Mobile Biometrics:
Iris, Fingerprint, Palmprint Recognition

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Jaihie Kim
Yonsei University
http://cherup.yonsei.ac.kr
Outlines

1. Mobile Biometrics
2. Mobile Iris Recognition
3. Mobile Fingerprint Recognition
4. Mobile Palmprint Recognition
4. Concluding Remarks
Why Mobile Biometrics?

- Needing a handheld or movable identifying solution
  - Police patrol, military, border security, public safety and justice, etc.
  - Ex. Police inspection on a car driver sitting in a car.

- More recently, smart phones have built-in biometric solutions.
  - For unlocking the phone instead of a password or a pattern
  - For phone-payment, etc.
HIDE (Morpho)*

For identifying others

Iris  (640*480 VGA monochrome)
Face (640*480 VGA color)
Fingerprint (500 dpi)

*http://www.l1id.com
EasyRead Handheld Biometric Reader
FROM DATASTRIP INC.

http://www.datastrip.com/index.html
Biometric Engineering Research Center - MMS 2.0

Operating range: 14 ~ 21 cm/iris, 25 ~ 95 cm/face
Processing time: less than 1 sec
Accuracy: EER of 0.44%/iris, 10.61%/face
Size: 15(W) × 10(H) × 8.3(D) cm³
Weight: 700 g
Maximum Enrollments: 3,200,000 persons
CPU: Intel 1.2 GHz
4.5” LCD Display
Expected Price: $2,000 (Others: $4,000 ~ $6,000)
AOptix Stratus Biometric Scanner*

- Multimodal Biometric Scanner
  - Face
  - Iris
  - Fingerprint
  - Voice

- iPhone Add-on: 2014: $199

(*http://www.aoptix.com/)
Those are for identifying others used by trained persons.

Unit price and accuracy are more important than user convenience.
They are not so successful!

No killer application for them.
Biometrics For Phone Unlocking

Unlocking the phone -> Killer application

Since 2014

iPhone 5S: Touch ID
www.apple.com/kr

Galaxy S5
http://www.samsung.com/sec/

Pantech Vega: Secrete Note
http://www.pantech.co.kr/
List of All Fingerprint Scanner Enabled Smartphones: Now

- Galaxy Note 5 and Galaxy S6 Edge Plus
- OnePlus 2
- HTC One M9+
- Elephone P7000 (exceptional high-end affordable phone)
- Motorola Atrix
- Apple iPhone 5S, iPhone 6 and 6 Plus
- HTC One Max
- Samsung Galaxy S5
- Samsung Galaxy Note 4 and Note Edge
- Galaxy S6
- Huawei Ascend Mate 7
- Xolo Q2100
- Meizu MX4 Pro
- Oppo N3

For phone unlocking, user convenience is more important than price or accuracy.
What will be the next killer application for mobile fingerprint recognition?
What will be the next killer application for mobile fingerprint recognition?

Mobile E-payment,
Which requires accuracy more than user convenience.
Keeping these backgrounds,

Points of my experiences in implementing mobile biometrics,

- With user’s cooperation for operating the mobile biometrics, system becomes easier to implement and more practical.
  - Ex. Guide interfaces
- Fast processing is needed for user convenience, but it also contributes to higher accuracy by performing multiple matches
- For usage like phone-payment other than unlocking the phone, high accuracy is more important than the user convenience.
Mobile Iris Recognition
Old model: Mobile Iris for Identifying Others

- Mobile iris scanner; XVISTA

http://www.xvista.co.uk
PIER (Portable Iris Enrollment and Recognition) handheld camera from Securimetrics, specializing in military and police deployments.  [http://www.securimetrics.com/](http://www.securimetrics.com/)

Operating range : 4” ~ 6”
operating time : 15 frame/sec
Dimensions : 8.9(W)×15.3(H)×4.6(D) cm³
weight : 0.468 Kg
Max. # of users : 200,000~400,000 subjects
System speed : 1.33 MHz, X86
Display : 240 by 320 LCD touch screen
Mobile Iris Rec. for Phone Unlocking

