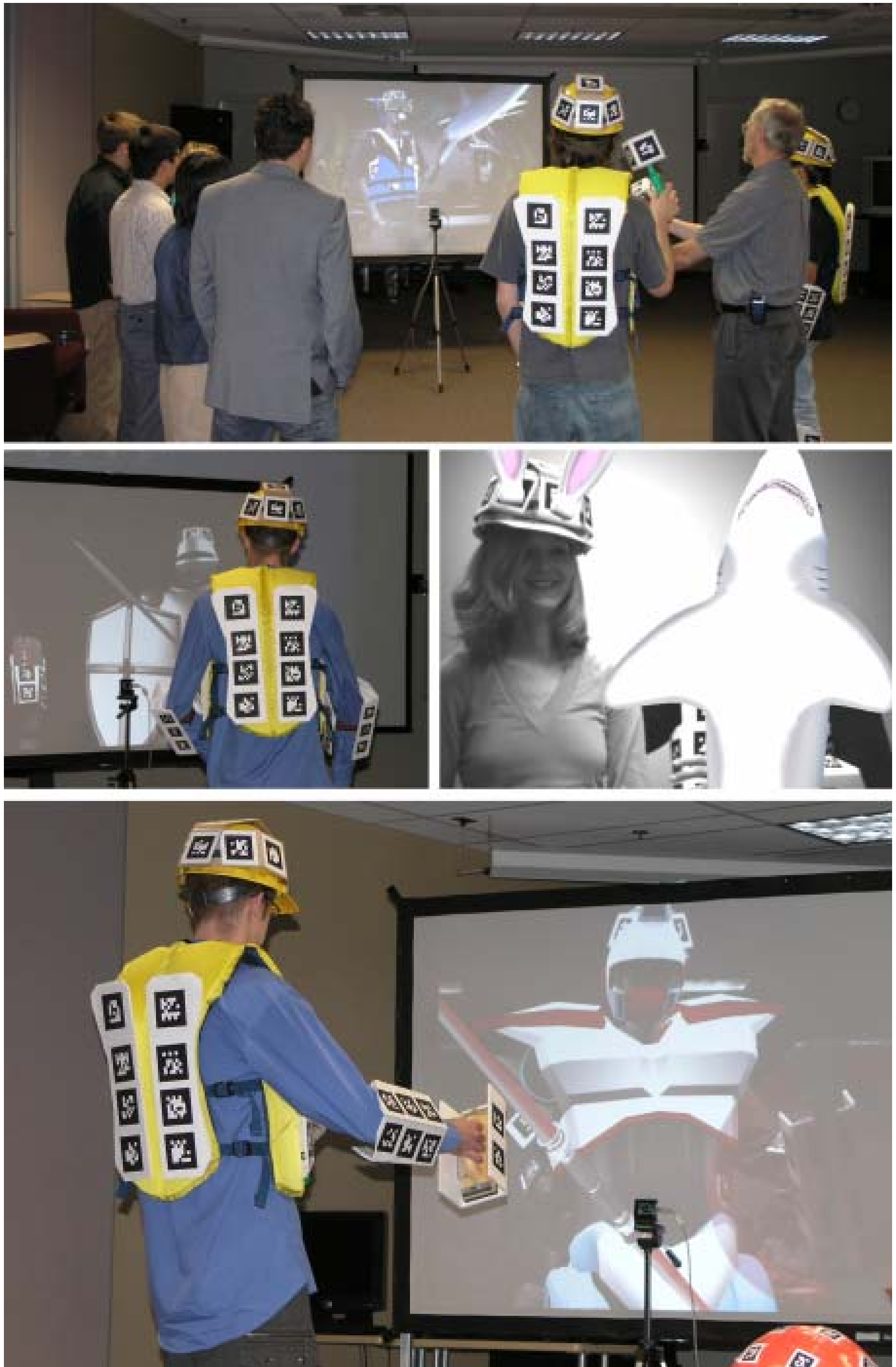
