# Visible Breadboard: System for Dynamic, Programmable, and Tangible Circuit Prototyping with Visible Electricity

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**Abstract.** This paper reports a new system for prototyping circuits called the Visible Breadboard. The Visible Breadboard is a solderless breadboard that allows users to make or erase physical wirings with tangible input by hand and to see the voltage level of each hole at all times by a colored LED light.

The Visible Breadboard has 60 solid-state relays set in parallel crosses and controlled by a micro-controller. These relays connect the 36 holes on the system surface. The connected holes work as wirings in the circuit into which users can insert electronic materials. Each hole has an AD converter function working as a voltmeter and a full-color LED. The voltage of each hole can be visualized by these full-colored LEDs. Users can operate this system by touching the surface with their fingertips. Users can also connect the Visible Breadboard to a PC. When the Visible Breadboard is connected to the PC, it functions as a new kind of interface for developing and sharing circuits.

Our experimental results showed that this device enables users to build circuits faster and more easily than an ordinary solderless breadboard.

**Keywords:** Rapid Prototyping, Physical Computing, HCI.

## 1 Introduction

Nowadays there is great interest in hobby electronics and DIY. Open source programming languages and IDEs such as Arduino [1] and Processing [2], are in widespread use. With the use of a solderless breadboard, soldering is no longer required to build electronic circuits for these purpose. The hobby electronics and DIY environments have become easy and accessible by spreading of instruction on web. Moreover, there are many communities and people interested in DIY and hobby electronics on the internet and their communications are seen on SNS.

Learning electronics and having a knowledge of electronic circuits help people understand what energy and system are. When we make a circuit, it is very easy to

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understand power consumption, for example, comparing an actuator that is very large to an LED that is small.

Many articles and tips regarding DIY and hobby electronics are available on the web. In these communities, it is easy to share schematic diagrams and pictures of circuits, but very difficult to share actual circuits.

Furthermore, although a great deal of information about hobby electronics and DIY is available, it is still difficult to understand what happens in the actual circuits and to share these circuits. IDEs have become more workable, but building a circuit is still manual work and difficult for a beginner. In the real world, we cannot see voltages in the circuit and are not able to "UNDO" our actions.

When we want to know the voltage in a circuit, we use a voltmeter. It shows us the voltage by analog meter or LCD display, but does not visualize the voltage on the circuit. It is also difficult to measure multi-points in the circuit at the same time. Moreover, when we teach electronics in the classroom or workshop, it is difficult to share a circuit. There are often mistakes made copying a circuit.

To address these problems, we have developed a new system, which we named the Visible Breadboard (Fig. 1). The Visible Breadboard has dynamic circuit connections for each hole using solid state relays and visualizes the voltage on the surface with a colored light.

From the viewpoint of programming materials [3], circuits made of solid state relays can be defined as "real programming material" that change physical characteristics through programming and using electricity.

This research paper will first cite some of the related researches and discuss the reason our research is relevant in section 2. Secondly, it will explain the implementation and function of device in section 3 (hardware), 4 (middleware), and 5 (software). Thirdly, it will show some of the conducted experiments in section 6. After that it will discuss the limitations and experimental results in section 7. Lastly, we will conclude with possible future work in section 8.

