ORIGINAL ARTICLE

Development of a Natural User Interface Based Cyclist Signaling Vest

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Abstract: A prototype for a wearable signaling device for cyclists is presented. Based on Natural User Interface design concepts, the prototype uses an accelerometer to automatically detect motion changes from turning and braking and to trigger appropriate warning lights in the vest. The system is integrated into a vest made of hard, waterproof cardboard, folded for wearing comfort. Field tests demonstrated that the device detects body movements that anticipate a directional change, and outputs corresponding signals using LED lights without active control from the cyclist. To predict motion changes, a second sensing unit was installed to detect cyclist hand gestures commonly used to inform others of upcoming turns and stops.

Keywords: cyclist safety; signaling device; wearable; natural user interface; tangible interaction design

Introduction

Sharing the road with motorists can be dangerous for cyclists. Unlike cars, bicycles typically lack turn or brake signals, and accidents frequently result from a cyclist turning or stopping without warning. To compensate, some cyclists use hand signals to communicate with drivers, for example fully extending the left arm horizontally to indicate an upcoming left turn, or extending their left arm out with the forearm handing down to indicate braking. However, this type of movement forces the cyclist to ride with only one hand on the handle bars, thus increasing the likelihood of his/her losing control of the bicycle. Many signaling devices have been developed to address this issue. Some are designed to be installed on the bicycle, while others are worn by cyclists [1-3]. Most such system use control systems similar to those used in motorcycles or automobiles and require active operation. However, cycling entails greater physical exertion than driving, thus the potential distraction caused by any additional body motion is more likely to cause a loss of control. In addition, such an active control system can only signal planned turns or braking, and cannot account for sudden reactions to unexpected events.

This study uses the concept of Natural User Interfaces to design and develop an interactive device that can automatically detect and signal impending turns and braking by cyclists. The system detects human body movements that anticipate turning or braking, and triggers corresponding light signals to alert nearby drivers. Field testing results verify that the constructed wearable device could effectively anticipate and respond to imminent turns or braking without rider intervention.

Design Concept

Natural User Interface (NUI) is a new design concept which seeks to make human-computer interfaces more intuitive [4, 5]. Here, NUI practices are adopted to develop a mechanism to signal turns and braking that requires no conscious effort or even awareness on the part of the cyclist.

Bicyclists make directional turns by both turning the front wheel via the handlebars and leaning their weight in the direction of the intended turn [6]. Figure 1 illustrates the mechanics of turning a bicycle. To make a turn, the center of mass should be shifted to the center of the curvature to generate the force required to turn the moving bicycle. This establishes a cause-and-effect relationship between the combination of body-leaning and weight-shifting and the directional turning of the bicycle. The presented wearable signaling device uses this particular cause-and-effect relationship by taking the initial body motion anticipating the attempted turn as the input, and outputs a light signal to indicate the upcoming change in the direction of motion.

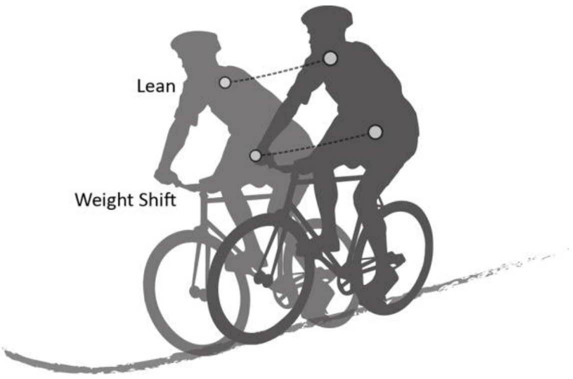

Figure 1. Mechanics of turning a bicycle.

Body motion sensing applications are already widespread, including gesture recognition and wearable computing [7-10]. Gesture recognition typically involves the use of some device as middleware to detect human motion through various sensing techniques. These motions are then interpreted to trigger appropriate hardware or software responses [11]. Many software development kits have been developed for gesture recognition devices to allow developers to implement new design concepts and construct prototypes. However, such devices use a variety of techniques to scan gestures in three-dimensional (3D) space and to track changes over time. As a result, the precision and reliability of these techniques depends on many variables such as sensor range, discrepancies between motions, and the background environment.