Easy/fast user interface is the first choice for phone unlocking

- **OKI mobile iris scanner: 2007**

  - Basic feature: Generate/Compare iris data, Encrypt iris data
  - Processing time: Authenticate in less than 0.5 seconds after capture
  - Authentication accuracy: FAR<1/100,000 (Tested on a 2Mpixel mobile phone camera)
Our Mobile Iris Recognition

Extra NIR LEDs  Extra Iris Camera

<Difficulty for mobile iris recognition>

*Small space for Iris LEDs and Iris Camera in addition to the built-in camera.
Iris Images

By Normal Mobile Phone Camera

Phone Camera with flash-on

With NIR (750~850 nm) LEDs.
Our Mobile Iris Recognition

Extra NIR LEDs  Extra Iris Camera

<Issues for mobile iris recognition>

* Locations for NIR LEDs (750~850 nm) and iris camera
* Location for guide window showing user’s iris image
* Operating distance between the phone and user’s eye
Guide Window

- The window guide shows the input user’s eye images in real time.
- The window guide has an eye shape template where the user fits his eye on it.
- The system captures a good iris image *automatically* among the input image stream in real time.
Location of Window Guide

Iris Camera & LEDs are placed at the top

Guide should be at upper part.

Shade and occlusion by eyelid and eyebrow
Positions for Iris Camera, LEDs

- To avoid Red-eye effect or glint on glass,
  - Camera and LEDs should be separated more than 5 degrees.
- Too far from each other makes a shadow at one side of an eye.

LEDs too close to camera

NIR LEDs  Iris Camera

LEDs far from camera
Shadow on eye
(a) four 750nm LEDs, good for iris boundary detection but too dark
(b) two 750nm LEDs and one 850nm LED, still dark
(c) **two 850nm LEDs, good for bright iris image but less clear**
**iris boundary**
Operating distance

Choice for Hot Spot:
- User convenience to see the window guide,
- LED power
- Iris image size in pixel
- Camera focal distance

<table>
<thead>
<tr>
<th>Operating Distance (cm)</th>
<th>Iris size in pixel</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>236</td>
</tr>
<tr>
<td>16</td>
<td>225</td>
</tr>
<tr>
<td>17</td>
<td>210</td>
</tr>
<tr>
<td>18</td>
<td>197</td>
</tr>
<tr>
<td>19</td>
<td>188</td>
</tr>
<tr>
<td>20</td>
<td>179</td>
</tr>
<tr>
<td>21</td>
<td>167</td>
</tr>
<tr>
<td>22</td>
<td>161</td>
</tr>
<tr>
<td>23</td>
<td>154</td>
</tr>
<tr>
<td>24</td>
<td>147</td>
</tr>
<tr>
<td>25</td>
<td>143</td>
</tr>
</tbody>
</table>

Hot spot 20-25 cm
Performance Example*

GAR = 100 - False Reject Ratio = True Accept Ratio

ROC Curve

<table>
<thead>
<tr>
<th>Enrollment</th>
<th>Valid code size</th>
<th>&gt; 1150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recognition</td>
<td>Valid code size</td>
<td>&gt; 850</td>
</tr>
<tr>
<td>EER (%)</td>
<td></td>
<td>0.5105</td>
</tr>
<tr>
<td>FAR vs GAR (%)</td>
<td>0.0427 : 98.5078</td>
<td>0.1399 : 98.9440</td>
</tr>
<tr>
<td></td>
<td>~0 : &lt; 97.0</td>
<td></td>
</tr>
<tr>
<td>FTA Rate (%)</td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td>FTE Rate (%)</td>
<td></td>
<td>2.1</td>
</tr>
</tbody>
</table>

(*2013, BERC & Samsung)
Why still not appeared in a smart phone?
Why still not appeared in a smart phone?
- To use it so many times whenever unlock the phone, it is not convenient enough.
- However, for phone-payment, it is usable.
- May appeared in a larger size Phone or Tablet PC, first.
Iris Rec. in a wearable (future appear*)

IRIS RECOGNITION ENABLED SMARTWATCH FOR PERSONAL SECURITY & DATA CONTROL

*http://www.fidelyswatch.com/#!about/cjg9

ADVANTAGES OF IRIS BIOMETRICS TECHNOLOGY

- Fast: The capture and verification process takes less than 2 seconds.
- Stable: The iris pattern is formed after 8 months of age and remains essentially unchanged throughout one's lifetime.
- Unique: The probability of having an identical iris is one-in-2 trillion individuals.
- Flexible: Easily integrates into existing security systems or operates as a standalone system.
- Secure: Has low false acceptance rate and an iris image cannot be replicated or forged.

