Inside ARToolKit

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But

- 40 min. is too short to talk everything.
- Focus into some important points.
- This is for people who has developed applications with ARToolKit.

Outline

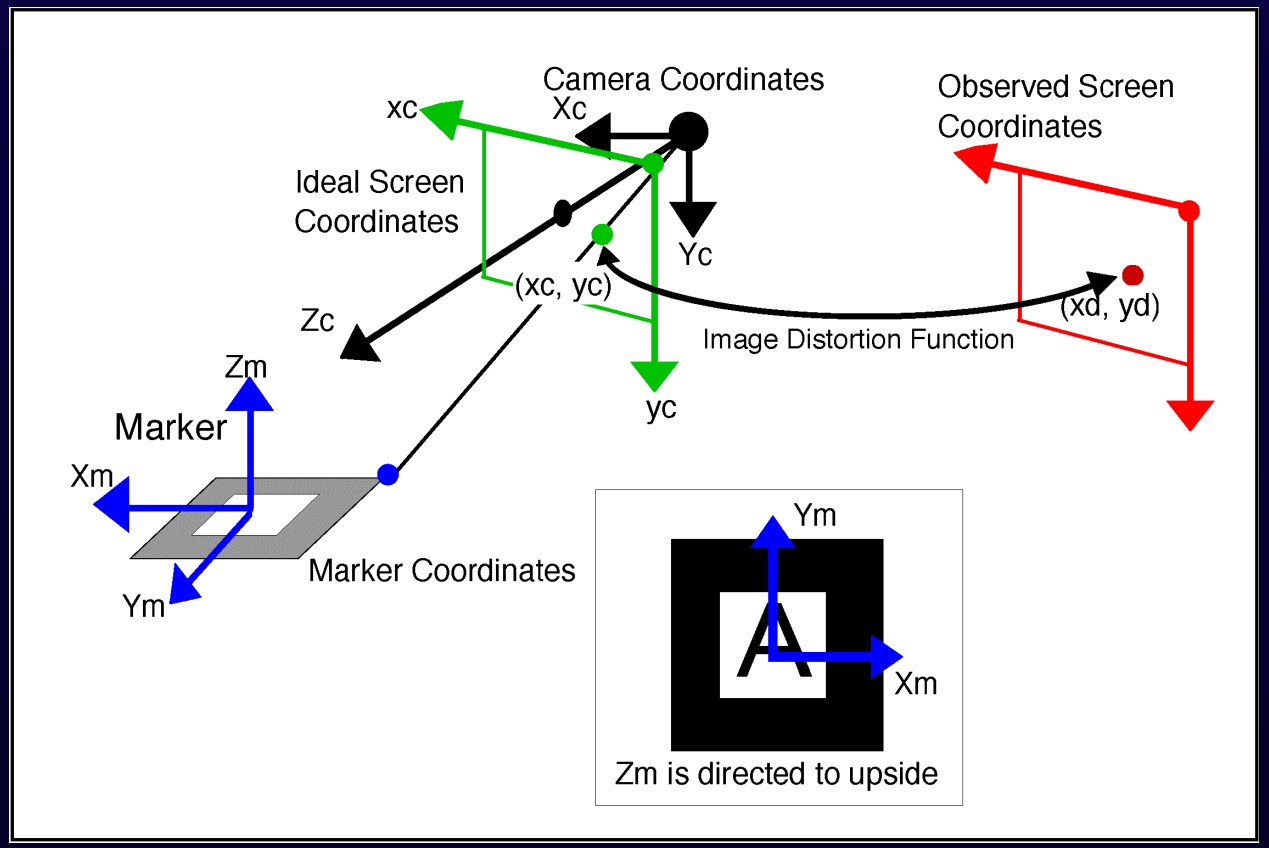
1. Mathematical & Algorithm Background
   - **Pose & Position Estimation**
   - **Rectangle Extraction**

2. Implementation
   - **Camera Calibration**
   - **Image Processing**
   - **Pose Estimation**
   - **Background Video Stream Display**