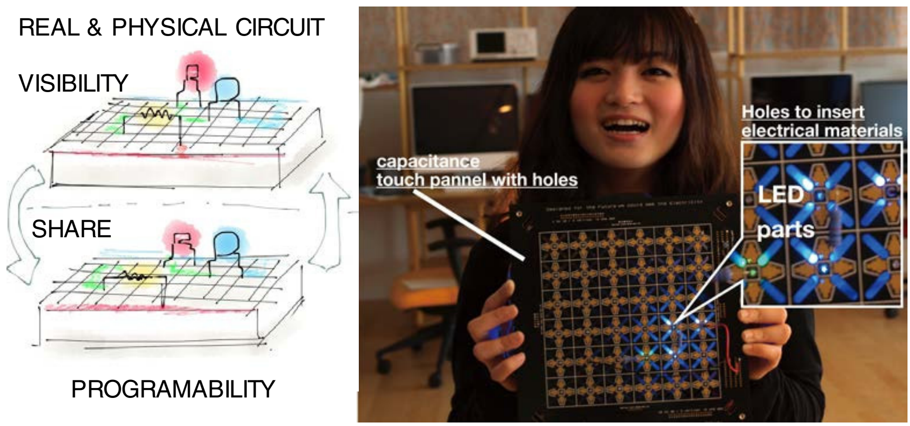


**Fig. 1.** (left) concept picture shows "real circuit", "visible voltage", "circuit programability", and "share" for prototyping purpose. (right)system overview

# 2 Related Work

## 2.1 Tangible Prototyping Tools

Many tangible devices for prototyping have been developed, such as the Algoblock, a development of Suzuki and Kato [4]. Algoblock is a tangible programming language, an advanced research, aimed at collaboration and visualization. It is good for collaborative learning and programing but it is not aimed at prototyping a circuit.

There are tangible prototyping tools for electronics, such as react3D Electricity [5] and Denshi blocks [6]. react3D Electricity is a tangible [7] circuit simulator but users cannot use real electronic materials. A Denshi block is a physical block that contains an electronic component. Users can make a circuit with these blocks but it is difficult to add other electronic materials, which are not included in the Denshi block package.

Research has been done on visualization of power consumption such as Flo [8]. As a visualization tool, however, it does not target hobby electronics or DIY. It is a tool for monitoring electricity in the home.

While there has been significant advanced research on prototyping tools, there is no research on tangible prototyping tools using real electronic materials.

## 2.2 Position of Study

Here we show the position of this study in Table 1. This study focused on the user experience with “real circuit”, “visualization of voltage”, and “circuit programability”.

**Table 1.** Position of this study

| | | Circuit Programability | |
|---|---|---|---|
| | | Available | Not available |
| Cirtuit | Real | This Research*<br>Denshi Block [6](nondigital) | Ordinary Solderless Breadboard |
| | Virtual | react3D electricity* [5] | |

*Visibility on electricity

# 3 Hardware Implementation

This section describes the composition of our system in 3.1. Following which we describe each modules by processing order.

## 3.1 Visible Breadboard System Prototype

The Visible Breadboard Prototype system is composed of two sub-systems. The first is a device that functions as a solderless breadboard. In this paper, we call this the

Visible Breadboard Device. The second is the software for a personal computer. We call this the Visible Breadboard Software. We describe the Visible Breadboard Software in Software section 5.

### 3.2 Visible Breadboard Device

From a functional viewpoint, the Visible Breadboard Device is separated into four modules: sensor board with holes, solid state relay board, voltage sensing board, and full color LED board. The connections for each module are shown in Fig. 2. These four modules are assembled into three physical layers.

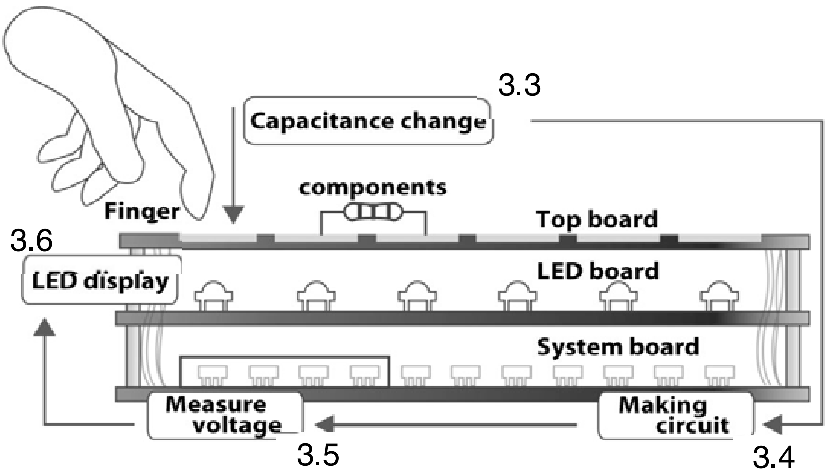


**Fig. 2.** System diagram and the connection for each four modules.(side view). Visible Breadboard device has the structure of three layers: Sensor board, LED board, and system board.

