Ryuji Hirayama

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Research Interests

Volumetric display, Holography, High-performance computing, Acoustic levitation, Multimodal system, Haptics, Parametric audio, Human-computer interaction, 3D Ambigram

Education

2014.03–2017.04	**PhD in Engineering**	
	Graduate School of Engineering, Chiba University, Japan	
	Theme: Volumetric display containing multiple 2D images	
2012.03–2014.04	**Master of Engineering**	
	Graduate School of Engineering, Chiba University, Japan	
2008.03–2012.04	**Bachelor of Engineering**	
	Faculty of Engineering, Chiba University, Japan	

Experience

2020.07–present	**Postdoctoral Research Fellow**
	Department of Computer Science, University College London, UK
2019.04–2020.06	**Postdoctoral Research Fellow**
	Interact Lab, School of Engineering and Informatics, University of Sussex, UK
2019.01–2019.03	**Rutherford Research Fellow**
	Interact Lab, School of Engineering and Informatics, University of Sussex, UK
2018.04–2018.12	**Research Fellow of the Japan Society for the Promotion of Science (PD)**
	Masuda Lab, Faculty of Industrial Science and Technology, Tokyo University of Science, Japan
2018.04–2018.09	**Visiting Research Fellow**
	Interact Lab, School of Engineering and Informatics, University of Sussex, UK
2017.04–2018.03	**Research Fellow of the Japan Society for the Promotion of Science (PD)**
	Itot Lab, Graduate School of Engineering, Chiba University, Japan
2015.04–2017.03	**Research Fellow of the Japan Society for the Promotion of Science (DC2)**
	Itot Lab, Graduate School of Engineering, Chiba University, Japan
2014.11–2015.03	**Research Assistant of the ImPACT Program**
	Graduate School of Engineering, Chiba University, Japan
2014.10–2015.03	**Teaching Assistant (Experiment of electrical and electronics engineering III)**
	Faculty of Engineering, Chiba University
2013.07–2014.10	**Student Assistant (Leaning support for undergraduates)**
	Academic Link Center, Chiba University

Journal Papers

1. D. M. Plasencia, **R. Hirayama**, R. Montano, and S. Subramanian, "GS-PAT: High-Speed Multi-point Sound-Fields for Phased Arrays of Transducers," ACM Transactions in Graphics (SIGGRAPH) (2020, accepted).

2. **R. Hirayama**, D. M. Plasencia, N. Masuda, and S. Subramanian, "A volumetric display for visual, tactile and audio presentation using acoustic trapping," Nature **575**, 320–323 (2019), highlighted in Nature Asia and Featured in Nature.

3. D. Matsumoto, **R. Hirayama**, N. Hoshikawa, H. Nakayama, T. Shimobaba, T. Ito, and A. Shiraki, "Interactive directional volumetric display that keeps displaying directional image only to a particular person in real-time," OSA Continuum **2**(11), 3309–3322 (2019).

4. **R. Hirayama**, H. Nakayama, A. Shiraki, T. Kakue, T. Shimobaba, and T. Ito, "Projection of multiple directional images on a volume structure with refractive surfaces," Optics Express **27**(20), 27637–27648 (2019).

5. Y. Yamamoto, N. Masuda, **R. Hirayama**, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "Special-purpose computer for electroholography in embedded systems," OSA Continuum **2**(4), 1166–1173 (2019).

6. A. Shiraki, D. Matsumoto, **R. Hirayama**, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "Improvement of an algorithm for displaying multiple images in one space," Applied Optics **58**(5), A1–A6 (2019).

7. T. Nishitsuji, Y. Yamamoto, T. Sugie, T. Akamatsu, **R. Hirayama**, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "Special-purpose computer HORN-8 for phase-type electro-holography," Optical Express **26**(20), 26722 (2018).

8. T. Kakue, Y. Wagatsuma, S. Yamada, Y. Endo, Y. Nagahama, **R. Hirayama**, T. Shimobaba, and T. Ito, "Review of real-time reconstruction techniques for aerial-projection holographic displays," Optical Engineering **57**(6), 061621 (2018).

