3D - PHOTOGRAMMETRY USING SMARTPHONE DEVICES

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PURDUE
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Introduction:

- Stereo point measurement - existing technology in Photogrammetry/Computer Vision
- Current generation smartphones offer support for faster image processing
- The ability to run user generated content and applications
- 3-D point measurement when object inaccessible
- Generate full resolution 3-D stereo model

Introduction:

- Mobile Development Environment

Apple iOS

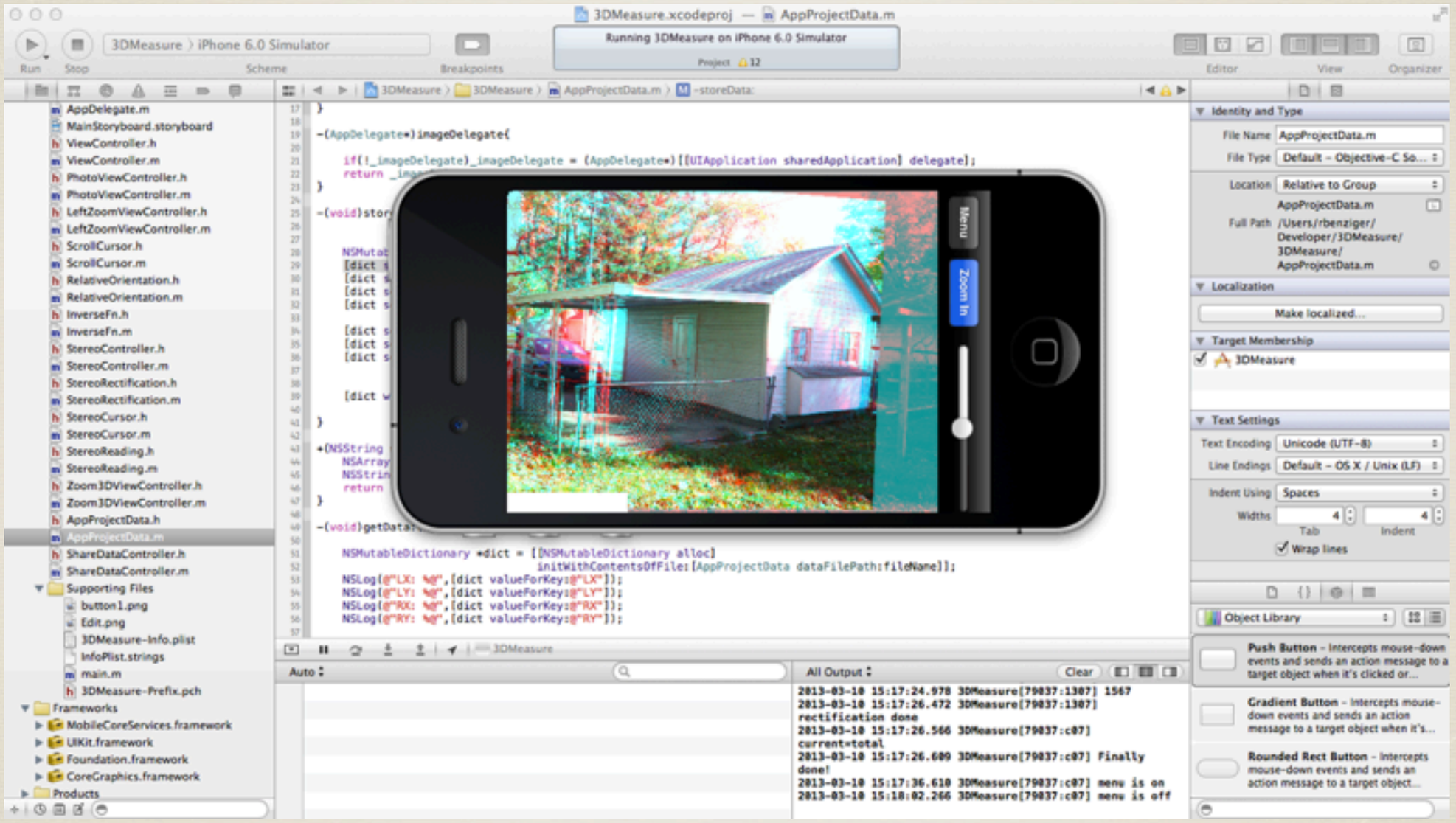
Google Android

Windows 8

Introduction:

