

BREAKING THE BARRIERS TO TRUE AUGMENTED REALITY

KEYNOTE AT 23RD INTERNATIONAL DISPLAY WORKSHOP

FUKUOKA, JAPAN

7 DECEMBER 2016

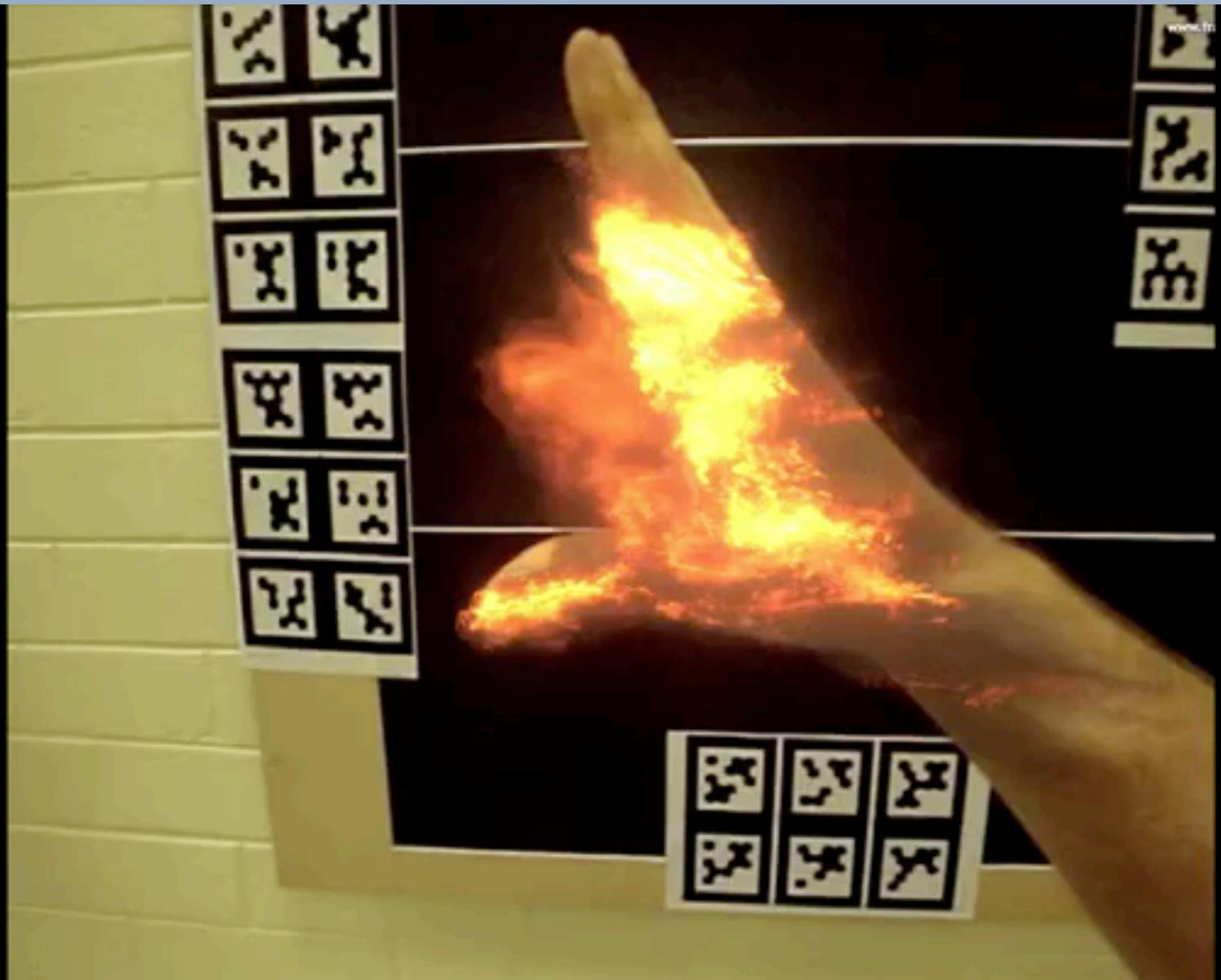
CHRISTIAN SANDOR
CHRISTIAN@SANDOR.COM



BURNAR: FEEL THE HEAT



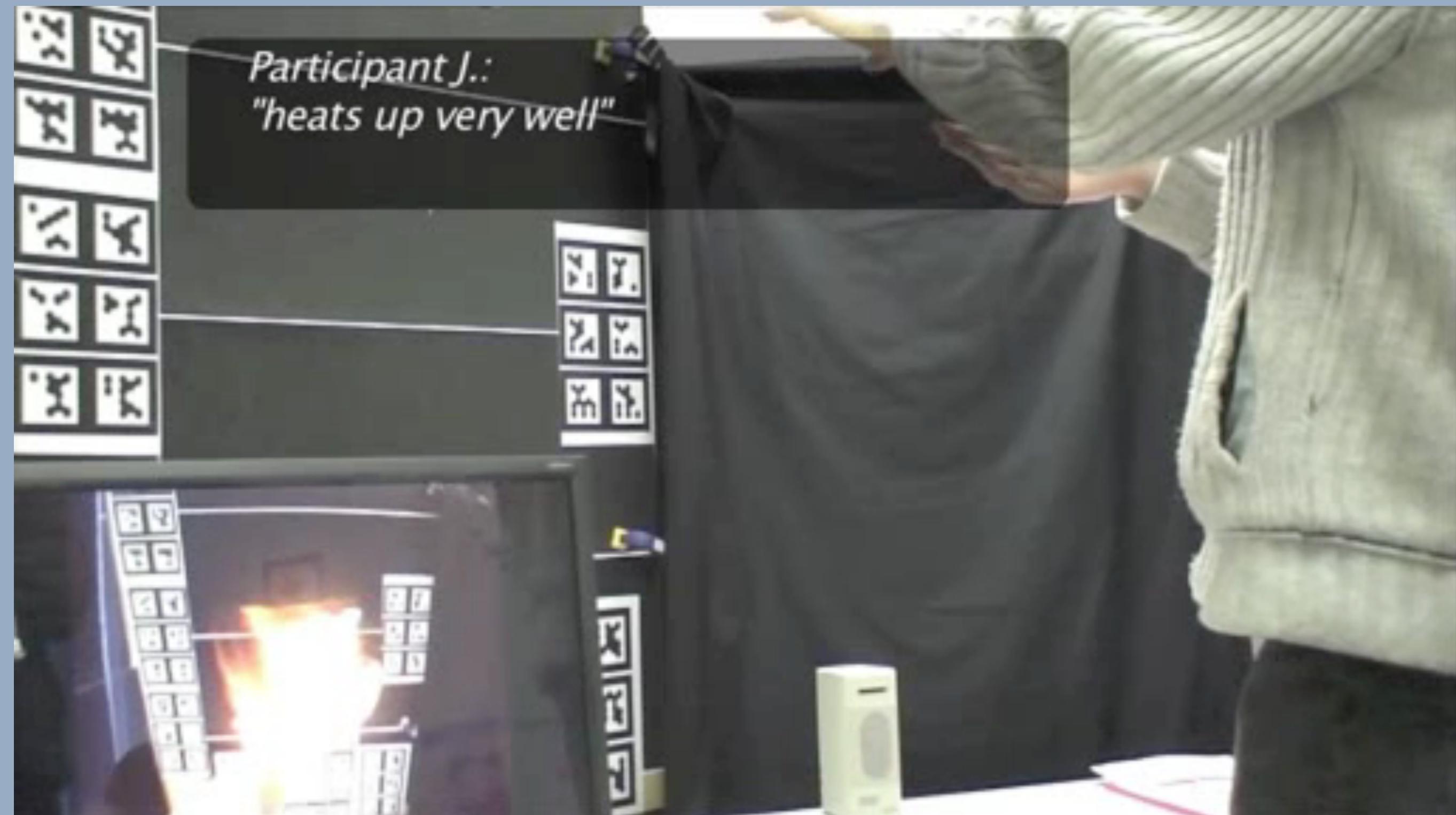
MATT SWOBODA, THANH NGUYEN, ULRICH ECK, GERHARD REITMAYR, STEFAN HAUSWIESNER,
RENE RANFTL, AND CHRISTIAN SANDOR. DEMO AT *IEEE INTERNATIONAL SYMPOSIUM ON MIXED
AND AUGMENTED REALITY*, BASEL, SWITZERLAND, OCTOBER 2011. **BEST DEMO AWARD**



Computer Vision

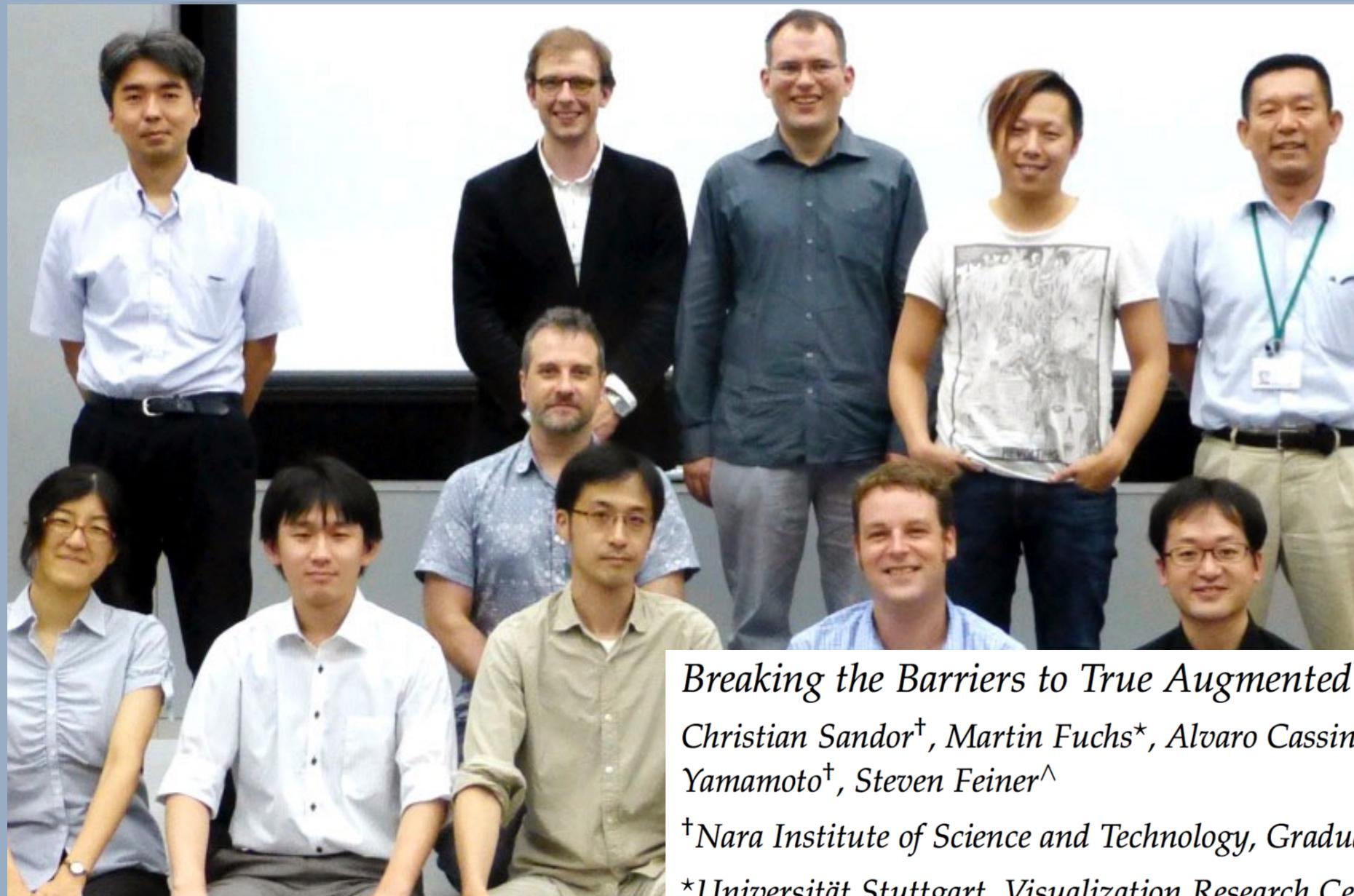
Computer Graphics

BURNAR: INVOLUNTARY HEAT SENSATIONS IN AR



PETER WEIR, CHRISTIAN SANDOR, MATT SWOBODA, THANH NGUYEN, ULRICH ECK, GERHARD REITMAYR, AND ARINDAM DEY. *PROCEEDINGS OF THE IEEE VIRTUAL REALITY CONFERENCE*, PAGES 43–46, ORLANDO, FL, USA, MARCH 2013.

WORKSHOP AT NAIST, AUGUST 2014



Breaking the Barriers to True Augmented Reality

Christian Sandor[†], Martin Fuchs^{}, Alvaro Cassinelli[†], Hao Li[○], Richard Newcombe[×], Goshiro Yamamoto[†], Steven Feiner[^]*

[†]Nara Institute of Science and Technology, Graduate School of Information Science, Japan

^{}Universität Stuttgart, Visualization Research Center, Germany*

[○]University of Southern California, Department of Computer Science, USA

[×]University of Washington, Department of Computer Science and Engineering, USA

[^]Columbia University, Department of Computer Science, USA

December 17, 2015

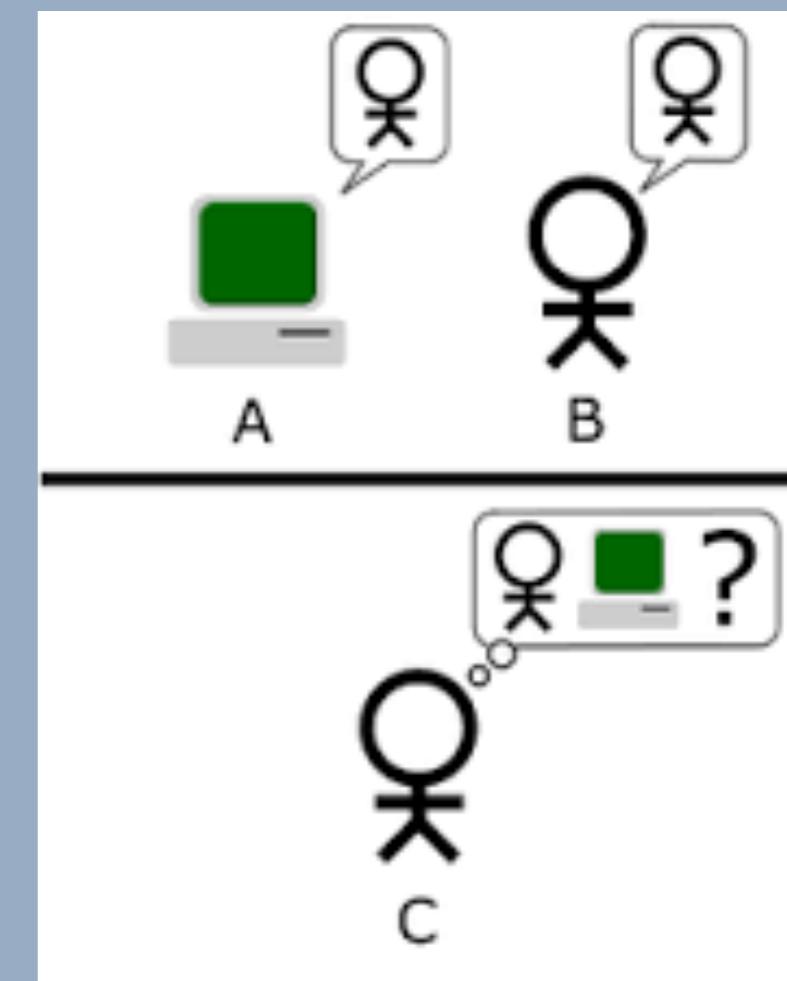
TRUE AR: WHAT?

DEFINITION:

1. UNDETECTABLE MODIFICATION OF USER'S PERCEPTION
2. GOAL: SEAMLESS BLEND OF REAL AND VIRTUAL WORLD

INSPIRED BY ALAN TURING'S IMITATION GAME

PURPOSE: TEST QUALITY OF AI



[HTTPS://EN.WIKIPEDIA.ORG/WIKI/TURING_TEST](https://en.wikipedia.org/wiki/Turing_test)

ALAN TURING. COMPUTING MACHINERY AND INTELLIGENCE. *MIND*, 59 (236): 433-460, OCTOBER 1950.

RELATION TO OTHER TURING TESTS

DIFFICULTY

AUGMENTED REALITY

VIRTUAL REALITY

VISUAL COMPUTING: QI SHAN, RILEY ADAMS, BRIAN CURLESS, YASUTAKA FURUKAWA, STEVEN M. SEITZ: THE VISUAL TURING TEST FOR SCENE RECONSTRUCTION. *3DV* 2013: 25-32

COMPUTER GRAPHICS: MICHAEL D. MCGUIGAN. GRAPHICS TURING TEST. *ARXIV E-PRINTS*, ARXIV:CS/0603132V1, 2006

TRUE AR: WHY?

TRAINING: SPORTS & SKILLS

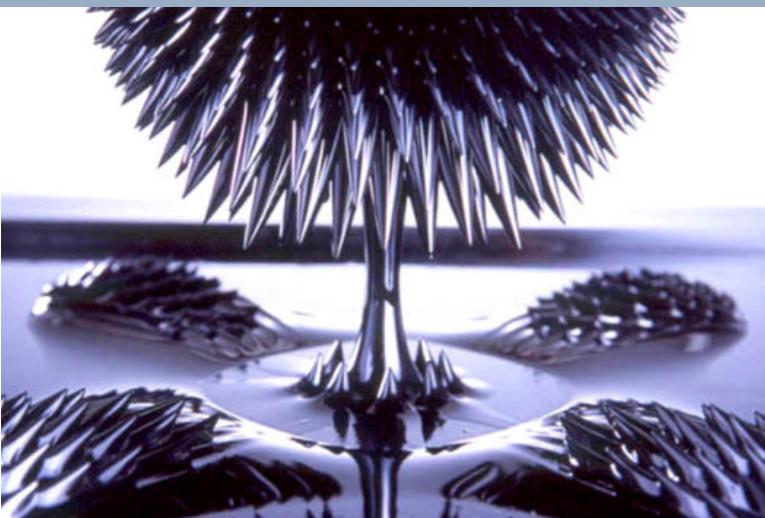
AMUSEMENT: INTERACTIVE STORIES

SCIENCE: PSYCHOLOGY & NEUROSCIENCE

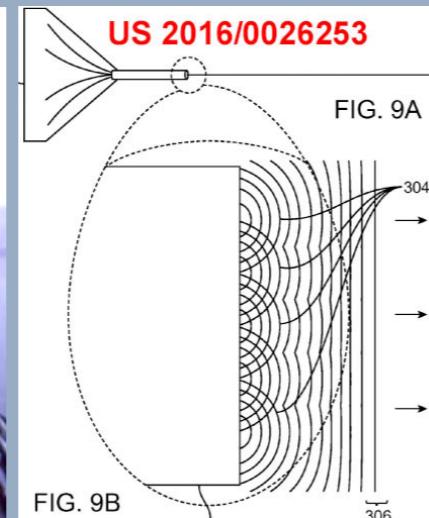
LAW: FORENSICS & LOGISTICS OF CRIME SCENE



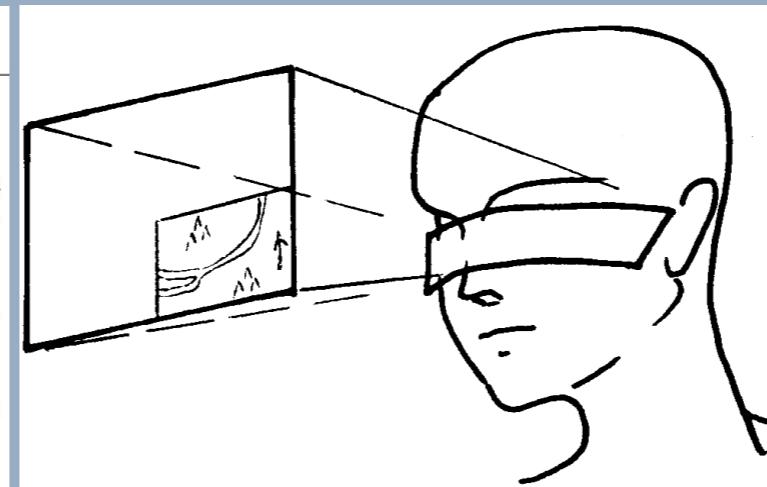
TRUE AR: HOW?



