Developer Toolkit and Utilities for Rapidly Prototyping Distributed

Physical User Interfaces

Nicolai Marquardt
Diploma Thesis Defence
May 2008

Cooperative Media Lab - Bauhaus-University Weimar
GroupLab - University of Calgary
The *Shared Phidgets* toolkit supports developers when building rapid prototypes of distributed physical user interfaces.
Outline

Introduction and Related Work
Requirements and Concept
Implementation
Case Studies, Evaluation, Future Work
“Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives.”

Mark Weiser, Xerox PARC
“Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives.”

“[…] its highest ideal is to make a computer so embedded, so fitting, so natural, that we use it without even thinking about it.”

Mark Weiser, Xerox PARC
Tangible and Physical Interfaces

Typical Graphical User Interfaces
Desktop Computer

Physical and Tangible User Interfaces
World will be Interface

Distributed Physical User Interfaces
Collaborative Interaction

Hiroshi Ishii,
Tangible Media Group, MIT
Definitions

- Physical and tangible user interfaces
- Information appliances vs. personal (mobile) devices
- Rapid prototyping and development cycle
- Developer support vs. end-user programming
Previous Research Projects

Tangible Bits
[Ishii and Ullmer, 2001]

HomeNote
[Sellen et al., 2006]

ActiveHydra
[Greenberg and Kuzuoka, 2000]

mediaBLOCKS
[Ullmer and Ishii, 1997]

Digital Family Portrait
[Mynatt and Rowan, 2001]

[Consolvo et al., 2004]

ambientROOM
[Ishii and Ullmer, 2001]

Gate Reminder
[Kim et al., 2004]

StickySpots
[Elliot et al., 2007]

Marble Answering Machine
by Durell Bishop
[Crampton Smith, 1995]

LumiTouch
[Chang et al., 2001]

Pad Prototype
[Weiser, 1996]

LiveWire
[Weiser and Brown, 1996]
Motivation

- Difficult to integrate physical hardware and build network
- Usually only local connected information appliances
- Single prototypes vs. iterative design cycle
### Related Work: Toolkits

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilitate extensions and integration of custom hardware (e.g., plug-in based)</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Software proxy objects for hardware components (e.g., Javascript, MVT)</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Seamless integration into development tools (e.g., infrastructure inspection as iUi plug-in)</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Event visualizations (e.g., network)</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
<tr>
<td>Testing and debugging support (e.g., Walk of Code simulations, test cases)</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
<td>![ ]</td>
</tr>
</tbody>
</table>

### Common Characteristics:
- Hardware integration
- Object-oriented programming

### Drawbacks:
- Partially only for local hardware, and not specifically designed for distributed architectures
- Expert knowledge needed
- High-level assemblies
1. Hide hardware implementation and provide shared access
2. Address *low threshold* and *high ceiling* [Myers et al., 2000]
3. Provide utilities for exploration and control
4. Support testing and debugging of distributed hardware and information appliances
5. Build extensible architecture
Building Prototypes

Physical Hardware

Implemented Software

Information Appliance Prototype

Nicolai Marquardt – Diploma Thesis Defence  Bauhaus-University Weimar, Cooperative Media Lab
Shared Phidgets Toolkit

Runtime Platform

Developer Support

Utilities
Architecture Overview

Nicolai Marquardt – Diploma Thesis Defence
Bauhaus-University Weimar, Cooperative Media Lab
Runtime Platform

Runtime Platform

Developer Support

Utilities
Physical Components

**INPUT**

- **SENSORS**
  - Pressure
  - Force
  - Vibration
  - Temperature
  - Light
  - Distance
  - Motion

**USER CONTROLS**

- Switches
- RFID Reader and Tags
- Accelerometer
- Slider Control

**OUTPUT**

- **ACTUATORS**
  - Motors
  - Servos

- **DISPLAYS**
  - Colour Graphic LC Display
  - Text LC Display

[Greenberg and Fitchett, 2001]
[Phidgets Inc., 2008]
Physical Components

**INPUT**

**SENSORS**
- Pressure
- Force
- Vibration
- Temperature
- Light
- Distance
- Motion

**USER CONTROLS**
- Switches
- RFID Reader and Tags
- Accelerometer
- Slider Control

**OUTPUT**

**ACTUATORS**
- Motors
- Servos

**DISPLAYS**
- Colour Graphic LC Display
- Text LC Display

[Greenberg and Fitchett, 2001]
[Phidgets Inc., 2008]
Physical Components

<table>
<thead>
<tr>
<th>INPUT</th>
<th>SENSAORS</th>
<th>USER CONTROLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Force</td>
<td>Switches</td>
</tr>
<tr>
<td>Temperature</td>
<td>Light</td>
<td>RFID Reader and Tags</td>
</tr>
<tr>
<td>Distance</td>
<td>Motion</td>
<td>Accelerometer</td>
</tr>
<tr>
<td>OUTPUT</td>
<td>ACTUATORS</td>
<td>Slider Control</td>
</tr>
<tr>
<td>Motors</td>
<td>Servos</td>
<td>Colour Graphic LC Display</td>
</tr>
</tbody>
</table>