Wearable computing, on the other hand, provides a simpler, more reliable and more affordable method to sense body movements. In addition, developments in wearable computing applications have been significantly accelerated by rapid prototyping through affordable digital fabrication technologies and open-source microcontrollers and related software [12]. The complete system configuration is illustrated in Fig. 2.

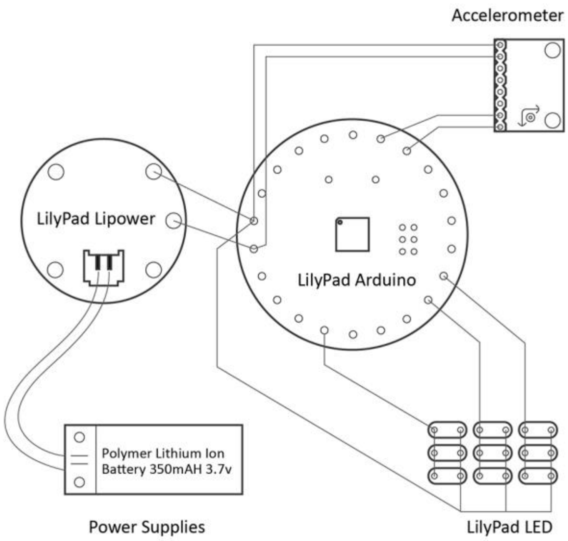

Figure 2. System configuration.

An accelerometer is an inertial sensor that can measure the magnitude and direction of acceleration (*g*-force) of a moving object. The presented prototype includes an accelerometer positioned at the center of the wearer's upper back to measure lateral change in the *g*-force when making a turn and the longitudinal change when braking.

The measured *g*-force values are sent to the connected LilyPad Arduino, a small computer that can be programmed using the open-source Arduino Integrated Development Environment [13] [14]. Figure 3 shows the algorithm flow. The forward traveling direction is defined as "Z" and the direction to the right is defined as "X" for the accelerometer. The threshold values are represented by "A_x" and "A_z," with default values of 0.3g. The values detected by the sensor are represented by "a_x" and "a_z." When the detected value, "a_x" exceeds the threshold "A_x" of 0.3g, the right turn LED indicator lights up; when "a_x" is smaller than the "$–A_x$" of –0.3g, the left turn LED indicator lights up. When the detected value of "a_z" is smaller than that of "$–A_z$" of –0.3g, the stop LED indicator will light up. The process is repetitive and starts over every 0.1 s.

Prototype Design

The interactive system is installed on a vest constructed from a garment that can be fabricated using

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laser-cutting technology. The design concept for the prototype's form factor and its manufacturing process aims to allow customization, using pipelined computer-aided design (CAD) processes and digital fabrication technologies. Figure 5 illustrates the design layout of the garment. The solid lines indicate the traces for the laser cutter to cut out the contours of the vest, while the dotted lines represent scoring tracks for easy folding, thus softening the vests form and increasing wearer comfort. Prototype production starts from a two-dimensional (2D) CAD drawing. The vest can be manufactured from readily available materials such as waterproof hard cardboard or sheets of raincoat fabric. In addition, the circular form factor permits the 2D CAD design drawing to be parametrically resized by simply applying a scale factor to create different vest sizes for different users. The folding pattern can further allow the LED lights to be arranged into symbols indicating left turn, right turn, and stop, as illustrated in Fig. 6.