FiDELYS AT FIRST GLANCE
Mobile Fingerprint Recognition
Mobile Fingerprint Recognition: For Phone Unlocking

iPhone 5S: Touch ID
www.apple.com/kr
2013.9

Galaxy S5
http://www.samsung.com/sec/
2014.2

Pantech Vega: Secrete Note
http://www.pantech.co.kr/
2013.8
Sensor at side power button: Sony Xperia Z5 (IFA 2015)

Sensor at front touch glass: To be appeared by Crucialtec (MWC 2015)
Sensor size vs # of minutiae

- **Optical sensor**: 40
- **Solid sensor1**: 35
- **Solid sensor2**: 20
- **Samsung S6**: 8
- **Apple**: 5

# of minutiae from thumb finger (estimated)

- **Solid sensor1**: (13mm×13mm)
- **Solid sensor2**: (9.6mm×9.6mm)
- **Optical sensor**: 14.2mm×16mm
- **Samsung, S6**: 10mm×4mm
- **Apple**: 4.5mm×4.5mm
### Sensor Size vs Recognition Accuracy

<table>
<thead>
<tr>
<th>Sensor Size in Pixels</th>
<th>192x192 (100.0%)</th>
<th>176x176 (84.0%)</th>
<th>160x160 (69.4%)</th>
<th>144x144 (56.3%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor size in mm²</td>
<td>9.6 x 9.6 = 92</td>
<td>8.8 x 8.8 = 77</td>
<td>8.0 x 8.0 = 64</td>
<td>7.2 x 7.2 = 51</td>
</tr>
<tr>
<td>Accuracy in EER (%)</td>
<td>1.75%</td>
<td>3.91%</td>
<td>8.69%</td>
<td>15.34%</td>
</tr>
</tbody>
</table>
Features in addition to minutia

- Pores in a high 1000 resolution image

<types of proposed micro ridge features>

Micro-features: BERG
## Performance of BERC Methods

### FVC 2002 DB 1

<table>
<thead>
<tr>
<th></th>
<th>90%</th>
<th>70%</th>
<th>50%</th>
<th>40%</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image Size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(W x H) pixel</td>
<td>231.9 x 324.2</td>
<td>193.7 x 286.0</td>
<td>157.0 x 249.4</td>
<td>136.8 x 229.1</td>
<td>114.1 x 206.4</td>
</tr>
<tr>
<td>Sensor Size</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(W x H) mm</td>
<td>11.8 x 16.5</td>
<td>9.8 x 14.5</td>
<td>8.0 x 12.7</td>
<td>7.0 x 11.6</td>
<td>5.8 x 10.5</td>
</tr>
<tr>
<td>Minutiae-based</td>
<td>0.00</td>
<td>0.07</td>
<td>3.01</td>
<td>5.94</td>
<td>11.99</td>
</tr>
<tr>
<td>HoG-based</td>
<td>1.82</td>
<td>2.00</td>
<td>2.95</td>
<td>3.97</td>
<td>15.07</td>
</tr>
<tr>
<td>Proposed method</td>
<td>0.00</td>
<td>0.03</td>
<td>0.98</td>
<td>2.97</td>
<td>5.99</td>
</tr>
</tbody>
</table>
Smart Enrollment

Use of partial and fused fingerprint images

Fusion of fingerprint images
By rubbing
<table>
<thead>
<tr>
<th>Sensor Size (mm)</th>
<th>5 Images</th>
<th>10 Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2 x 7.2 (56.3%)</td>
<td>18.59%</td>
<td>15.34%</td>
</tr>
<tr>
<td>8.0 x 8.0 (69.4%)</td>
<td>12.17%</td>
<td>8.69%</td>
</tr>
<tr>
<td>8.8 x 8.8 (84.0%)</td>
<td>7.04%</td>
<td>3.91%</td>
</tr>
<tr>
<td>9.6 x 9.6 (100.0%)</td>
<td>4.48%</td>
<td>1.75%</td>
</tr>
</tbody>
</table>
Mobile Touchless Fingerprint Recognition