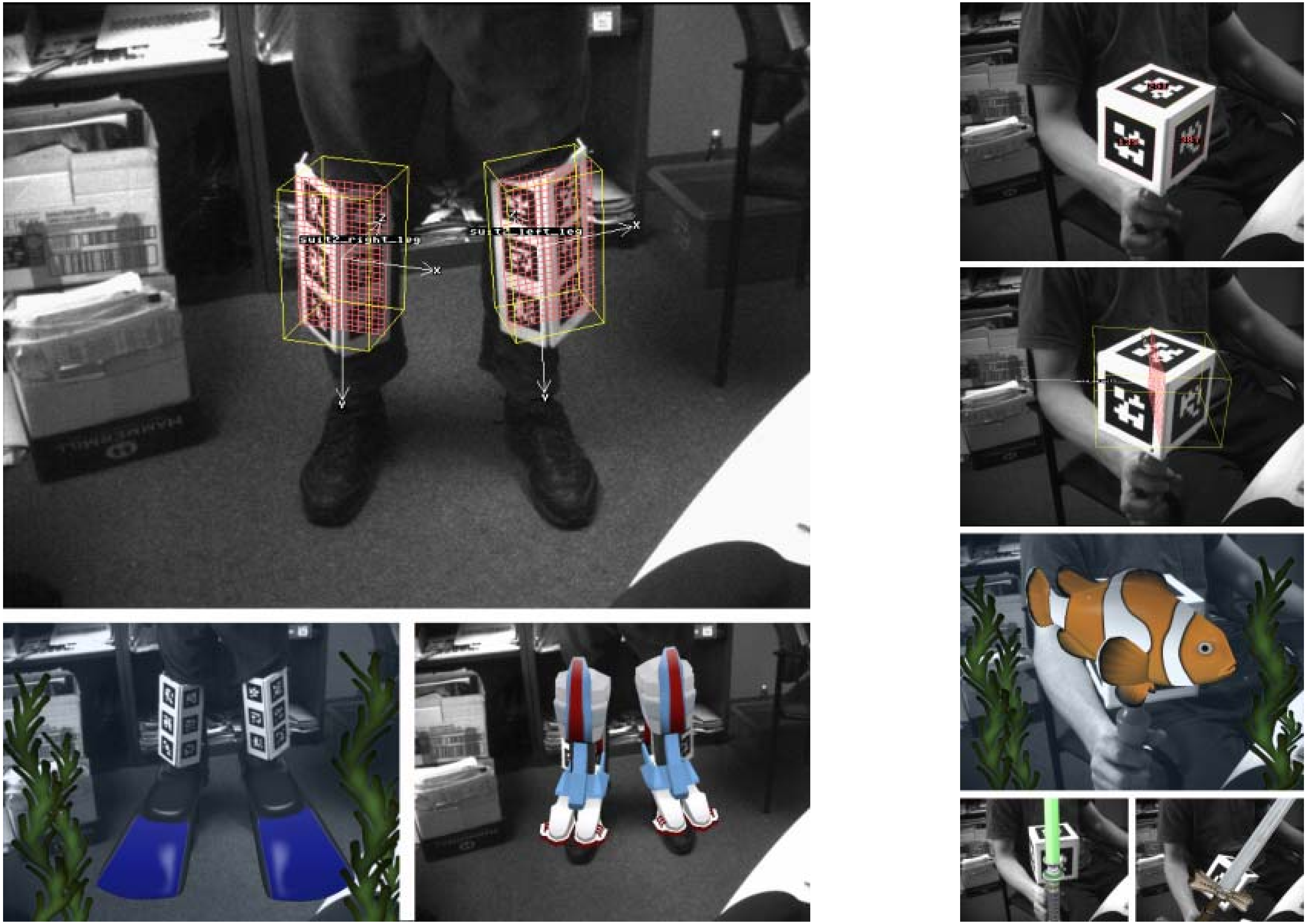
M200: Magic Mirror Application