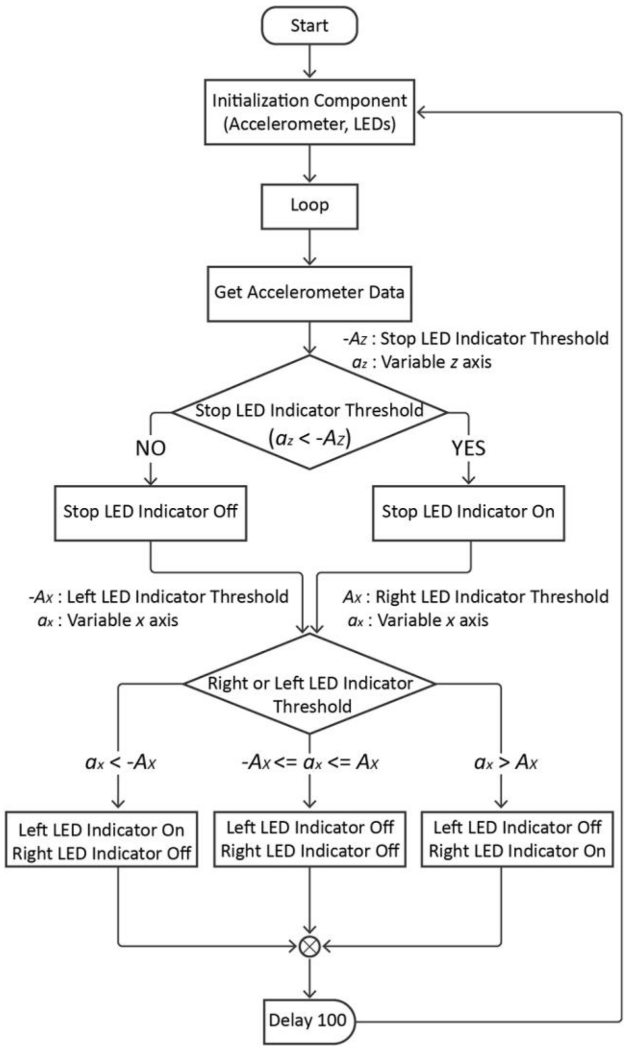


Figure 3. Algorithm flow.

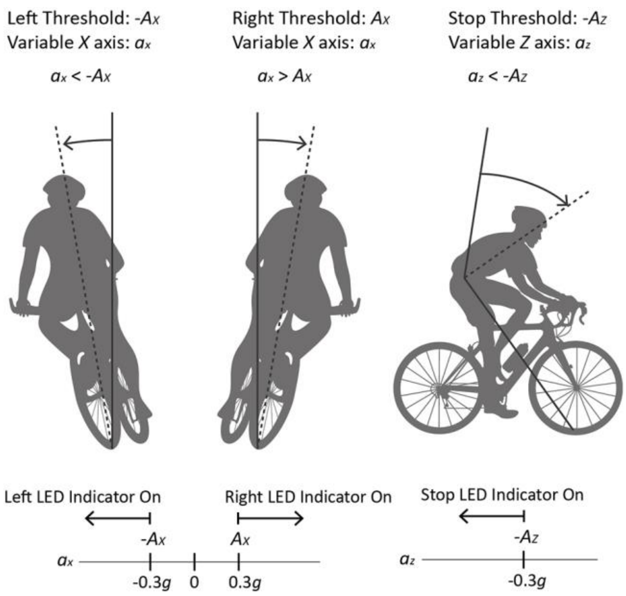


Figure 4. Body motions and signal detections.

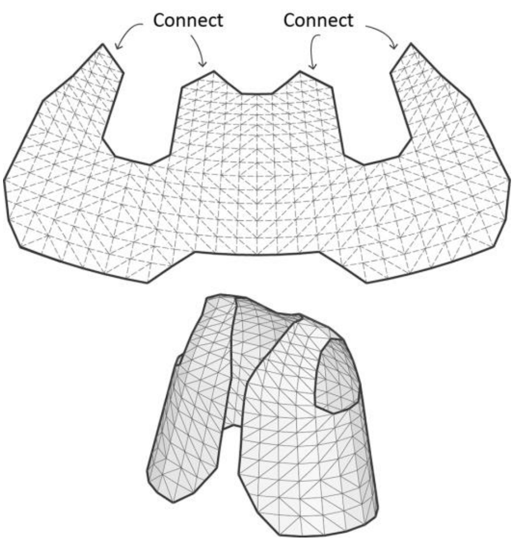


Figure 5. 2D garment and the 3D assembled vest.

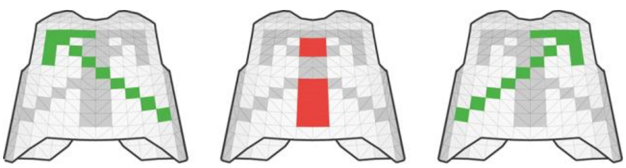


Figure 6. LED signal patterns.

Functionality Evaluation

A pilot study was conducted to evaluate system performance. Figure 7 displays the constructed prototype. Black hard cardboard with a waterproof coating was used to manufacture the vest. The accelerometer was attached to the upper-back center of the vest. The LilyPad Arduino and the power supplies were respectively sewn into the left and right inner front sides, to balance the weight. Three LilyPad LED modules, arranged to form turn and stop signal patterns, were sewn on the outer side of the back of the vest and connected to the LilyPad Arduino.