- iOS SDK Environment
- Ideal for Photogrammetry
- Hardware compatibility
- Huge User base
- Software fragmentation and Adoption rate
- iPhone camera sensor

X-Code Objective-C Environment



iOS SDK and Sandbox

* Apps installed in self contained location
* iOS file system access restricted
* Can store files only within sandbox
* No sharing data between apps
* Low-memory notifications

Camera Calibration Module

* Target Arrangement

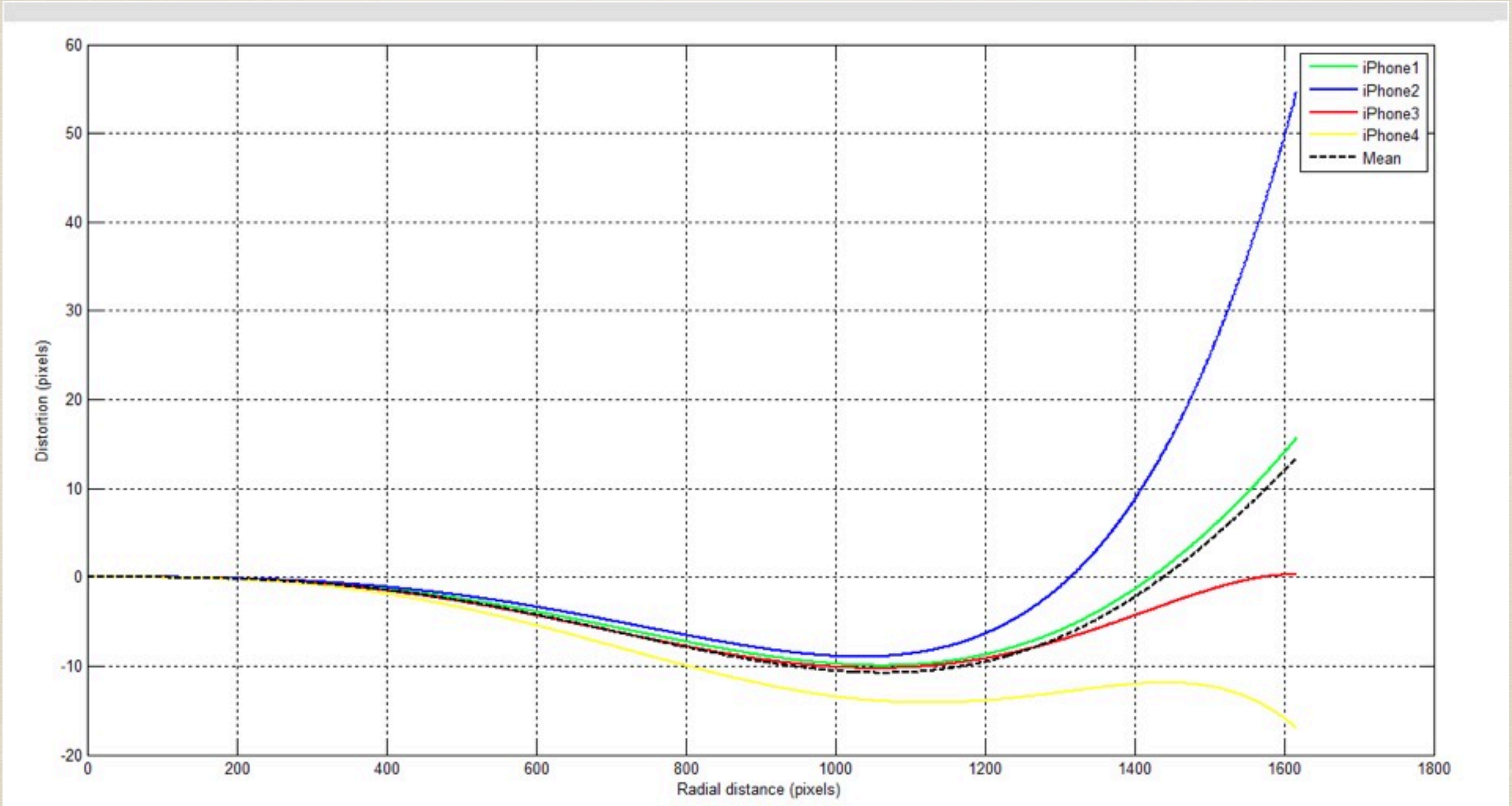
Target layout idea borrowed from iWitness commercial program