9. T. Sugie, T. Akamatsu, T. Nishitsuji, **R. Hirayama**, N. Masuda, H. Nakayama, Y. Ichihashi, A. Shiraki, M. Oikawa, N. Takada, Y. Endo, T. Kakue, T. Shimobaba, and T. Ito, "High-performance parallel computing for next-generation holographic imaging," Nature Electronics **1**, 254–259 (2018).

10. T. Shimobaba, Y. Endo, T. Nishitsuji, T. Takahashi, Y. Nagahama, S. Hasegawa, M. Sano, **R. Hirayama**, T. Kakue, A. Shiraki, and T. Ito, "Computational ghost imaging using deep learning," Optics Communications **413**, 147–151 (2018).

11. T. Shimobaba, K. Matsushima, T. Takahashi, Y. Nagahama, S. Hasegawa, M. Sano, **R. Hirayama**, T. Kakue, and T. Ito, "Fast, large-scale hologram calculation in wavelet domain," Optics Communications **412**, 80–84 (2018).

12. A. Shiraki, M. Ikeda, H. Nakayama, **R. Hirayama**, T. Kakue, T. Shimobaba, and T. Ito, "Efficient method for fabricating a directional volumetric display using strings displaying multiple images," Applied Optics **57**(1), A33–A38 (2018).

13. T. Shimobaba, N. Kuwata, M. Honma, T. Takahashi, Y. Nagahama, M. Sano, S. Hasegawa, **R. Hirayama**, T. Kakue, A. Shiraki, N. Takada, and T. Ito, "Convolutional neural network-based data page classification for holographic memory," Applied Optics **56**(26), 7327–7330 (2017).

14. **R. Hirayama**, A. Shiraki, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "Operating scheme of a light-emitting diode array for a volumetric display exhibiting multiple full-color dynamic images," Optical Engineering **56**(7), 073108 (2017).

15. **R. Hirayama**, T. Suzuki, T. Shimobaba, A. Shiraki, M. Naruse, H. Nakayama, T. Kakue, and T. Ito, "Inkjet printing-based volumetric display projecting multiple full-colour 2D patterns," Scientific Reports **7**, 46511 (2017).

16. T. Shimobaba, Y. Endo, **R. Hirayama**, Y. Nagahama, T. Takahashi, T. Nishitsuji, T. Kakue, A. Shiraki, N. Takada, N. Masuda, and T. Ito, "Autoencoder-based holographic image restoration," Applied Optics **56**(13), F27–F30 (2017).

17. T. Shimobaba, Y. Endo, **R. Hirayama**, D. Hiyama, Y. Nagahama, S. Hasegawa, M. Sano, T. Takahashi, T. Kakue, M. Oikawa, and T. Ito, "Holographic micro-information hiding", Applied Optics **56**(4), 833–837 (2017).

18. **R. Hirayama**, A. Shiraki, M. Naruse, S. Nakamura, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "Optical Addressing of Multi-Colour Photochromic Material Mixture for Volumetric Display," Scientific Reports **6**, 31543 (2016).

19. T. Shimobaba, M. Makowski, Y. Nagahama, Y. Endo, **R. Hirayama**, D. Hiyama, S. Hasegawa, M. Sano, T. Kakue, M. Oikawa, T. Sugie, N. Takada, and T. Ito, "Color computer-generated hologram generation using the random phase-free method and color space conversion," Applied Optics **55**(15), 4159–4165 (2016).

20. **R. Hirayama**, H. Nakayama, A. Shiraki, T. Kakue, T. Shimobaba, and T. Ito, "Image quality improvement for a 3D structure exhibiting multiple 2D patterns and its implementation," Optics Express **24**(7), 7319–7327 (2016).

21. T. Sanpei, T. Shimobaba, T. Kakue, Y. Endo, **R. Hirayama**, D. Hiyama, S. Hasegawa, Y. Nagahama, M. Sano, M. Oikawa, T. Sugie, and T. Ito, "Optical encryption for large-sized images," Optics Communications **361**, 138–142 (2016).

22. T. Shimobaba, T. Kakue, Y. Endo, **R. Hirayama**, D. Hiyama, S. Hasegawa, Y. Nagahama, M. Sano, M. Oikawa, T. Sugie, and T. Ito, "Improvement of the image quality of random phase-free holography using an iterative method," Optics Communications **355**, 596–601 (2015).