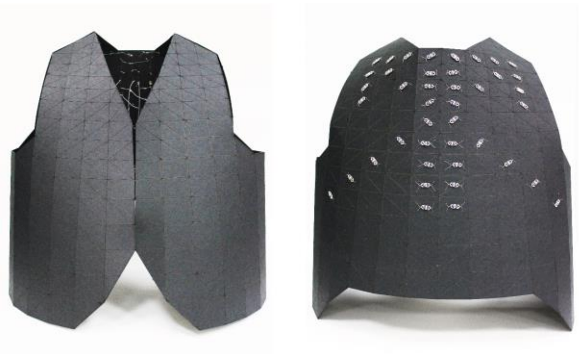


Figure 7. Constructed prototype.

Validation testing was conducted on a university campus in multiple rounds following code modification performed in the lab. Testing sought to determine the best location to attach the accelerometer, and to derive default threshold values that are sufficiently sensitive to allow the system to detect initial turn and braking movements in the cyclist. Figure 8 illustrates the visual effects of the light indicators for left-turn, braking, and right-turn signals in a dark environment to simulate nighttime use. However, the final appearance of such images greatly depends on the camera's exposure settings. High Dynamic Range (HDR) photography technique was used to objectively document the visual effects, where digital photographs of the same scene are taken with multiple exposure settings and assembled into a single image such that each pixel contains the complete luminance range data to provide physical accuracy [15, 16]. Various tone-reproduction methods have been developed to show the HDR scene on a common display with limited display range. The photoreceptor tone-reproduction method can be used to compress the HDR scene into a displayable image. The photoreceptor tone-reproduction method is based on how photoreceptor processes visual stimuli, and thus provides a reliable visual appearance of the tone-mapped image, which is very similar to the real scene [17]. As illustrated in Fig. 8, the LED signals contrasting with the black vest provide the necessary visibility to alert the drivers behind the cyclist.

Figure 9 shows the field test environment. The tile pattern divided the hallway into three meter-wide lanes: left, middle, and right. The distance between the start line, middle line, and finish line is about 7 m. The researcher rode a bicycle straight from the start line along the left lane, changed to the middle lane after the middle line, and then stopped at the finish line. A digital camera recorded the process from 50 cm behind the start line. Sequential images are shown in Table 1 to illustrate the evaluation. When moving straight, no indicators light up. As the rider leans right to make a lane change, the right-turn indicator lights up and remains lit the whole time the bicycle moves from the left to the middle lane. When rider started to brake, the stop indicator lit up and remained on until the bicycle had stopped completely. This result suggests the system is reliable and accurate.

Figure 8. Visual effects of the three conditions of the prototype.

Figure 9. Field test environment.