The Visible Breadboard Device is controlled by a single micro-controller (Arduino MEGA with ATMEGA 1280)

### 3.3 Sensor Board with Hole

This module detects a user's finger position on the surface by sensing a capacitance change (like SmartSkin [9]). A finger touch changes the capacitance of the metal pads, which are set on the surface of the top board. This module enables users to input by finger touching and tracing the surface. Four pads seen around the hole are connected horizontally and vertically, enabling the system to detect a coordinate position of the finger, as shown by the arrows in Fig. 3. This module looks for a capacitance change by cross-sensing: vertical and horizontal position sensing. Each hole on this board is connected to both the solid state relay and voltage sensing module.

### 3.4 Solid State Relay Board

The Solid State Relay Board is placed in the bottom physical layer of the Visible Breadboard Device (Fig. 2). This module (Fig. 4) has 60 solid state relays placed between the 36 holes connected to the Sensor Board. By switching these solid state relays ON / OFF, the connection status of the holes is changed dynamically. Active solid state relays form the wiring between the holes and complete a circuit with the electronic materials inserted into the Sensor Board.

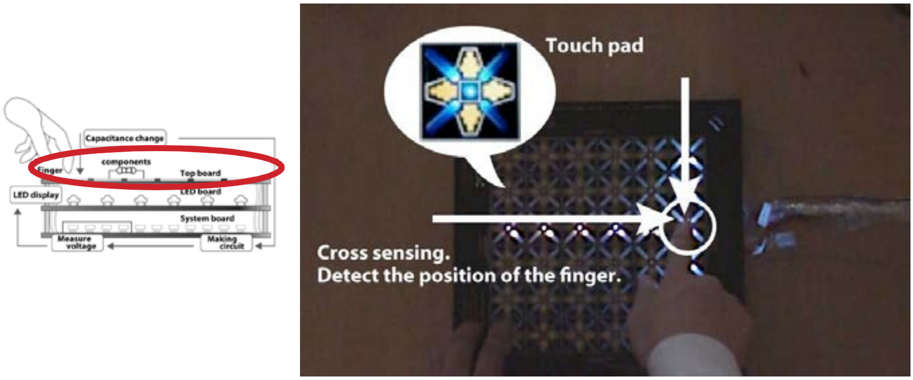


**Fig. 3.** Top view of Visible Breadboard device

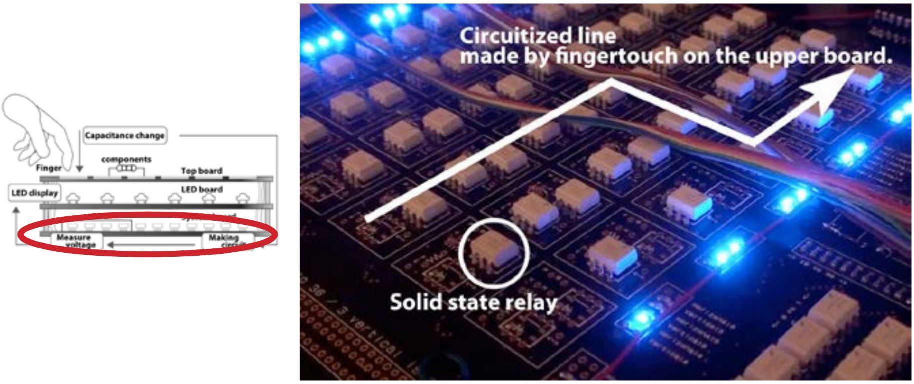


**Fig. 4.** SSR board on bottom layer of Visible Breadboard device

These solid state relays are controlled by eight shift registers. The shift registers are controlled by a micro controller with serial connections.