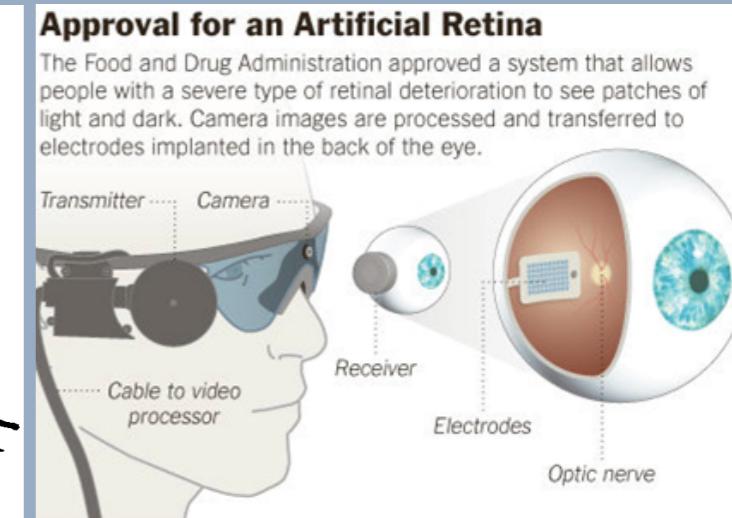
CONTROLLED
MATTER



SURROUND
AR



PERSONALIZED AR



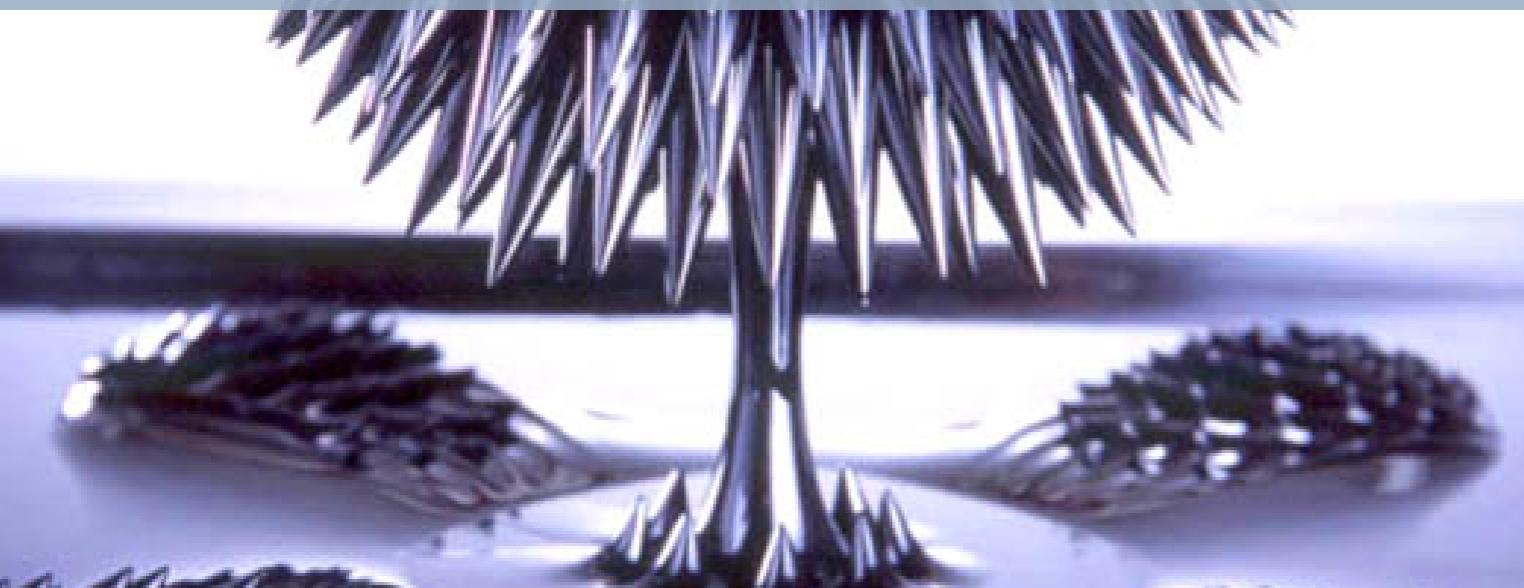
IMPLANTED AR



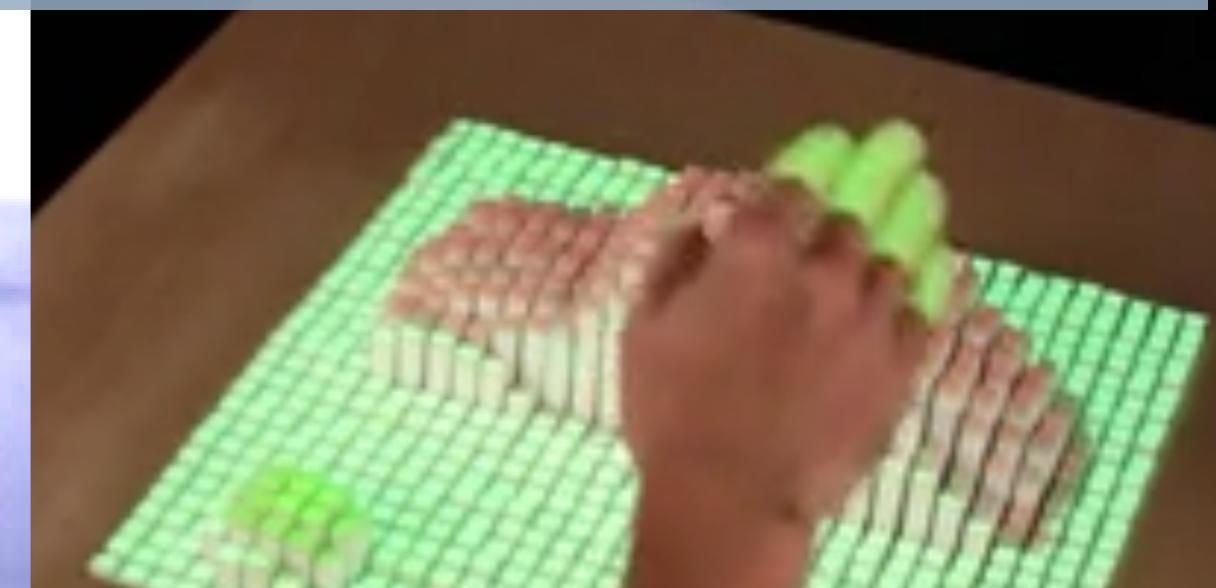
MANIPULATING
ATOMS

MANIPULATING
PERCEPTION

CONTROLLED MATTER



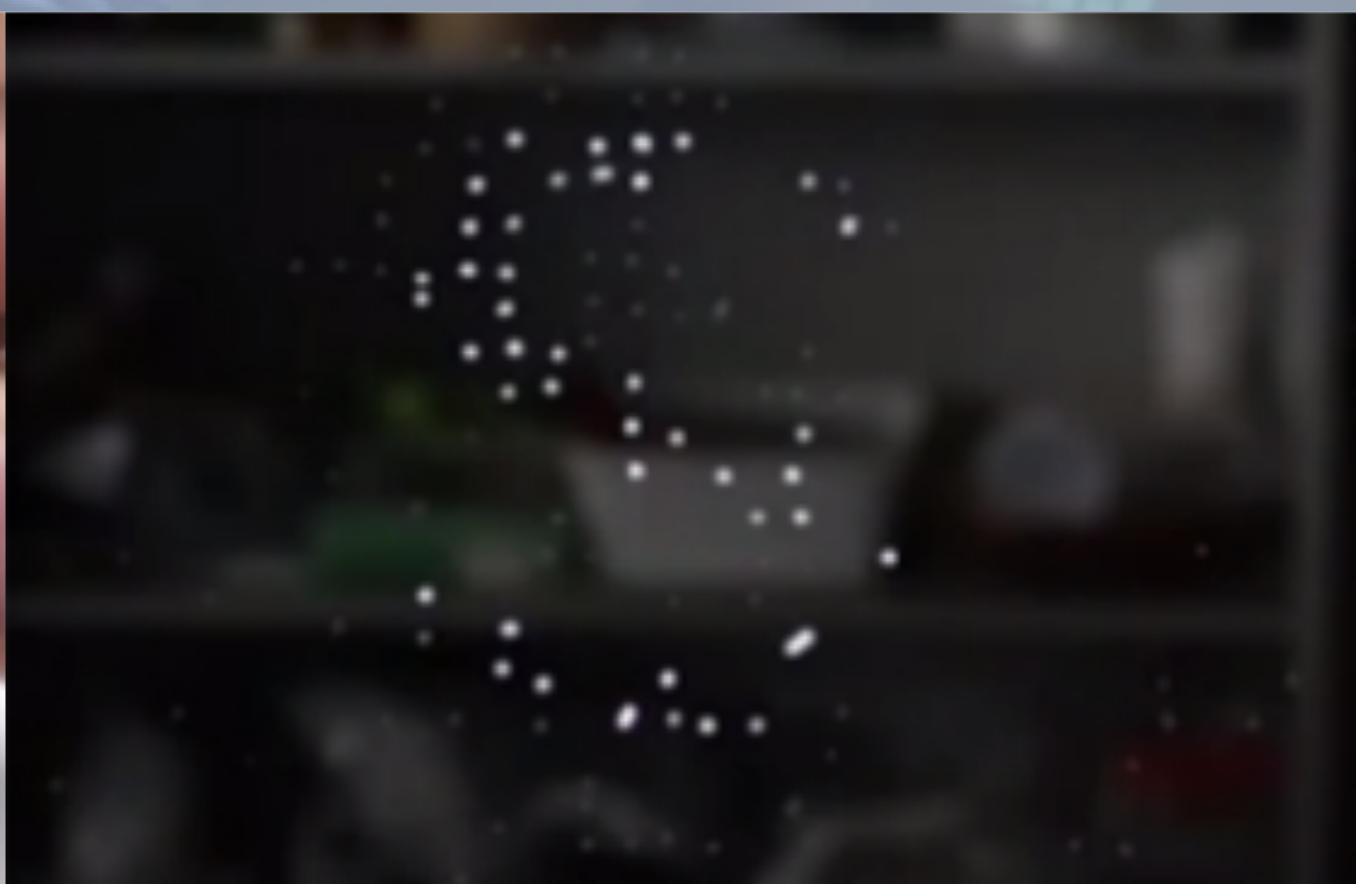
SACHIKO KODAMA. PROTRUDE, FLOW. ACM SIGGRAPH 2001 ART GALLERY.



[HTTP://TANGIBLE.MEDIA.MIT.EDU/PROJECT/INFORM](http://tangible.media.mit.edu/project/inform)



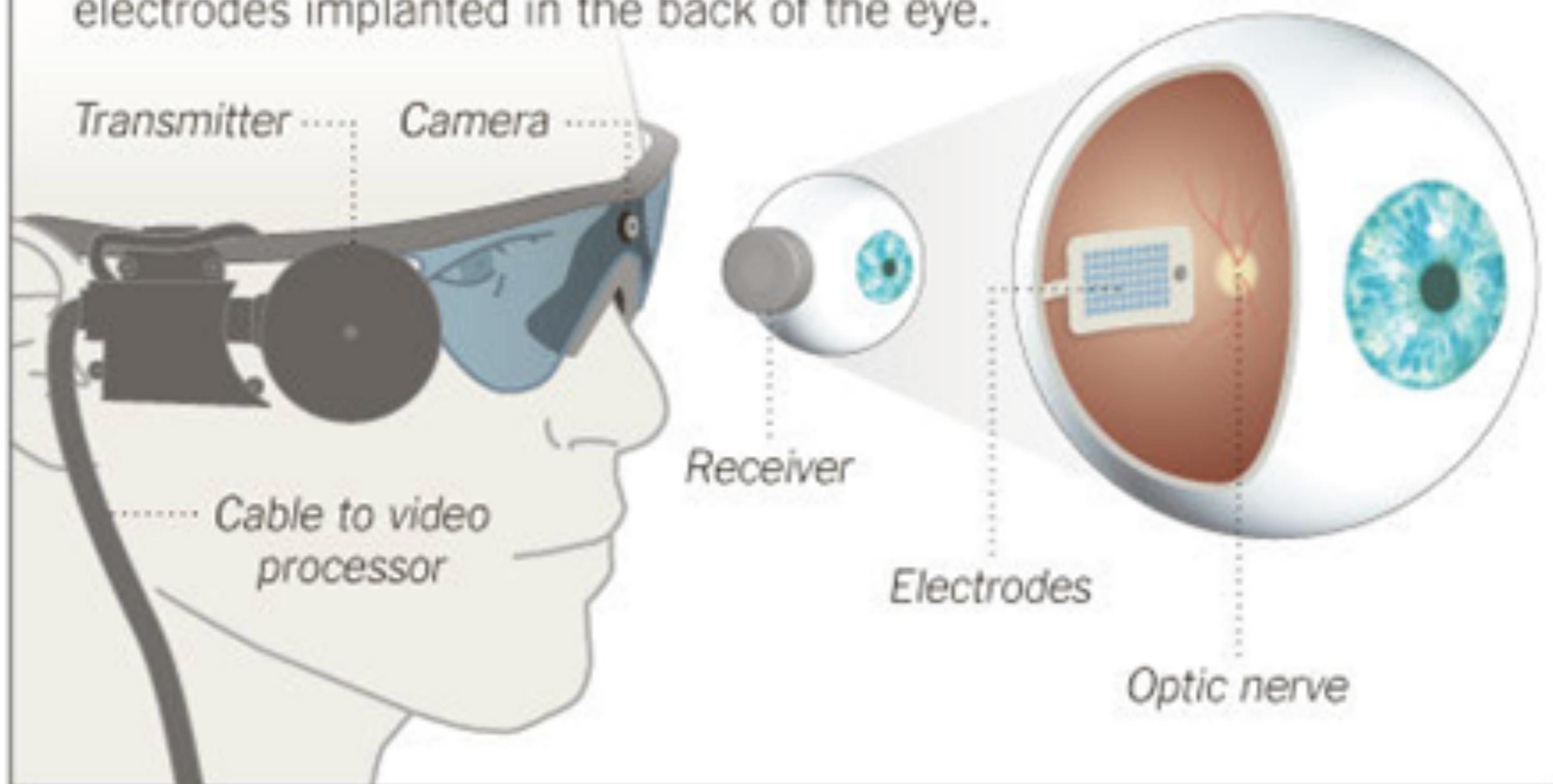
[HTTP://PIXIEDUSTTECH.COM](http://pixiedusttech.com)



IMPLANTED AR

Approval for an Artificial Retina

The Food and Drug Administration approved a system that allows people with a severe type of retinal deterioration to see patches of light and dark. Camera images are processed and transferred to electrodes implanted in the back of the eye.

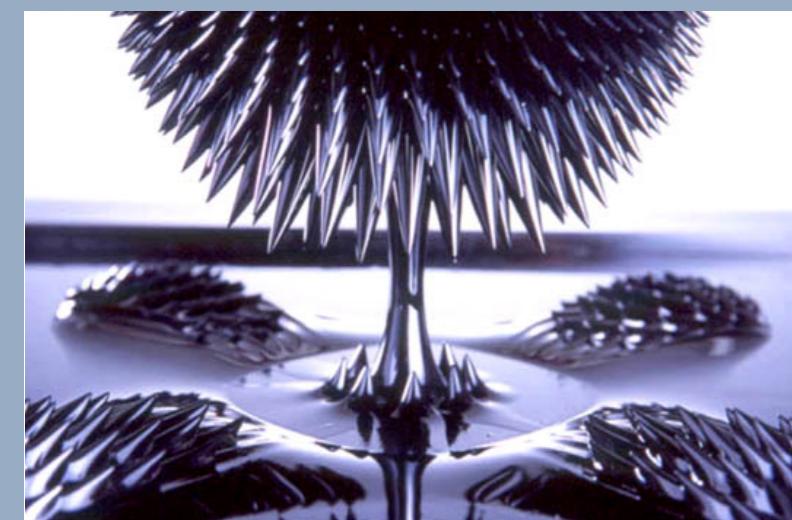


SURROUND VS. PERSONALIZED AR

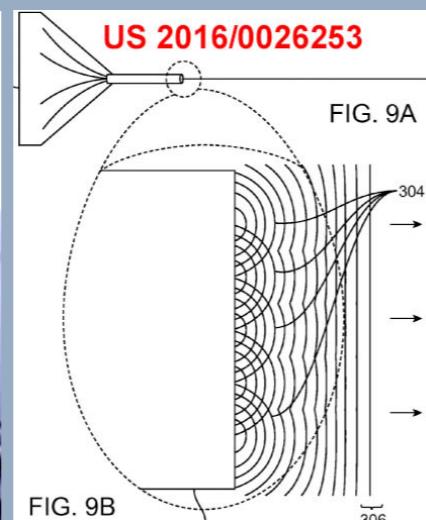
LIGHT FIELD DISPLAYS:

