INTRODUCTION

- General-purpose computing devices like personal computers, tablets and smartphones.
- Developing embedded solution based on custom microcontroller circuit.
- Hardware development systems such as Arduino and Phidgets.
- Processor speed, amount of memory and nature of supported input and output modalities are different.
- Several toolkits require skills in either programming or electronics.
- Sometimes the resulting prototype can run standalone.
- Some toolkits are generic in nature while others are particularly suited for building specific types of prototype.
APPROACHES TO ELECTRONICS PROTOTYPING

• Type 1 - Prototyping with Discrete Components
  ▪ It would be difficult to build a copy of a circuit
  ▪ Requires significant knowledge of electronics

• Type 2a: Integrated Microcontroller Development Boards
  ▪ Any given design typically requires integration with components that are not present on the ready-made MCU

• Type 2b: Breakout Boards and Wireless Modules
  ▪ Need to be combined with Type 2a and/or Type 1
  ▪ The Advantage of Type 2 electronics prototyping over Type 1 is speed and robustness

• Type 3: Integrated Modular Systems
  ▪ Adding discrete components or building custom modules is often hard.
  ▪ It simplifies and expedite electronics prototyping
Toolkits

- Generic breakout boards
- Programmable low-cost WiFi modules
- Silicon vendor development boards
- FPGA development boards

Bosch BNO055 IMU sensor
ESP32
TI Lanchpad
ELECTRONIC PROTOTYPING PLATFORM TAXONOMY

• Nature and Application

<table>
<thead>
<tr>
<th>Specific toolkits</th>
<th>Generic Breakout boards</th>
<th>Low-cost WiFi modules</th>
<th>Silicon vendor MCU dev. boards</th>
<th>FPGA dev. boards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of electronics</td>
<td>Type 2a (35%)</td>
<td>Type 2b</td>
<td>Type 2a</td>
<td>Type 2a</td>
</tr>
<tr>
<td></td>
<td>Type 2b (10%)</td>
<td></td>
<td>Type 2a</td>
<td>Type 2a</td>
</tr>
<tr>
<td></td>
<td>Type 3 (65%)</td>
<td></td>
<td>Type 2a</td>
<td>Type 3</td>
</tr>
<tr>
<td>Electronic sub-domain</td>
<td>Wearables/textiles (15%)</td>
<td>Home automation (3%)</td>
<td>Interactive paper (3%)</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Robotic vehicles/drones (3%)</td>
<td>Musical instruments (2%)</td>
<td>Biomedical sensing (2%)</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>AI/ML (2%)</td>
<td>n/a (70%)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Promoted with user groups (multi-value)</td>
<td>K-12 Education (50%)</td>
<td>Makers (77%)</td>
<td>Electronic engineers (35%)</td>
<td>Makers</td>
</tr>
</tbody>
</table>

• Assembly of Prototypes

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Type of connection</td>
<td>Individual conductors (45%)</td>
<td>Individual conductors</td>
<td>Individual conductors</td>
<td>Individual conductors</td>
</tr>
<tr>
<td></td>
<td>Multi-wire cables (27%)</td>
<td></td>
<td>Individual conductors</td>
<td>Individual conductors</td>
</tr>
<tr>
<td></td>
<td>Direct module-to-module (38%)</td>
<td></td>
<td>Individual conductors</td>
<td>Individual conductors</td>
</tr>
<tr>
<td>Connection mechanism (multi-value)</td>
<td>Friction fit (67%)</td>
<td>Magnetic (6%)</td>
<td>Locking (7%)</td>
<td>Friction fit</td>
</tr>
<tr>
<td></td>
<td>Crocodile clips (8%)</td>
<td>Adhesive (3%)</td>
<td>Thread (3%)</td>
<td>Friction fit</td>
</tr>
<tr>
<td></td>
<td>Screws (2%)</td>
<td>Wireless (5%)</td>
<td></td>
<td>Friction fit</td>
</tr>
<tr>
<td>Connection topology</td>
<td>Star (45%)</td>
<td>Hybrid (25%)</td>
<td>Bus (30%)</td>
<td>Star</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Star</td>
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<td>Star</td>
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</tbody>
</table>
**ELECTRONIC PROTOTYPING PLATFORM TAXONOMY (1)**

- **Deploying and Configuring**

<table>
<thead>
<tr>
<th>Programming style</th>
<th>Specific toolkits</th>
<th>Generic Breakout boards</th>
<th>Low-cost WiFi modules</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Physical configuration (20%)</td>
<td>n/a (10%)</td>
<td>n/a</td>
<td>Software configuration</td>
<td>Software configuration</td>
</tr>
<tr>
<td></td>
<td>Software configuration (75%)</td>
<td>n/a</td>
<td>Software configuration</td>
<td>Software configuration</td>
<td>Software configuration</td>
</tr>
<tr>
<td></td>
<td>n/a (10%)</td>
<td></td>
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</tbody>
</table>