1.1 Pose & Position Estimation

- Coordinates System
- Equations
- Calculation
- Initial Condition Problem

Coordinate Systems



Relationships: Marker & Camera

Rotation & Translation

$$\begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & T_1 \\ R_{21} & R_{22} & R_{23} & T_2 \\ R_{31} & R_{32} & R_{33} & T_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_M \\ Y_M \\ Z_M \\ 1 \end{bmatrix}$$

$$= \mathbf{T_{CM}} \begin{bmatrix} X_M \\ Y_M \\ Z_M \\ 1 \end{bmatrix}$$

Relationships: Camera & Ideal Screen

Perspective Projection

$$\begin{bmatrix} hX_I \\ hY_I \\ h \end{bmatrix} = \begin{bmatrix} sf_x & 0 & x_c & 0 \\ 0 & sf_y & y_c & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix} = \mathbf{C} \begin{bmatrix} X_C \\ Y_C \\ Z_C \\ 1 \end{bmatrix}$$

C : Camera Parameter

Image Distortion

Image Distortion Parameters

Relationships between Ideal and Observed Screen Coordinates

$$d^2 = \left(x_I - x_0\right)^2 + \left(y_I - y_0\right)^2$$

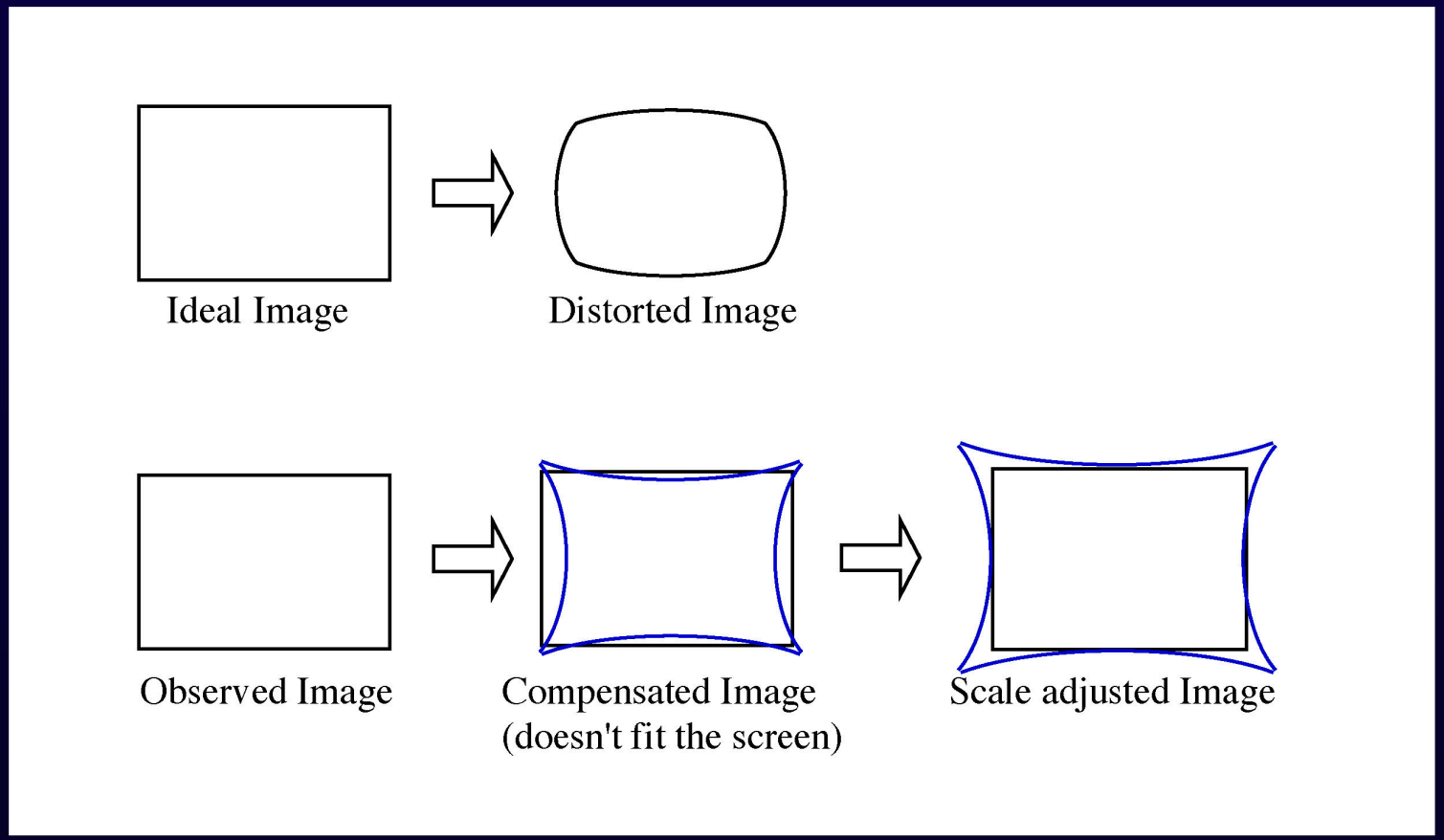
$$p = \left\{1 - fd^2\right\}$$

$$x_O = p\left(x_I - x_0\right) + x_0, \quad y_O = p\left(y_I - y_0\right) + y_0$$

(x_0, y_0) : Center Coordinates of Distortion

f: Distortion Factor

Scaling Parameter for Size Adjustment



Implementation of Image Distortion parameters

$$x = s(x_i - x_0), y = s(y_i - y_0)$$

$$d^2 = x^2 + y^2$$

$$p = \{1 - fd^2\}$$

$$x_d = px + x_0, \quad y_d = py + y_0$$

$$dist\_factor[0] = x_0$$

$$dist\_factor[1] = y_0$$

$$dist\_factor[2] = 100000000.0 * f$$

$$dist\_factor[3] = s$$

What is pose & position estimation?

Marker Coordinates: (X_m, Y_m, Z_m)