Camera Calibration Module

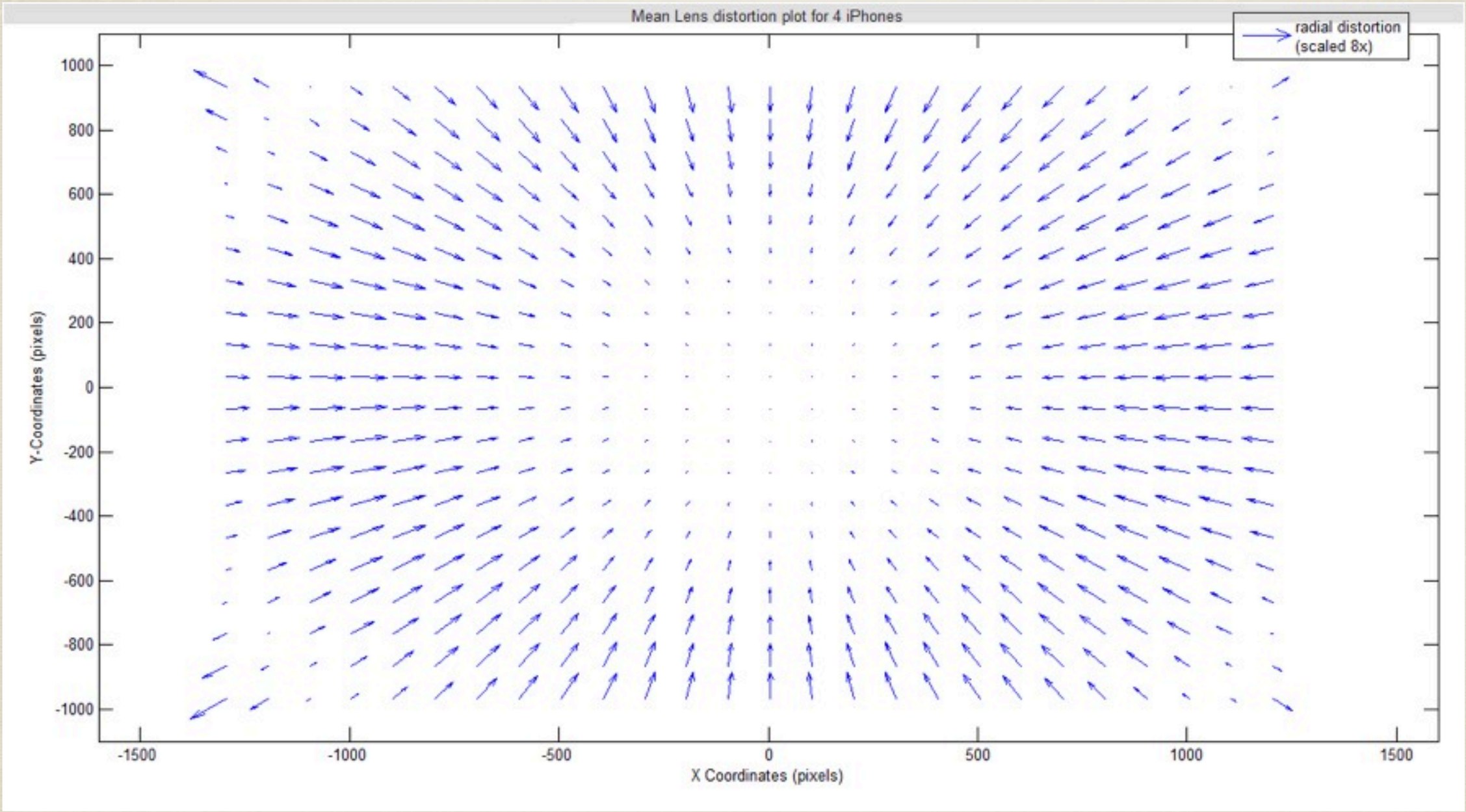
Phone	iPhone1 (Data A)	iPhone2 (Data B)	iPhone2 (Data A)	iPhone2 (Data B)	iPhone3	iPhone4
xo	13.62	12.175	-11.441	-4.8	21.872	27.19
yo	-4.883	-14.863	-18.494	-17.982	-18.046	-1.134
f	2492.324	2481.87	2423.991	2410.461	2469.348	2466.868
k1	-0.061239676	-0.061008142	-0.06170645	-0.088055701	-0.048727903	-0.070032411
k2	0.12267294	0.10647417	0.075147862	0.17589271	0.05673563	0.14104677
k3	-0.056867979	-0.035692384	0.01269821	-0.09835266	0.025970739	-0.070823946
p1	1.93E-09	4.21E-10	-1.39E-08	1.50E-08	-2.70E-09	2.77E-09
p2	1.08E-08	6.74E-11	-1.40E-08	-7.55E-09	-8.59E-09	9.96E-09
rms-x	0.221	0.207	0.284	0.325	0.261	0.23
rms-y	0.229	0.185	0.272	0.275	0.272	0.229