23. T. Shimobaba, T. Kakue, Y. Endo, **R. Hirayama**, D. Hiyama, S. Hasegawa, Y. Nagahama, M. Sano, M. Oikawa, T. Sugie, and T. Ito, "Random phase-free kinoform for large objects," Optics Express **23**(13), 17269–17274 (2015).

24. **R. Hirayama**, M. Naruse, H. Nakayama, N. Tate, A. Shiraki, T. Kakue, T. Shimobaba, M. Ohtsu, and T. Ito, "Design, implementation and characterization of a quantum-dot-based volumetric display," Scientific Reports **5**, 8472 (2015), *highlighted in Nature Japan*

25. D. Arai, T. Shimobaba, K. Murano, Y. Endo, **R. Hirayama**, D. Hiyama, T. Kakue, and T. Ito, "Acceleration of computer-generated hologram using tilted wavefront recording plane method," Optics Express **23**(2), 1740–1747 (2015).

26. T. Shimobaba, M. Makowski, T. Kakue, N. Okada, Y. Endo, **R. Hirayama**, D. Hiyama, S. Hasegawa, Y. Nagahama, and T. Ito, "Numerical investigation of lensless zoomable holographic projection to multiple tilted planes," Optics Communications **333**, 274–280 (2014).

27. T. Shimobaba, T. Kakue, N. Okada, Y. Endo, **R. Hirayama**, D. Hiyama, and T. Ito, "Ptychography by changing the area of probe light and scaled ptychography," Optics Communications **331**, 189–193 (2014).

28. T. Shimobaba, T. Kakue, M. Oikawa, N. Takada, N. Okada, Y. Endo, **R. Hirayama**, and T. Ito, "Calculation reduction method for color computer-generated hologram using color space conversion", Optical Engineering, **53**(2), 024108 (2014).

29. T. Shimobaba, T. Kakue, M. Oikawa, N. Okada, Y. Endo, **R. Hirayama**, N. Masuda, and T. Ito, "Non-uniform sampled scalar diffraction calculation using non-uniform fast Fourier transform," Optics Letters **38**(23), 5130–5133 (2013).

30. T. Shimobaba, M. Makowski, T. Kakue, M. Oikawa, N. Okada, Y. Endo, **R. Hirayama**, N. Masuda, and T. Ito, "Lensless zoomable holographic projection using scaled Fresnel diffraction," Optics Express **21**(21), 25285–25290 (2013).

31. T. Shimobaba, H. Yamanashi, T. Kakue, M. Oikawa, N. Okada, Y. Endo, **R. Hirayama**, and T. Ito, "Inline digital holographic microscopy using a consumer scanner," Scientific Reports **3**, 2664 (2013).

32. H. Nakayama, A. Shiraki, **R. Hirayama**, N. Masuda, T. Shimobaba, and T. Ito, "Three-dimensional volume containing multiple two-dimensional information patterns," Scientific Reports **3**, 1931 (2013).

Conference Proceedings

1. **(invited) R. Hirayama**, D. M. Plasencia, N. Masuda, and S. Subramanian, "Multimodal Acoustic Trapping Volumetric Display," SPIE Optics + Photonics 2020, Online conference (2020, accepted).

2. D. M. Plasencia, **R. Hirayama**, R. Montano, and S. Subramanian, "GS-PAT: High-Speed Multi-point Sound-Fields for Phased Arrays of Transducers," SIGGRAPH 2020, Online conference (2020.08, accepted)

3. D. Matsumoto, **R. Hirayama**, N. Hoshikawa, H. Nakayama, T. Shimobaba, T. Ito, and A. Shiraki, "GPU Acceleration of Algorithm to Design Directional Volumetric Display for Real-time," IDW 2019 / 3DSA 2019, Sapporo, Japan (2019.11).

4. T. Murase, **R. Hirayama**, N. Hoshikawa, H. Nakayama, T. Shimobaba, T. Ito, and A. Shiraki, "Development of Volumetric Display Capable of Transmitting Information in Different Languages Using Language Identification," IDW 2019 / 3DSA 2019, Sapporo, Japan (2019.11).