T_{mc} : ???? KNOWN

Camera Coordinates

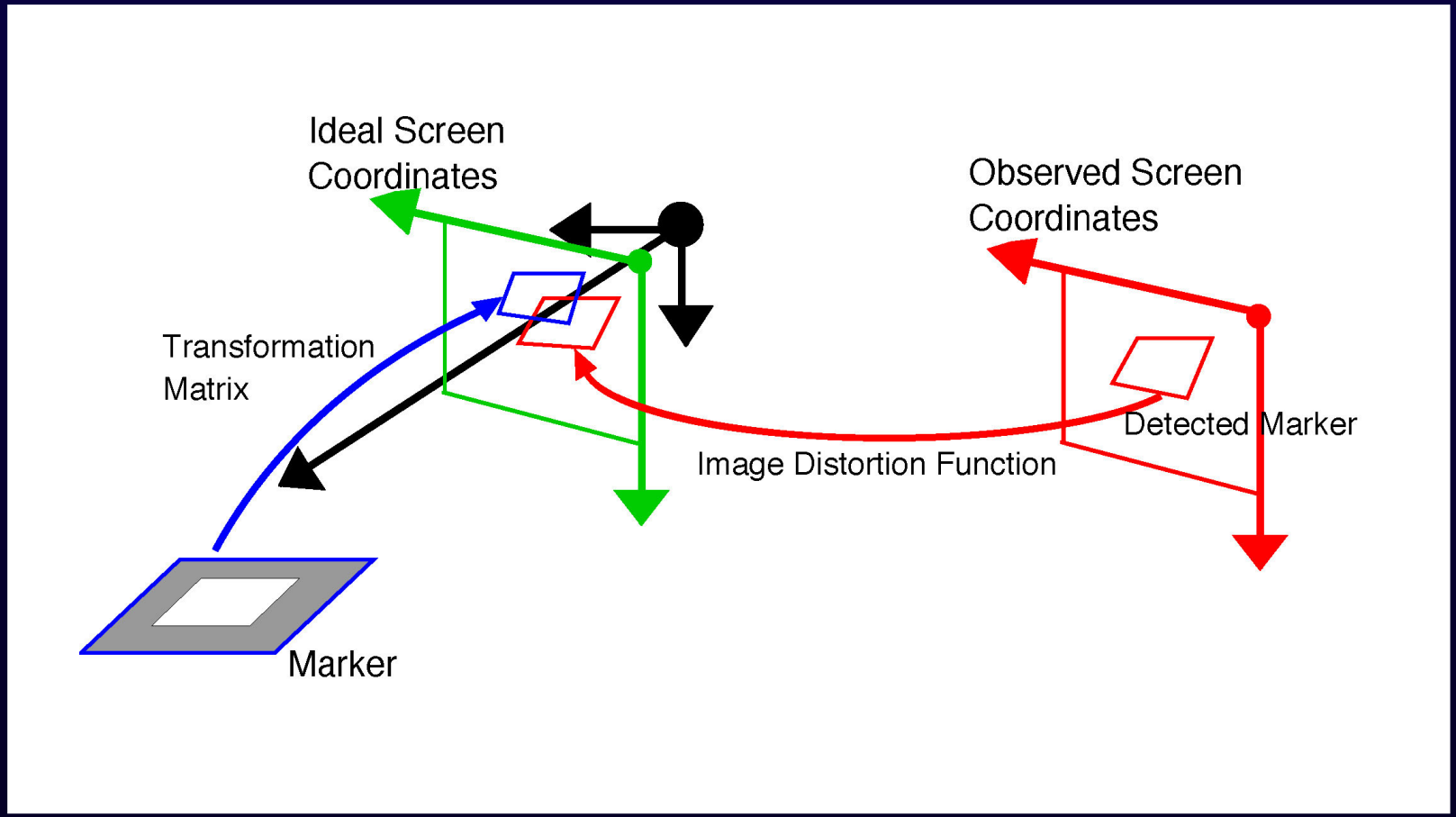
KNOWN

Ideal Screen Coordinates

KNOWN GET by Image Processing

Observed Screen Coordinates: (x_o, y_o)

How to get T_{CM}



Search T_{cm} by Minimizing Error

Optimization

- Iterative process

$$\begin{bmatrix} h\hat{x}_i \\ h\hat{y}_i \\ h \end{bmatrix} = \mathbf{C}\cdot\mathbf{T}_{\mathbf{CM}} \begin{bmatrix} X_{Mi} \\ Y_{Mi} \\ Z_{Mi} \\ 1 \end{bmatrix}, \quad i = 1,2,3,4$$

$$err = \frac{1}{4} \sum_{i=1,2,3,4} \left\{ \left(x_i - \hat{x}_i\right)^2 + \left(y_i - \hat{y}_i\right)^2 \right\}$$

How to set the initial condition for optimization process

Geometrical calculation based on 4 vertices coordinates

- Independent in each image frame: Good feature.
- Unstable result (Jitter occurs.): Bad feature.

Use of information from previous image frame

- Needs previous frame information.
- Cannot use for the first frame.
- Stable results. (This dose not mean accurate results.)

ARToolKit supports both.
See 'simpleTest2'.

1.2 Rectangle Extraction

1. Thresholding, Labeling,
   Feature Extraction (area, position)
2. Contour Extraction
3. Four straight lines fitting

- Little fitting error => Rectangle.

This method is very simple. Then it works very fast.

2. Implementation

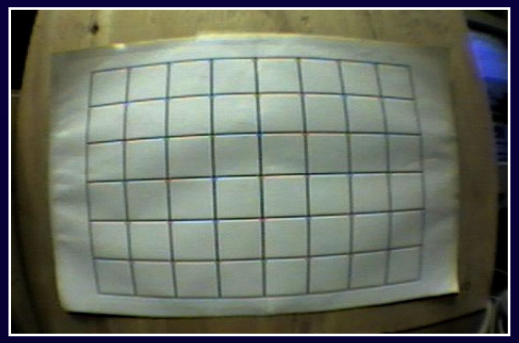
- Camera Calibration Method
- Image Processing
- Pose Estimation
- Background Video Stream Display