FULL

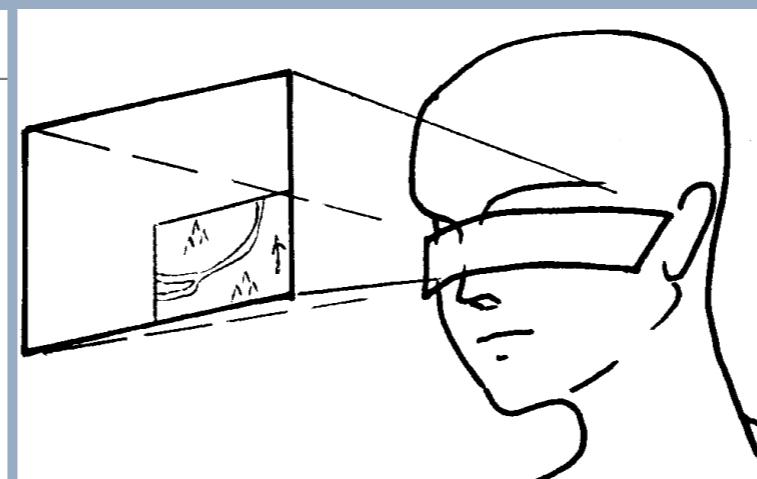
PERCEIVABLE
SUBSET



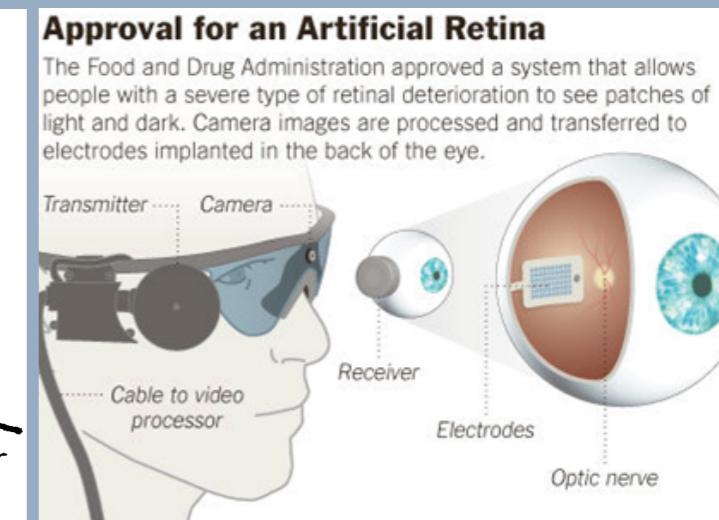
CONTROLLED
MATTER



SURROUND
AR



PERSONALIZED AR



IMPLANTED AR

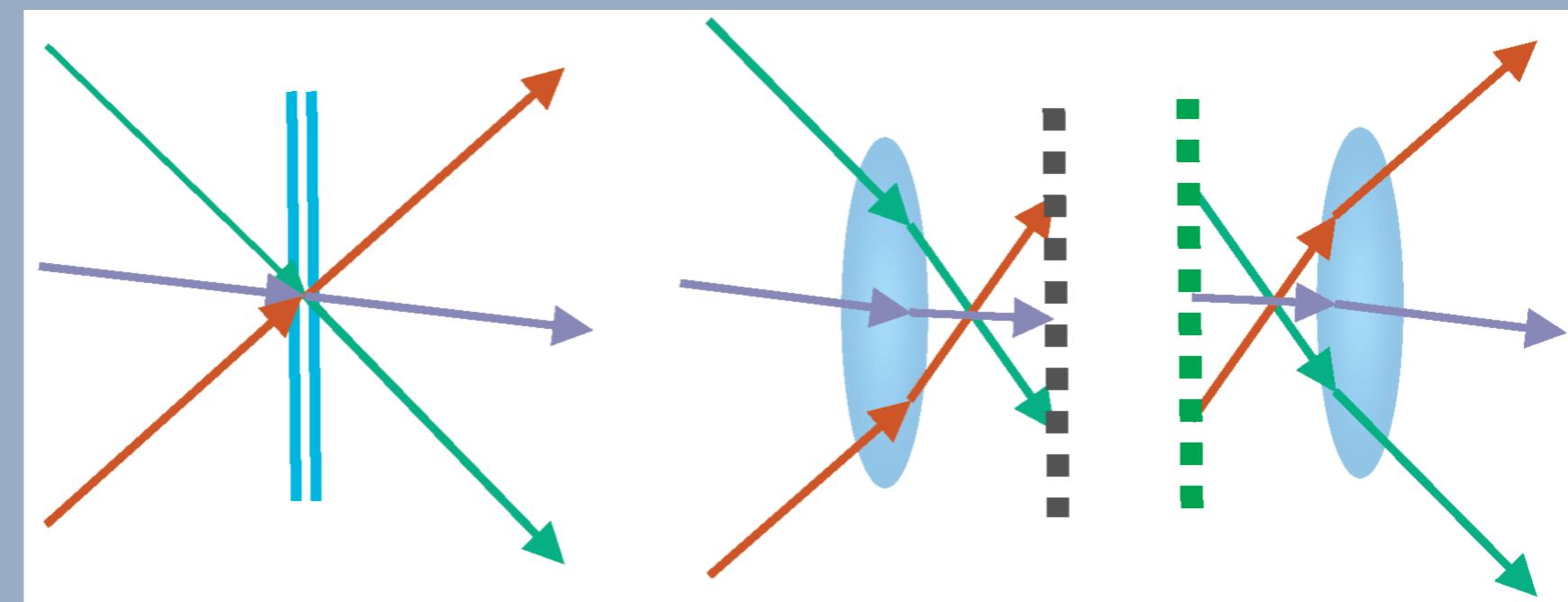


MANIPULATING
ATOMS

MANIPULATING
PERCEPTION

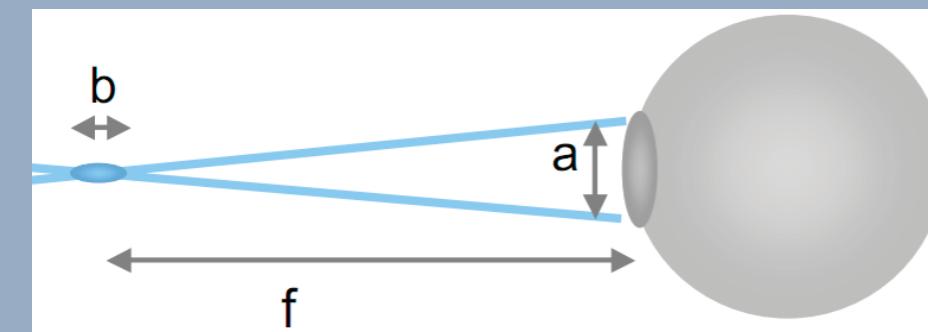
LIGHT FIELD DISPLAYS

VISION:
DISPLAY AS WINDOW

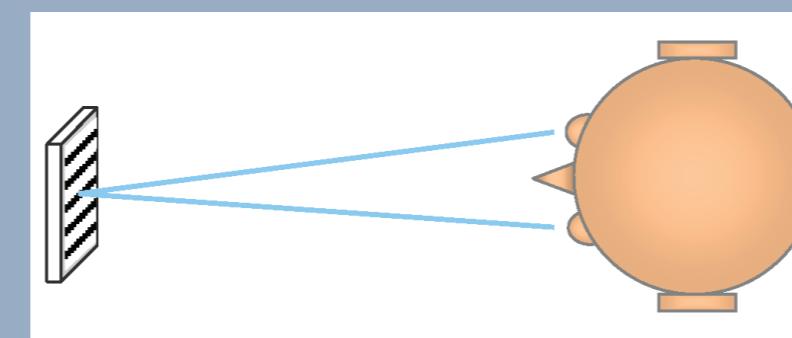


SENSOR DISPLAY
ARRAY ARRAY

GOAL: NATURAL HUMAN VISUAL PERCEPTION

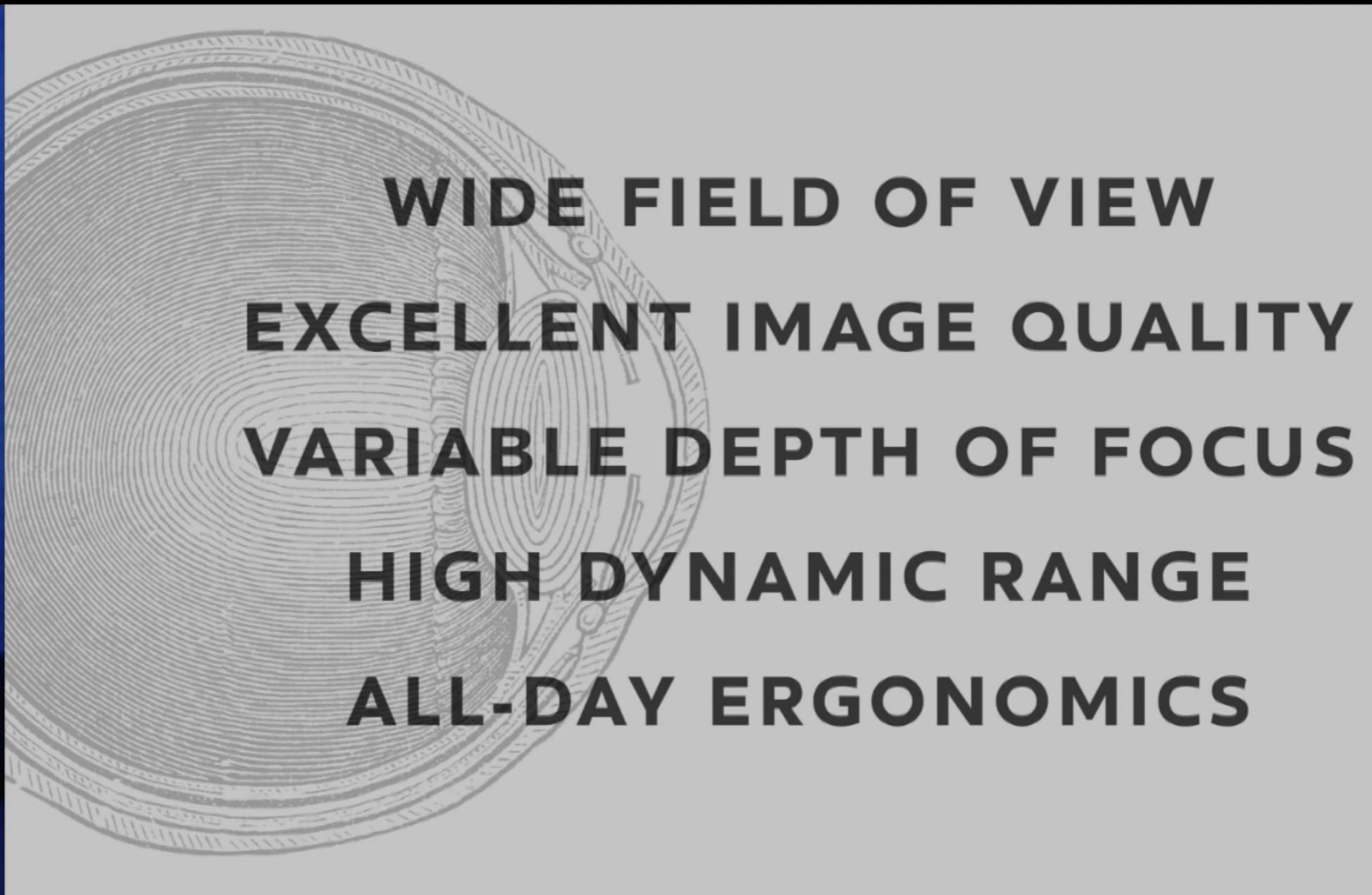


ACCOMMODATION



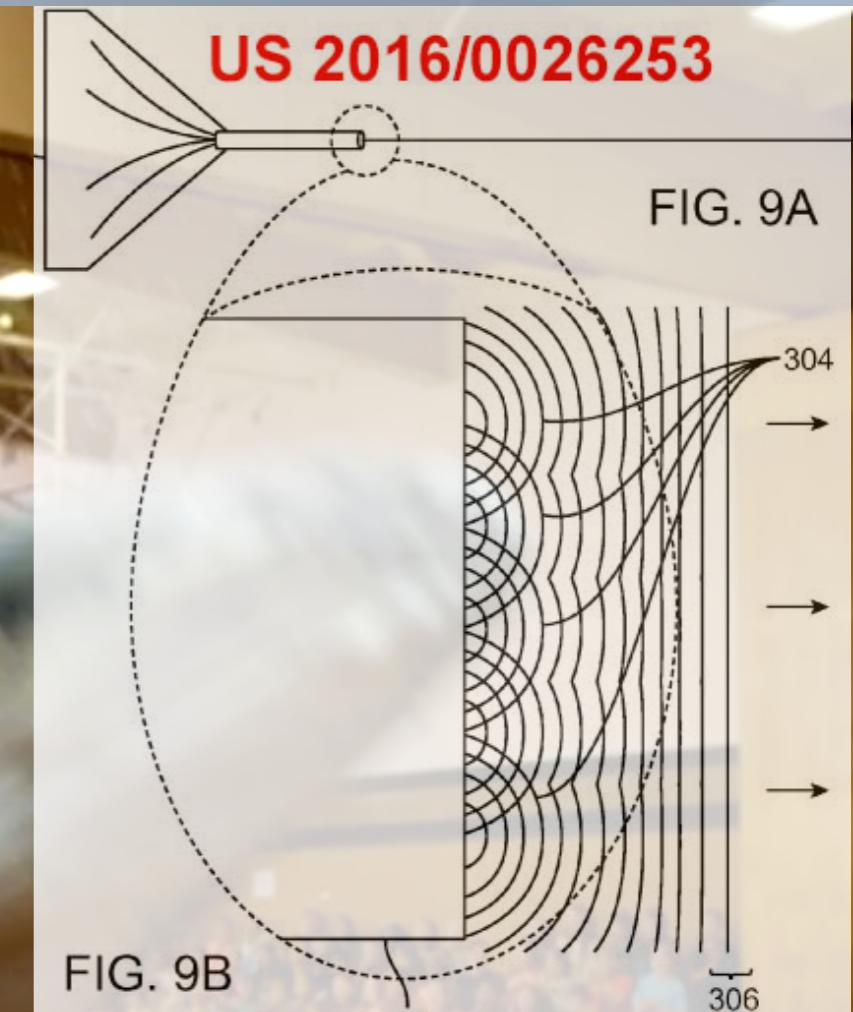
VERGENCE

FUTURE OCULUS DISPLAYS



MICHAEL ABRASH. OCULUS CONNECT 2 KEYNOTE. OCTOBER 2015

SURROUND AR: MAGIC LEAP



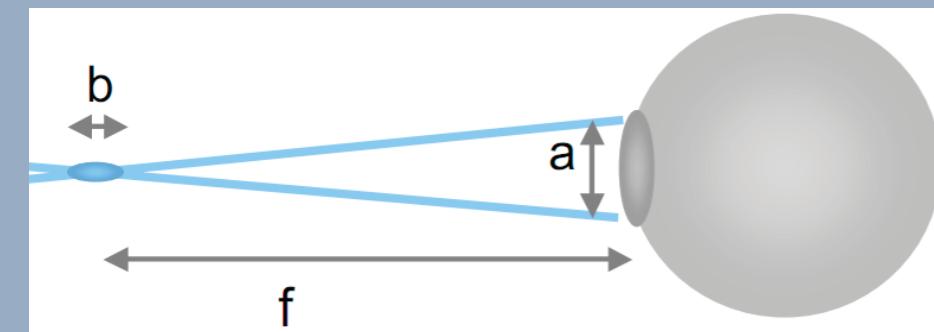
Funding Rounds (3) - \$1.39B

UPDATE

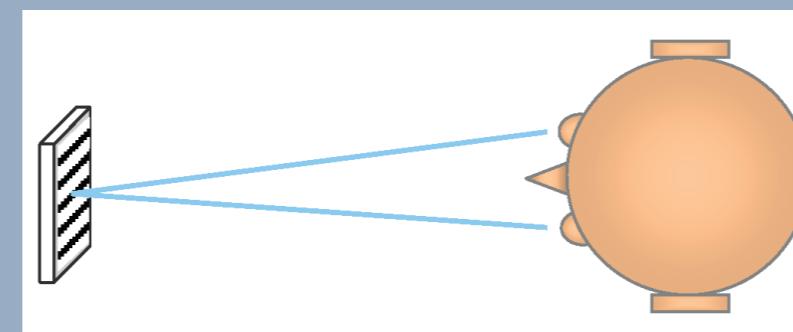
Date	Amount / Round	Valuation	Lead Investor	Investors
Feb, 2016	\$793.5M / Series C	—	Alibaba	9
Oct, 2014	\$542M / Series B	—	Google	8
Feb, 2014	\$50M / Series A	—	—	0

PERSONALIZED AR: A SMARTER APPROACH

KEY IDEA: MEASURE HUMAN VISUAL SYSTEM & DISPLAY SUBSET OF LIGHT FIELD



ACCOMMODATION

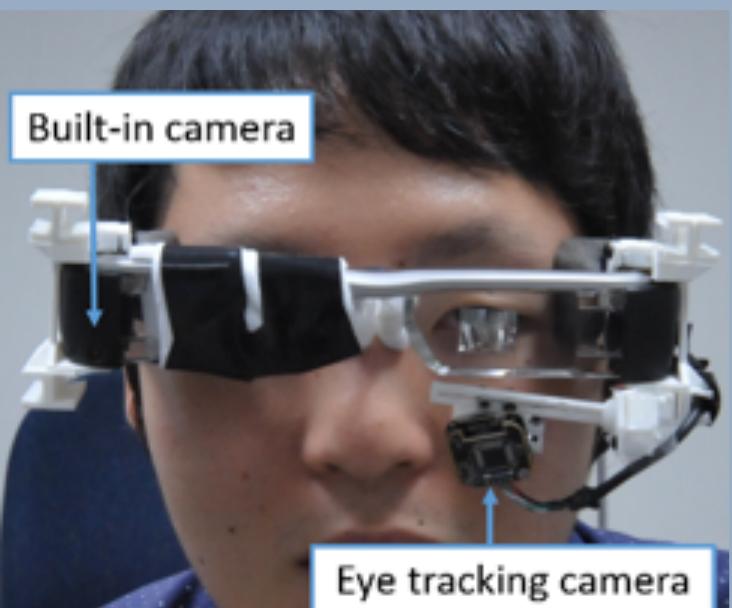


VERGENCE

BENEFIT: REDUCE REQUIRED DISPLAY PIXELS BY SEVERAL ORDERS OF MAGNITUDE

WILL BE ACHIEVED WELL BEFORE SURROUND AR!

DISPLAYS

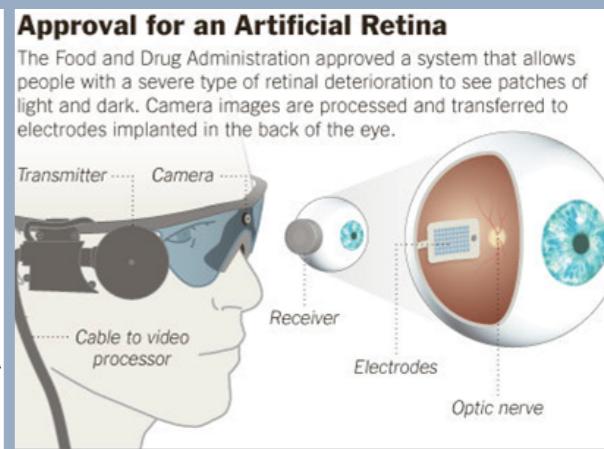
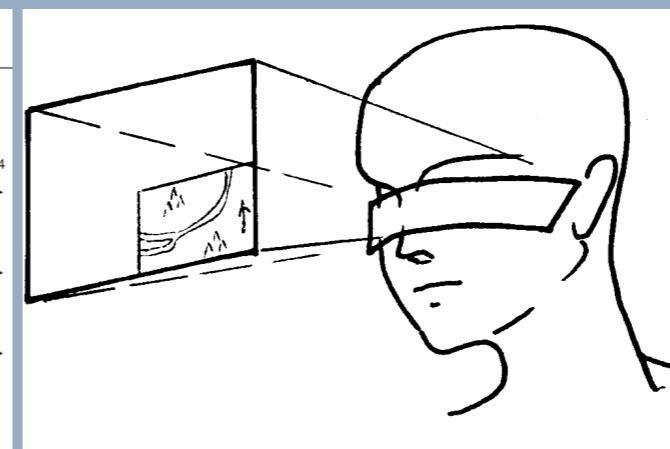
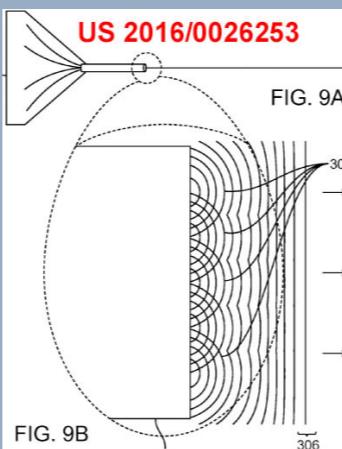
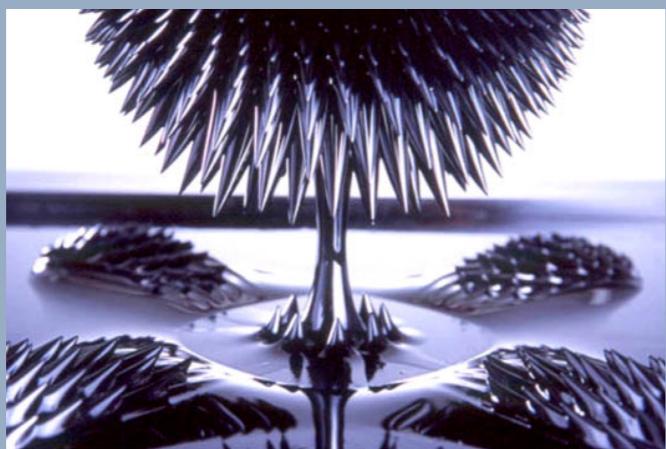


REMOVE
GEOMETRIC ALIGNMENT ARTIFACTS

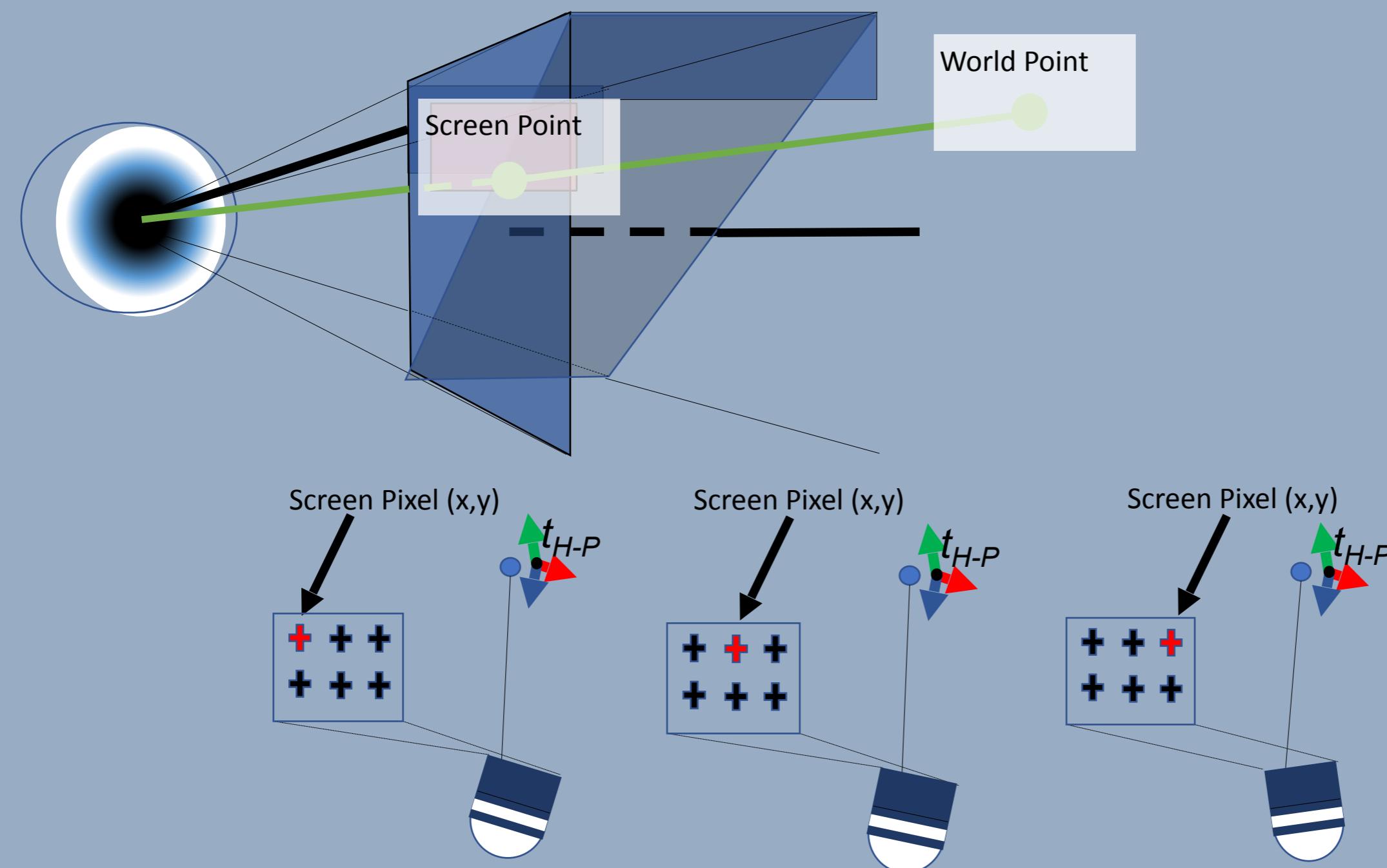
CREATE
CORRECT
BLUR



PHILOSOPHY: TRUE AUGMENTED REALITY

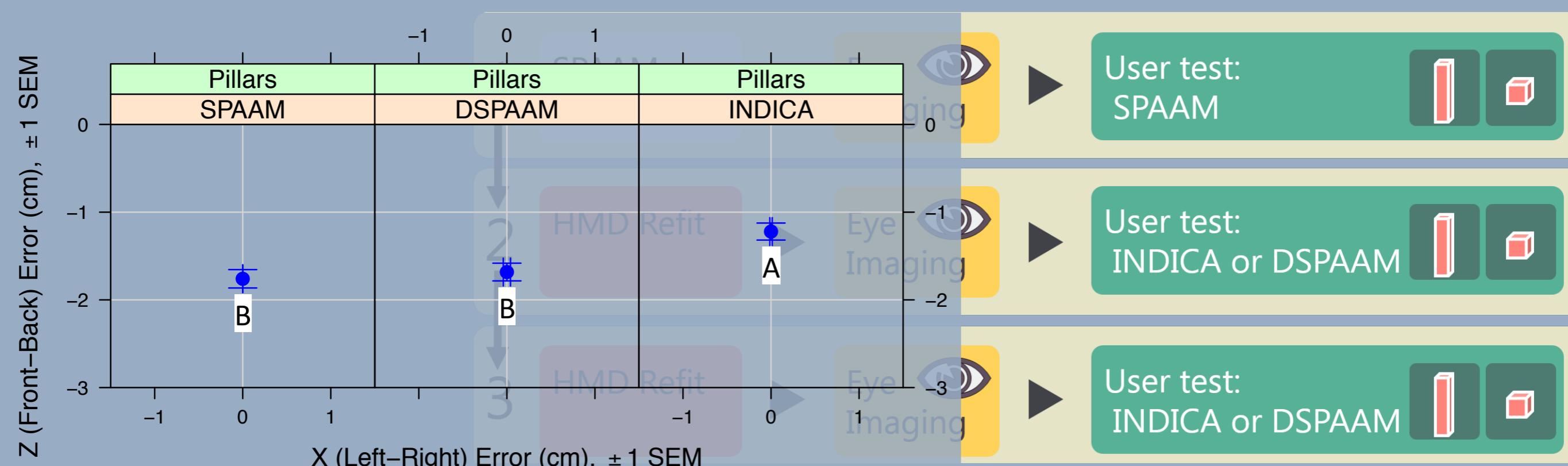


GEOMETRIC ALIGNMENT: SPAAM



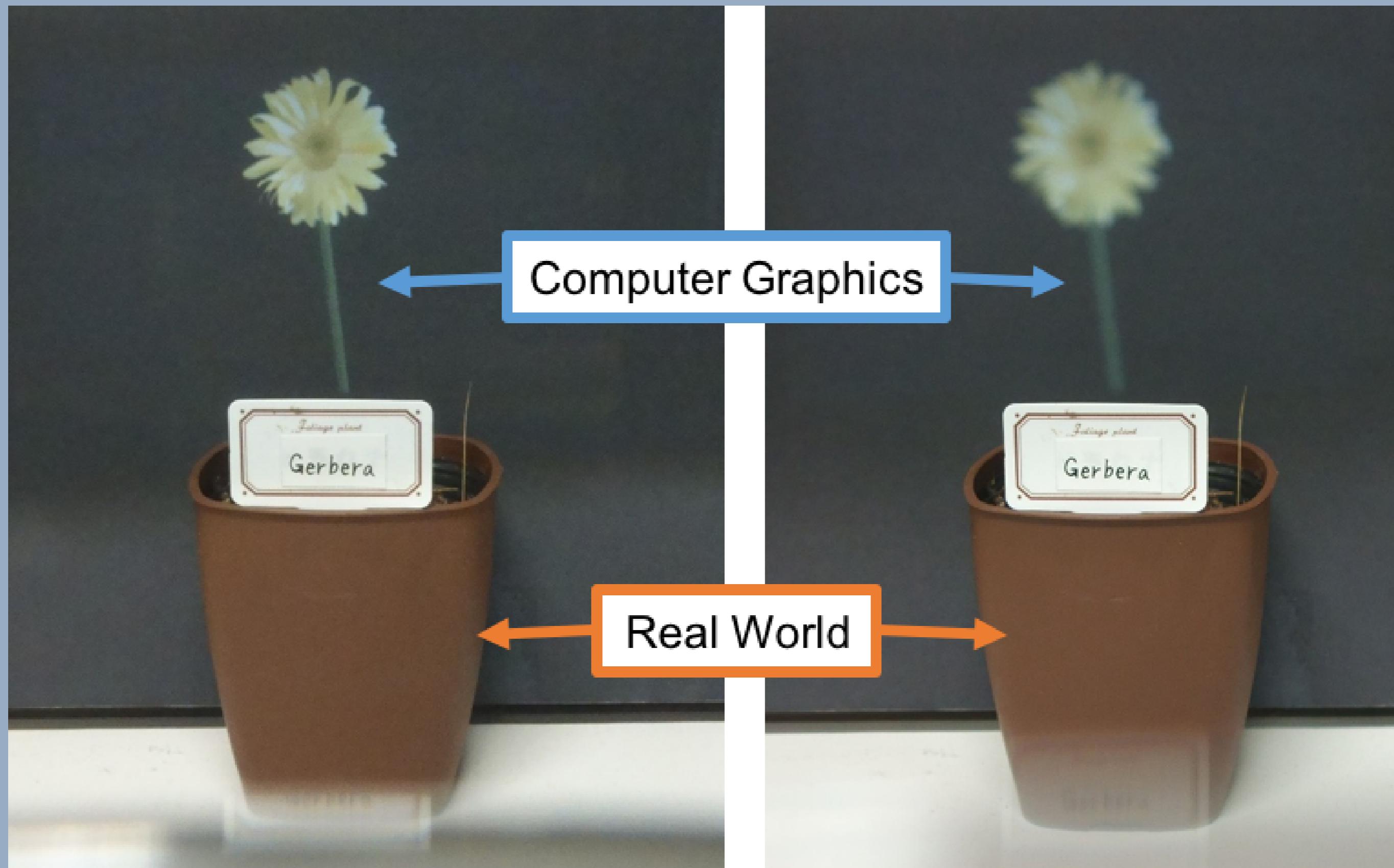
MIHRAN TUCERYAN, YAKUP GENC, AND NASSIR NAVAB. SINGLE-POINT ACTIVE ALIGNMENT METHOD (SPAAM) FOR OPTICAL SEE-THROUGH HMD CALIBRATION FOR AUGMENTED REALITY. *PRESENCE: TELEOPERATORS AND VIRTUAL ENVIRONMENTS*, 11(3):259-276, JUNE 2002.

OUR METHOD: ONLY SPAAM ONCE



KENNETH MOSER, YUTA ITOH, KOHEI OSHIMA, EDWARD SWAN, GUDRUN KLINKER, AND CHRISTIAN SANDOR. SUBJECTIVE EVALUATION OF A SEMI-AUTOMATIC OPTICAL SEE-THROUGH HEAD-MOUNTED DISPLAY CALIBRATION TECHNIQUE. *IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS*, 21(4):491–500, MARCH 2015.