* Data adjusted with p1,p2~0
* Final data used with p1,p2 and k3~0

Camera Sensor Distortion

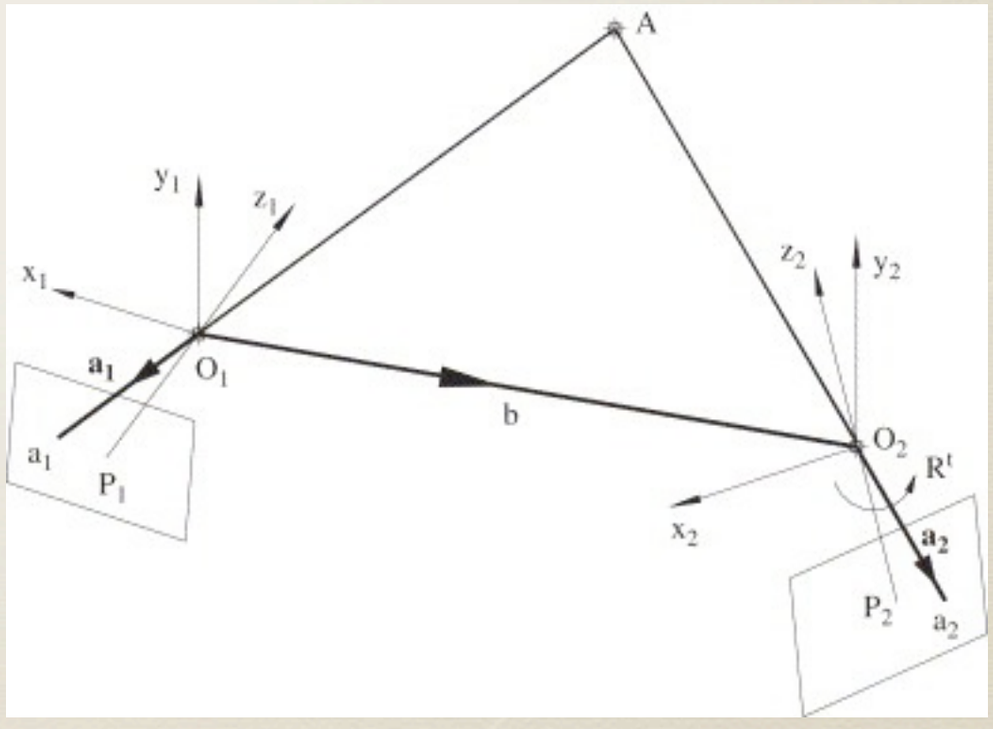


Camera Sensor Distortion



Data Collection

- Left and Right Images captured using Single iPhone Camera
- Base-height ratio of 0.3-0.4
- Image overlap of 90% for good output stereo



Source:[1]