M200: Magic Mirror



M200: Magic Mirror Application



AR Solutions from M3E

- **M200:** ***Magic mirror*** **software – for moveable 3D arrays and stationary camera**
- **Sample Applications**
  - **M200 used for *Magic Mirror***
  - **M200 used for *Anatomy***

Show magic_mirror.wmv

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Show anatomy.mov

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Configuring content with M100, M200

- **Show magic_mirror.cfg**

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AR Solutions from M3E

- **M200:** ***Magic mirror*** **software – for moveable 3D arrays and stationary camera**

- **Creating 3D array models for M200 - offline – likely a web server service to M200 clients who create their own content.**
  1. **Capture 10-25 images of object with ARTag markers attached**
  2. **Upload images to server – server performs bundle adjustment**
  3. **Download 3D model (.wrl file)**
  4. **Import .wrl into 3D software (eg. 3DSMax), rotate/translate/scale to fit 3D object, export .wrl file**
  5. **Run wrl2cf program, creates .cf file for M200 software**
  6. **Associate 3D model with this 3D array, 3D model or animation is now rendered on top of camera image aligned with 3D array.**

Future Possible Industry 2D AR Solutions from M3E

- Technology
  - 2D overlays with instruction, labels, fixed or variable messages
  - For wearable computing (PDA with glasses-mounted viewfinder)

- Applications
  - Assembly line workers
  - Maintenance technicians (fuse panels, network closets, etc)
  - Package info for warehouses

- Looking for partners in specific market domains

Millennium 3 Engineering

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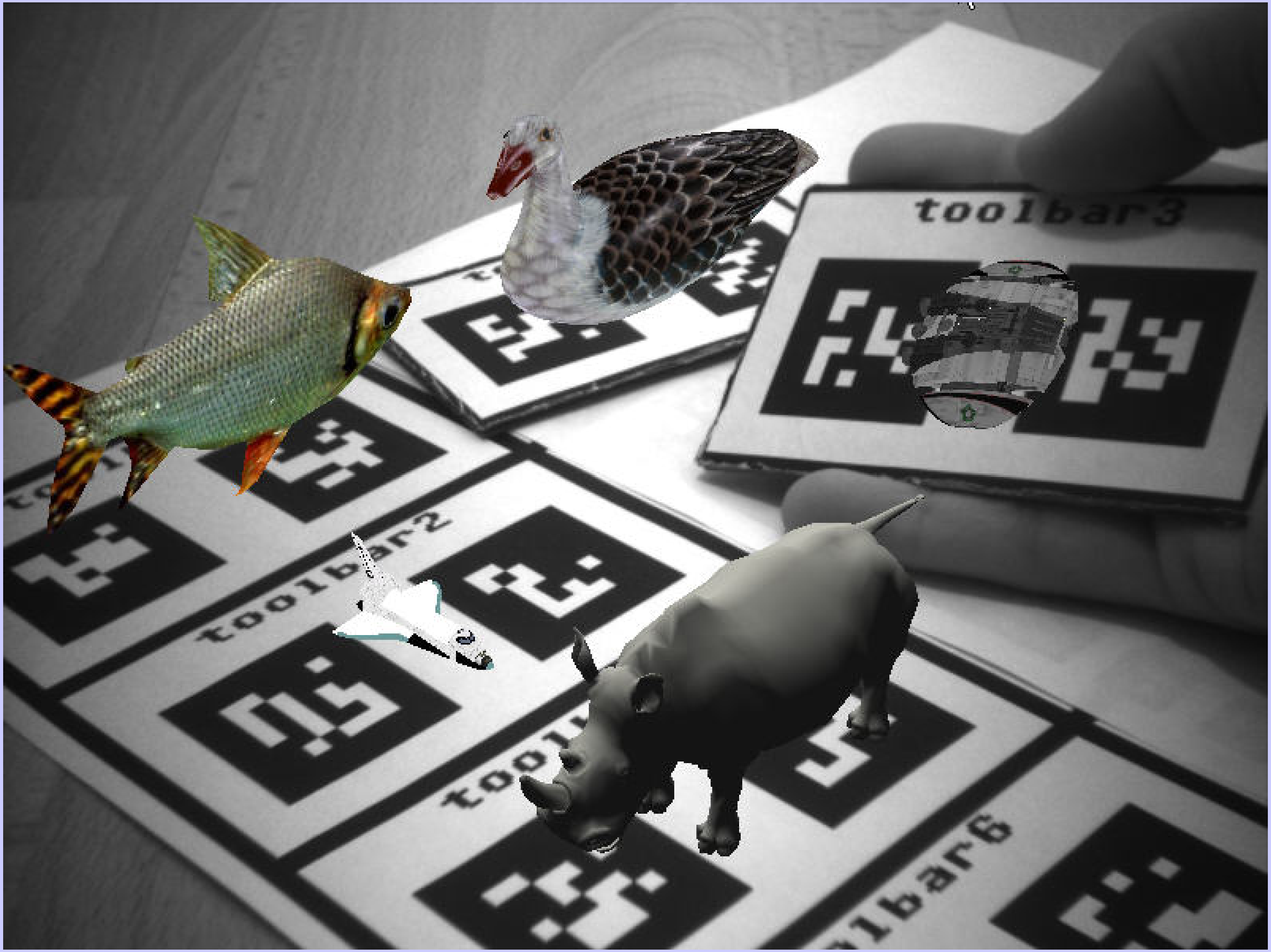
    - -content is delivered from server, client doesn't restart