### 3.5 Drive Sensing Voltage of Each Hole

This module (Fig. 5) measures the voltage value of the 36 points. The drive control of the solid state relays enables switching the connection of the micro-controller AD converter

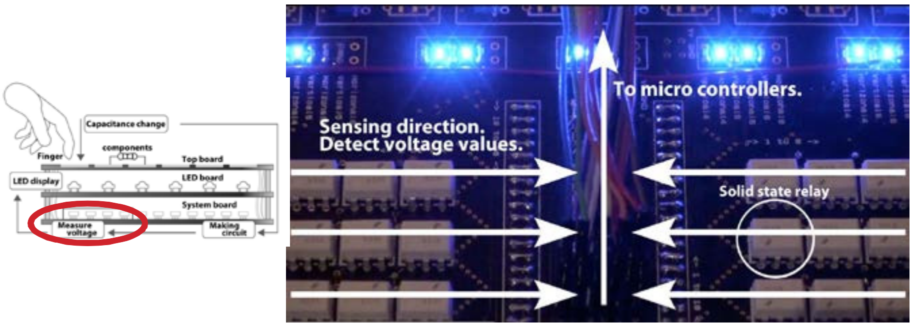


**Fig. 5.** Drive sensing module by SSR in bottom layer. ( close-up )

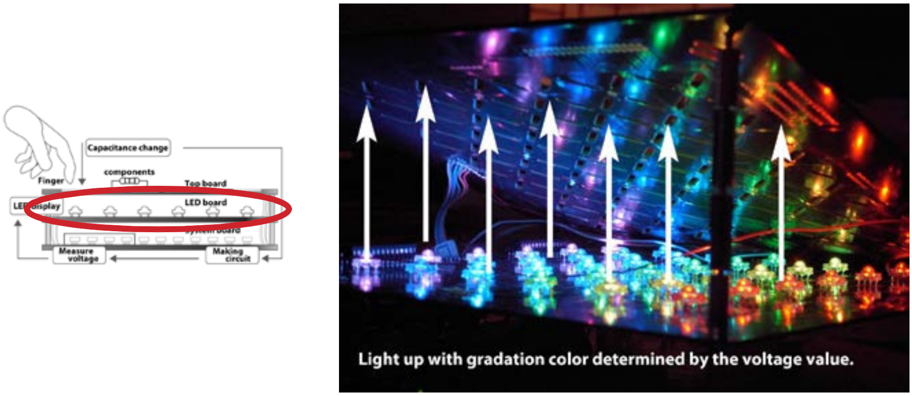


**Fig. 6.** LED displaying modules ( with opening top board)

and the holes of the Sensor Board into which the users inserts the electronic materials. Though this module can measure only six points at once, we think that it is sufficient for this device because the full-color LED system (showing the voltage in color) in this device is lighted by the drive control system (six LEDs at once).

### 3.6 Displaying The Voltage

User can choose the "start voltage color" and the "end voltage color" in the configuration mode. This module (Fig. 6) changes its LED color by gradation corresponding to the voltage value (Fig. 7). The color is determined by Equation (1).

$$C = v\left(\frac{Re - Rs}{L}, \frac{Ge - Gs}{L}, \frac{Be - Bs}{L}\right) \tag{1}$$

C = color of full color LED, v = voltage

(Rs,Gs,Bs):start color (Re,Ge,Be):end color

L = ADConverter' s maximum value

### 3.7 Hardware Specification of the Visible Breadboard Device

The hardware specification of the Visible Breadboard Device is shown in Table 2. We developed four Visible Breadboard Devices. They can be connected to each other to make 144 holes available. There is a resistance value between the holes because this device uses Solid State Relays for the wiring. However, this is an allowable margin error for the circuits that can be built on this hardware. The distance between two holes is approximately 12 times larger than found on an ordinary solderless breadboard. This is large, but allows users to use extensions (Fig.7) for small electronic materials or IC chips.