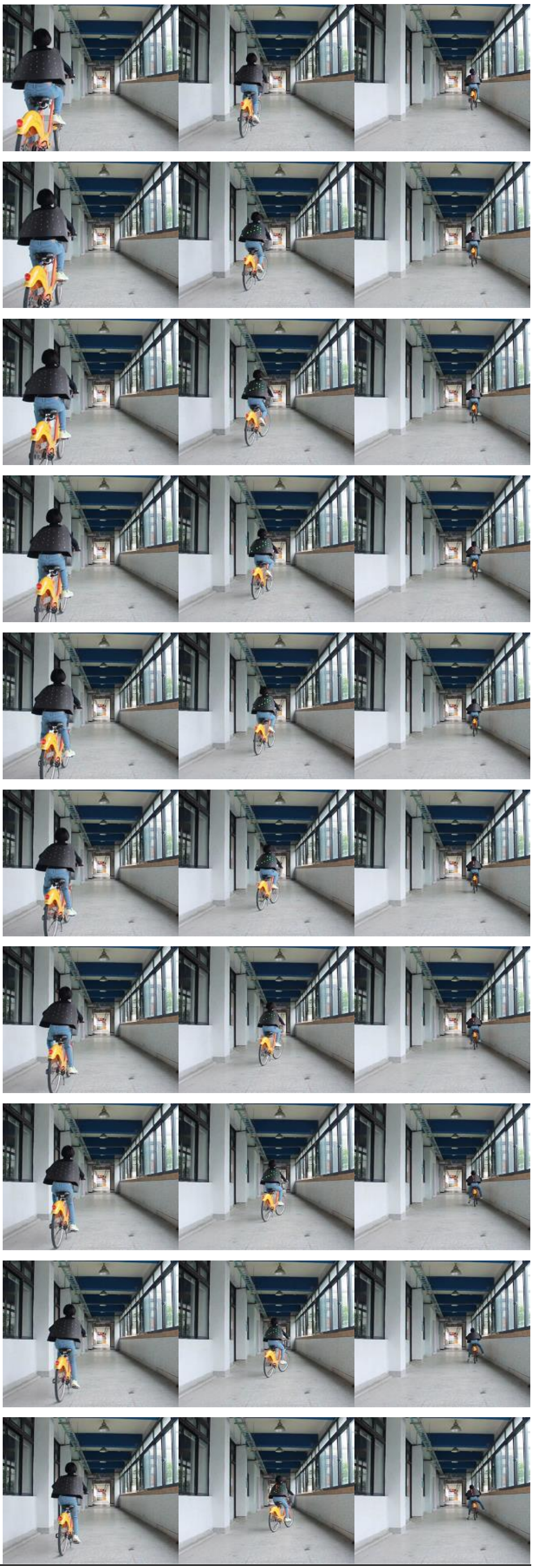
Discussions and Conclusions

This paper presents an innovative interactive system that can respond to natural body mechanics and provide signals using light indicators. The presented prototype uses the detected body movements of a cyclist making a direction change as the input, and promptly outputs the relevant signals using LED lights. In addition, the current prototype used a pipeline concept of CAD and digital fabrication technology, thus allowing for affordable customization. Installing the interactive system on a wearable device provides more reliable body movement detection.

Although the current prototype effectively detects body motion that indicates an imminent turn or braking, it does not provide as much advance warning as a (properly used) manual turn signal such as might be used in a car or motorcycle. Therefore, the presented system should be considered as a supplementary safety device.

Table 1. Time-lapse sequential images of functionality analysis.

ΔT (s)	Moving straight	Changing lane	Brake to stop
0.0			
0.1			
0.2			
0.3			
0.4			
0.5			
0.6			
0.7			
0.8			
0.9			



To address this problem, an active control system was developed to extend the functionality of the signaling device. As illustrated in Fig. 10, another sensing unit is attached to the forearm. This sensing unit has the same configuration as the body-sensing unit and consists of a LilyPad Arduino microcontroller connected to a GY-80 accelerometer. With different threshold value settings for the *x*, *y*, and *z* axes, the forearm sensing unit can detect the motion of commonly used hand gestures used to relay the riding intent of the cyclist, and activate corresponding light indicators. The hand motions that trigger the signaling light indicators are those that cyclists should use regardless of whether they are wearing the signaling device or not. Thus, this extended active control system follows the initial design concept of the natural user interface. Cyclists can ride the same way as when no signaling device is worn, using hand gestures to inform the intent in advance, and the indicator will automatically enhance the expression of those intents through the light signals on the vest. If the rider forgets or is not in the habit of using hand gestures when riding, the preluding body motion can still initiate the light indicator to provide a last-second alert for the drivers behind. For rider who prefer to keep both hands on the handle bars at all times, the proposed prototype can also further develop a wireless switch system installed on the handlebar for use similar to motorcycle turn signals. In conclusion, the proposed interactive system not only can be customized for its form factor, but also can be customized in terms of its controlling system, thus providing different degrees of road safety.

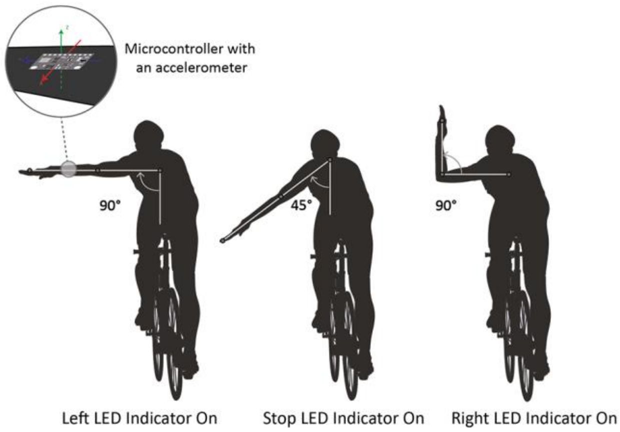


Figure 10. Active control utilizing hand gestures.