- SDK's (Software Development Kits) – available Q1 07
  - MDEV100: Use to make custom stand-alone *Magic Lens* apps. –for use with OPENGL
  - MNDEV100: Stand-alone and networked SDK's

Solutions for customers

- Complete exhibit: software and 3D content (M3E contracts 3D artists)
- *Magic mirror* and *magic lens* software: client adds content (no programming)
- Stand-alone and networked SDK's for custom AR applications.

Cell Phone AR – client device for MC100



Show cell phone demo

Millennium 3 Engineering

Augmented Reality Product Offerings

Looking for distributors, marketing assistance and partnerships!

The END – thank you for listening

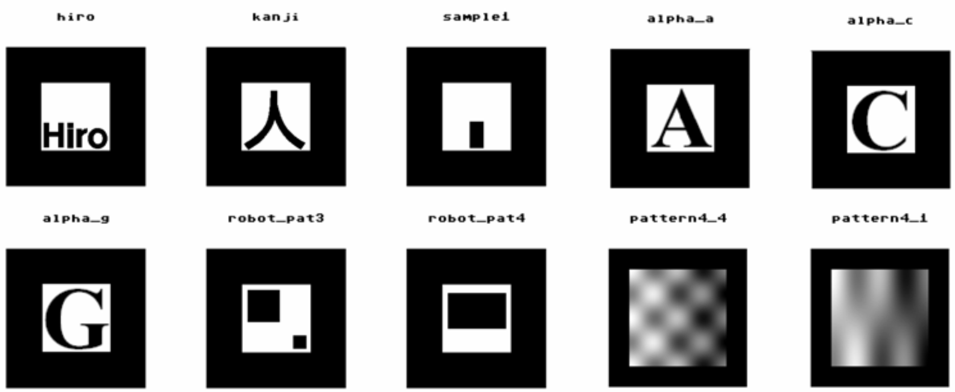
www.mill3eng.com   www.artag.net

Contact: Mark Fiala
mark.fiala@nrc-cnrc.gc.ca
mark.fiala@gmail.com

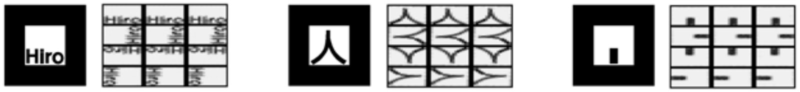
Millennium 3 Engineering

ARToolkit Fiducial Marker System

- Developed by Dr. Hirokazu Kato (Osaka University)
- Internationally popular – used in AR, HCI projects
- Freely downloadable



Must load marker file and correlate for every marker to be detected.



False Positives.

ARToolkit Drawbacks:

- **False Detection-** marker reported that dosen't exist.
- **Inter-marker confusion-** wrong marker ID reported.
- **Must set *c.f.* threshold**

ARToolkit reports markers with a *Confidence Factor* 0<*c.f.*<1

Fiducial Marker System Design: Hamming Distance between Patterns

Hamming Distance: Definition = # of different bits

10010 and 10001 H.D. = 2

Pattern A	***Pattern B***
1 0 0 1 0 1	**1 0 0 1 1 1**
0 0 0 0 0 0	**0 0 0 0 0 0**
1 1 1 1 1 1	**1 1 0 1 1 1**
1 0 1 1 0 1	**1 0 1 1 0 1**
0 0 1 1 0 0	**0 0 1 1 0 0**
1 1 0 0 1 1	**1 0 0 1 1 1**