- **Dependencies for programming (multi-value)**

<table>
<thead>
<tr>
<th>Dependencies for programming</th>
<th>Specific toolkits</th>
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<th>FPGA dev. boards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully self-contained</td>
<td>n/a (8%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected wireless</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tethered to computer</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- **Dependencies during deployment**

<table>
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<td></td>
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</tbody>
</table>

- **Availability and Adoption**

<table>
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<th>FPGA dev. boards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing use</td>
<td>In commercial products (7%)</td>
<td>Multiple copies (7%)</td>
<td>Only used in one-offs (86%)</td>
<td>Multiple copies</td>
<td>Only used in one-offs</td>
</tr>
<tr>
<td></td>
<td>Simple examples (7%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercially available</td>
<td>Yes (67%)</td>
<td>No longer (2%)</td>
<td>Never (31%)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third party use</td>
<td>Yes (86%)</td>
<td>No (17%)</td>
<td>Never (31%)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
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</tr>
<tr>
<td>Open source</td>
<td>Fully (45%)</td>
<td>Partial (42%)</td>
<td>Closed (13%)</td>
<td>Fully</td>
<td>Fully</td>
</tr>
</tbody>
</table>
ANALYZING THE CHARACTERISTICS

• The level of electronics expertise required.
  ▪ Type of connection
  ▪ Connection topology

• The level of programming expertise required.
  ▪ Programming style

• The ease of construction of a prototype.

• Ease of moving from a prototype to a product.
  ▪ Existing use
  ▪ Dependency during deployment
  ▪ Open source
ANALYZING THE CHARACTERISTICS (1)

• Ranking of prototyping platforms
SURVEY ON ELECTRONICS TOOLKITS

122 participants

- 40% self-identified as an electrical engineer, 18% as a mechanical or mechatronics engineer, 15% as an engineer with a different specialization, 17% as a product or industrial designer and 59% as a computer scientist or programmer.

- 97% of respondents having heard of more than 4 and 75% of more than 7.

- 33% had experimented with 7 or more platforms, 65% with 4 or more, and 98% had experimented with at least 2 platforms.

- Electronic engineers:
  - Prototype is easy to iterate
  - Prototype is easy to debug
  - **Easy to evolve to custom PCB**
  - Platform is commercially available
  - Platform is open source
  - *Quick to build more copies*
  - **Use favorite programming language**
  - Platform is cheap
  - Modules are reusable
  - Prototype is durable
  - Platform is comprehensive
  - Prototype is self-contained
  - Prototype can communicate
  - Modules are easy to connect
  - Easy to integrate into enclosure
  - Prototype has low power consumption
  - Many physical module configurations
  - Prototype is small
  - No special tools required
  - Platform supports mechatronic systems
  - Prototype looks like a real product
  - Little programming expertise required
  - Prototype is reprogrammed wirelessly
  - Platform is established in education
  - **Little electronics expertise required**
  - No wires are visible in prototype

- Other disciplines:
  - Prototype is easy to iterate
  - Prototype is easy to debug
  - Prototype is durable
  - Modules are reusable
  - Platform is cheap
  - Platform is commercially available
  - Prototype can communicate
  - Prototype is self-contained
  - Platform is open source
  - Platform is comprehensive
  - Modules are easy to connect
  - Quick to build more copies*
  - Prototype has low power consumption
  - Use favorite programming language**
  - Many physical module configurations
  - Easy to integrate into enclosure
  - Prototype is small
  - Little electronics expertise required**
  - Platform supports mechatronic systems
  - Prototype looks like a real product
  - Easy to evolve to custom PCB**
  - No special tools required
  - Little programming expertise required
  - Platform is established in education
  - Prototype is reprogrammed wirelessly
  - No wires are visible in prototype

Legend:
- Red: Always unimportant
- Orange: Usually unimportant
- Green: Usually important
- Dark green: Always important
SURVEY ON ELECTRONICS TOOLKITS (1)

• Only 10% of our respondents often started the prototyping process with a Type 3 toolkit.

• 39% of respondents reported they often make copies using a custom PCB.

• 12% of respondents often make copies using the same prototyping platform as used for the one-off prototype.

• 53% of all respondents often start the process with Type 2a development boards, 44% often start with solderless breadboard.