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References

[1] A. Carton, "Design of a context aware signal glove for bicycle and motorcycle riders," in proceeding of *2012 ACM Conference on Ubiquitous Computing*, Pittsburgh, Pennsylvania, Sept. 5-8, 2012, pp. 635–636.
doi: 10.1145/2370216.2370341

[2] T. Grosse-Puppendahl, O. Bechtold, L. Strassel, D. Jakob, A. Braun, and A. Kuijper, "Enhancing traffic safety with wearable low-resolution displays," in proceeding of *WOAR '15 the 2nd international Workshop on Sensor-based Activity Recognition and Interaction*, Rostock, Germany, June 25-26, 2015 Article no. 10.
doi: 10.1145/2790044.2790059

[3] A. Dancu, V. Vechev, A. A. Ünlüer, S. Nilson, O. Nygren, S. Eliasson, J. Barjonet, J. Marshall, and M. Fjeld, "Gesture bike: Examining projection surfaces and turn signal systems for urban cycling," in proceeding of *2015 International Conference on Interactive Tabletops & Surfaces*, Madeira, Portugal, Nov. 15-18, 2015, pp. 151–159.
doi: 10.1145/2817721.2817748

[4] S. Mann, "An historical account of the 'WearComp' and 'WearCam' inventions developed for applications in 'Personal Imaging,'' in proceeding of *1st IEEE International Symposium on Wearable Computers*, Cambridge, MA, USA, Oct. 13-14, 1997, p. 66.
doi: 10.1109/ISWC.1997.629921

[5] D. Wigdor and D. Wixon, *Brave NUI World: Designing Natural User Interfaces for Touch and Gesture*, 1st ed. Burlington, Mass: Morgan Kaufmann, 2011.

[6] L. A. Bloomfield, *How Things Work: The Physics of Everyday Life*, 5th ed., Hoboken, NJ: Wiley, 2013.

[7] J. A. Jacko, Ed., *Human Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications,* 3rd ed., Boca Raton, FL: CRC Press, 2012.

[8] A. Jaimes and N. Sebe, "Multimodal human–computer interaction: A survey," *Computer Vision and Image Understanding*, vol. 108, no. 1–2, pp. 116–134, 2007.
doi: 10.1016/j.cviu.2006.10.019

[9] R. P. Sharma and G. K. Verma, "Human computer interaction using hand gesture," *Procedia Computer Science*, vol. 54, pp. 721–727, 2015.
doi: 10.1016/j.procs.2015.06.085

[10] S. Mann, "Smart clothing: The wearable computer and wearcam," *Personal Technologies*, vol. 1, no. 1, pp. 21–27, 1997.
doi: 10.1007/BF01317885

[11] V. I. Pavlovic, R. Sharma, and T.-S. Huang, "Visual interpretation of hand gestures for human-computer interaction: A review," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 19, no. 7, pp. 677–695, 1997.
doi: 10.1109/34.598226

[12] J. M. Pearce, "Building research equipment with free, open-source hardware," *Science*, vol. 337, no. 6100, pp. 1303–1304, 2012.
doi: 10.1126/science.1228183

[13] L. Buechley and B. M. Hill, "LilyPad in the wild: How hardware's long tail is supporting new engineering and design communities," in proceeding of *8th ACM Conference on Designing Interactive Systems*, Aarhus, Denmark, August 16-20, 2010, pp. 199–207.
doi: 10.1145/1858171.1858206

[14] C. Severance, "Massimo banzi: Building arduino," *Computer*, vol. 47, no. 1, pp. 11–12, 2014.

[15] P. Debevec and J. Malik, "Recovering high dynamic range radiance maps from photographs," in proceeding of *24th Annual Conference on Computer Graphics and Interactive Techniques*, Los Angeles, CA, USA, August 3-8, 1997, pp. 369–378.
doi: 10.1145/258734.258884

[16] E. Reinhard, W. Heidrich, P. Debevec, S. Pattanaik, G. Ward, and K. Myszkowski, *High Dynamic Range Imaging: Acquisition, Display, and Image-Based Lighting*, 2nd ed., Burlington, MA: Morgan Kaufmann, 2010.

[17] E. Reinhard and K. Devlin, "Dynamic range reduction inspired by photoreceptor physiology," *IEEE Transactions on Visualization and Computer Graphics*, vol. 11, no. 1, pp. 13–24, 2005.
doi: 10.1109/TVCG.2005.9