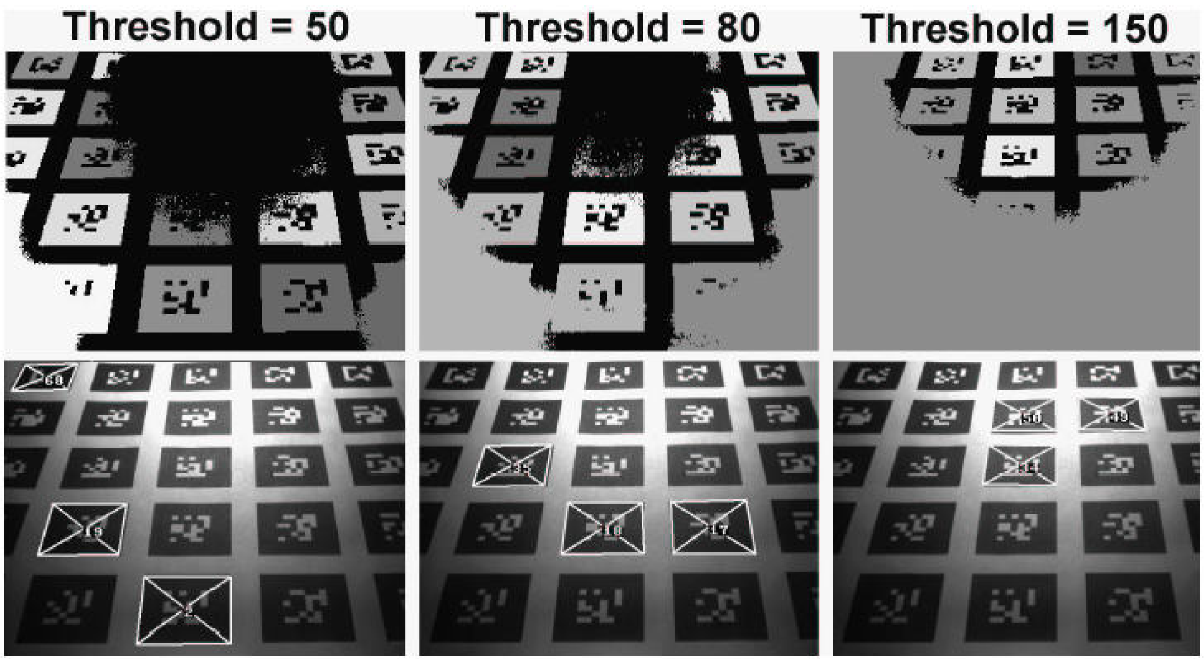
Hamming Distance between Patterns A and B