Using Built-in Camera

www.yonsei.ac.kr
Recent Examples

<table>
<thead>
<tr>
<th></th>
<th>Samsung Galaxy S5</th>
<th>LG G Pro 2</th>
<th>Apple I-phone 5S</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resolution</strong></td>
<td>16 M (5312 x 2988)</td>
<td>13 M (4160 x 3120)</td>
<td>8 M (2448 x 3264)</td>
</tr>
<tr>
<td><strong>Depth of Field</strong></td>
<td>Very good</td>
<td>Very good</td>
<td>Not so good</td>
</tr>
<tr>
<td>In the macro mode</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Easiness of image capture)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BERC: Window Guide

- Guide window for three fingerprints
- Easy/fast detection and segmentation for foreground finger image

2013 with Samsung DMC
Image Capturing for Touchless Fingerprint Recognition

Mobile Fingerprint Recognition

Shape of the guide window
Line Profile Checks on Window Guide

To check a finger image is in the guide
To check three fingers are in the guide

Fingerprint segmentation

Fitting check for input finger images
Performance example*

Indoor condition, 5 image enrollment, S3/4 with 2 M pixel auto-selection
(fusion of first and second fingerprints)

<table>
<thead>
<tr>
<th>FAR</th>
<th>10%</th>
<th>1%</th>
<th>0.7%(EER)</th>
<th>0.1%</th>
<th>0.01%</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAR (FRR)</td>
<td>99.78% (0.22%)</td>
<td>99.35% (0.65%)</td>
<td>99.3% (0.7%)</td>
<td>98.9% (1.1%)</td>
<td>98.4% (1.6%)</td>
</tr>
</tbody>
</table>
## Accuracy Change with Multiple Matches

<table>
<thead>
<tr>
<th># of Matches</th>
<th>1:1</th>
<th>1:2</th>
<th>1:3</th>
<th>1:4</th>
<th>1:5</th>
</tr>
</thead>
<tbody>
<tr>
<td>EER</td>
<td>1.1%</td>
<td>0.6%</td>
<td>0.4%</td>
<td>0.24%</td>
<td>0.19%</td>
</tr>
</tbody>
</table>

Decide Yes for at least one Yes among N matches.
Touchless Mobile Palmprint recognition*


Image Capturing with a Guide
Image Capturing for Palmprint Recognition

Mobile Palmprint Recognition

Shape of the guide window
Use of Guide Window

- Easy to check if the hand is fitting to the guide.
  - Simple line profile check for skin-background-skin
  - No need of foreground hand image segmentation
- Simple line check for valley point detection
ROI Detection by Valley points

Locating ROI from Valley Points

All these processes are done simply and quickly due to the use of Window Guide.
**Verification performance (in EER)**


<table>
<thead>
<tr>
<th>DATABASE</th>
<th>COMP CODE</th>
<th>OLOF</th>
<th>BOCV</th>
<th>FCM</th>
<th>PROPOSED METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>PolyU DB</td>
<td>0.09%</td>
<td>0.13%</td>
<td>0.15%</td>
<td>0.09%</td>
<td>0.11%</td>
</tr>
<tr>
<td>BERC DB1</td>
<td>6.14%</td>
<td>5.14%</td>
<td>6.35%</td>
<td>5.48%</td>
<td>2.88%</td>
</tr>
<tr>
<td>BERC DB2</td>
<td>5.87%</td>
<td>5.33%</td>
<td>7.64%</td>
<td>7.10%</td>
<td>3.15%</td>
</tr>
<tr>
<td>IITD DB</td>
<td>6.33%</td>
<td>5.26%</td>
<td>5.69%</td>
<td>5.67%</td>
<td>5.19%</td>
</tr>
</tbody>
</table>
Performance by N Matches

(*2013. 11. 15, BERC DB1)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>EER</th>
</tr>
</thead>
<tbody>
<tr>
<td>One time match</td>
<td>2.88%</td>
</tr>
<tr>
<td>Five time matches</td>
<td>0.97%</td>
</tr>
</tbody>
</table>

Performance Improvement by Multiple Matches
Concluding Remarks

- With a little user’s cooperation for operation, system becomes easier to implement and can be more practical.
  - Ex. Guide on interface screen

- Fast processing or multiple matches contribute to improve the accuracy.