Manual Image Matching module

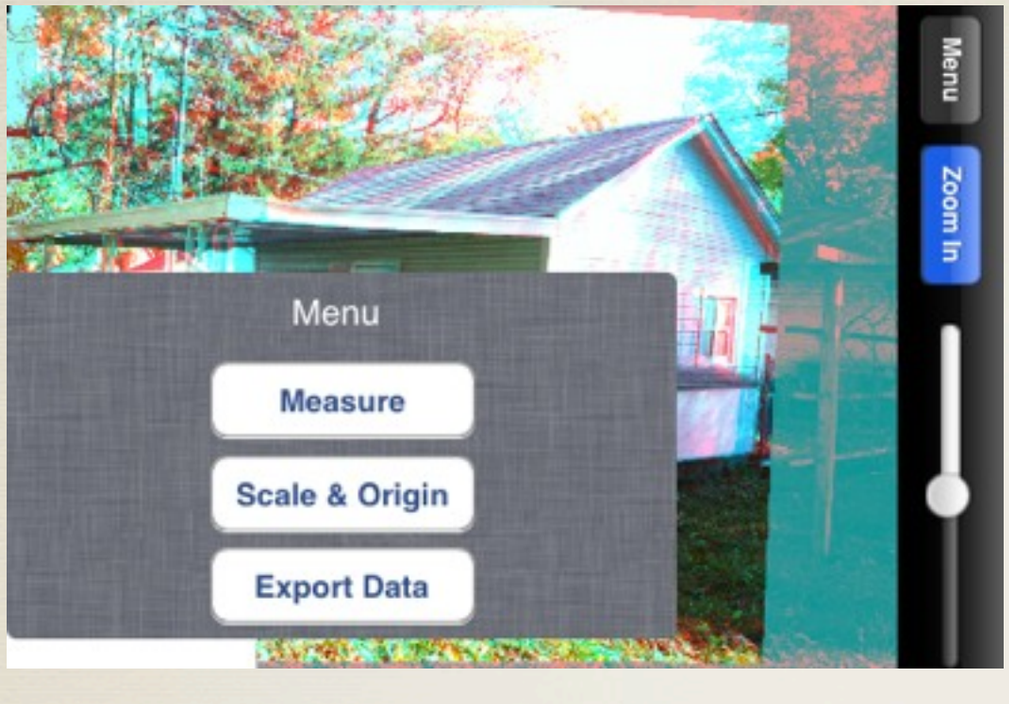
- iPhone App manual module
- Intuitive GUI for fast manual matching
- Match 6 or more points on Left-Right Image Pair
- Relative Orientation computed using Least-squares regression


3D Measure
INSTRUCTIONS:
1. USE ONLY LANDSCAPE IMAGES
2. USE MANUAL CALIBRATION FOR ACCURATE RESULTS
Enter


3D Measure
INSTRUCTIONS:
Input Method
Camera
Photo Library
Cancel


Done


Menu
Zoom In

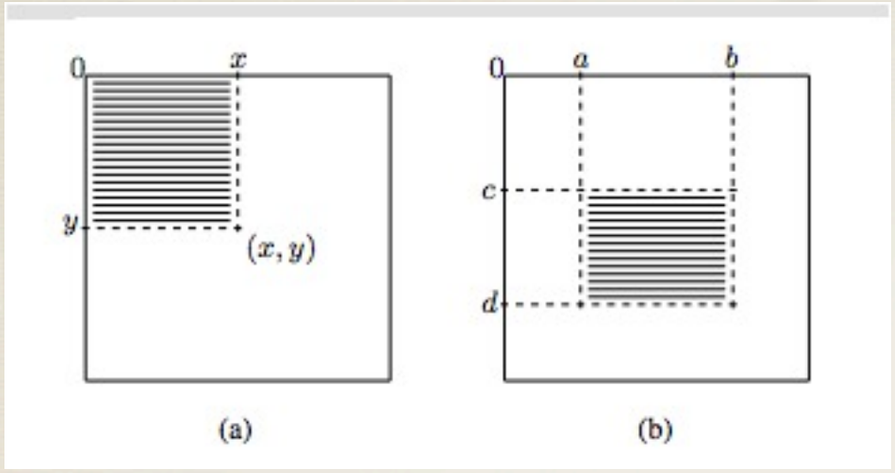


* Manual module development complete
* Stereo Environment for 3-D point measurement
* Intuitive GUI for non-photogrammetric users

Automatic Image Matching module

- Integral Images used for computational efficiency
- Automatic Interest Point detection using KLT corner detector
- Image matching using Normalized mean cross-correlation
- Relative image orientation using RANSAC based 8-point algorithm

Integral Images

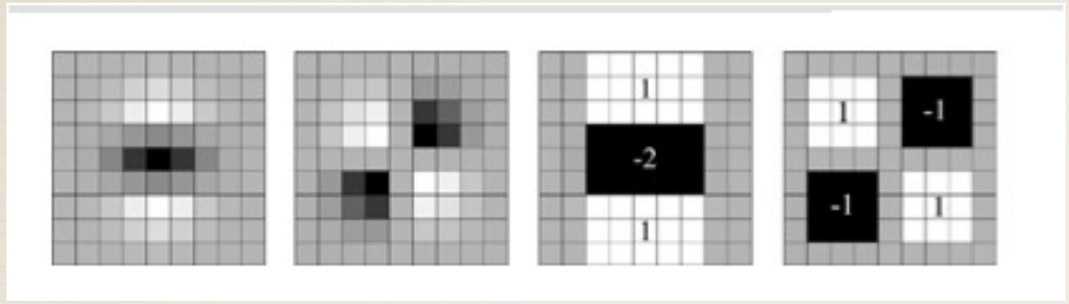


$$I(x,y) = \sum_{x' \le x, y' \le y} f(x,y).$$

Source:[2]