5. M. Baba, **R. Hirayama**, N. Hoshikawa, H. Nakayama, T. Shimobaba, T. Ito, and A. Shiraki, "Implemented of Images and Sounds Person Tracking System using Directional Volumetric Display," IDW 2019 / 3DSA 2019, Sapporo, Japan (2019.11).

6. D. Matsumoto, T. Murase, **R. Hirayama**, H. Nakayama, T. Shimobaba, T. Ito, and A. Shiraki, "Subjective Image Quality Evaluation to Compare Algorithms for Designing a Directional Volumetric Display," IDW 2018, Nagoya, Japan (2018.12).

7. T. Murase, D. Matsumoto, **R. Hirayama**, H. Nakayama, T. Shimobaba, T. Ito, and A. Shiraki, "Image Quality Improvement for 3D Structure Exhibiting Multiple 2D Patterns Using Convolutional Neural Networks," IDW 2018, Nagoya, Japan (2018.12).

8. D. Matsumoto, A. Shiraki, **R. Hirayama**, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "Improvement of the Algorithm for Designing a 3D Object Exhibiting Multiple 2D Images," 3DSA 2018, Taipei, Taiwan (2018.08).

9. M. Ikeda, A. Shiraki, **R. Hirayama**, T. Kakue, T. Shimobaba, and T. Ito, "Simulation of the Projection Mapping to a Directional Volumetric Display," IDW 2017, Sendai, Japan (2017.12).

10. **R. Hirayama**, H. Nakayama, A. Shiraki, T. Kakue, T. Shimobaba, and T. Ito, "Controllable color particles in a 3D crystal projecting multiple dynamic full-color images," ACM SIGGRAPH 2017 Posters, 73, Los Angeles, USA (2017.07).

11. **R. Hirayama**, T. Suzuki, T. Shimobaba, A. Shiraki, M. Naruse, H. Nakayama, T. Kakue, and T. Ito, "Inkjet-printed 3D structure projecting multiple full-color images," OPIC IP2017, IP-20AM-1-5, Yokohama, Japan (2017.04).

12. F. Kawashima, **R. Hirayama**, A. Shiraki, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito "Gradation expression by overlap of voxels in volumetric display composed of photochromic materials," IDW / AD 2016, 3DSAp2/3Dp2-1, Fukuoka, Japan (2016.12).

13. **R. Hirayama**, A. Shiraki, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "3-D crystal with a curved surface projecting multiple 2-D images," ACM SIGGRAPH Asia 2016 Posters, 41, Macao, China (2016.12).

14. **R. Hirayama**, A. Shiraki, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "Refraction-compensating algorithm for a 3D glass structure exhibiting multiple 2D images," FiO / LS 2016, JTh2A-68, Rochester, USA (2016.10).

15. M. Oikawa, D. Hiyama, **R. Hirayama**, S. Hasegawa, Y. Endo, T. Sugie, N. Tsumura, M. Kuroshima, M. Maki, G. Okada, C. Lei, Y. Ozeki, K. Goda, and T. Shimobaba, "A computational approach to real-time image processing for serial time-encoded amplified microscopy," SPIE Photonics West BIOS 2016 (Proc. SPIE 9720), 97200E, San Francisco USA (2016.03).

16. (invited) A. Shiraki, H. Nakayama, **R. Hirayama**, T. Kakue, T. Shimobaba, and T. Ito, "Volumetric display containing multiple two dimensional information patterns," IDW 2015, PRJ1-1, Otsu, Japan (2015.12).

17. **R. Hirayama**, A. Shiraki, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "3-D crystal exhibiting multiple 2-D images with directivity," ACM SIGGRAPH Asia 2015 Posters, 1, Kobe, Japan (2015.11).

18. **(invited) R. Hirayama**, A. Shiraki, H. Nakayama, T. Kakue, T. Shimobaba, and T. Ito, "3-D crystal exhibiting multiple 2-D images with directivity," VRCAI 2015, 33, Kobe, Japan (2015.10).

19. **R. Hirayama**, A. Shiraki, M. Naruse, H. Nakayama, N. Tate, T. Kakue, T. Shimobaba, and T. Ito, "Optically controlled quantum-dot-based volumetric display exhibiting multiple patterns," JSAP-OSA Joint Symposia 2015, 15p-2F-10, Nagoya, Japan (2015.09).