2.1 Camera Calibration

- **Camera Parameters**
  1. Perspective Projection Matrix
  2. Image Distortion Parameters
- **ARToolKit has 2 methods for camera calibration.**
  1. Accurate 2 steps method
  2. Easy 1 step method

Accurate 2 steps method

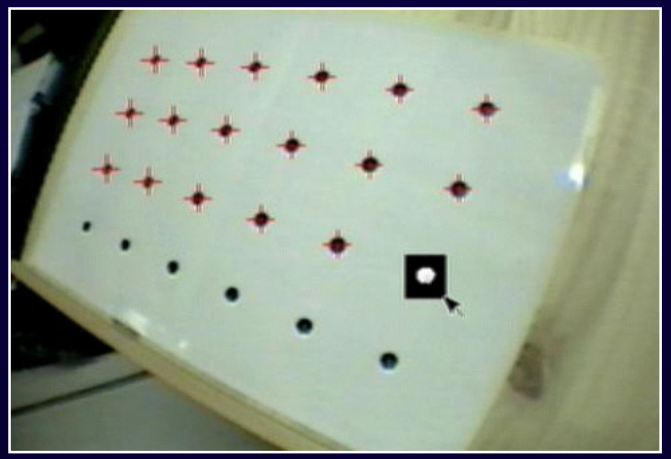
Using dot pattern and grid pattern



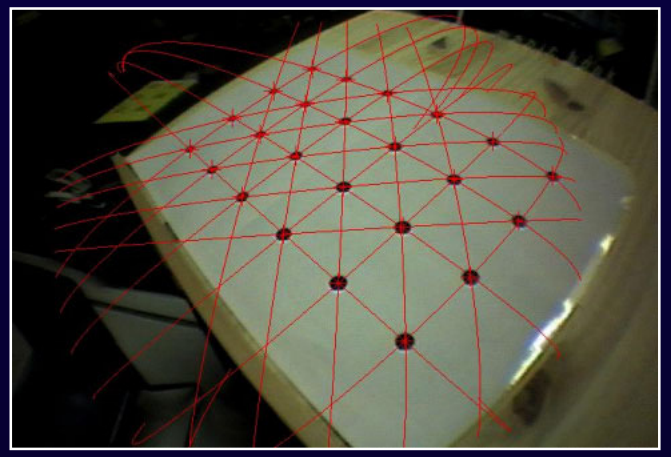
2 step method

- 1) Getting distortion parameters
- 2) Getting perspective projection parameters

Step 1: Getting distortion parameters 'calib_dist'