**Table 2.** Hardware Specification

| | |
|---|---|
| weight | 1200g |
| size | 24.2cm (W) 24.2cm (L) 6cm (H) |
| number of holes | 36holes |
| distance between 2holes | 3.2cm |
| voltage sampling frequency | 30Hz |
| AD Converter | 1024 steps (0- 5V) |
| LED Color steps | RGB Color 8096 steps |
| Micro-controler | Atmega1028 (ArduinoMEGA) |
| Clock | 16MHz |
| Input Voltage | 0-5V<br>with Optional OPAMP<br>max voltage 48V |
| Resistance value between holes | 2Ω |

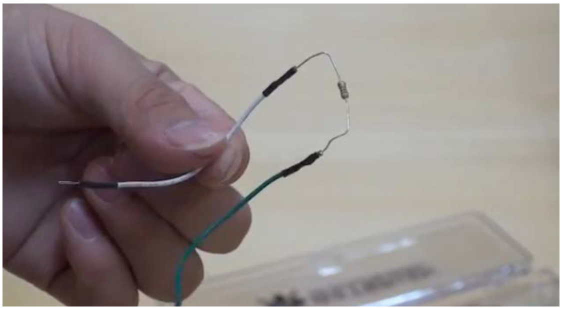

**Fig. 7.** Parts extension for Visible Breadboard device ( wire with socket )

## 4 Middleware Implementation

The Visible Breadboard Device has several features for interaction with users. The following sections describe basic wiring and visualization, checking the connection function, UNDO/REDO, and digital color mode.

### 4.1 Basic Wiring and Visualization

Users can control the Visible Breadboard Device by touching the pads on the surface. This section describes the connection algorithm. If users touch one hole (Fig. 8 (left).1) and then another next to it (Fig. 8 (left).2), these two holes are connected or cut (Fig. 8 (left).3). If a hole is connected to others, the LED for the voltage visualization (placed below the sensor board) turns on. For example, users can make the circuit shown in Fig. 8 (right).

*Example 1: Fig. 8 (right-up) is a circuit with resistors, an LED, and a capacitor. The RED light shows that the voltage is Vcc (5 V) and the BLUE light shows that the voltage is GND (0 V). In Fig. 10, LED (A) is on because there is an electric current in the circuit.*

*Example 2: Fig. 8 (right-bottom) is a circuit with resistors only. The RED light shows that the voltage is GND (0 V) and the BLUE light shows that the voltage is Vcc (5 V). In Fig. 11, the holes on each side of interval (A) have different colors because there is no connection (left hole shows GND and right hole shows Vcc).*

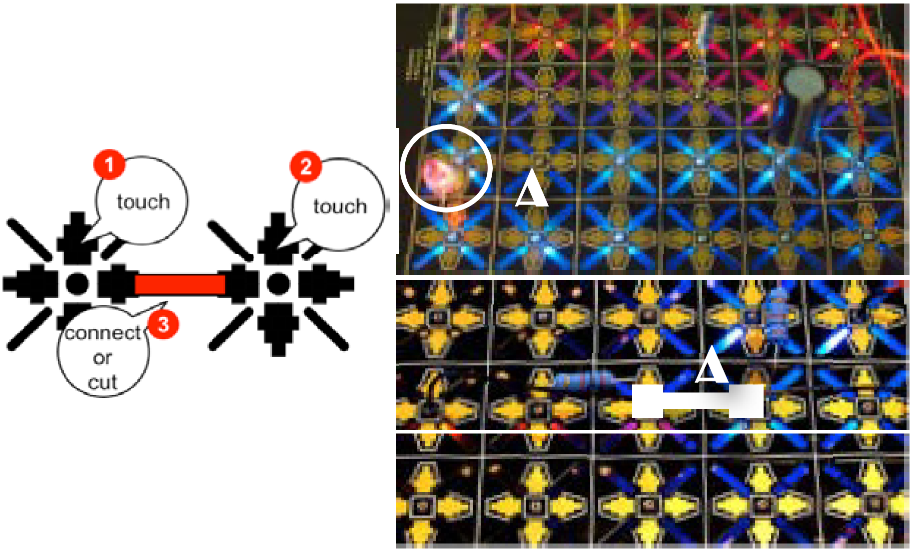


**Fig. 8.** (left) Connection Algorithm (right-up) Example 1: RED is V+, BLUE is GND (right-bottom) Example 2: RED is GND, BLUE is V+