* I(x,y) corresponds to the sum of all column and row pixels from origin to (x,y)
* Rectangular window pixel sums computed with four arithmetic operations
* Image gradient computation time reduced

Box Filter Approximations



a b c d

Source:[3]

* The gaussian second order partial derivative in y and xy direction (a & b)
* Approximations for the second order Gaussian partial derivative in y and xy direction.

KLT Corner Detector

- Compute Image gradients for all Image pixels
- Gradients computed over variable window sizes using box-filter approximations
- Box filter output are termed as Dxx, Dyy, Dxy
- Compute eigen values(e1,e2) for a matrix constructed using Box-filter output
- The smaller eigen value is subjected to a threshold and sorted in descending order

KLT Corner Detector

- The Integral images used to generate gradient data over 3 different scale-space
- The computed eigen values over different scale-space compared to find local maxima
- Generated Interest Points sorted in terms of cornerness
- Points within close distance and less cornerness measure removed

Interest Point Detection

Image Correspondence

$$c(u,v) = \frac{\sum (u_i - \bar{u}) \times (v_i - \bar{v})}{\left[\sum (u_i - \bar{u})^2 \times \sum (v_i - \bar{v})^2\right]^{\frac{1}{2}}}$$

- where c is cross-correlation
- u, ū and v, $\bar{v}$; pixel data of template window and right image
- All matches above a threshold used for RANSAC

8-Point algorithm using RANSAC

* Randomly selected matched point pairs used for computing Essential Matrix (E)
* $[u\ v\ 1]^1 \cdot E \cdot \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}_2$, where $u = \frac{(x\text{-}xo)}{-fo}$ $v = \frac{(y\text{-}yo)}{-fo}$

* Iterated N times to determine E with most inliers
* $$N = \frac{log(1\text{-}p)}{log\left(1\text{-}(1\text{-}e)^s\right)}$$ *where, e=probability of outlier p=desired probability of output s=sample population*

8-Point algorithm using RANSAC

- The E with most number of inliers selected for 8-point algorithm
- Rotation matrix using Singular Value Decomposition of E (LAPACK is available in iOS)
- Relative orientation determined by coplanarity and scale restraint condition

Check Distances

Actual	Measure1 (cm)	Measure2 (cm)	Measure3 (cm)	Error1 (in cm)	Error2 (in cm)	Error2 (in cm)	Avg Diff (in cm)	Pix Diff
91.3	91.2	90.072	91.3	-0.1	-1.228	0	-0.4427	-2.951
39.0	38.89	38.917	38.95	-0.11	-0.083	-0.05	-0.0810	-0.5400
51.2	51.189	51.365	51.3	-0.011	0.165	0.1	0.08467	0.5644
64.0	63.9	63.871	64.233	-0.1	-0.129	0.233	0.0013	0.0089
43.0	42.873	43.114	42.97	-0.127	0.114	-0.03	-0.0143	-0.0956
87.8	86.651	88.072	87.779	-1.149	0.272	-0.021	-0.2993	-1.9956
63.4	62.833	63.245	62.64	-0.567	-0.155	-0.76	-0.4940	-3.2933
153.2	152.767	153.012	152.881	-0.433	-0.188	-0.319	-0.3133	-2.0889

* AVerage error:-1.039 pixels
* RMS Error: 0.667 pixels

Further Development

- Decreasing image processing time by using iPhone GPU
- Mobile users expect output in a few seconds
- Generate 3D texture model using image mapping
- Support for device screens that can support polarization (no need 3D anaglyph glasses)

Citations

* 1. Ph.D thesis, Purdue University, in progress, of Jae Sung Kim 2013

* 2. P. Arias[a], C. Ordóñez 2007

* 3. APPROXIMATING IMAGE FILTERS WITH BOX FILTERS(Bernardo Rodrigues Pires, Karanhaar Singh and Jose M. F. Moura)

* 4. Speeded-Up Robust Features (SURF)Herbert Bay [a], Andreas Ess [a,*], Tinne Tuytelaars [b], Luc Van Gool [a,b]