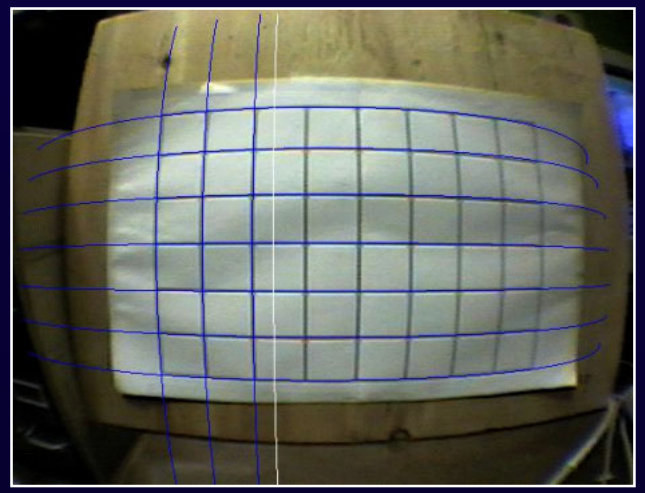
Selecting dots with mouse



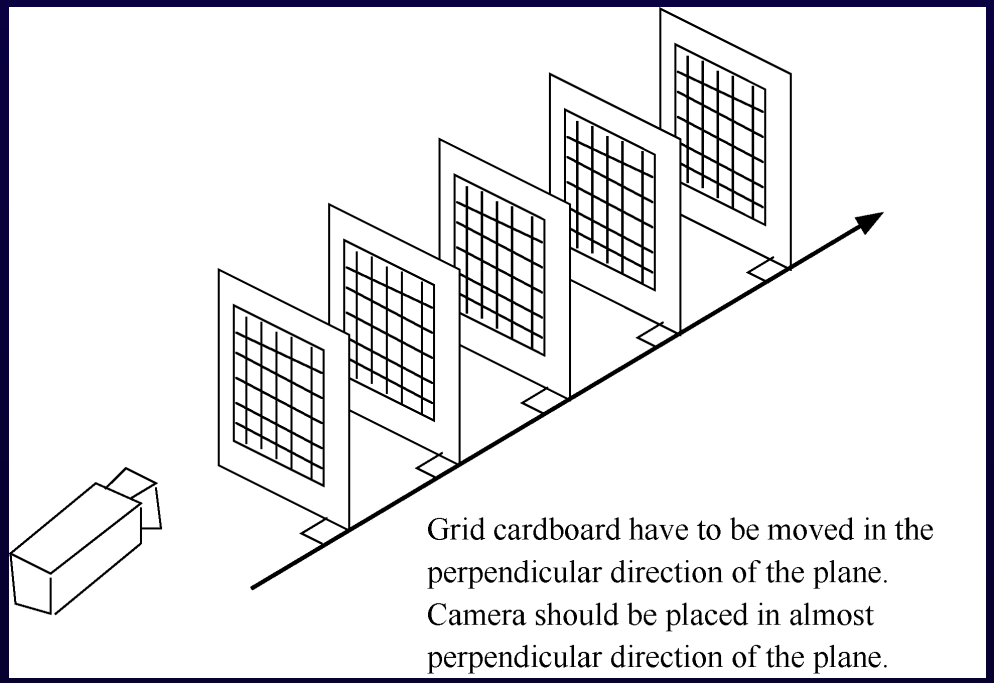
Getting distortion parameters by automatic line-fitting

- Take pattern pictures as large as possible.
- Slant in various directions with big angle.
- 4 times or more

Step2: Getting perspective projection matrix 'calib_cparam'



Manual line-fitting



Easy 1 step method: 'calib_camera2'

- Same operation as 'calib_dist'.
- Getting all camera parameters including distortion parameters and perspective projection matrix.
- Not require careful setup.
- Accuracy is good enough for image overlay.
  (Not good enough for 3D measurement.)

Camera Parameter Implementation

Camera parameter structure

- ```
  typedef struct {
      int      xsize, ysize;
      double   mat[ 3][ 4] ;
      double   dist_factor[ 4] ;
  } ARParam;
  ```

Adjust camera parameter for the input image size

- ```
  int arParamChangeSize( ARParam *source,
                         int xsize, int ysize,
                         ARParam *newparam );
  ```