BLUR ARTIFACTS

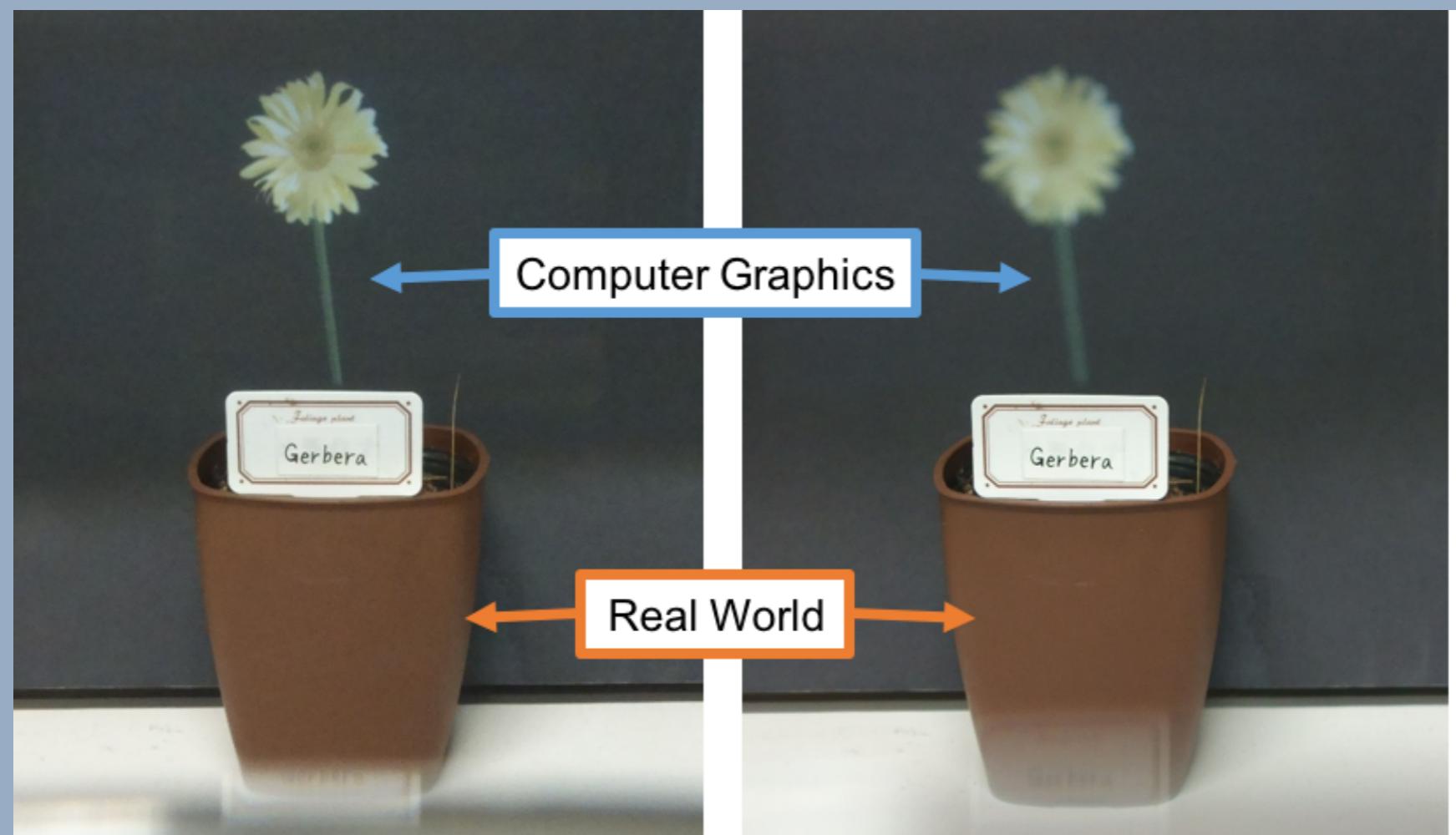
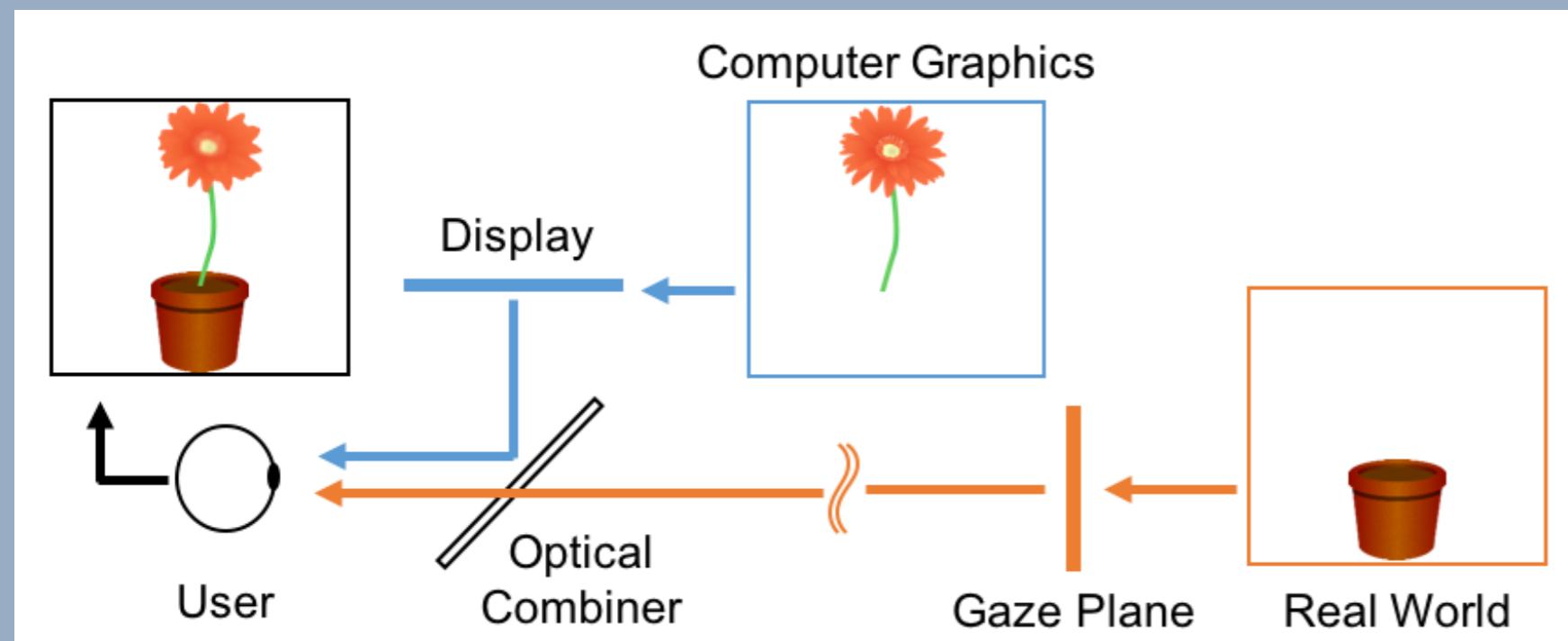


DESIRED

MOST DISPLAYS

BLUR ARTIFACTS

REAL PHOTO

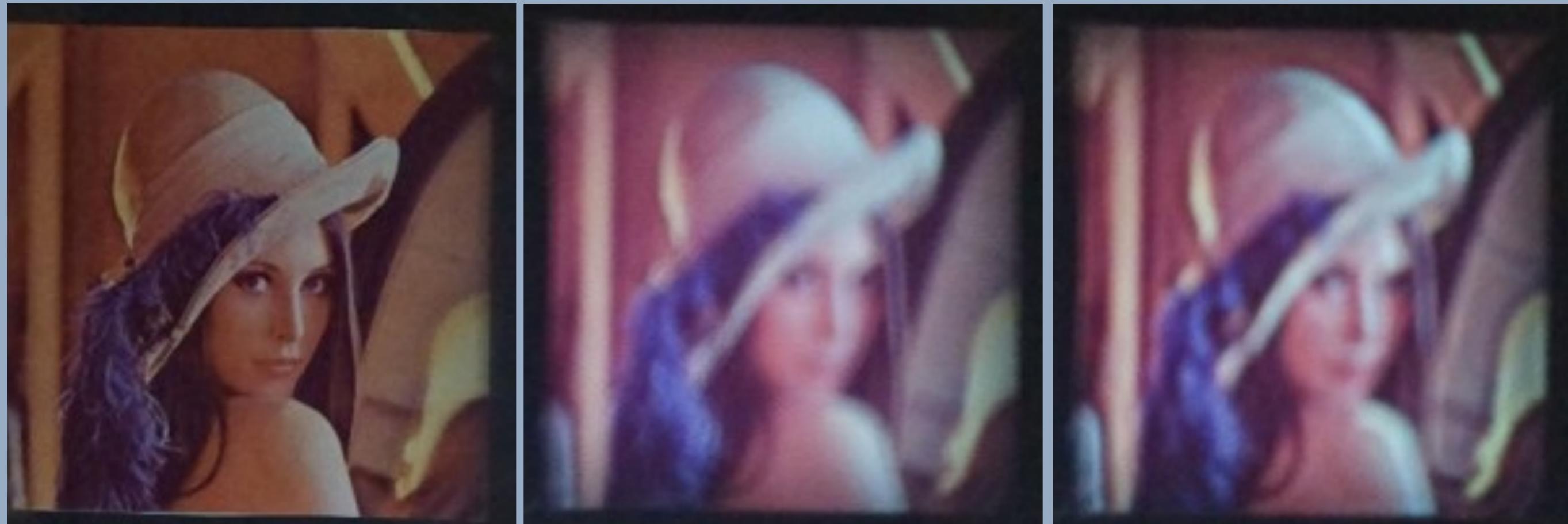


DESIRED

MOST DISPLAYS

"MATCHING" IMAGE

OUR METHOD: SHARPVIEW



REAL PHOTO

"MATCHING" IMAGE

SHARPVIEW

KOHEI OSHIMA, KENNETH R MOSER, DAMIEN CONSTANTINE ROMPAPAS, J EDWARD SWAN II, SEI IKEDA, GOSHIRO YAMAMOTO, TAKAFUMI TAKETOMI, CHRISTIAN SANDOR, AND HIROKAZU KATO. IMPROVED CLARITY OF DEFOCUSSED CONTENT ON OPTICAL SEE-THROUGH HEAD-MOUNTED DISPLAYS. IN *IEEE SYMPOSIUM ON 3D USER INTERFACES*, PAGES 173–181, GREENVILLE, SOUTH CAROLINA, USA, MARCH 2016.

BASIC IDEA: PRE-SHARPENING

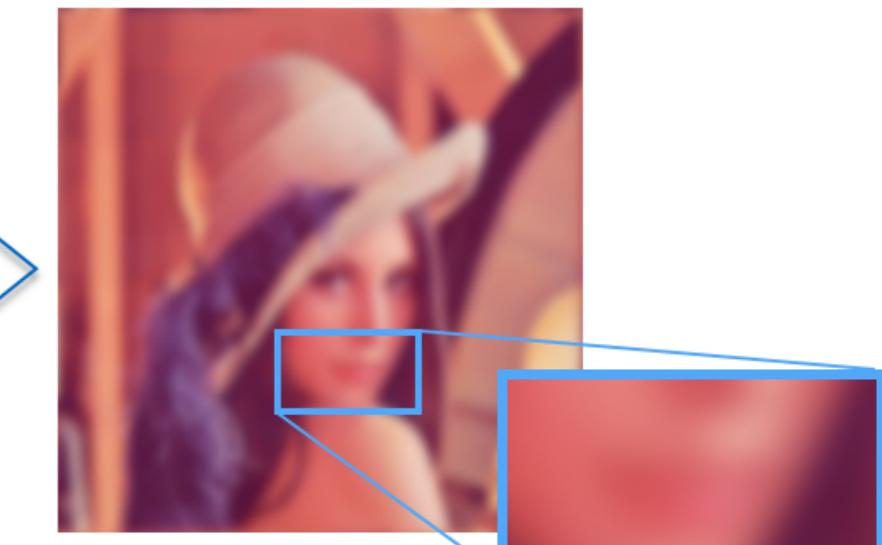
Focus blur is represented by convolution

$$o * p = b$$

※ p : Point Spread Function (PSF)



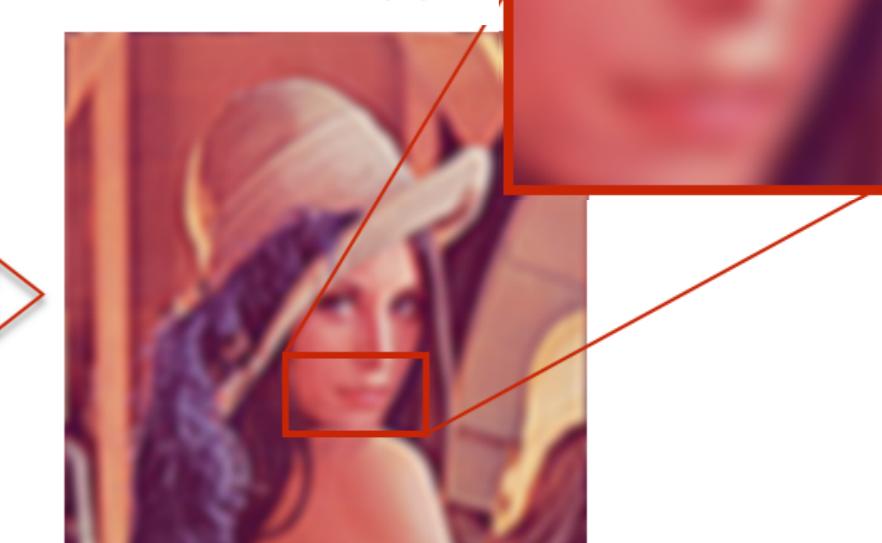
Original(o)



Blurred(b)



Sharpened(s)

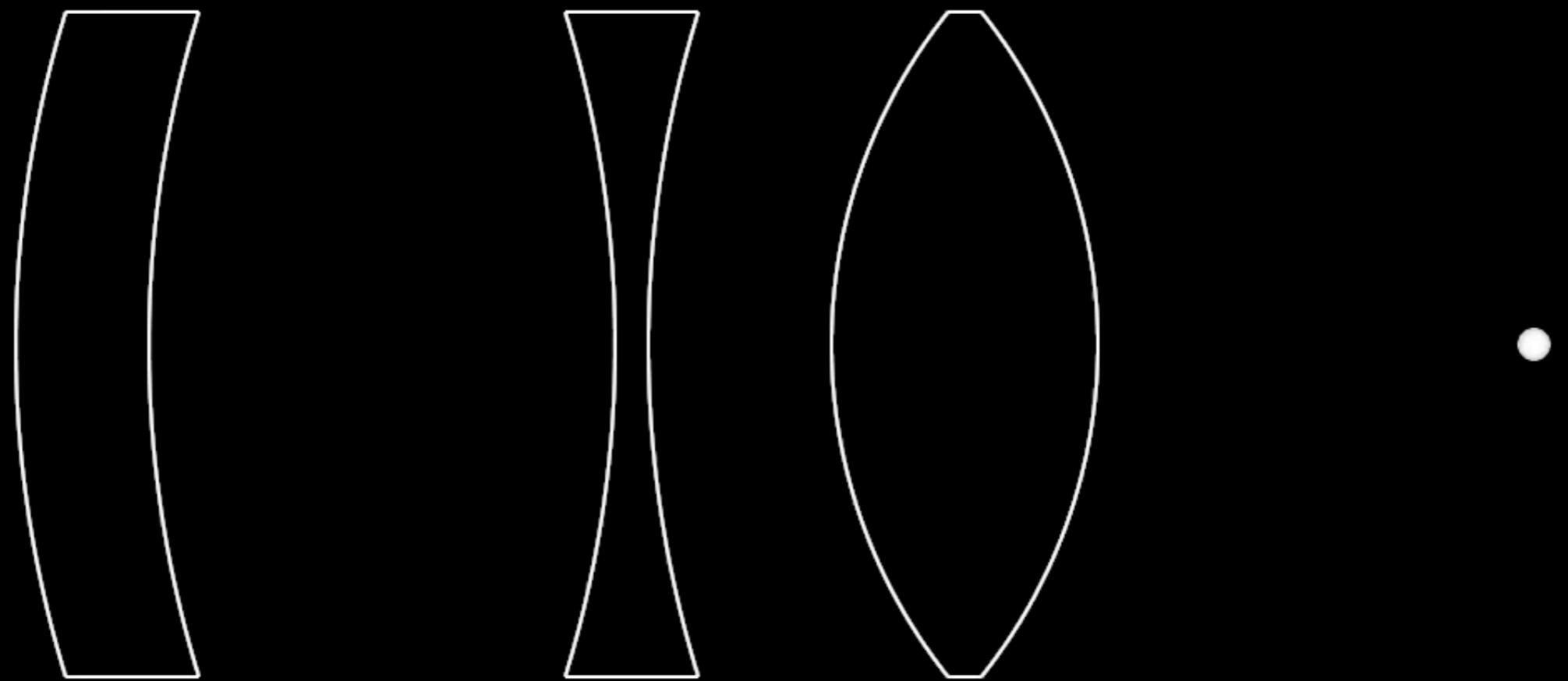


Restored(r)

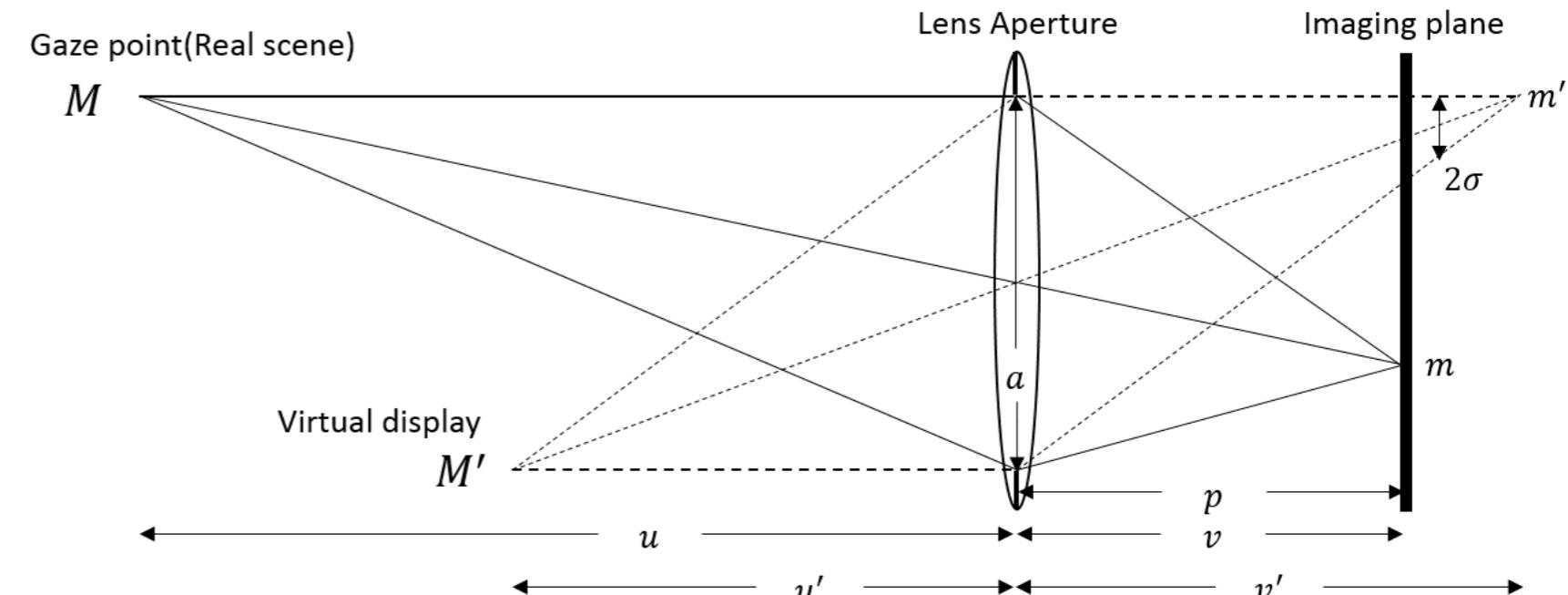
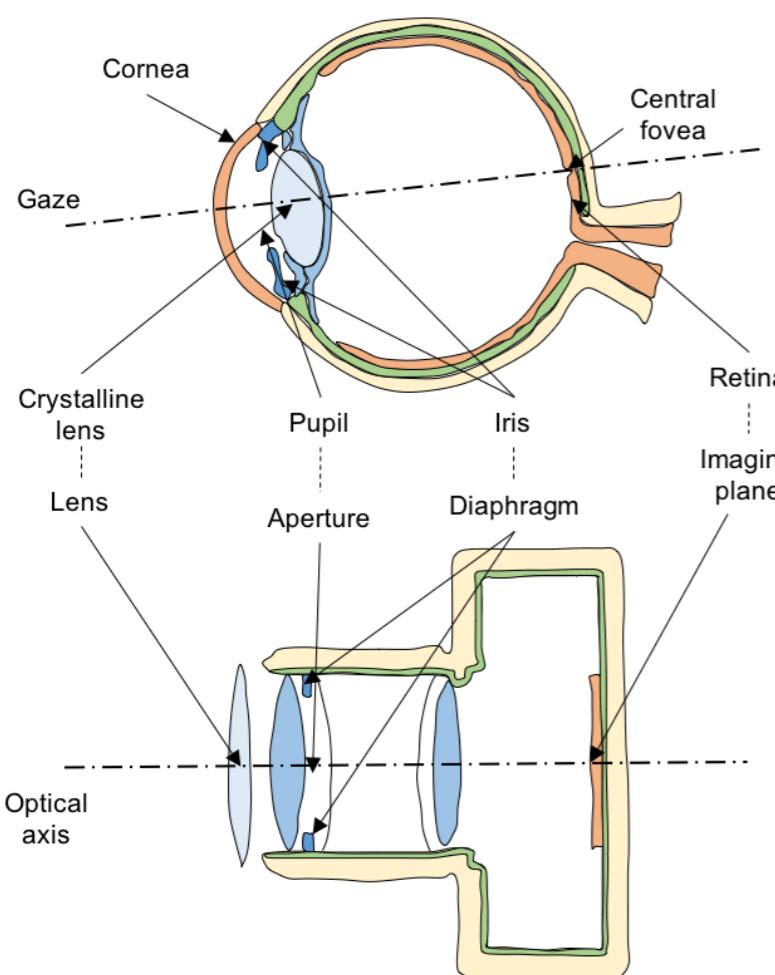
Over sharpened image is improved by focus blur