[Greenberg and Fitchett, 2001]
[Phidgets Inc., 2008]
Physical Components

**INPUT**

**SENSORS**
- Pressure
- Force
- Vibration
- Temperature
- Light
- Distance
- Motion

**USER CONTROLS**
- Switches
- RFID Reader and Tags
- Accelerometer
- Slider Control

**OUTPUT**

**ACTUATORS**
- Motors
- Servos

**DISPLAYS**
- Colour Graphic LC Display
- Text LC Display

References:
- Greenberg and Fitchett, 2001
- Phidgets Inc., 2008
Data Model

Concept

[Boyle and Greenberg, 2005]
Hardware Data Model

\sharedphidgets

\servo\418

\version 2.00
\attached true
\attacheddate 3/28/2006 9:39:41 PM

\servoposition0 90
\setservoposition0 90
\motorcount 1

\metadata\location Home Hallway
\metadata\owner Chris
\metadata\ip 136.159.7.123
\metadata\keywords appliance private static
[...]
\metadata\geolocation [Longitude:55.328462...]
\metadata\appliance HomeAwarenessAppliance
\metadata\rfidtag 12ff81864c
Path expressions to access the hardware data model directly:

```plaintext
/sharedphidgets/servo/*/setservoposition/*/ 
/sharedphidgets/*/sensor/0/ 
/sharedphidgets/*/metadata/geolocation/
```
Path expressions to access the hardware data model directly:

```
/sharedphidgets/servo/*/setservoposition/*
/sharedphidgets/*/*/sensor/0/
/sharedphidgets/*/*/metadata/geolocation/
```

Appliance data model:

```
/appliance/<guid>/applianceName = Sticky Spots
/appliance/<guid>/timestamp = 20/10/2007 04:56:45
/appliance/<guid>/ip = 192.168.178.20

/appliance/<guid>/components/<cid>/type = rfid
/appliance/<guid>/components/<cid>/serial = 2967
/appliance/<guid>/components/<cid>/externalSerial = 2967
/appliance/<guid>/components/<cid>/path = /sharedphidgets/rfid/2967/
/appliance/<guid>/components/<cid>/timestamp = 20/10/2007 05:22:07
```

```
/appliance/<guid>/processing/<subpath1> = 42
/appliance/<guid>/processing/<subpath2> = True
```
Developer Support

Runtime Platform

Developer Support

Utilities
Development Support

Concept

- **Development using the Shared Phidgets .NET Library**
  - **Development with Direct Access to the Shared Data Model**
    - Efficient and powerful access
    - Advanced knowledge about the hardware and the shared data model necessary

- **Application Development with Hardware Proxy Objects**
  - Communication with physical devices through simplified programming interfaces

- **Hardware Proxy Objects and Interface Stimuli**
  - Real-time interaction with hardware

**Shared Data Space**

- **Connector and Plug-Ins**
  - Plug-In A
  - Plug-In B

**Hardware**
Development Support

Concept

Development using the Shared Phidgets .NET Library

Development with Direct Access to the Shared Data Model
- Efficient and powerful access
- Advanced knowledge about the hardware and the shared data model necessary

Application Development with Hardware Proxy Objects
- Encapsulated API: properties, events, methods
- Individual implementation for each hardware type

Hardware Proxy Objects and Interface Skins
- Debugging and testing
- Exploration, for beginners

Shared Data Space

Hardware

Connector and Plug-Ins

Plug-In A

Plug-In B
Development Support

Development using the Shared Phidgets .NET Library

- Development with Direct Access to the Shared Data Model
  - Efficient and powerful access
  - Advanced knowledge about the hardware and the shared data model necessary

- Application Development with Hardware Proxy Objects
  - Encapsulated API: properties, events, methods
  - Individual implementation for each hardware type

Shared Data Space

Event Subscriptions

Hardware Proxy Objects

Hardware Proxy Objects and Interface Skins

- Debugging and testing
- Exploration, for beginners

Plug-in A

Plug-in B

Hardware and Plug-Ins

Concept
Development Support

Concept

Development using the Shared Phidgets .NET Library

Development with Direct Access to the Shared Data Model
- Efficient and powerful access
- Advanced knowledge about the hardware and the shared data model necessary

Application Development with Hardware Proxy Objects
- Encapsulated API: properties, events, methods
- Individual implementation for each hardware type

Hardware Proxy Objects and Interface Skins
- Debugging and testing
- Exploration, for beginners

Shared Data Space

Hardware

Connector and Plug-Ins
Plug-in A
Plug-in B
Interface Skins

Concept
Interface Skins

Concept
Utilities

Runtime Platform

Developer Support

Utilities
Utilities

Appliance Level
- Observe appliances
- Reconfigure (change hardware connections)
- View processing events

Hardware Level
- View current hardware status
- Initialise hardware
- Explore hardware capabilities