20. **(invited) R. Hirayama**, M. Naruse, H. Nakayama, A. Shiraki, T. Kakue, T. Shimobaba, and T. Ito, "Optically controlled volumetric display exhibiting multiple two-dimensional patterns," CC3DMR 2015, 340–341, Busan, South Korea (2015.06).

21. **R. Hirayama**, H. Nakayama, A. Shiraki, T. Kakue, T. Shimobaba, and T. Ito, "Development of volumetric display based on multi-bit color LED," APCCAS 2014, 547–550, Okinawa, Japan (2014.11).

22. **R. Hirayama**, H. Nakayama, A. Shiraki, T. Kakue, T. Shimobaba, and T. Ito, "Volumetric display containing multiple two-dimensional color motion pictures," SPIE DSS 2014 (Proc. SPIE 9117), 911717, Baltimore, USA (2014.05).

23. (invited) T. Kakue, N. Masuda, Y. Endo, **R. Hirayama**, N. Okada, T. Shimobaba, and T. Ito, "Special-purpose computer for real-time reconstruction of holographic motion picture," OIT 2013 (Proc. SPIE 9042), 90420B, Beijing, China (2013.11).

24. **R. Hirayama**, R. Omura, Y. Kobayashi, A. Shiraki, H. Nakayama, T. Kakue, N. Masuda, T. Shimobaba, and T. Ito, "Development of a digitized volumetric display containing multiple two-dimensional patterns," 3DSA 2013, P7-2, Osaka, Japan (2013.06).

25. **R. Hirayama**, H. Ando, A. Shiraki, H. Nakayama, T. Kakue, N. Masuda, T. Shimobaba, and T. Ito, "Image-quality improvement of multiple two-dimensional patterns contained in three-dimensional volume,"3DSA 2013, S11-1, Osaka, Japan (2013.06).

26. **R. Hirayama**, T. Shimobaba, H. Nakayama, A. Shiraki, T. Kakue, N. Masuda, and T. Ito, "Optical encryption using three-dimensional volume containing multiple two-dimensional information patterns," DHIP 2012, C015, Tokushima, Japan (2012.09).

News Articles

1. **R. Hirayama**, A. Shiraki, T. Kakue, T. Shimobaba, and T. Ito, "Optical addressing method for full-color 3D display," SPIE Newsroom (2016).

Media

1. **El Hormiguero 3.0** (Prime-time Spanish TV show), "LEVITACIÓN ACÚSTICA" (2020.02).

2. **ITV News** (British TV show), "How holograms could be the future of medicine, advertising and entertainment" (2019.11).

3. **BBC Radio** (British radio channel), "Science in Action" (2019.11).

4. **The Guardian** (British Newspaper), " Hologram-like device animates objects using ultrasound waves" (2019.11).

5. **Discover Magazine** (American science magazine), "With a Floating Bead, This Device Makes Truly 3D Holographs" (2019.11).

6. **Scientific American** (American science magazine), "Hearing Is Seeing: Sound Waves Create a 3-D Display" (2019.11).

7. **Science Magazine** (News site of AAAS/Science), "See the new Star Wars–like display that could 'revolutionize' virtual reality" (2019.11).

8. **NBC News** (American news site), "With a single bead of plastic, scientists tease interactive 3D" (2019.11).

9. **NewScientist** (British science magazine), "We can now make animated 'sound holograms' that you can touch" (2019.11).

10. 日本経済新聞 (Japanese Newspaper), "立体映像とともに音・触感を再現　英大学が技術" (2019.11).

11. **Dagens Nyheter** (Swedish Newspaper), "Ny teknik skapar 3D-bilder som låter och känns" (2019.11).

12. **NRC Handelsblad** (Dutch Newspaper), "3D-beeld gevangen in geluidsgolven" (2019.11).

13. **Neue Zürcher Zeitung** (Swiss Newspaper), "Fast ein richtiges Holodeck" (2019.11).

14. **Cité des sciences et de l'industrie** (French museum webcite), "Du virtuel au bout des doigts!" (2019.11).

15. **OSA Publishing, Image of the Week**, "Projection of multiple directional images on a volume structure with refractive surfaces" (2019.10).