- For usages other than unlocking the phone, high accuracy are more important and it will compensate the less convenient user interface.
Thank You!
夜雪

踏雪夜中去
不须胡乱行
今日我行迹
遂作后人程

*西山大师  1520~1604
夜雪*

踏雪夜中去
不須胡亂行
今日我行蹟
遂作後人程

*西山大師 1520~1604
Implementational issues in mobile biometrics:

- User convenience: for users of all ages, cultures, races, educations
- Data Acquisition: focus, DoF, pose, illumination, blurring
- Various Environments: indoor/outdoor, temperature
- Processing time: limit of processing power
- Recognition Performance
Empirical Issues:
  - Use of mobile biometrics
  - Use of guide window
  - Use of FTA and sequence images

Pattern Recognition for Mobile Biometrics
  - Features and pattern matching

Biometrics Modules for Mobile Applications
  - For 3rd party applications
  - Standard issues

Secure Biometrics for Mobile
  - Spoof detection
Multimodal Mobile Biometrics

(*http://www.bi2technologies.com)

- Multimodal Biometric Scanner by smart phone add-on
  - Face
  - Iris
  - Fingerprint

Phone Add-on $3000
모바일 지문 인식 성능

2차 품질 평가에 따른 인식률/FTA 변화

<table>
<thead>
<tr>
<th>2차 품질평가 (good quality ratio)</th>
<th>30% 이상</th>
<th>25%</th>
<th>20%</th>
<th>15%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>EER</td>
<td>0.20%</td>
<td>0.24%</td>
<td>0.54%</td>
<td>0.7%</td>
<td>0.9%</td>
</tr>
<tr>
<td>FTA 사전 제거된 영상</td>
<td>9.9% (941/9526)</td>
<td>6.9% (657/9526)</td>
<td>4.1% (391/9526)</td>
<td>1.6% (152/9526)</td>
<td>0.6% (52/9526)</td>
</tr>
</tbody>
</table>

매칭 영상수에 따른 인식률 변화

<table>
<thead>
<tr>
<th>Sequence images</th>
<th>1:1</th>
<th>1:2</th>
<th>1:3</th>
<th>1:4</th>
<th>1:5</th>
</tr>
</thead>
<tbody>
<tr>
<td>사용 subjects (Test 영상 수)</td>
<td>117 subjects (8232 장)</td>
<td>116 subjects (8176 장)</td>
<td>116 subjects (8124 장)</td>
<td>116 subjects (8044 장)</td>
<td>116 subjects (7980 장)</td>
</tr>
<tr>
<td>EER</td>
<td>1.1%</td>
<td>0.6%</td>
<td>0.4%</td>
<td>0.24%</td>
<td>0.19%</td>
</tr>
</tbody>
</table>