Network Level
- Review hardware data model and events
- View and change metadata

Shared Data Space (Network)
- Hardware Model A
- Hardware Model B
- Hardware Model C
- Hardware Model D

Appliance 1
- Hardware Proxy A (API)

Appliance 2
- Hardware Proxy B (API)
- Hardware Proxy C (API)
Simulations

Concept

Simulated Hardware D
Simulated Hardware C

Wizard of Oz Controls

Appliance 1
Appliance 2

Hardware Proxy A (API)
Hardware Proxy B (API)
Hardware Proxy C (API)

Shared Data Space (Network)

Hardware Model A
Hardware Model B
Hardware Model C
Hardware Model D

Simulated Hardware D
Simulated Hardware C
Utilities: Visualisation

Concept

- Detailed View and Control
- Events and Data Flow
- Appliances and Connections
- Hardware Devices
- Metadata and Regions
- Geographic Groundlayer and Overlay Tiles
Utilities: Visualisation

Concept

Map Explorer

Detailed View and Control: Components, Events, Graphs
Events and Data Flow
Appliances and Connections
Components
Metadata and Regions
GIS Groundlayer and Overlay Tiles

Sensor and Actuator Events

Connectors

Control

Interact

Appliances

Appliance Model

Component Model

Shared Dictionary Data Space

Skins
Events
Dynamic Mappings
Appliances
Metadata
Map Cruncher
Virtual Earth

Development: Create, Modify, Control, Observe

Observe, Interact

Nicolai Marquardt – Diploma Thesis Defence
Bauhaus-University Weimar, Cooperative Media Lab

.NET framework 2.0

Language: C# (supported are furthermore J#, Visual Basic, and C++)

Integration into VisualStudio IDE
Plug-in Architecture
IDE Integration

**Appliance project template**

**Visual designer integration**

**Tutorials and examples**

**IDE infrastructure exploration**

**IDE code framework generator**

Nicolai Marquardt – Diploma Thesis Defence  Bauhaus-University Weimar, Cooperative Media Lab
IDE Integration

Implementation

Appliance project template
Visual designer integration
Tutorials and examples
IDE infrastructure exploration
IDE code framework generator
Utilities

Implementation

Explorer

Selected Hardware Component:
Phidget Accelerometer

Device List

Hardware Component

Device Type:
- rfid
- accelerometer
- colorDisplay
- colorDisplay
- colorDisplay

Used Hardware Components:

Device:
- Serial:
- Status:

Phidget Accelerometer

Explorer

Graph Plot - Phidget Accelerometer (7634)

Accelerometer - Serial # 7634

Microsoft Virtual Earth
Chapter 7 Case Studies and Discussion

Figure 7.8: Infrastructure visualisation of the distributed hardware

The implemented source code of the appliance is shown in Figure 7.9. At first, the callback method for the sensor uses a separate method to determine the current availability status. In this method, lines 4-7 in Figure 7.9 show how the sensor values are interpreted and the method returns the estimated availability status. This is then used to change the servo position and the display text accordingly. Lines 8 and 9 in Figure 7.9 finally add a high-level entry to the shared data space.

Discussion

While this prototype is only a simple implementation of an awareness display, it highlights the process of aggregating sensor values to high-level interpretations and indicating awareness information abstracted from the sensors to remote located actuators. With this example, concepts of the Physical But Digital Surrogates [Greenberg and Kuzuoka, 2021] and the Door Mouse [Buxton, 1997] are illustrated. The example appliance demonstrates the processing of sensor data, interpretation of raw sensor values, and deriving contextual information about the presence of a person. This information is easily published to the shared data model and therefore available as high-level event to all other connected appliances. Because the toolkit facilitates the access to the sensor information, local and remote located developers can explore the possible aggregations and interpretations of sensor data to derive high-level context information. These can be important steps to evaluate the applicability of such an appliance. Especially when...
Evaluation by applying the toolkit for rapid prototyping

- Utilised in two HCI courses as well as academic and industrial research labs
- 10 thesis case study information appliances
Case Studies

- Tangible digital media
- Location-based messaging
- Ambient displays and awareness
- Location-dependent object controller
- Augmented map
- Assigning digital metadata
- Sensor processing
- LumiTouch reimplementation
Evaluation

Discussion

- Applicability of the toolkit
- Ease of use and *low threshold*
- Advanced programming and *high ceiling*
- Performance, scalability, latency, reliability
- Usability of tangible user interfaces
Future Work

- Further evaluations: developers, end users
- Library extensions: hardware, filters, skins
- Sensor data processing: high-level events
- Utilities and visualisation: history, advanced interaction
Summary

- Introduction of tangible user interfaces
- Motivation and research overview
- Requirements
- Concept: Runtime Platform, Development Library, Utilities
- Implementation details
- Using connector, library, utilities
- Case studies and prototyping
- Discussion
References I


Thank you for your attention!

Nicolai Marquardt
Diploma Thesis Defence
May 2008

Cooperative Media Lab - Bauhaus-University Weimar
GroupLab - University of Calgary