### 4.2 "Checking the Connection" Function

The Visible Breadboard Device has an indicator for voltage visualization but there is no indicator for the connection of the holes. To compensate for this, the Visible Breadboard Device has a "checking the connection" function. When users press the button on the right side of the sensor board, the voltage visualization LEDs blink in sequence to show the connection of each hole.

### 4.3 UNDO/REDO

The Visible Breadboard Device has a wiring UNDO and REDO function. Using this, users can erase and remake a connection easily. Furthermore, if the users push the UNDO and REDO button repeatedly, the wiring in the circuit repeats the cutting and connecting rapidly. Users can make a high-speed voltage change. This is useful to view the waves on the breadboard.

Additionally, if the users push the REDO button slowly, they can see, slowly and in order, what happens in the circuit when the connection is made.

### 4.4 Digital Color Mode

The Visible Breadboard Device has two visualization modes. The first is a basic visualization using gradation of the LED color, like thermography. The second is a "digital color mode". In this mode, the LED shows a different color for every 1V step. It is helpful for checking and understanding what happens in the digital circuit.

### 4.5 Other Features

The Visible Breadboard Device has some other features: "Sound", "Auto Save", and "Color palette for the voltage". The Sound system gives users visual and sound feedback. The Auto Save system enables users to emulate an ordinary solderless breadboard. With an ordinary solderless breadboard, the circuit remains connected without electricity. With the Visible Breadboard, the circuit that users develop disappears if the power is turned off. The Auto Save features compensates for this shortcoming. With Color palette for the voltage, users can set their preferred color configuration.

## 5 Software Implementation on PC

The Visible Breadboard Software, which runs on the PC, has several utilities for the Visible Breadboard Device. This section describes the "Voltage visualization on the PC" and "Copy the data from device" functions.

### 5.1 Voltage Visualization on PC

The Visible Breadboard Software has a voltage visualization feature (Fig. 9). When the Visible Breadboard Device is connected to a PC via a USB cable, data from the

AD Converter are sent to the PC. The software captures the voltage data of the 36 holes on the Visible Breadboard Device and shows them as a 3D bar graph. The colors on the bar graph change corresponding to the color settings of the Visible Breadboard Device's voltage visualization.

| tasks \ users | A | B | C | D | E | F | G | H | I | J | AVG |
|---|---|---|---|---|---|---|---|---|---|---|---|

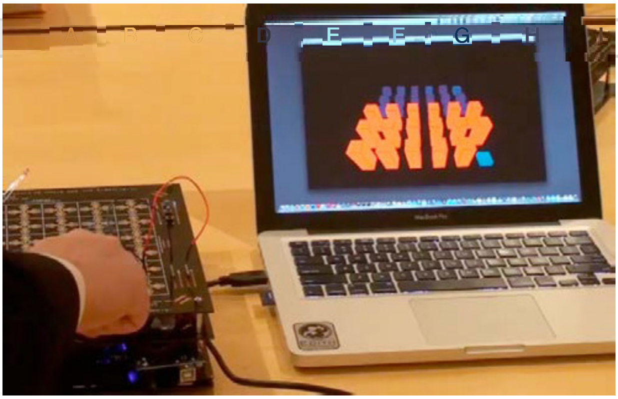

**Fig. 9.** Voltage visualization on PC. Also user can share the circuit built with this device via internet.

### 5.2 Circuit Share

The Visible Breadboard Software can capture all the data (connection data of holes, visualization data, and settings) from the Visible Breadboard Device. This software can import and export these data as files. It enables users to copy and share the actual physical circuit via internet or email.