2차 품질 평가 FTA: 4.8% (405/8364)
Other Guides

Fitting by hand outline

- Dimitri Raftopoulos
- Duolabs

Fitting by valley points

- Zhou Chang
- K.K. AMUZENET
- KDDI

www.yonsei.ac.kr
## Performance of BERC Methods

<table>
<thead>
<tr>
<th>FVC 2002 DB 1</th>
<th>100%</th>
<th>90%</th>
<th>70%</th>
<th>50%</th>
<th>40%</th>
<th>30%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Image Size (W x H) pixel</strong></td>
<td>261.8 x 354.2</td>
<td>231.9 x 324.2</td>
<td>193.7 x 286.0</td>
<td>157.0 x 249.4</td>
<td>136.8 x 229.1</td>
<td>114.1 x 206.4</td>
<td>87.6 x 180.0</td>
</tr>
<tr>
<td><strong>Sensor Size (W x H) mm</strong></td>
<td>13.3 x 18.0</td>
<td>11.8 x 16.5</td>
<td>9.8 x 14.5</td>
<td>8.0 x 12.7</td>
<td>7.0 x 11.6</td>
<td>5.8 x 10.5</td>
<td>4.5 x 9.1</td>
</tr>
<tr>
<td><strong>Avg. # of minutiae</strong></td>
<td>38.5</td>
<td>37.0</td>
<td>29.5</td>
<td>21.5</td>
<td>17.2</td>
<td>12.7</td>
<td>8.1</td>
</tr>
<tr>
<td><strong>EER (%)</strong></td>
<td>Minutiae-based matching</td>
<td>0.00</td>
<td>0.07</td>
<td>3.01</td>
<td>5.94</td>
<td>11.99</td>
<td>20.99</td>
</tr>
<tr>
<td></td>
<td>Proposed method</td>
<td>0.00</td>
<td>0.03</td>
<td>1.01</td>
<td>3.02</td>
<td>8.01</td>
<td>17.01</td>
</tr>
</tbody>
</table>
### Performance of BERC Methods

<table>
<thead>
<tr>
<th>FVC 2002 DB 1</th>
<th>90%</th>
<th>70%</th>
<th>50%</th>
<th>40%</th>
<th>30%</th>
<th>20%</th>
</tr>
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<tr>
<td><strong>Image Size</strong></td>
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<td></td>
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</tr>
<tr>
<td><strong>Sensor Size</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(W x H) mm</td>
<td>11.8 x 16.5</td>
<td>9.8 x 14.5</td>
<td>8.0 x 12.7</td>
<td>7.0 x 11.6</td>
<td>5.8 x 10.5</td>
<td>4.5 x 9.1</td>
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<tr>
<td><strong>Minutiae-based</strong></td>
<td>0.00</td>
<td>0.07</td>
<td>3.01</td>
<td>5.94</td>
<td>11.99</td>
<td>20.99</td>
</tr>
<tr>
<td><strong>HoG-based</strong></td>
<td>1.82</td>
<td>2.00</td>
<td>2.95</td>
<td>3.97</td>
<td>15.07</td>
<td>31.74</td>
</tr>
<tr>
<td><strong>Proposed method</strong></td>
<td>0.00</td>
<td>0.03</td>
<td>0.98</td>
<td>2.97</td>
<td>5.99</td>
<td>14.95</td>
</tr>
</tbody>
</table>
Unlocking the phone becomes a killer application for mobile fingerprint recognition.
‘Depth of Field’ in the macro mode of the mobile camera is crucial for clear fingerprint image!
Performance1*


Verification performance (in EER)

<table>
<thead>
<tr>
<th>DATABASE</th>
<th>COMPNAME</th>
<th>OLOF</th>
<th>BOCV</th>
<th>FCM</th>
<th>PROPOSED METHOD</th>
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</thead>
<tbody>
<tr>
<td>PolyU DB</td>
<td>0.09%</td>
<td>0.13%</td>
<td>0.15%</td>
<td>0.09%</td>
<td>0.11%</td>
</tr>
<tr>
<td>BERC DB1</td>
<td>6.14%</td>
<td>5.14%</td>
<td>6.35%</td>
<td>5.48%</td>
<td>2.88%</td>
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<tr>
<td>BERC DB2</td>
<td>5.87%</td>
<td>5.98%</td>
<td>7.64%</td>
<td>7.10%</td>
<td>3.15%</td>
</tr>
<tr>
<td>IITD DB</td>
<td>6.33%</td>
<td>5.26%</td>
<td>5.69%</td>
<td>5.67%</td>
<td>5.19%</td>
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</tbody>
</table>

**TABLE 1. Processing Times**

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>PROCESSING TIME ON A PC (MILLISECONDS)</th>
<th>ESTIMATED PROCESSING TIME ON A MOBILE PHONE (MILLISECONDS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast Image Acquisition</td>
<td>0.47</td>
<td>8.13</td>
</tr>
<tr>
<td>Valley Point Detection / Valley Point Verifier</td>
<td>1.36</td>
<td>23.12</td>
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<tr>
<td>ROI Extraction</td>
<td>11.03</td>
<td>187.51</td>
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<tr>
<td>Feature Extraction</td>
<td>27.45</td>
<td>466.65</td>
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</tbody>
</table>