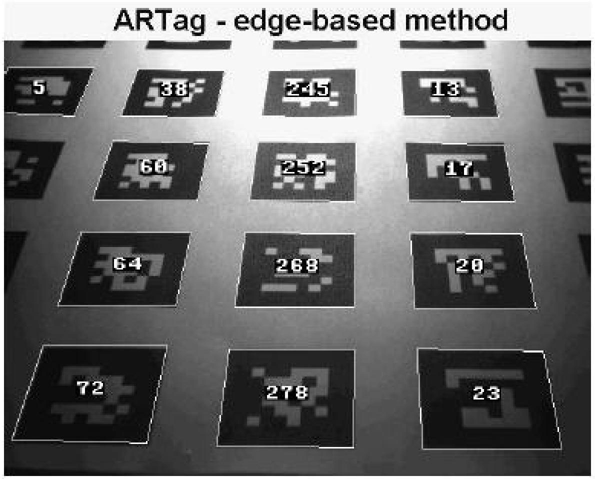
= 4

Comparing ARTag and ARToolkit, ARToolkit Plus

Lighting immunity

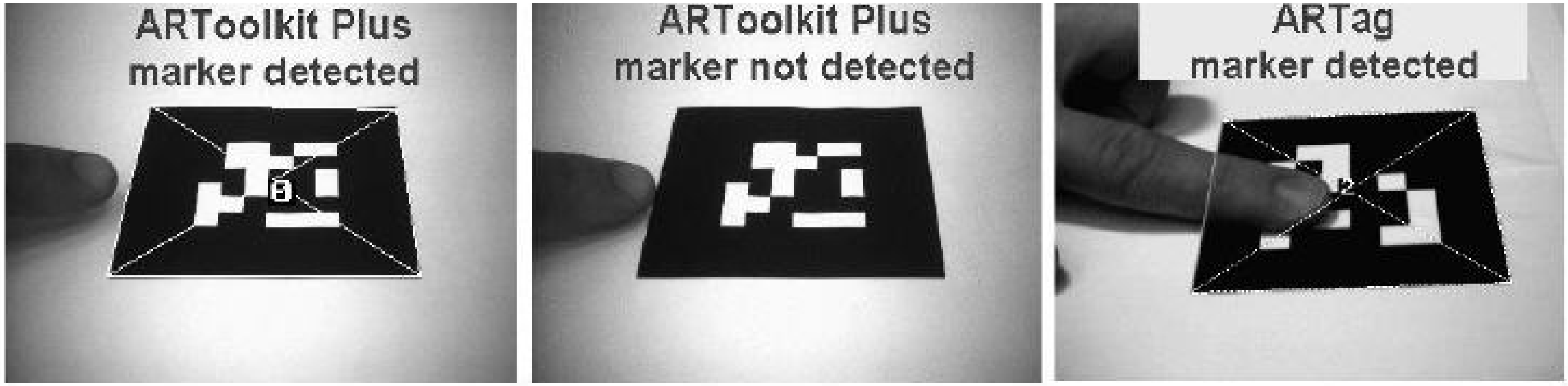
ARToolkit or ARToolkit Plus:
thresholding/binary morphology based





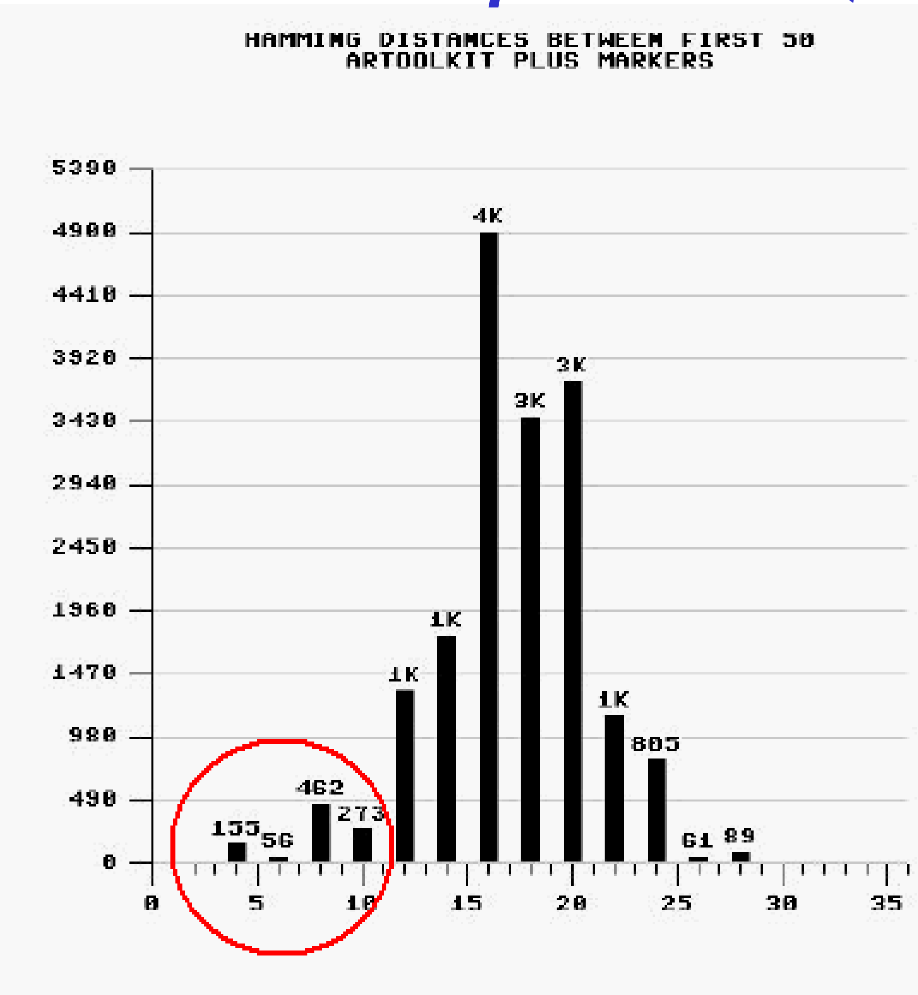
Comparing ARTag and ARToolkit, ARToolkit Plus