## 6 Evaluation

### 6.1 Experimental Design and Participants

We ran a task-oriented circuit-building test with ten users, nine male and one female, with average age 20.8.

Before starting the test, we explained, for two minutes, how to use an ordinary solderless breadboard and the Visible Breadboard. We let the participants practice for a few minutes on each. Then all participants knew how to use both systems.

For the first test, users made 25 connections on the Visible Breadboard. This was to verify the capacitance sensor and resistance of the participant's finger skin.

### 6.2 Questionare

After the wiring test, there were eight tasks relating to making a circuit. We tested four kinds of circuit ((a), (b), (c), and (d)) and users made these on both the ordinary solderless breadboard and the Visible Breadboard. For (a) and (b), we showed the participants a picture of the correct circuits and the users made the circuits from the picture. In experiments (c) and (d), we showed the participants a schematic. They then made the circuits on both the ordinary solderless breadboard and the Visible Breadboard.

**Table 3.** Experimental Result of 10 users on wiring task (unit: second)

| **Make Wiring on Visible Breadboard** | 12 | 16 | 14 | 12 | 15 | 10 | 11 | 10.8 | 30 | 10.9 | 14.17 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **(a) Breadboard** | 74 | 214 | 112 | 71 | 152 | 84 | 53 | 155 | 98 | 51 | 106.4 |
| **(a) Visible Breadboard** | 50 | 60 | 49 | 29 | 49 | 57 | 23 | 36 | 51 | 24 | 42.8 |
| **(b) Breadboard** | 102 | 221 | 157 | 129 | 137 | 106 | 89 | 183 | 150 | 45 | 131.9 |
| **(b) Visible Breadboard** | 30 | 45 | 36 | 35 | 43 | 65 | 22 | 66 | 95 | 57 | 49.4 |
| **(c) Breadboard** | 115 | 154 | 101 | 39 | 62 | 87 | 26 | 63 | 77 | 55 | 77.9 |
| **(c) Visible Breadboard** | 37 | 42 | 37 | 26 | 32 | 60 | 15 | 26 | 31 | 85 | 39.1 |
| **(d) Breadboard** | 81 | 119 | 189 | 94 | 83 | 30 | 32 | 116 | 38 | 51 | 83.3 |
| **(d) Visible Breadboard** | 37 | 58 | 52 | 49 | 30 | 45 | 27 | 77 | 52 | 63 | 49 |

### 6.3 Results

The results of the user experiments are shown in Table 2. There were ten participants, A to J. It is seen in the average column that for every circuit tested in this experiment, the Visible Breadboard was faster than the ordinary solderless breadboard.

After the wiring experiment, we tested the voltage visualization effect of this device. All of the people who took part in this experiment answered the question: “Where is the GND or Vcc?”, correctly. It was easy for people to distinguish the Vcc from the GND with the Visible Breadboard.

## 7 Discussion

The difference of the speed between the ordinary solderless breadboard and the Visible Breadboard depended on the complexity of the circuit. When people used many bread wires to develop the circuit on the ordinary solderless breadboard, the difference of the speed increased quickly.

The Visible Breadboard accelerates building the circuit, enables users to share the circuit, and visualize the voltage in the circuit. It is useful for the first circuits that beginners make or children make in the school.

We presented this system in many places including SIGGRAPH [10]. People suggested that the full-color LED display should be replaced by an LCD display because the drive control makes the LED display blink. We think this will be better when the LCD displays become lighter.

## 8 Conclusion and Future work

We would like to make this system a product and gather additional data for future research. This paper introduced a new kind of system for prototyping and sharing circuits. It makes building circuits easier and faster. Moreover, the ability to visual the voltage was certainly very effective for people using the device.

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## Appendix

Visible Breadboard Instruction Movie (Video on YouTube).

`http://www.youtube.com/watch?v=nsL8t_pgPjs`

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