$$s * p = r$$

VISUALIZATION OF PSF

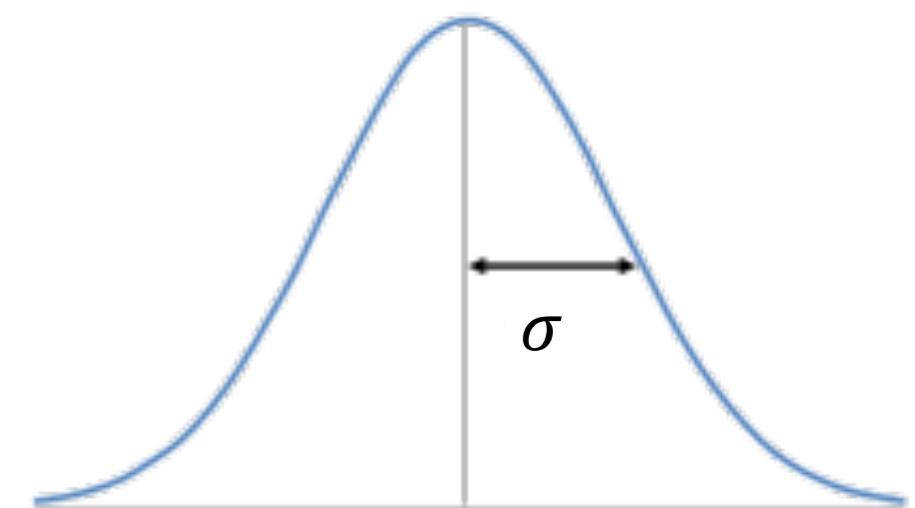


ESTIMATING EYE PSF

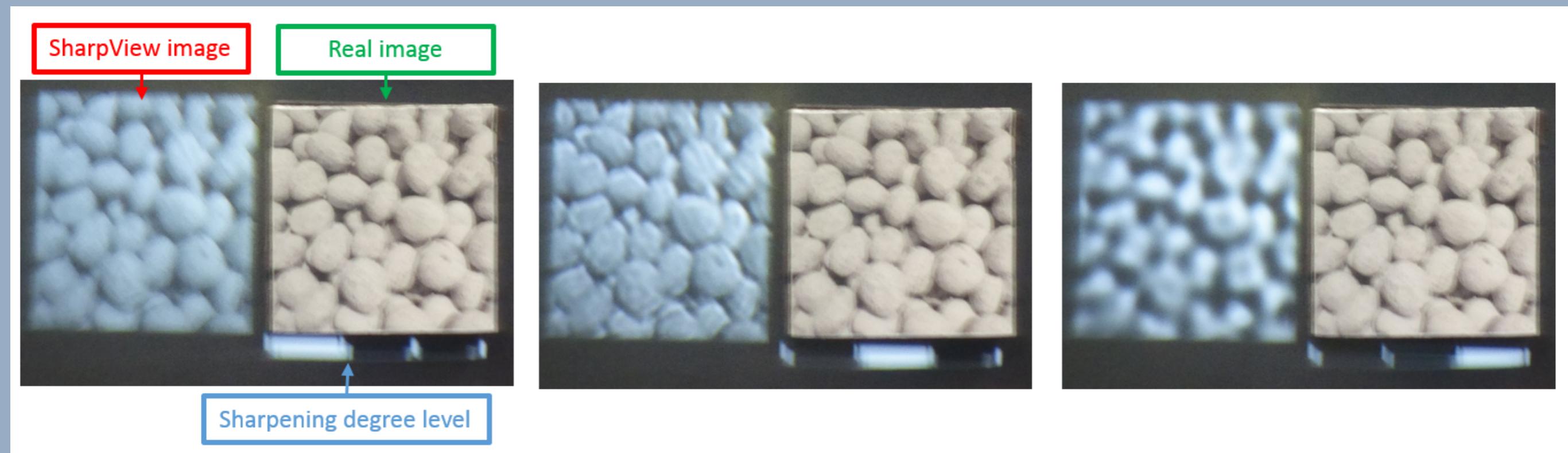
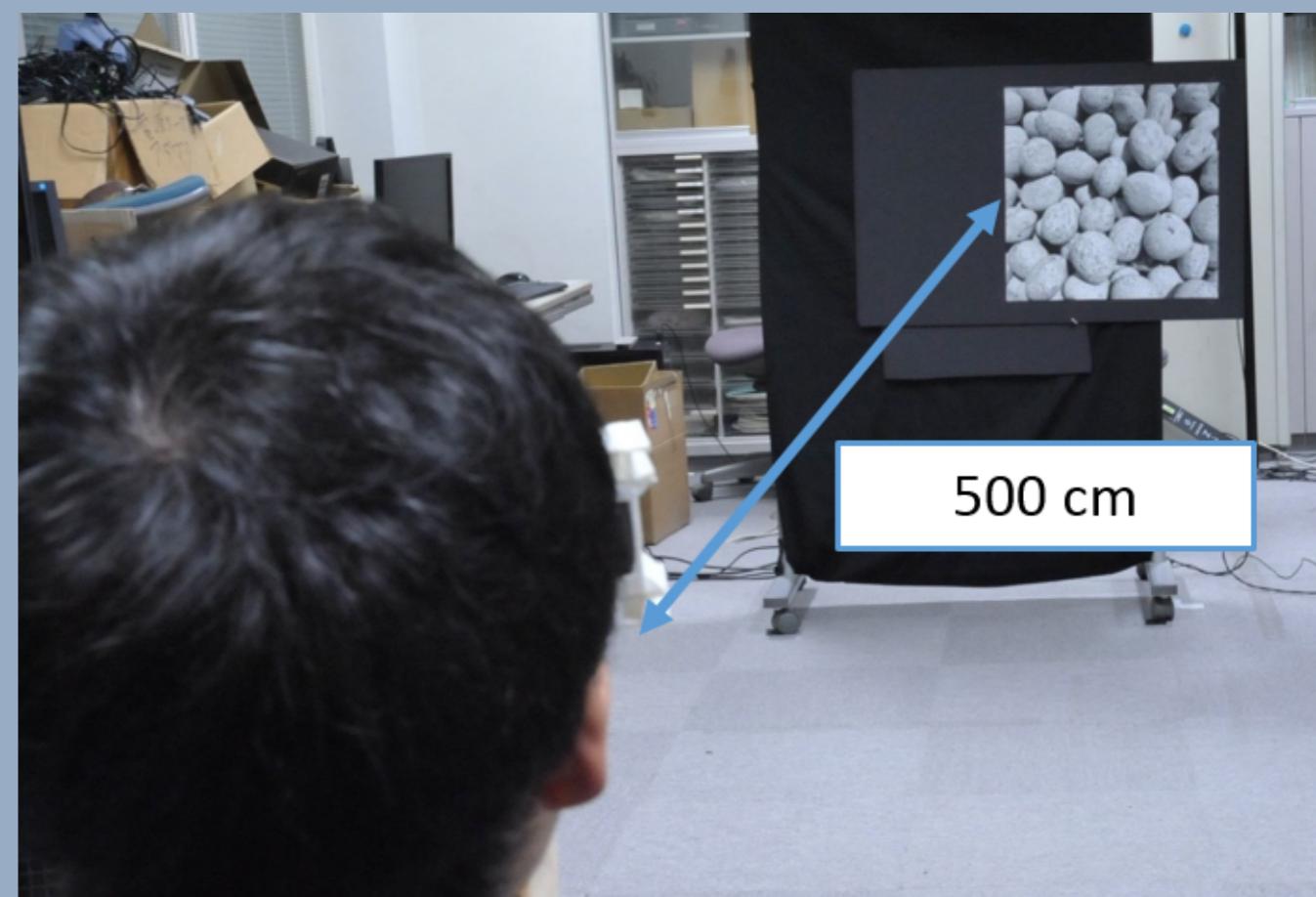
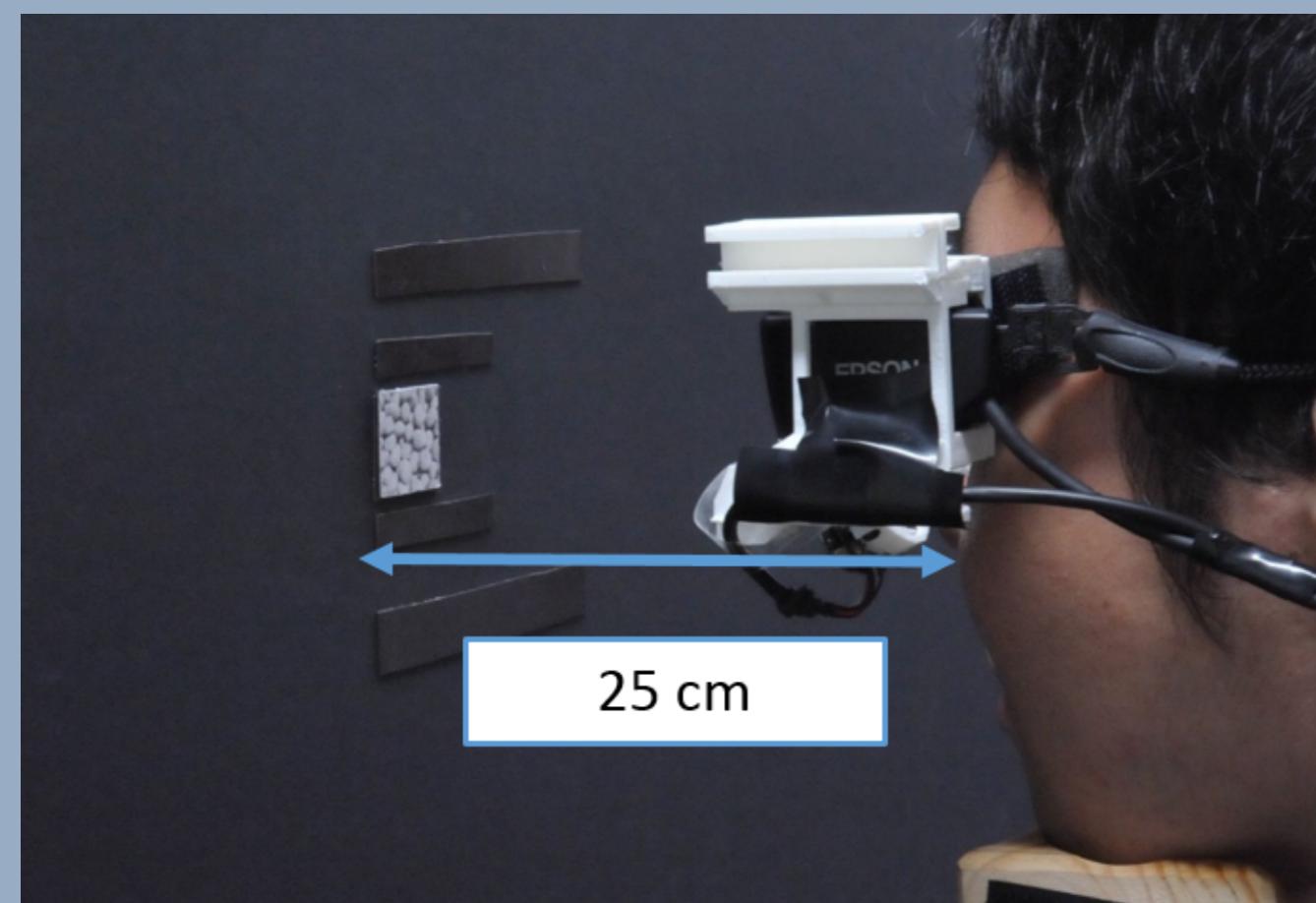


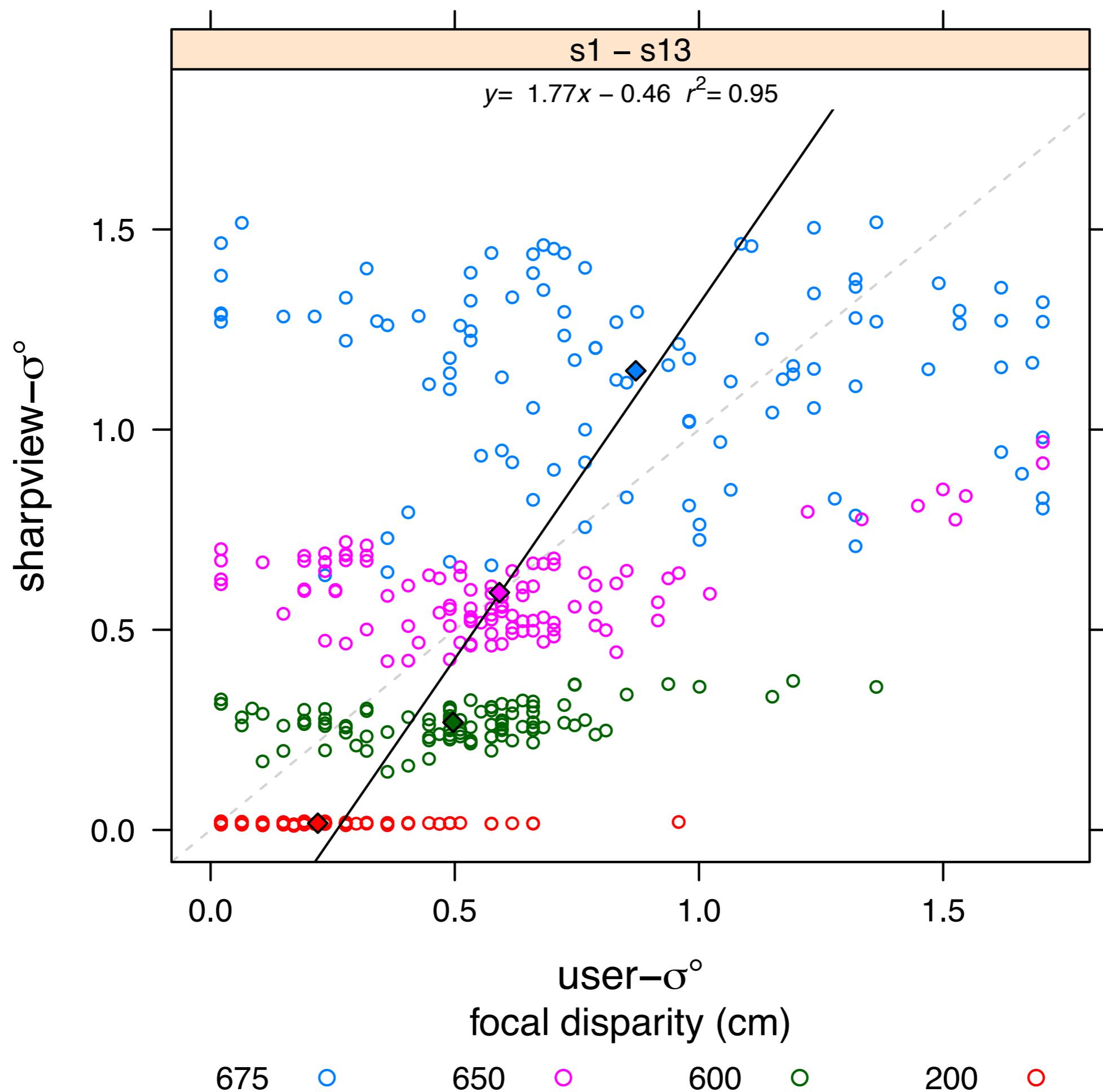
$$\sigma_d = \frac{a}{2} \left(1 - \frac{u'}{u} \right)$$

$$P(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right)$$

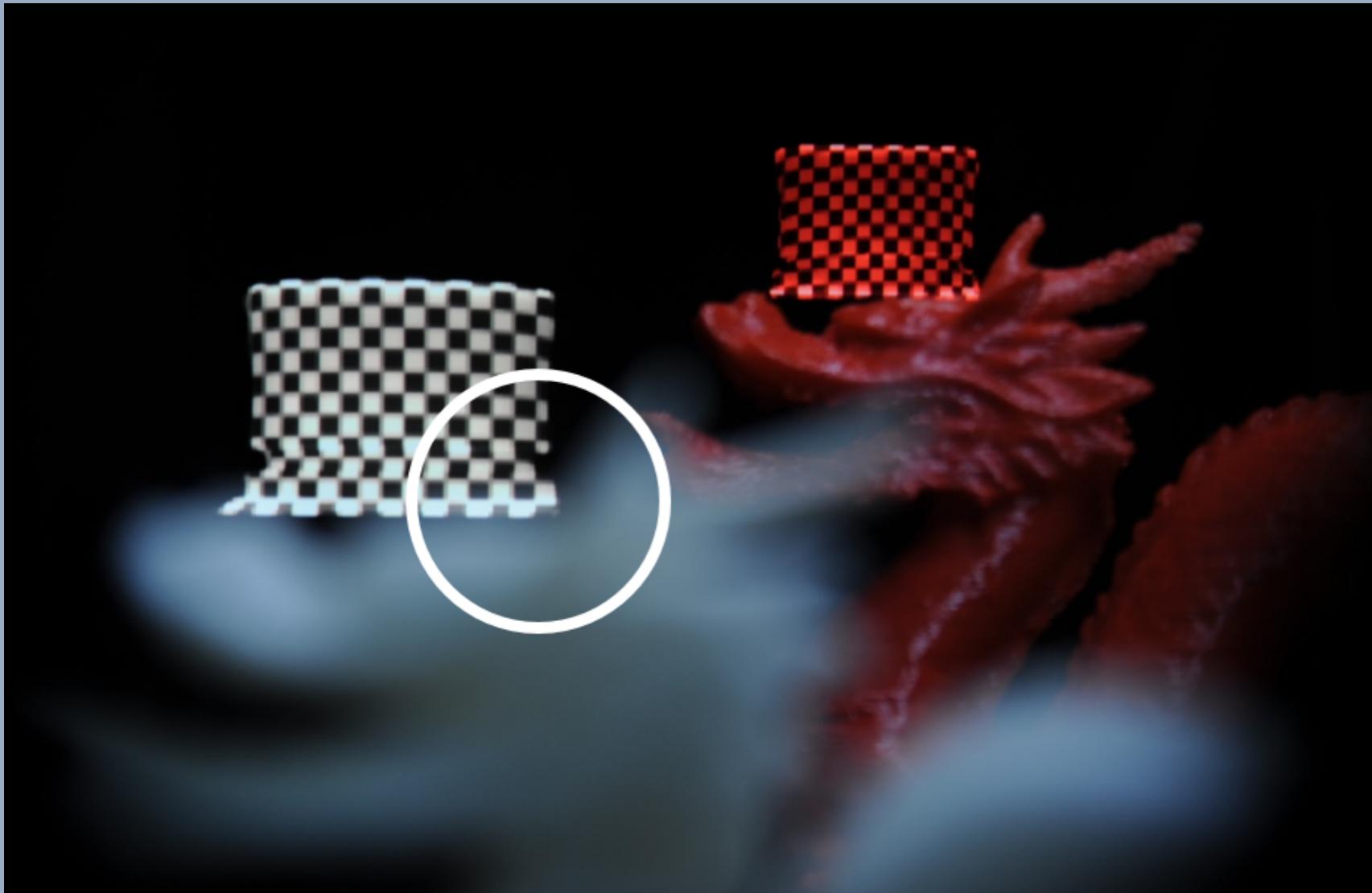


OUR EXPERIMENT





MATCHING BLUR: REAL & VIRTUAL



MOST DISPLAYS



OUR DISPLAY

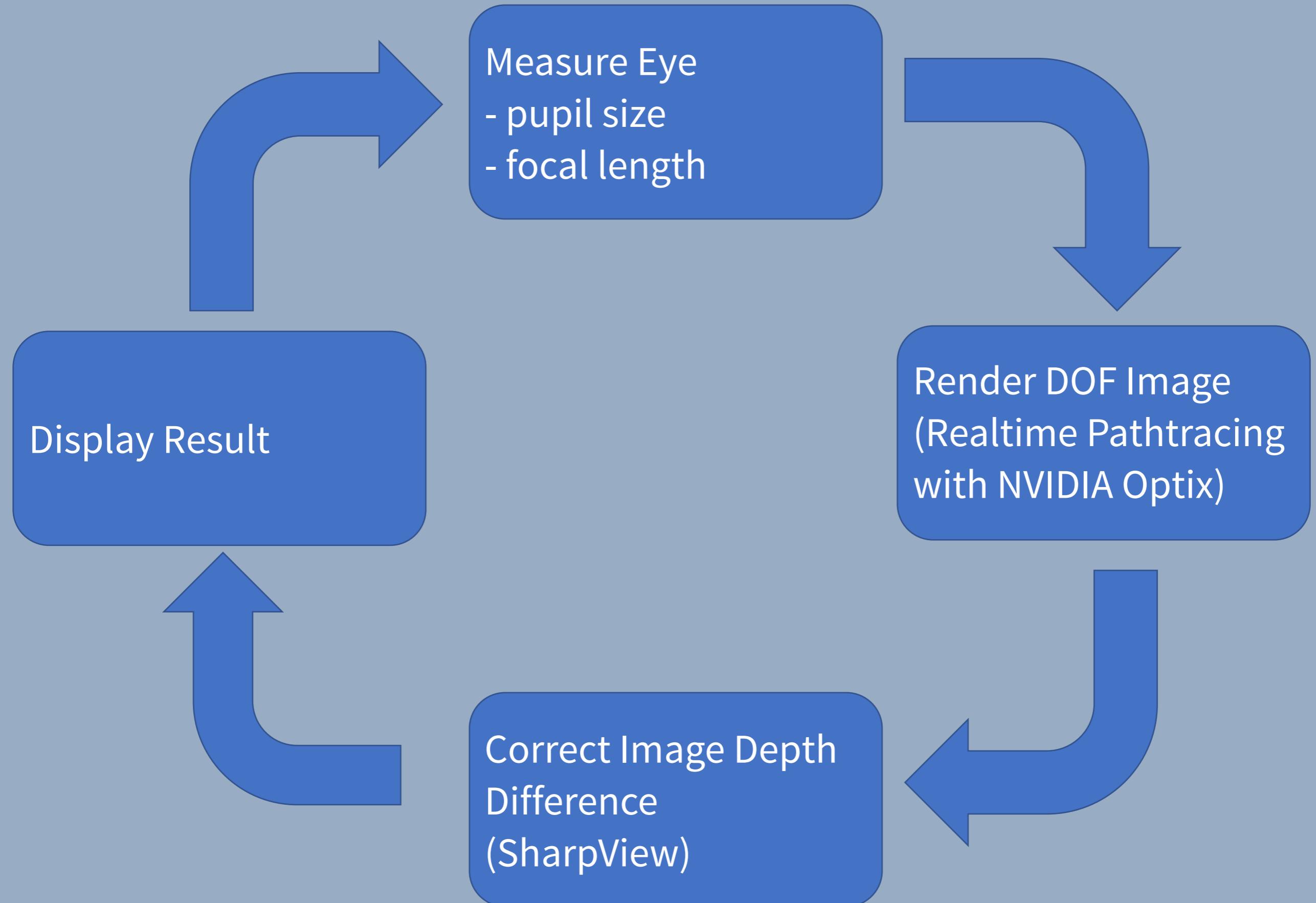
DAMIEN CONSTANTINE ROMPAPAS, AITOR ROVIRA, SEI IKEDA, ALEXANDER PLOPSKI, TAKAFUMI TAKETOMI, CHRISTIAN SANDOR, AND HIROKAZU KATO.
EYEAR: REFOCUSABLE AUGMENTED REALITY CONTENT THROUGH EYE
MEASUREMENTS. DEMO AT *IEEE INTERNATIONAL SYMPOSIUM ON MIXED AND
AUGMENTED REALITY*, MERIDA, MEXICO, SEPTEMBER 2016. BEST DEMO AWARD

MATCHING BLUR: REAL & VIRTUAL

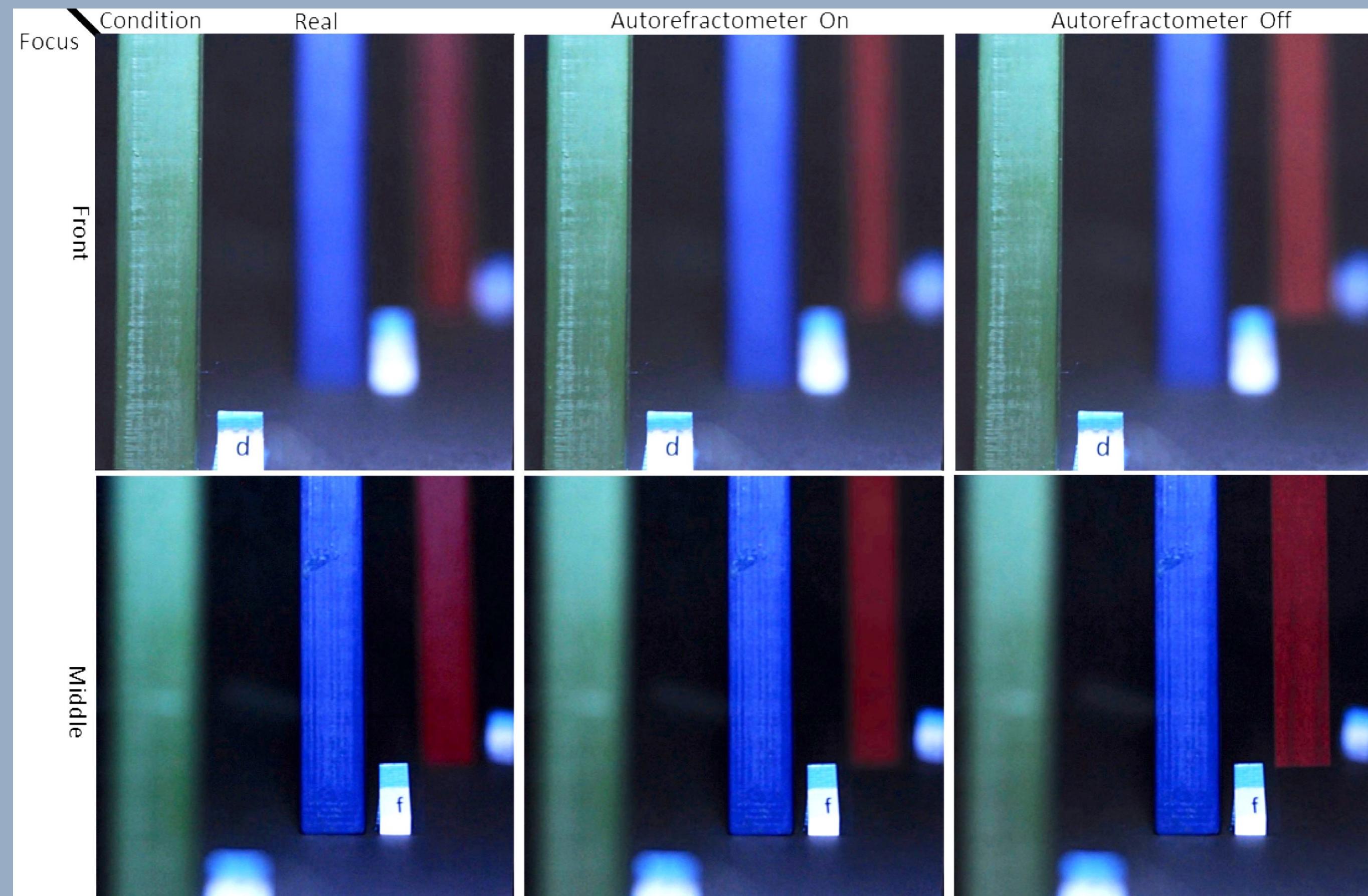


Our display prototype accurately matches the DoF of virtual objects (hats) to real objects (dragons).