Occlusion immunity

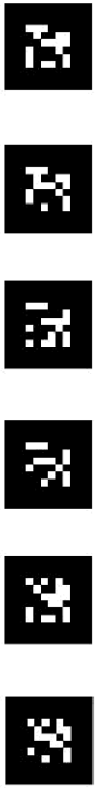


Comparing ARTag and ARToolkit Plus

Inter-marker confusion rate *(how often is marker ID wrong)*

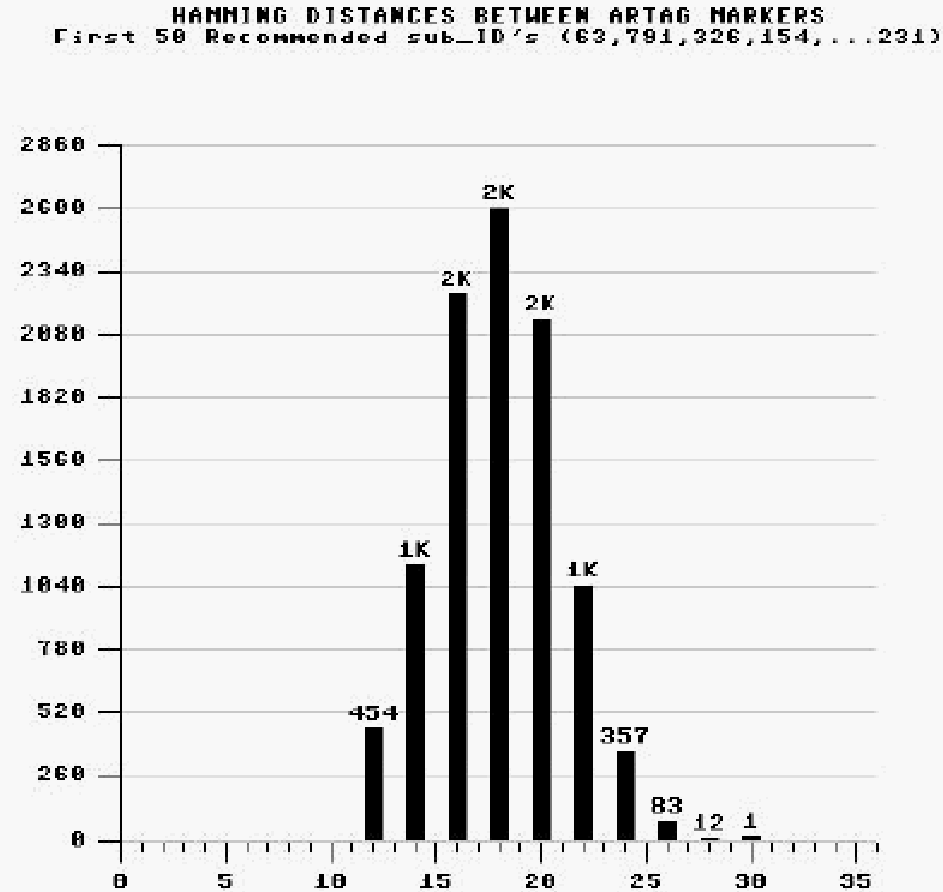


HAMMING DISTANCE	NUMBER
0:	0
1:	0
2:	0
3:	0
4:	155
5:	0
6:	56
7:	0
8:	462
9:	0
10:	273
11:	0
12:	1350
13:	0
14:	1778
15:	0
16:	4959
17:	0
18:	3478
19:	0
20:	3751
21:	0
22:	1158
23:	0
24:	805
25:	0
26:	61
27:	0
28:	89
29:	0
30:	0
31:	0
32:	0
33:	0
34:	0