Read camera parameters from the file

- ```
  int    arParamLoad( char *filename, int num,
                      ARParam *param, ...);
  ```
  ```

2.2 Notes on Image Processing

- Image size for marker detection
- Use of tracking history
- Accuracy v.s. Speed on pattern identification

(1) Image size for image processing

AR_IMAGE_PROC_IN_FULL

- Full size images are used for marker detection.
- Taking more time but accuracy is better.
- **Not good for interlaced images**

AR_IMAGE_PROC_IN_HALF

- Re-sampled half size images are used for marker detection.
- Taking less time but accuracy is worse.
- Good for interlaced images

External variable: arImageProcMode in 'ar.h'

Default value: DEFAULT_IMAGE_PROC_MODE in 'config.h'

(2) Use of tracking history

Marker Detection

- With tracking history: arDetectMarker();
- Without tracking history: arDetectMarkerLite();

How to use tracking history

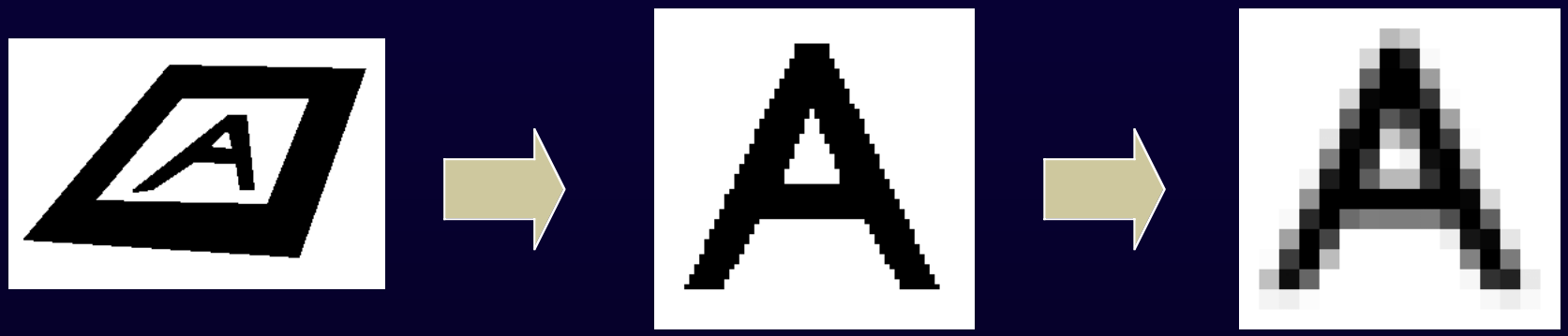
- Error correction of pattern identification
- Lost marker insertion

(3) Accuracy v.s. Speed on pattern identification

Pattern normalization takes much time.

This is a problem in use of many markers.

- Normalization process.



Normalization Resolution convert

In 'config.h'

```
#define   AR_PATT_SAMPLE_NUM   64
#define   AR_PATT_SIZE_X       16
#define   AR_PATT_SIZE_Y       16
```

	Identification Accuracy	Speed
Large size	Good	Slow
Small size	Bad	Fast

2.3 Pose & Position Estimation

- Two types of initial condition
- Use of estimation accuracy

(1) Two types of initial condition

1. Geometrical calculation based on 4 vertices in screen coordinates

```
double arGetTransMat( ARMarkerInfo *marker_info,
                      double center[2], double width,
                      double conv[3][4] );
```

2. Use of information from previous image frame

```
double arGetTransMatCont( ARMarkerInfo *marker_info,
                          double prev_conv[3][4],
                          double center[2], double width,
                          double conv[3][4] );
```

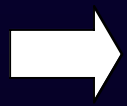
- See 'simpleTest2.c'

(2) Use of estimation accuracy

$$\begin{bmatrix} h\hat{x}_i \\ h\hat{y}_i \\ h \end{bmatrix} = \mathbf{C} \cdot \mathbf{T}_{\mathbf{CM}} \begin{bmatrix} X_{Mi} \\ Y_{Mi} \\ Z_{Mi} \\ 1 \end{bmatrix}, \quad i = 1,2,3,4$$

$$err = \frac{1}{4} \sum_{i=1,2,3,4} \left\{ \left(x_i - \hat{x}_i \right)^2 + \left(y_i - \hat{y}_i \right)^2 \right\}$$

`arGetTransMat()` minimizes the *'err'*.
It returns this minimized *'err'*.
If *'err'* is still big,



Miss-detected marker.
Use of camera parameters by bad calibration.

2.4 Background video display

Texture mapping v.s. glDrawPixels()

- Performance depends on hardware and OpenGL driver.

external variable: argDrawMode in 'gsub.h'

#define DEFAULT_DRAW_MODE in 'config.h'

- AR_DRAW_BY_GL_DRAW_PIXELS
- AR_DRAW_BY_TEXTURE_MAPPING

Note: glDrawPixels() dose not compensate image distortion.

See 'examples/test/graphicsTest.c' and 'modeTest'

Some notes

- ARToolKit has limitation as a 3D measurement system because of monocular camera setup.
- Lighting conditions and Marker materials are also important.

Coming next

- **In a half year**
  - Stereo version of ARToolKit
- **In a year**
  - Shadow representation with VRML paser
  - Texture tracking (kind of natural feature tracking)