CONCEPT OF EYEAR



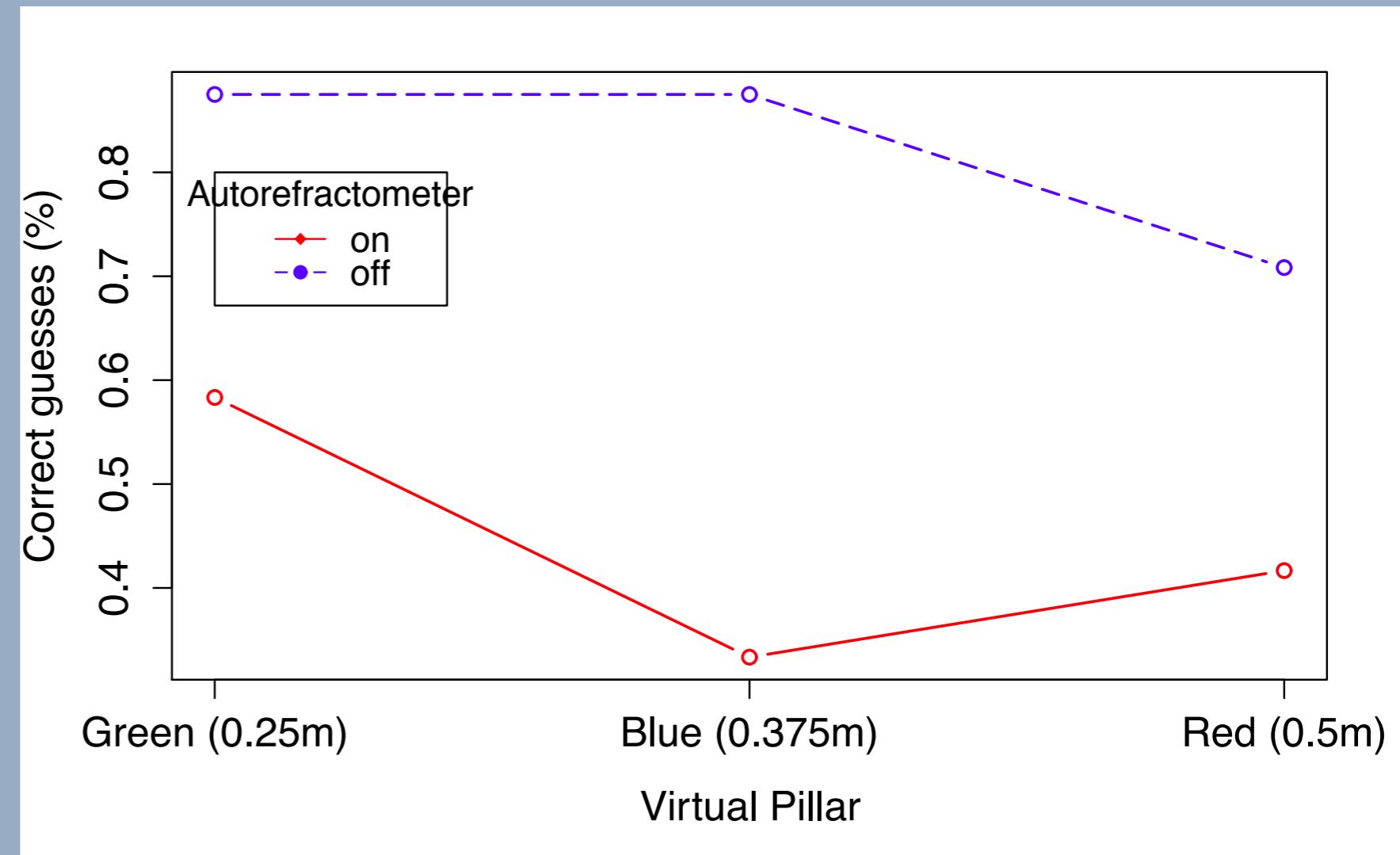
OUR FIRST AR TURING TEST



OUR FIRST AR TURING TEST

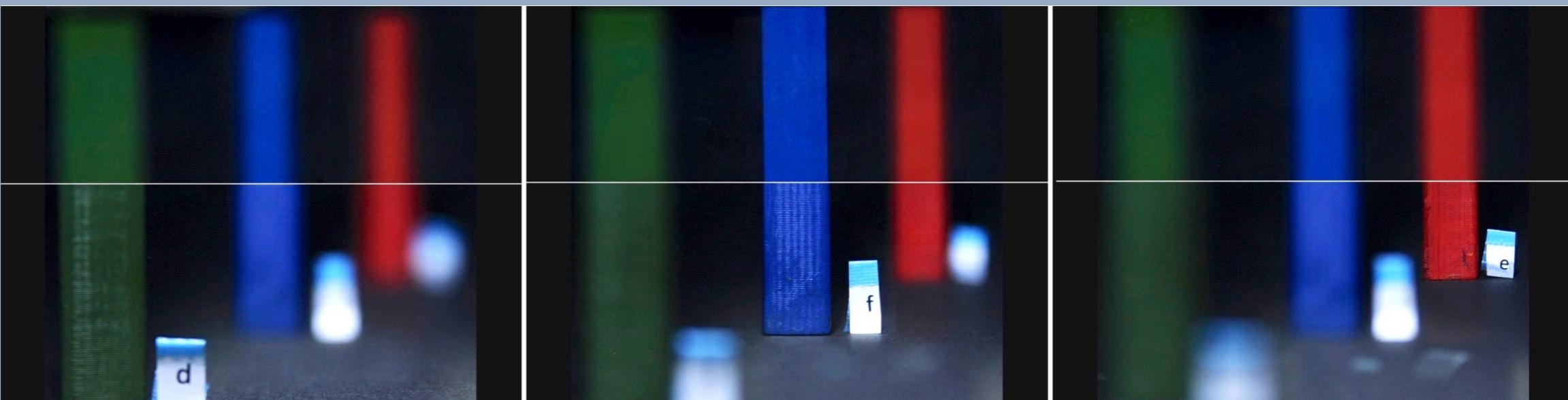
12 PARTICIPANTS

12 GUESSES



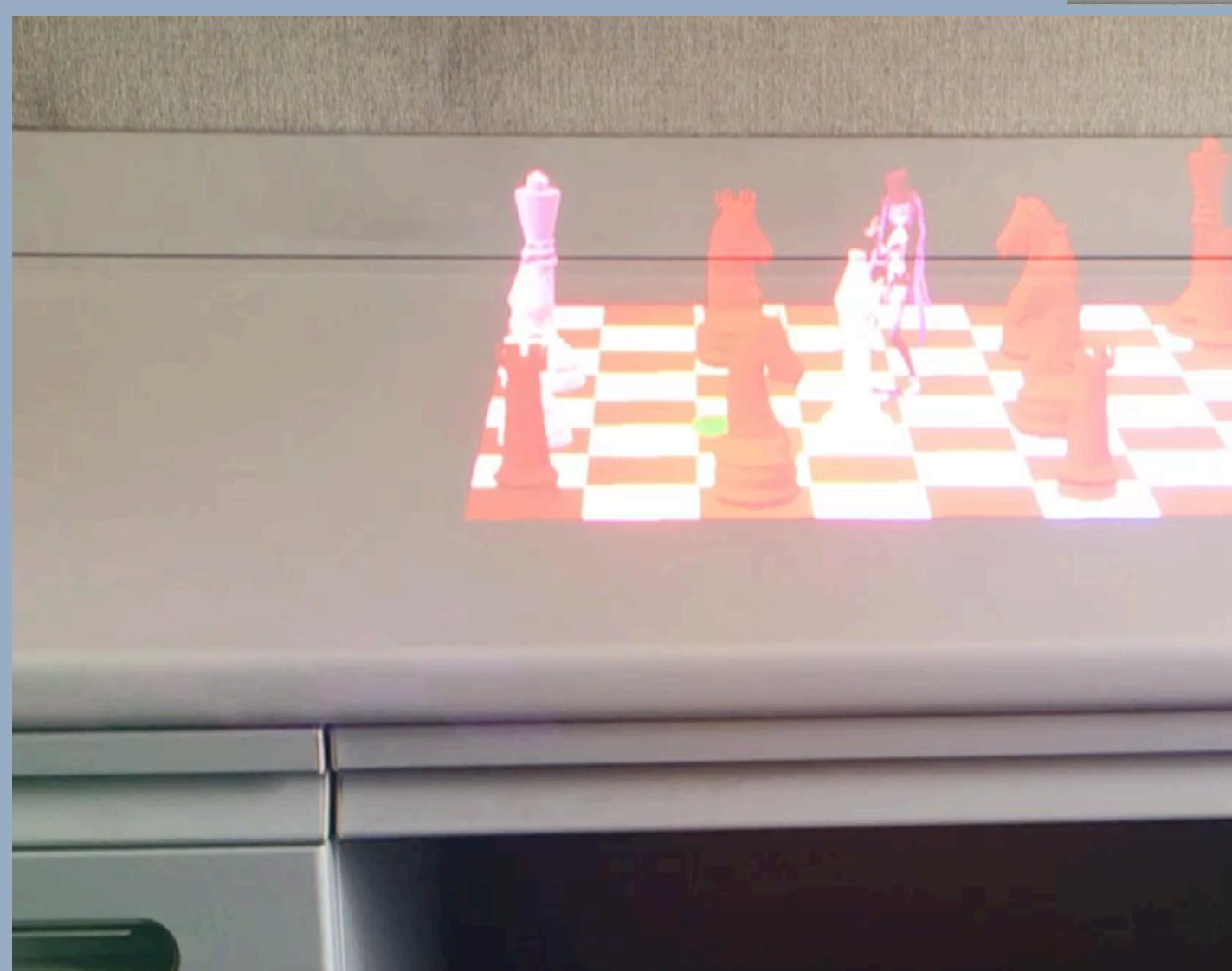
VIRTUAL

REAL



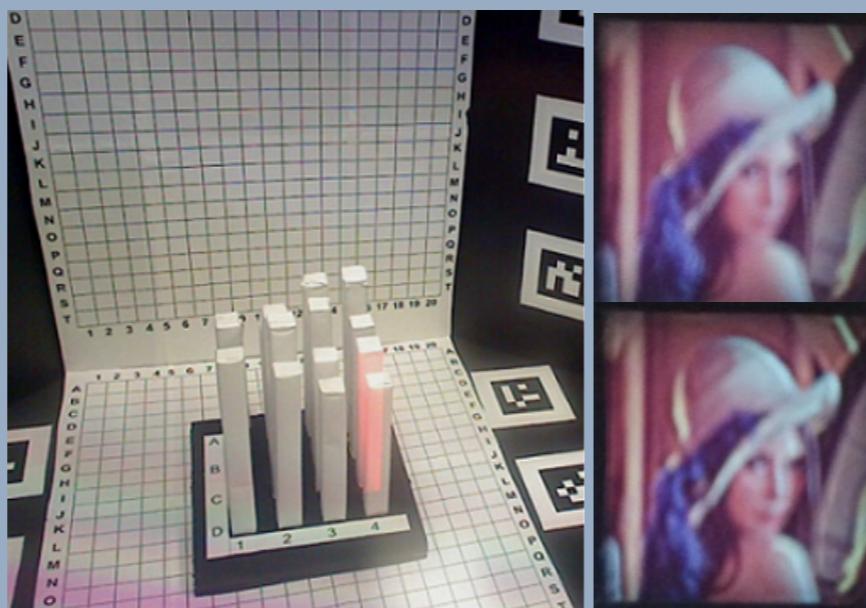
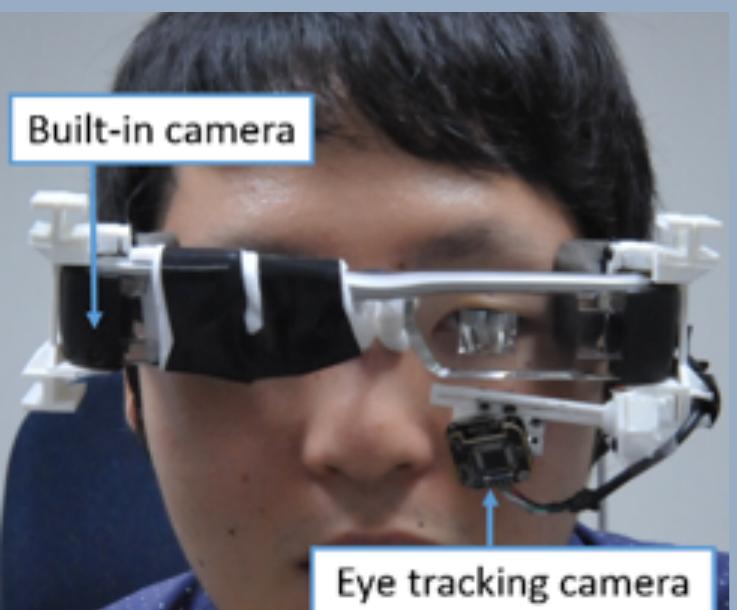
HOLOLENS VERSION

OUR METHOD
(EXAGGERATED BLUR)

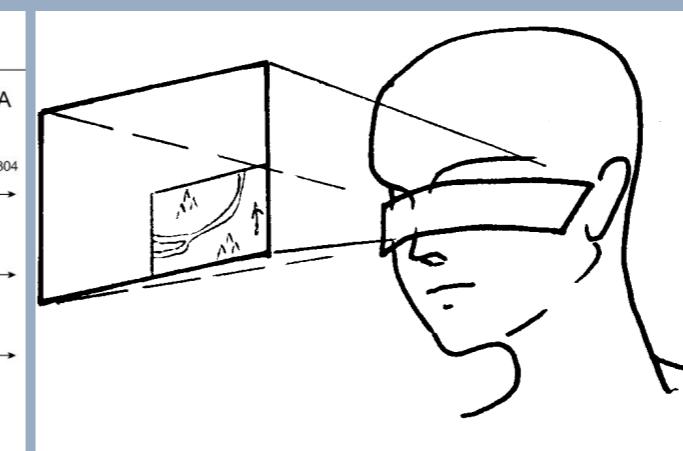
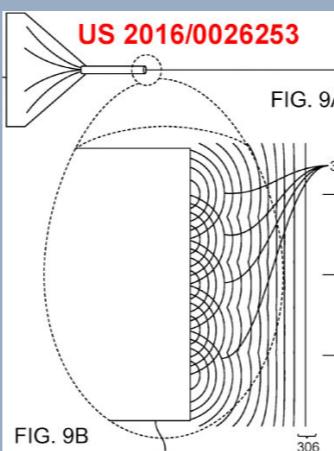
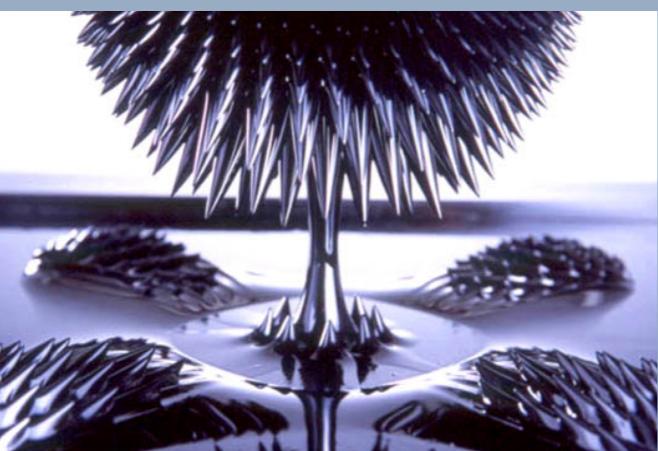
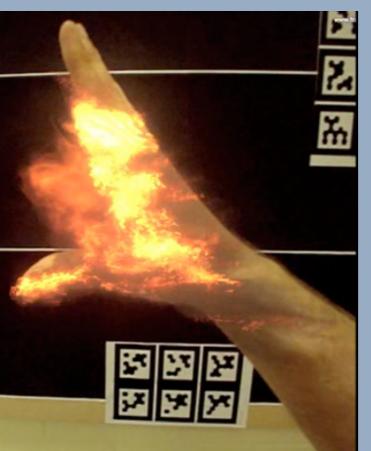


CONVENTIONAL

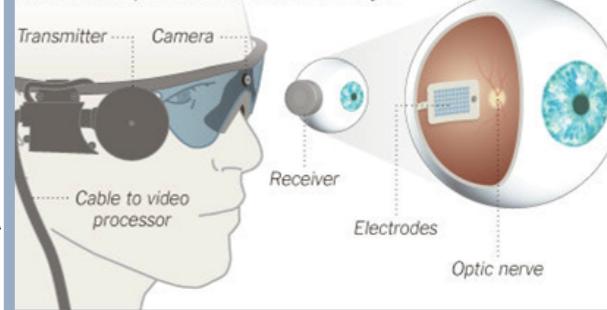
DISPLAYS



PHILOSOPHY: TRUE AUGMENTED REALITY



Approval for an Artificial Retina
The Food and Drug Administration approved a system that allows people with a severe type of retinal deterioration to see patches of light and dark. Camera images are processed and transferred to electrodes implanted in the back of the eye.



TEDX ADELAIDE 2010



DEMO ONLY: [HTTPS://WWW.YOUTUBE.COM/WATCH?V=3MEALLE8Kzs](https://www.youtube.com/watch?v=3MEALLE8Kzs)

FULL TALK: [HTTP://WWW.YOUTUBE.COM/ WATCH?V=U2YE2LHULWA](http://www.youtube.com/watch?v=u2ye2lhulwa)

SLIDES: [HTTP://WWW.SLIDESSHARE.NET/CHRISTIANSANDOR/TEDX10-SANDOR](http://www.slideshare.net/christiansandor/tedx10-sandor)

CREW

THROUGHPUT OF HUMAN SENSES

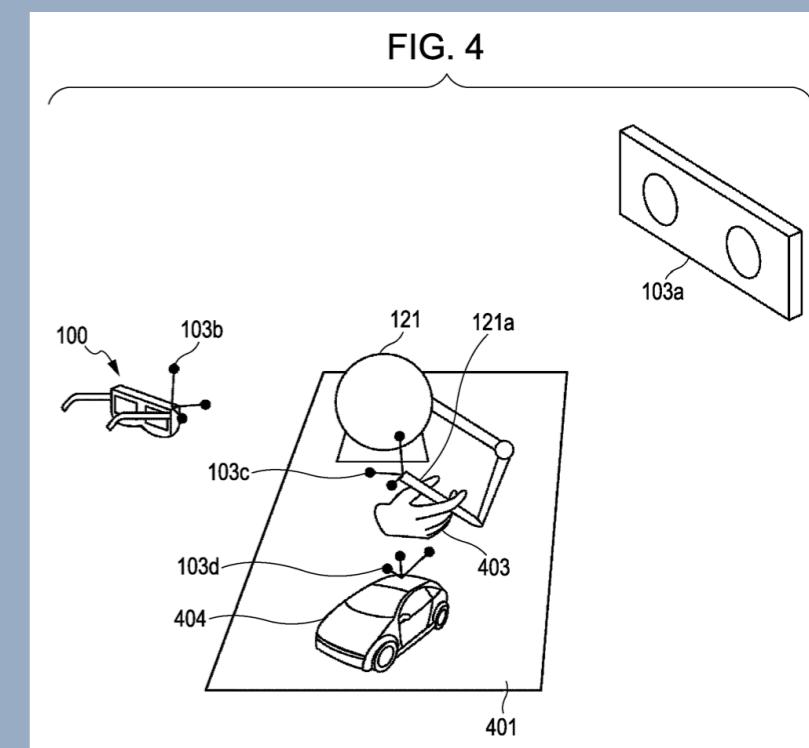


SOURCE: DAVID MCCANDLESS'S TED TALK (2010)

RESEARCH IN CANON



FIG. 4



CHRISTIAN SANDOR, TSUYOSHI KUROKI, AND SHINJI UCHIYAMA. INFORMATION PROCESSING METHOD AND DEVICE FOR PRESENTING HAPTICS RECEIVED FROM A VIRTUAL OBJECT. JAPANESE PATENT 2006117732 (FILED 4/2006). PATENT IN CHINA, EUROPE, AND US 8,378,997 (FILED 19 APRIL 2007). [HTTP://GOO.GL/V3DAX](http://GOO.GL/V3DAX)

RESEARCH IN CANON



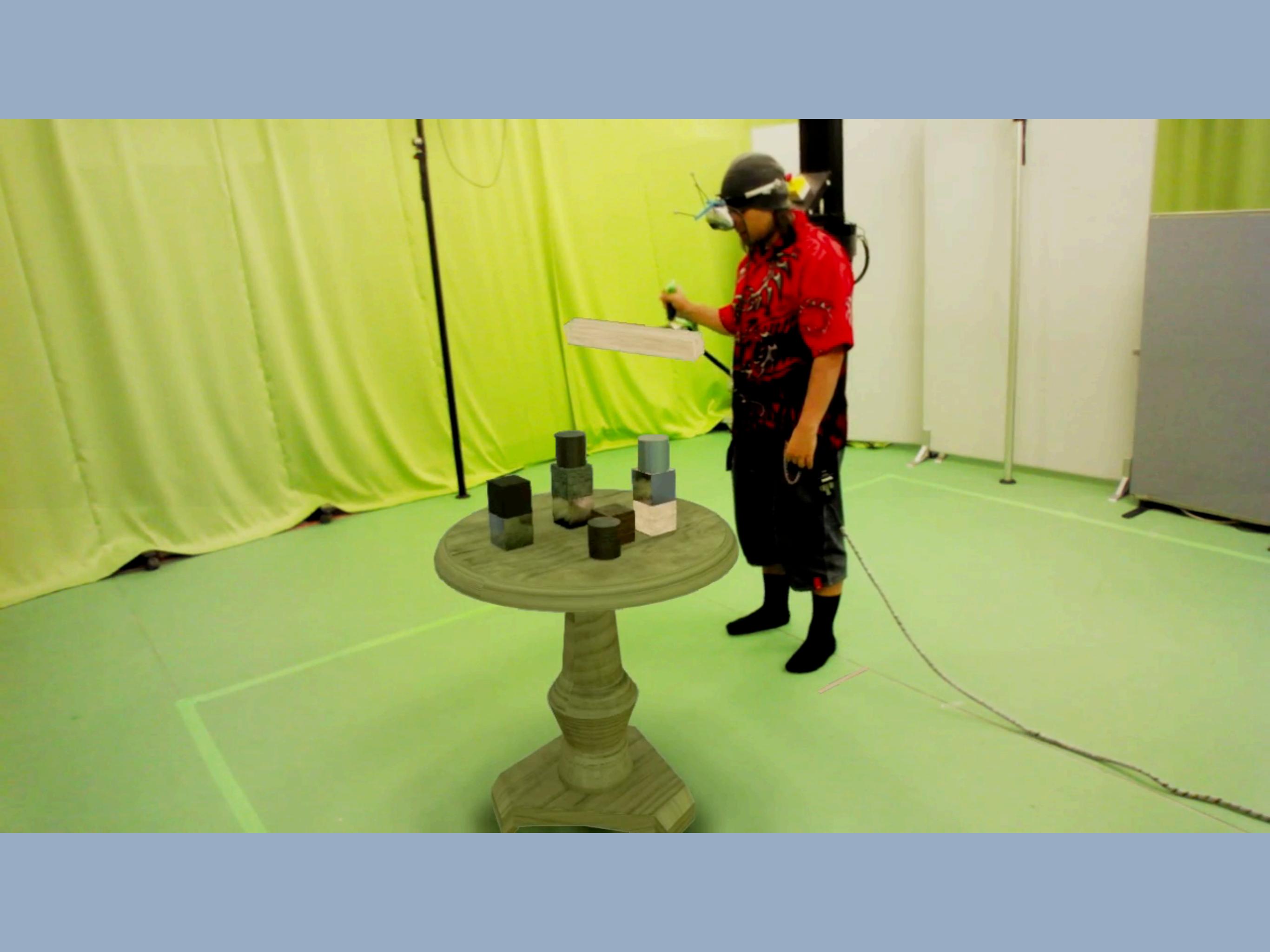
CHRISTIAN SANDOR, SHINJI UCHIYAMA, AND HIROYUKI YAMAMOTO. VISUO-HAPTIC SYSTEMS: HALF-MIRRORS CONSIDERED HARMFUL. IN *PROCEEDINGS OF THE IEEE WORLD HAPTICS CONFERENCE*, PAGES 292–297. IEEE, MARCH 2007. TSUKUBA, JAPAN.