Comparing ARTag and ARToolkit Plus

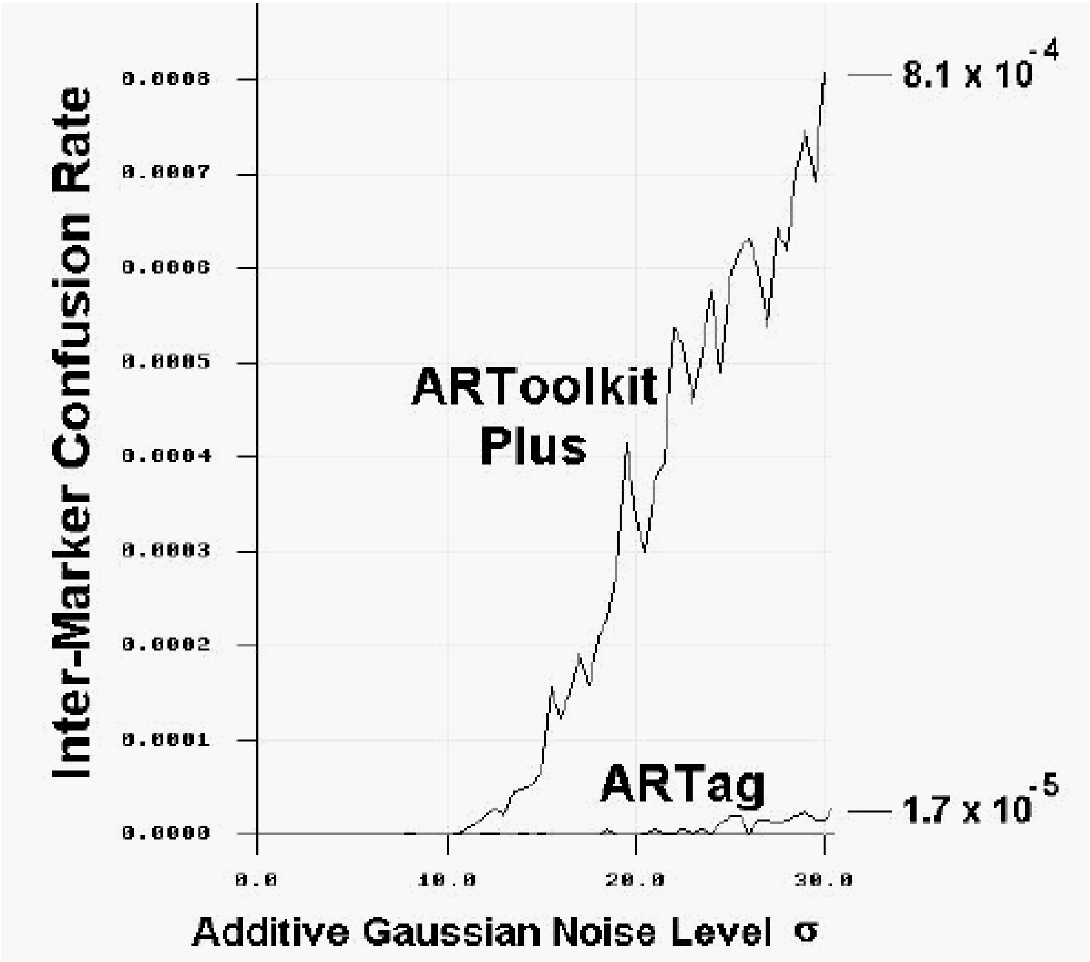
Inter-marker confusion rate *(how often is marker ID wrong)*



HAMMING DISTANCE	NUMBER
0:	0
1:	0
2:	0
3:	0
4:	0
5:	0
6:	0
7:	0
8:	0
9:	0
10:	0
11:	0
12:	454
13:	0
14:	1128
15:	0
16:	2251
17:	0
18:	2670
19:	0
20:	2146
21:	0
22:	1040
23:	0
24:	357
25:	0
26:	83
27:	0
28:	12
29:	0
30:	1
31:	0
32:	0
33:	0
34:	0

Comparing ARTag and ARToolkit Plus

Inter-marker confusion rate (how often is marker ID wrong)



Comparing ARTag and ARToolkit Plus

False Negative rate (how often is marker missed)