16. **OSA Publishing, Image of the Week**, " Image quality improvement for a 3D structure exhibiting multiple 2D patterns and its implementation" (2016.04).

17. 科学新聞 (Japanese scientific newspaper), "育志賞 - 18人に" (2016.03).

18. **TBS** (Japanese TV show), "未来の起源" (2015.09).

19. 日経産業新聞 (Japanese newspaper), "紫外線当て3D表示—千葉大など装置考案" (2015.04).

20. 日刊工業新聞 (Japanese newspaper), "光を当てると各面に異なる画像を表示—千葉大, 新原理の立体ディスプレー開発" (2015.02).

21. テレビ東京 (Japanese TV show), "ワールドビジネスサテライト (トレンドたまご)" (2013.09).

22. 日刊工業新聞 (Japanese newspaper), "見る位置で違う映像に—千葉大ディスプレイ開発" (2013.09).

23. 日刊工業新聞 (Japanese newspaper), "見る方向で違い—千葉大技術開発" (2011.06).

Grants and Awards

1. **Grant-in-Aid for JSPS Fellows**, No. 18J01002, Japan Society for the Promotion of Science, 1,300,000 JPY (about £9.7k) + salary (about £24.2k) (2018.04–2018.12).

2. **Inoue Research Award for Young Scientists**, Inoue Foundation for Science, 500,000 JPY (about £3.7k) (2018.02).

3. **Young Researcher Award**, Kenjiro Takayanagi Foundation, 2,000,000 JPY (about £14.9k) (2018.01).

4. **President Award for the Excellent Record**, Chiba University (2017.03).

5. **Dean Award for the Excellent Record**, Graduate School of Engineering, Chiba University (2017.03).

6. **GP Program to Support Sending Graduate Students Abroad**, Institute for Global Prominent Research, Chiba University, 136,000 JPY (about £1.0k) (2017.12).

7. **Program to Support Sending Graduate Students Abroad**, Chiba University, 136,000 JPY (about £1.0k) (2017.10).

8. **Grant-in-Aid for JSPS Fellows**, No. 16J30007, Japan Society for the Promotion of Science, 2,300,000 JPY (about £17.1k) + salary (about £35.7k) (2016.04–2018.03).

9. **JSPS Ikushi Prize**, Japan Society for the Promotion of Science, 2,000,000 JPY (about £14.9k) (2016.03).

10. **KONICA MINOLTA Science and Technology Foundation Award**, The Optical Society of Japan, 50,000 JPY (about £0.4k) (2015.06).

11. **Scholarship Loan Forgiveness for Academic Excellence** (Full Amount), Japan Student Services Organization (2015.05).

12. **Best Poster Award (FORUM 8 Award)**, Computer Graphic Arts Society (2015.03).

13. **Outstanding Paper Award for Young C&C Researchers**, NEC C&C Foundation (2015.01).

14. **Grant-in-Aid for JSPS Fellows**, No. 15J07684, Japan Society for the Promotion of Science, 1,200,000 JPY (about £9.0k) + salary (about £17.9k) (2015.04–2016.03)

15. **Scholarship Loan Forgiveness for Academic Excellence** (Full Amount), Japan Student Services Organization (2014.05).

16. **Program to Support Sending Graduate Students Abroad**, Chiba University, 150,000 JPY (about £1.1k) (2014.04).

17. **Grants for Researchers Attending International Conferences**, NEC C&C Foundation, 200,000 JPY (about £1.5k) (2014.04).

18. **President Award for the Excellent Record**, Chiba University (2014.03).

19. **Dean Award for the Excellent Record**, Graduate School of Engineering, Chiba University (2014.03).

Membership

2016.10–present	Association for Computing Machinery (ACM)
2016.08–present	The Optical Society (OSA)

Skills

Programming

C, C++, C#, Python, CUDA, OpenCL, Matlab, VHDL, Verilog HDL, OpenGL, OpenCV, HTML/CSS

Others

Electronics (FPGA design and Microcontroller), Real-time system (GPU computing, Multi threads, and FPGA), Fabrication (3D printer, Laser cutter, and Luminescent materials), Projection mapping, 2D/3D design (Illustrator and Maya).