Visuo-Haptic Augmented Reality Demo for TEDx

Team: Christian Sandor - Ulrich Eck
Quang Le - Peter Weir
Donald Urquhart

LARGE SCALE HAPTICS DISPLAY AT NAIST (UNPUBLISHED)



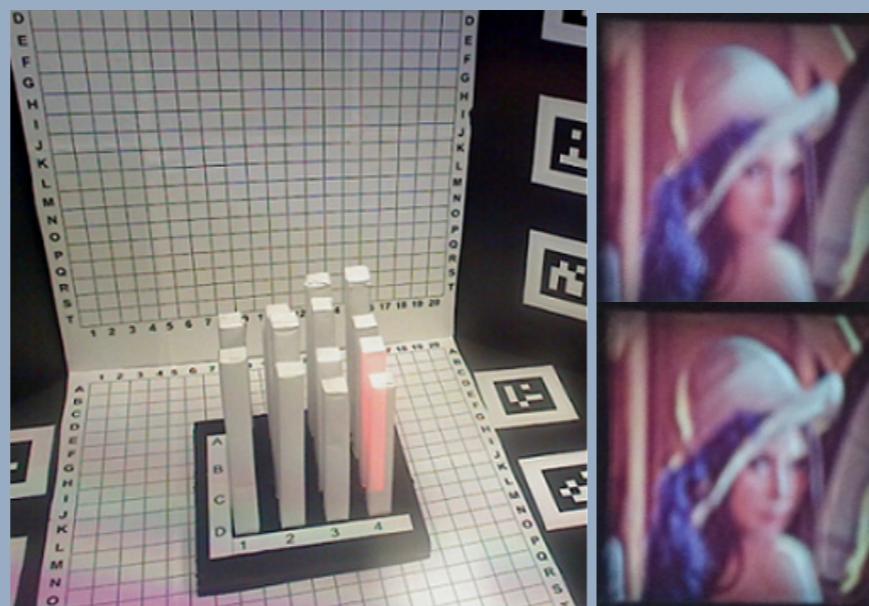
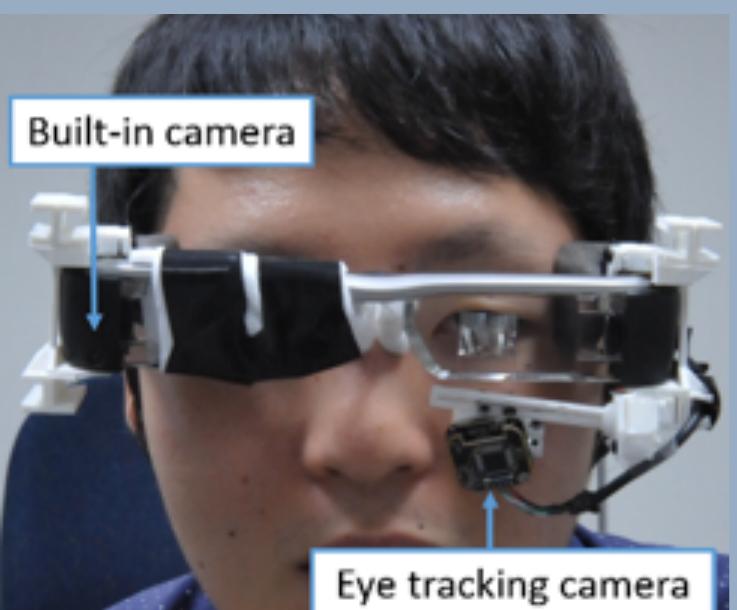




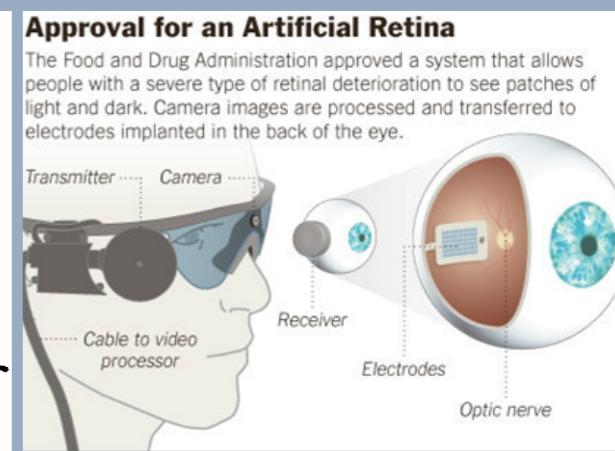
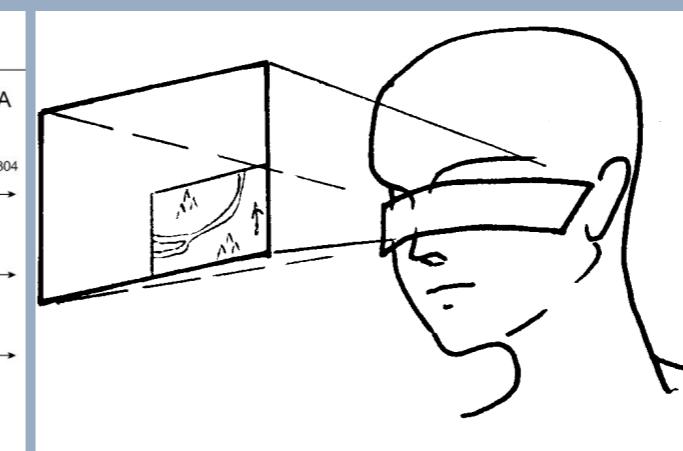
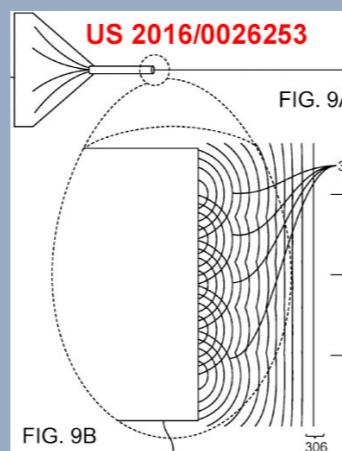
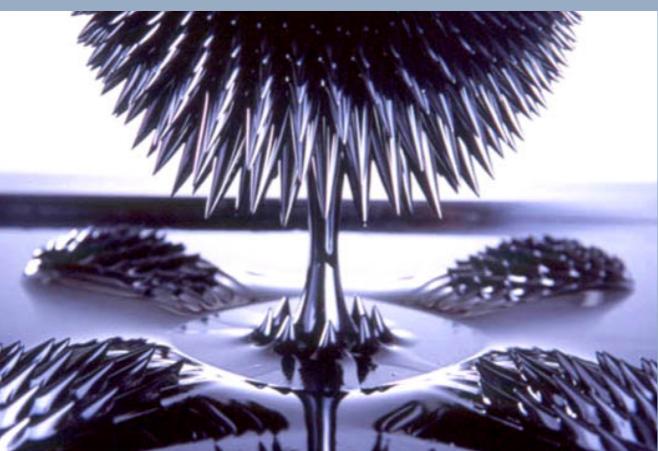
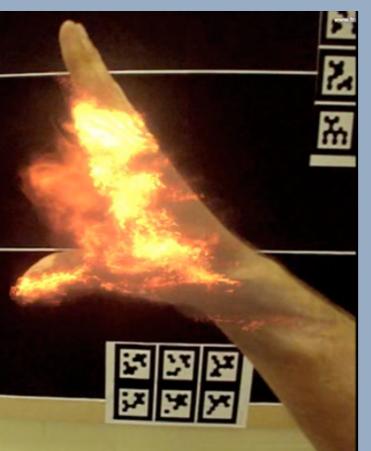
DISPLAYS



APPLICATIONS



PHILOSOPHY: TRUE AUGMENTED REALITY



EDGE-BASED X-RAY



BENJAMIN AVERY, CHRISTIAN SANDOR, BRUCE H. THOMAS. IMPROVING SPATIAL PERCEPTION FOR AUGMENTED REALITY X-RAY VISION. IN *PROCEEDINGS OF THE IEEE VIRTUAL REALITY CONFERENCE*, PAGES 79–82. IEEE, MARCH 2009. LAFAYETTE, LOUISIANA, USA.



Layer	Background
1	Background
2	Car
3	Background
4	Roof
5	Building
6	Building
7	Building
8	Building

Layer	Background
1	Background
2	Car
3	Background
4	Tunnel
5	Building
6	Building
7	Building

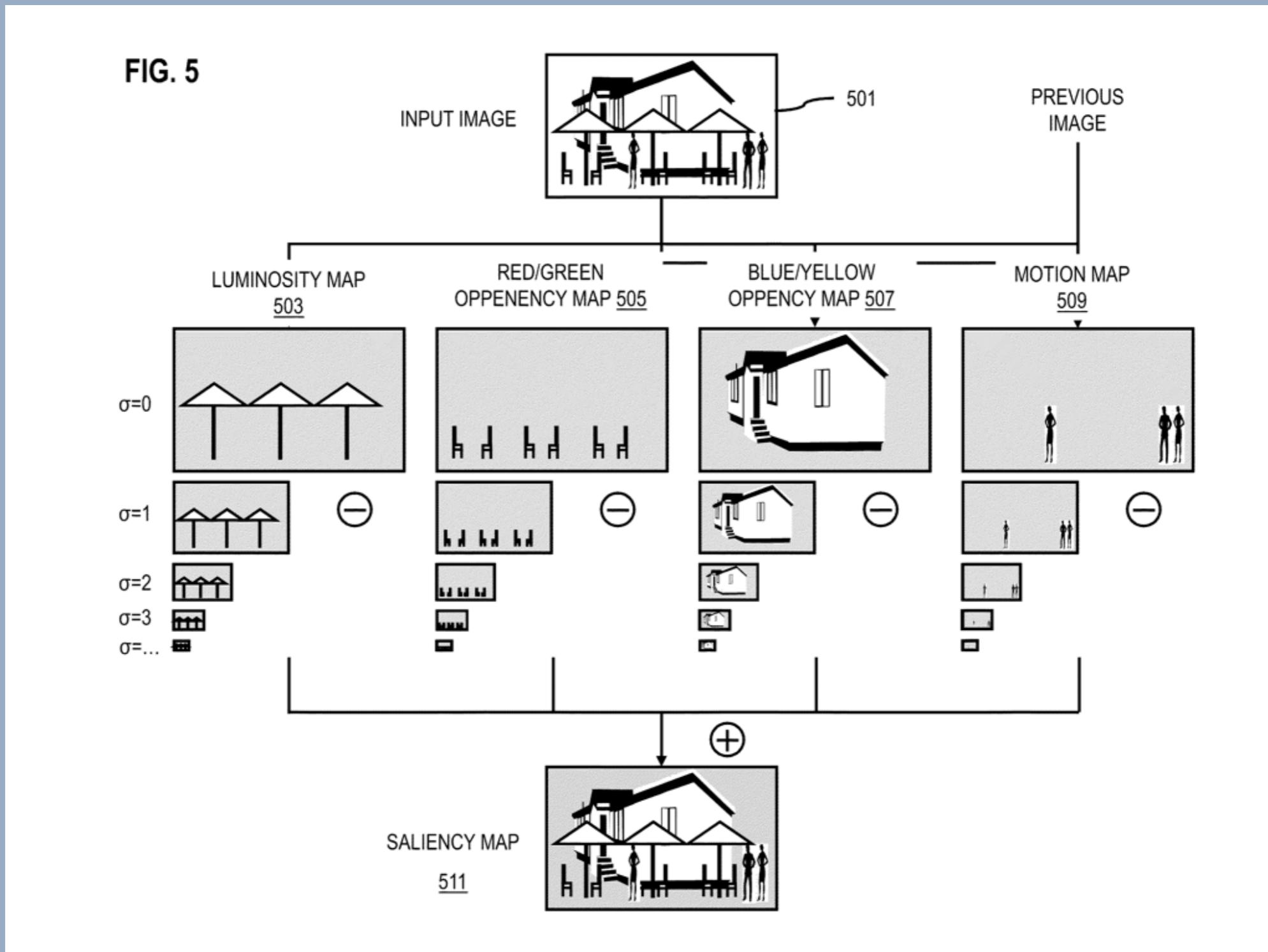
SALIENCY X-RAY



CHRISTIAN SANDOR, ANDREW CUNNINGHAM, ARINDAM DEY, AND VILLE-VEIKKO MATTILA. AN AUGMENTED REALITY X-RAY SYSTEM BASED ON VISUAL SALIENCY. IN *PROCEEDINGS OF THE IEEE INTERNATIONAL SYMPOSIUM ON MIXED AND AUGMENTED REALITY*, PAGES 27–36, SEOUL, KOREA, OCTOBER 2010.

SALIENCY X-RAY

FIG. 5



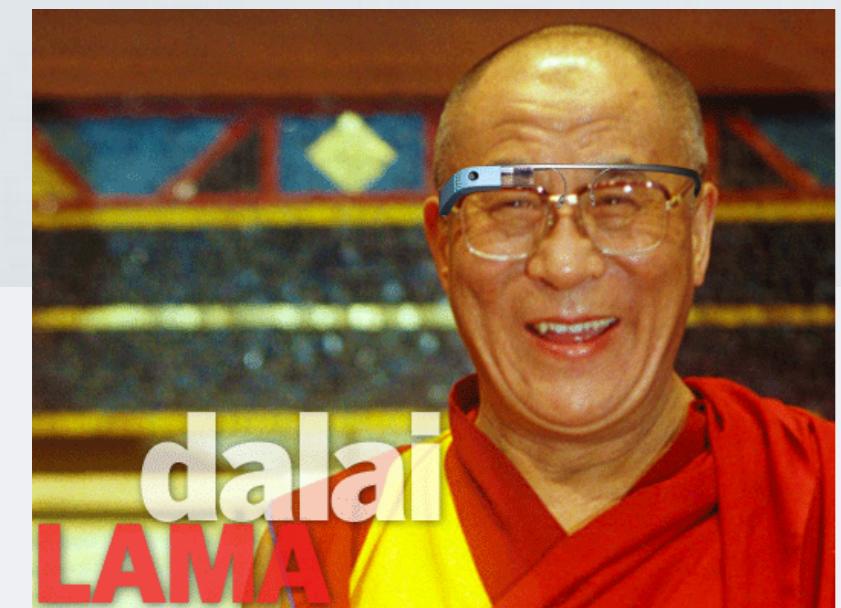
CHRISTIAN SANDOR, ANDREW CUNNINGHAM, AND MATTILA VILLE-VEIKKO.
METHOD AND APPARATUS FOR AN AUGMENTED REALITY X-RAY. US PATENT
APPLICATION 12/785,170 (FILED 21 MAY 2010). [HTTP://GOO.GL/NCVZJ](http://GOO.GL/NCVZJ)

MELTING



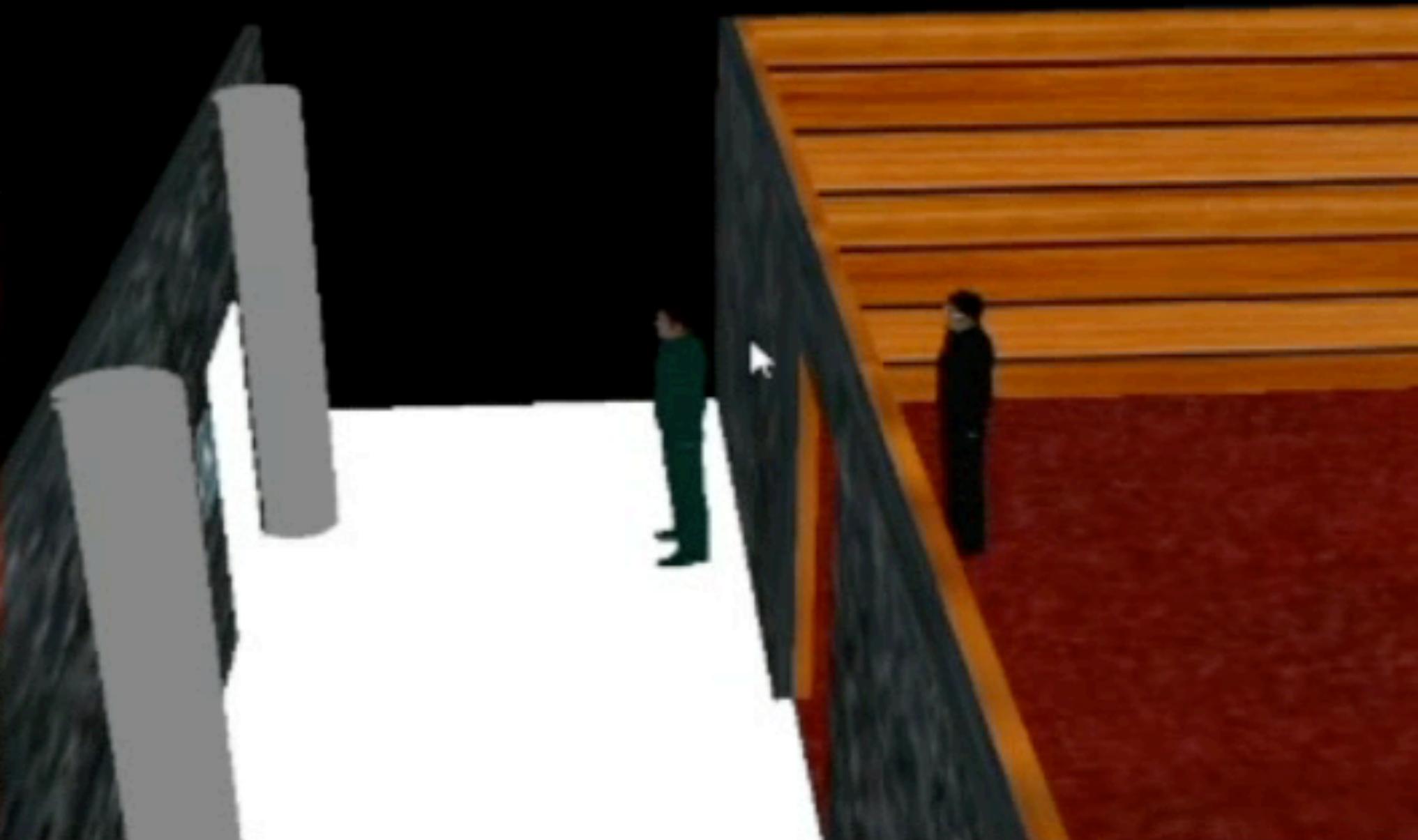
CHRISTIAN SANDOR, ANDREW CUNNINGHAM, ULRICH ECK, DONALD URQUHART, GRAEME JARVIS,
ARINDAM DEY, SEBASTIEN BARBIER, MICHAEL R. MARNER, SANG RHEE. EGOCENTRIC SPACE-DISTORTING
VISUALIZATIONS FOR RAPID ENVIRONMENT EXPLORATION IN MOBILE MIXED REALITY. IN *PROCEEDINGS
OF THE IEEE VIRTUAL REALITY CONFERENCE*, PAGES 47–50, WALTHAM, MA, USA, MARCH 2010.

AUGMENTED REALITY X-RAY FOR GOOGLE GLASS



GOOGLE FACULTY AWARD (2014)

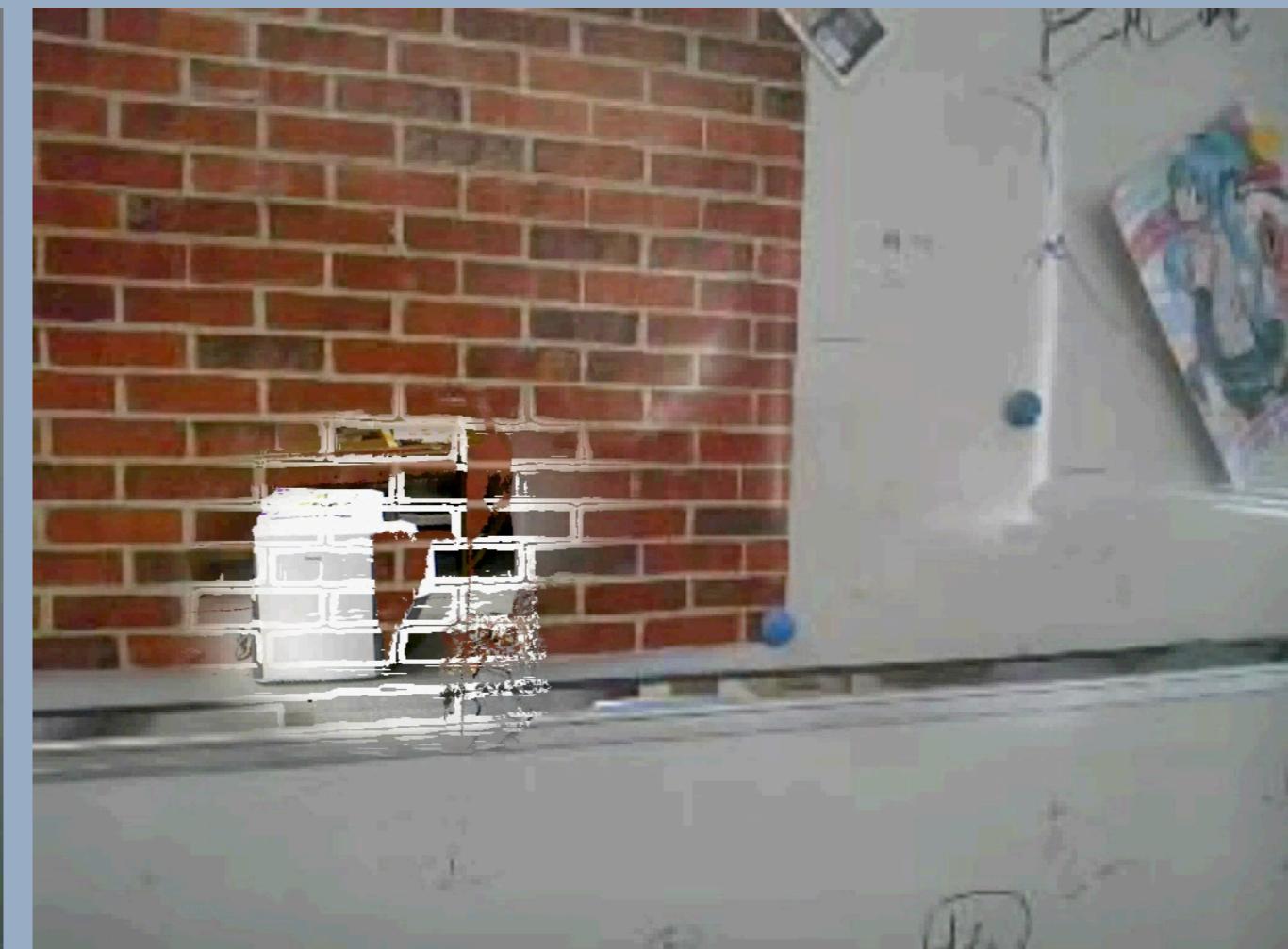
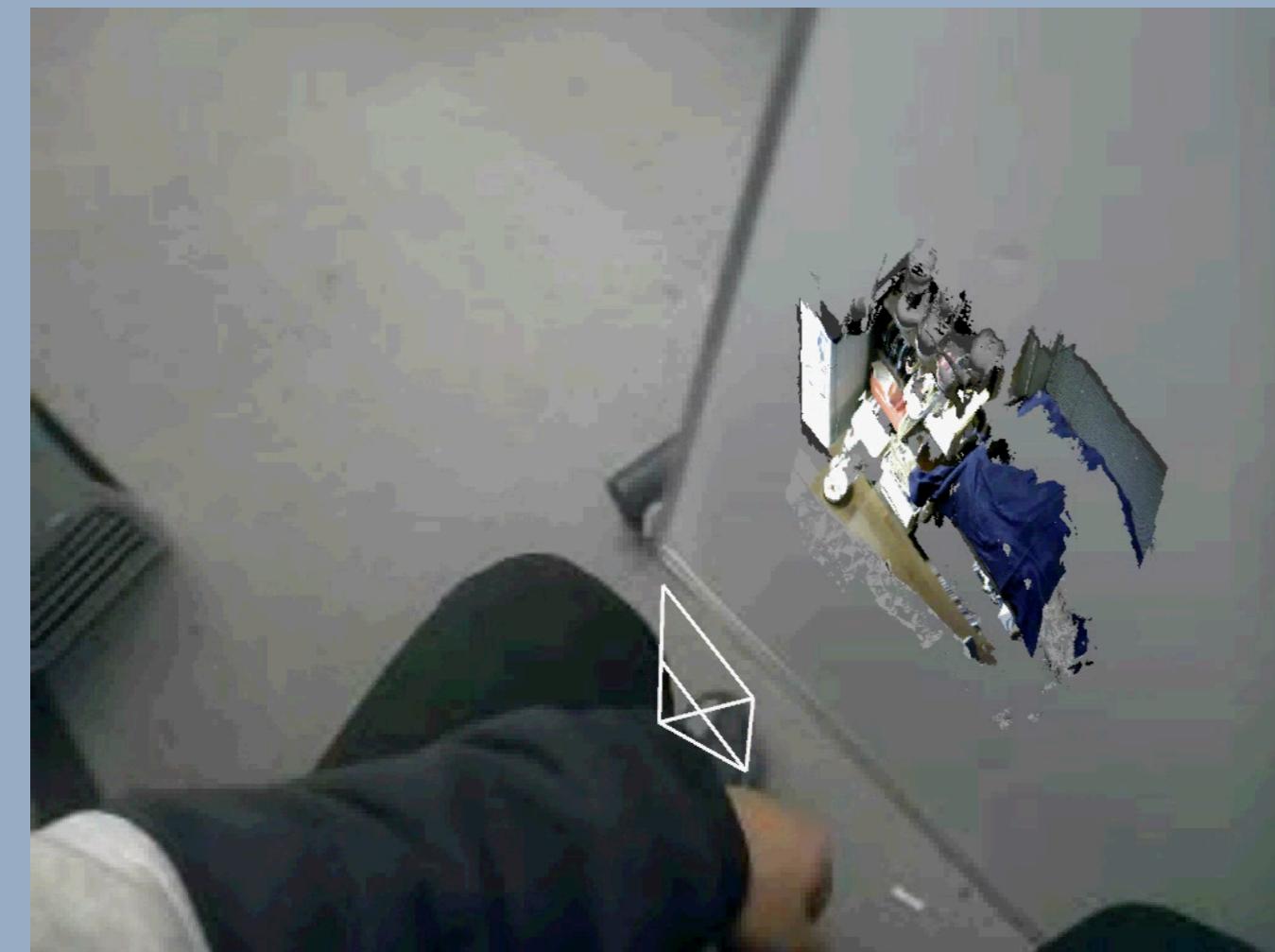
DEMO AT SIGGRAPH ASIA (12/2014)



FINAL DEMO (4/2015)



FINAL DEMO (4/2015)



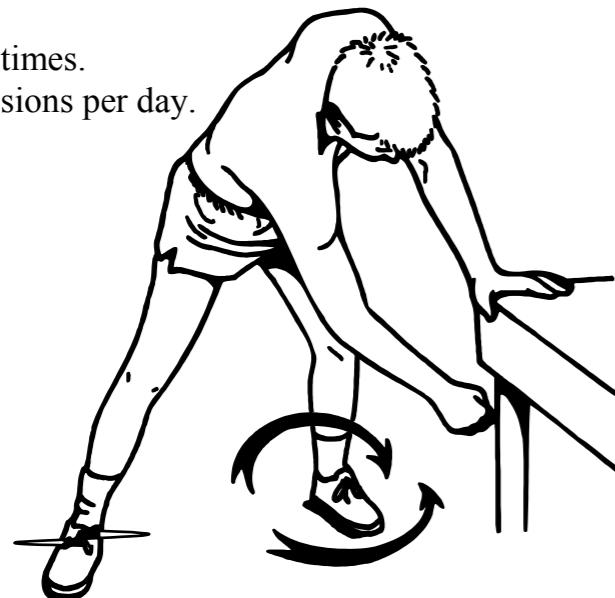
FUTURE WORK: MEDICAL APPLICATIONS

SHOULDER - 26

Range of Motion Exercises:
Pendulum (Circular)

Let arm move in a circle
clockwise, then counter-
clockwise, by rocking body
weight in a circular pattern.

Repeat 10 times.
Do 3-5 sessions per day.

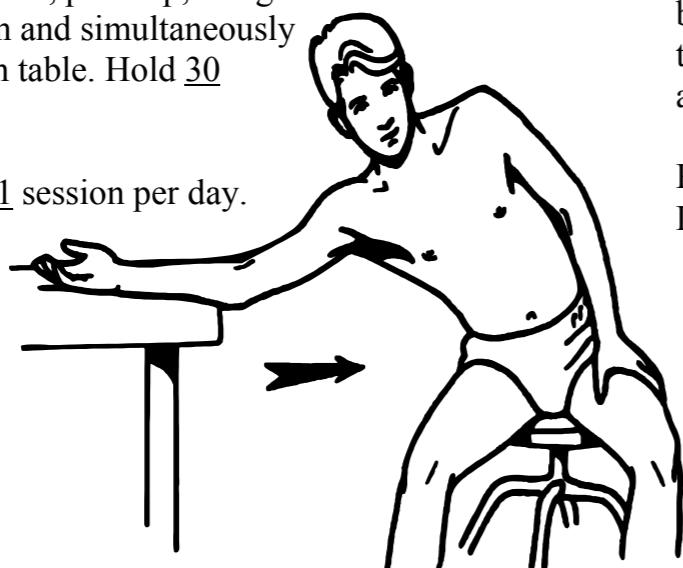


SHOULDER - 9

Range of Motion Exercises (Self-
Stretching Activities): Abduction

With arm resting on table, palm up, bring
head down toward arm and simultaneously
move trunk away from table. Hold 30
seconds.

Repeat 1-4 times Do 1 session per day.



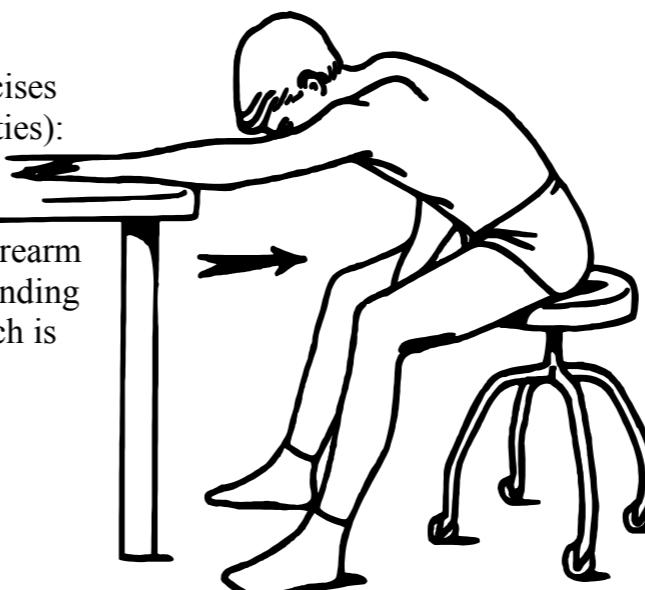
Rehabilitation & Sports Medicine Frozen Shoulder

SHOULDER - 7

Range of Motion Exercises
(Self-Stretching Activities):
Flexion

Sitting upright, slide forearm
forward along table, bending
from waist until a stretch is
felt. Hold 30 seconds.

Repeat 1-4 times
Do 1 session per day.



SHOULDER - 73

Towel Stretch for Internal
Rotation

Pull involved arm up
behind back by pulling
towel upward with other
arm. Hold 30 seconds.

Repeat 1-4 times
Do 1 session per day.



SHOULDER - 11

Range of Motion Exercises
(Self-Stretching Activities):
External Rotation (alternate)

Keep palm of hand against
door frame, and elbow bent at
90°. Turn body from fixed
hand until a stretch is felt.
Hold 30 seconds.

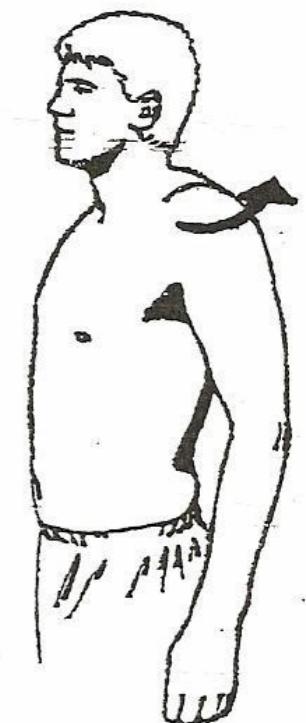
Repeat 1-4 times
Do 1 session per day.



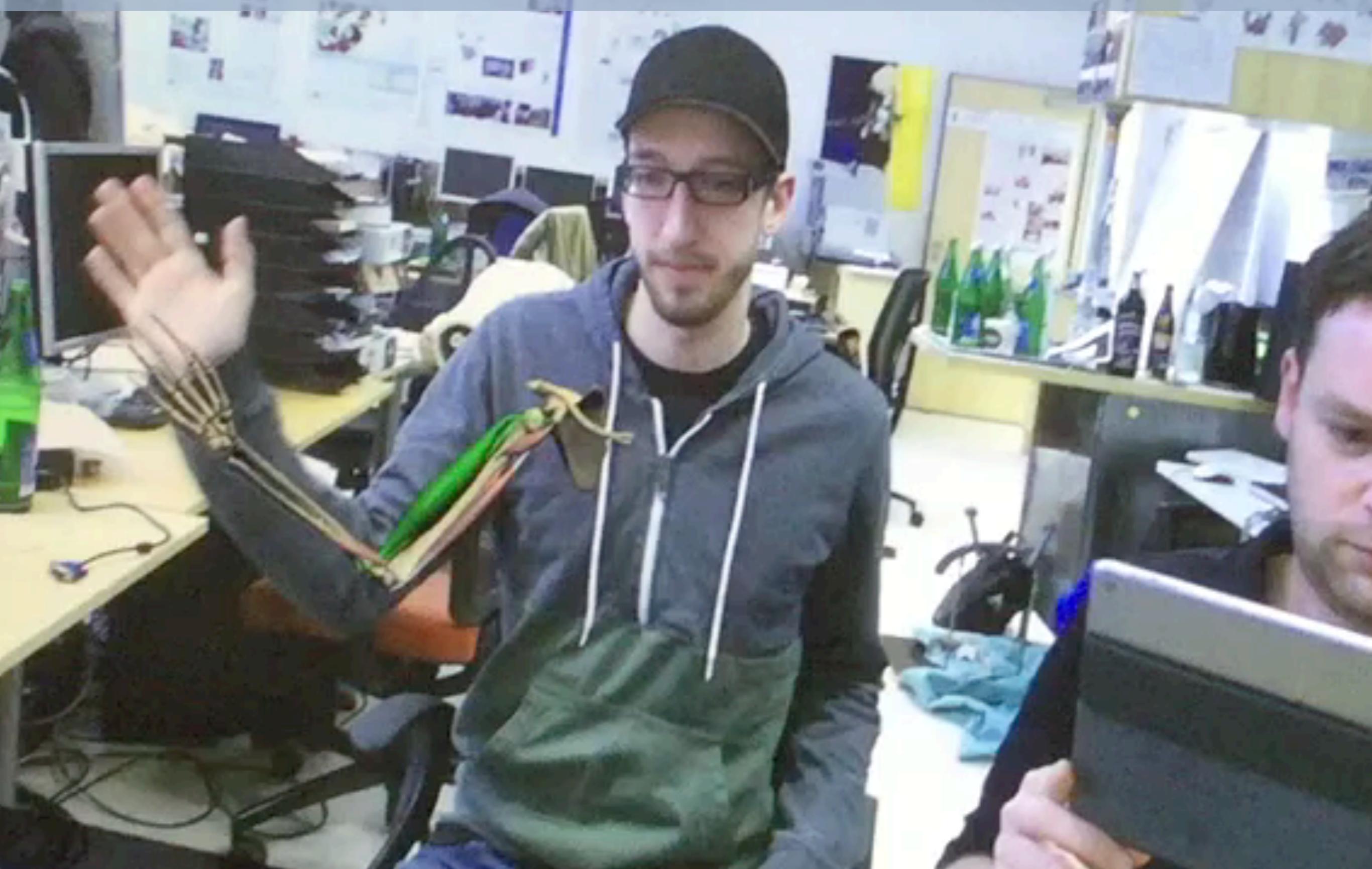
SCAP SETS

Pull your shoulders back,
pinching the shoulder
blades together. Do not let
the shoulders come
forward. Hold 5-10
seconds.

Repeat 10 times
Do 1 session per day.

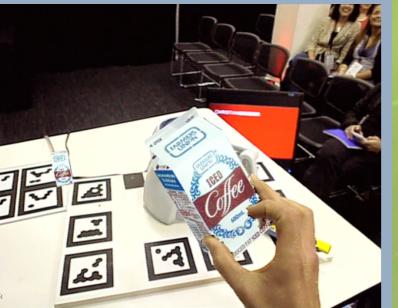


FUTURE WORK: MEDICAL APPLICATIONS

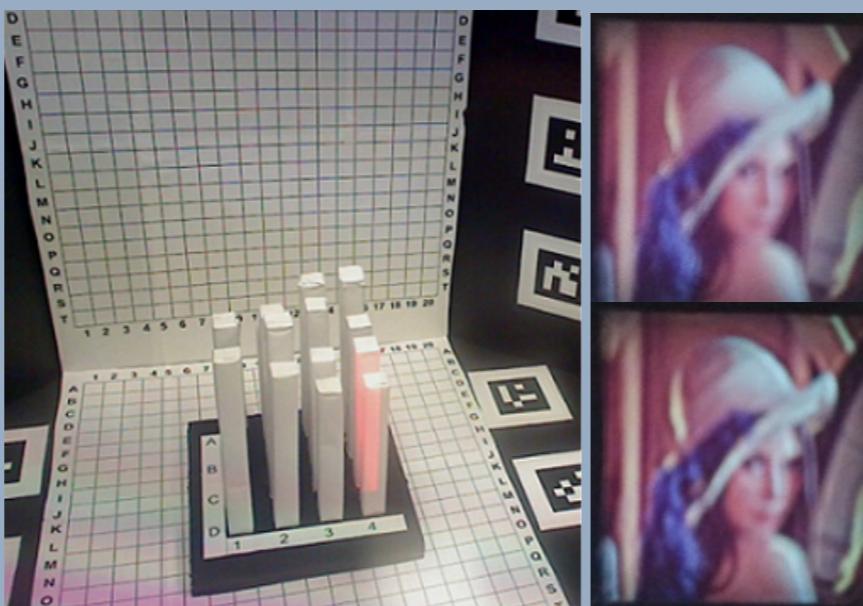
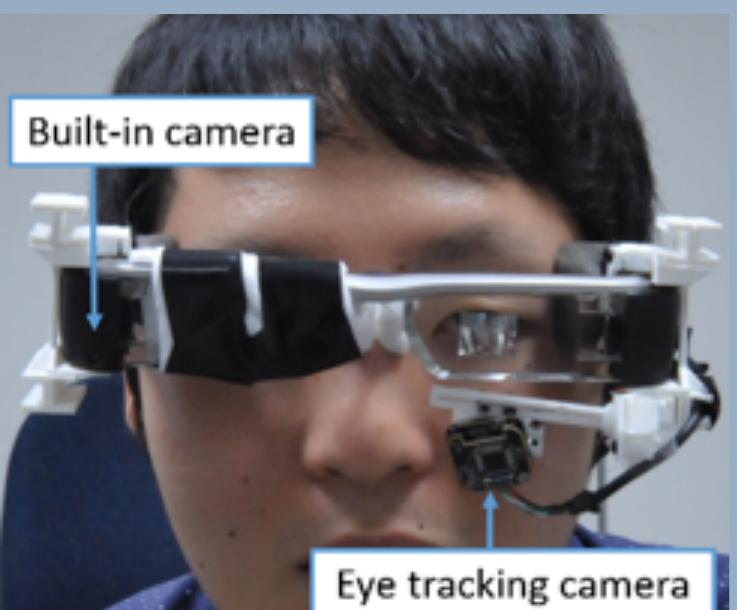


COURTESY OF [HTTP://CAMPAR.IN.TUM.DE/MAIN/FELIXBORK](http://CAMPAR.IN.TUM.DE/MAIN/FELIXBORK)

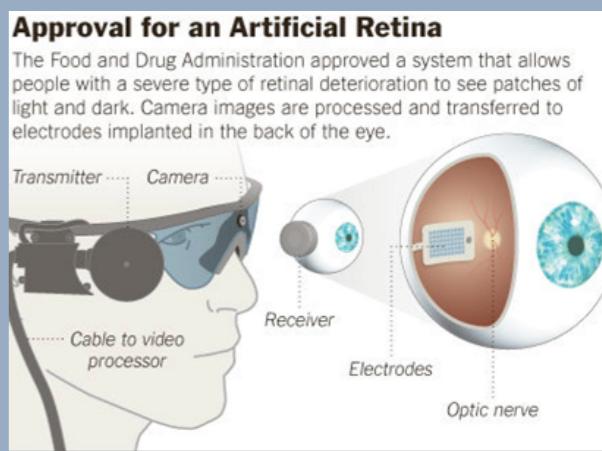
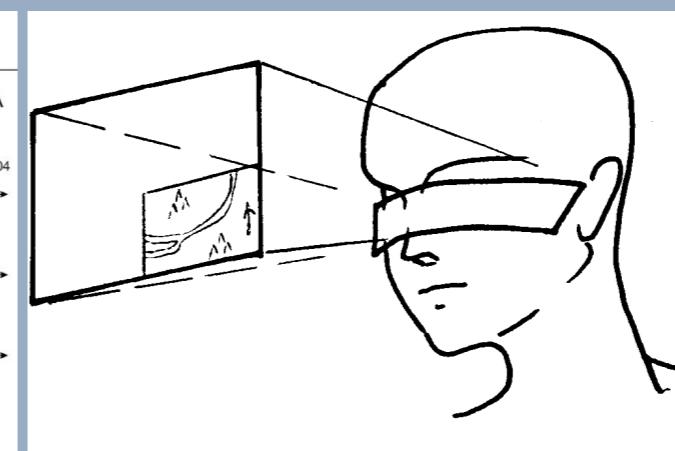
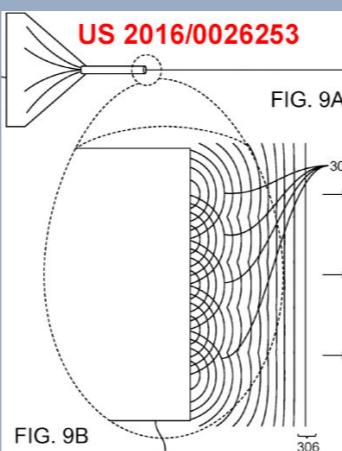
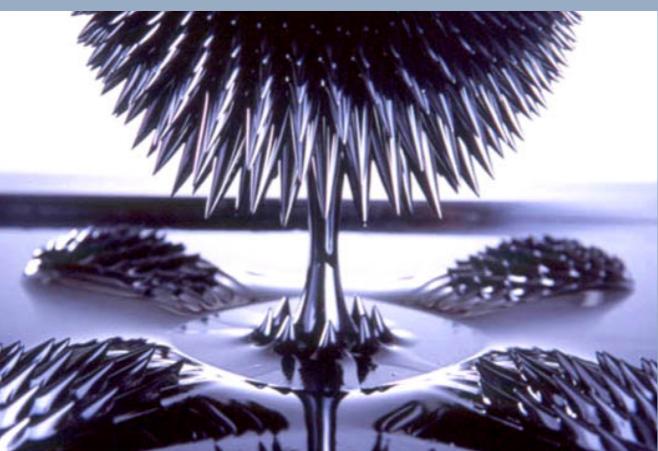
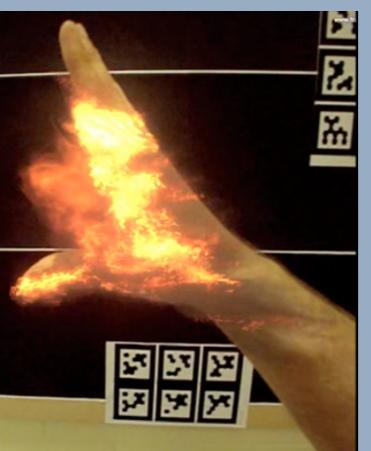
DISPLAYS



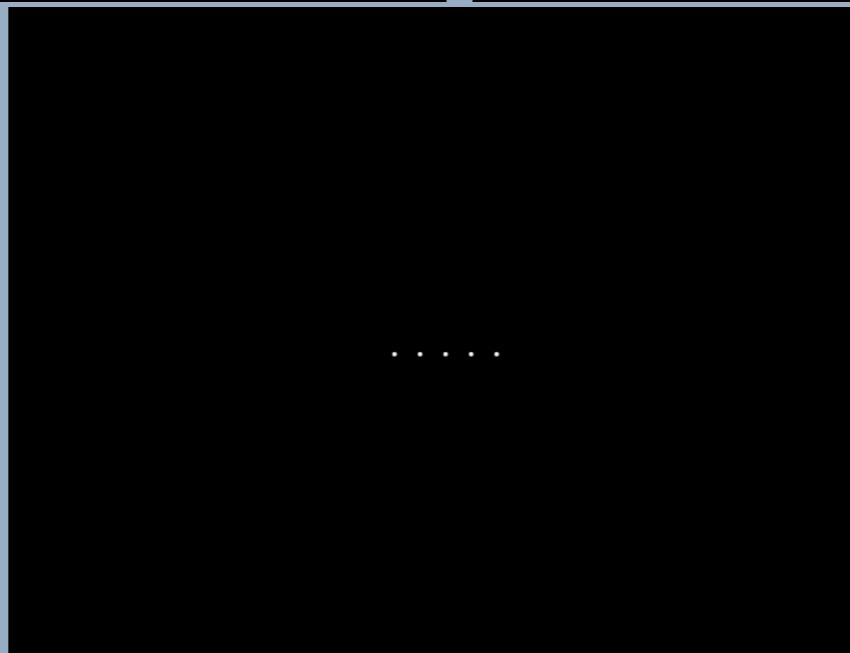
APPLICATIONS



PHILOSOPHY: TRUE AUGMENTED REALITY



TRANSMEDIA CINEMATOGRAPHY



[HTTPS://WWW.YOUTUBE.COM/WATCH?V=9JPWITVR0GA](https://www.youtube.com/watch?v=9JPWITVR0GA)

YŌKAI (妖怪)



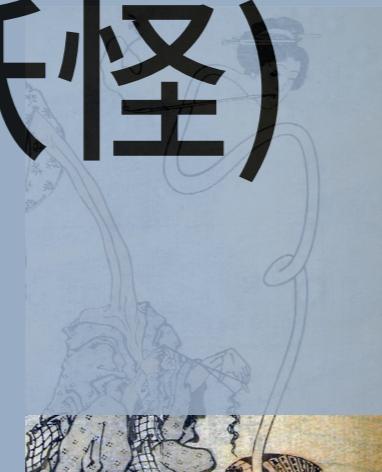
Nurikabe



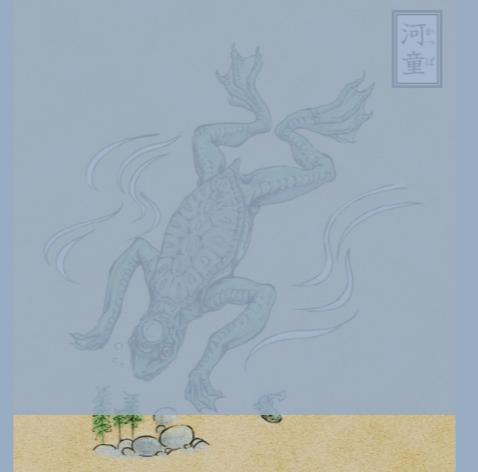
Mokumokuren



Tsuchigumo



Long neck woman



Big centipede



Kappa



Nopperabou



Paper umbrella haunted



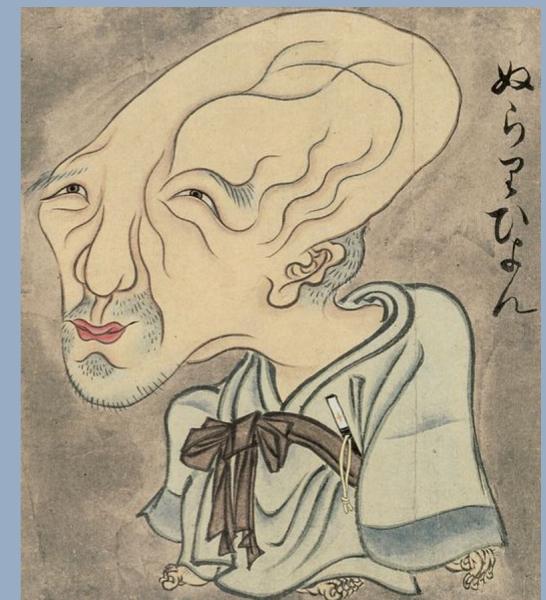
Umibouzu



Gasyadokuro



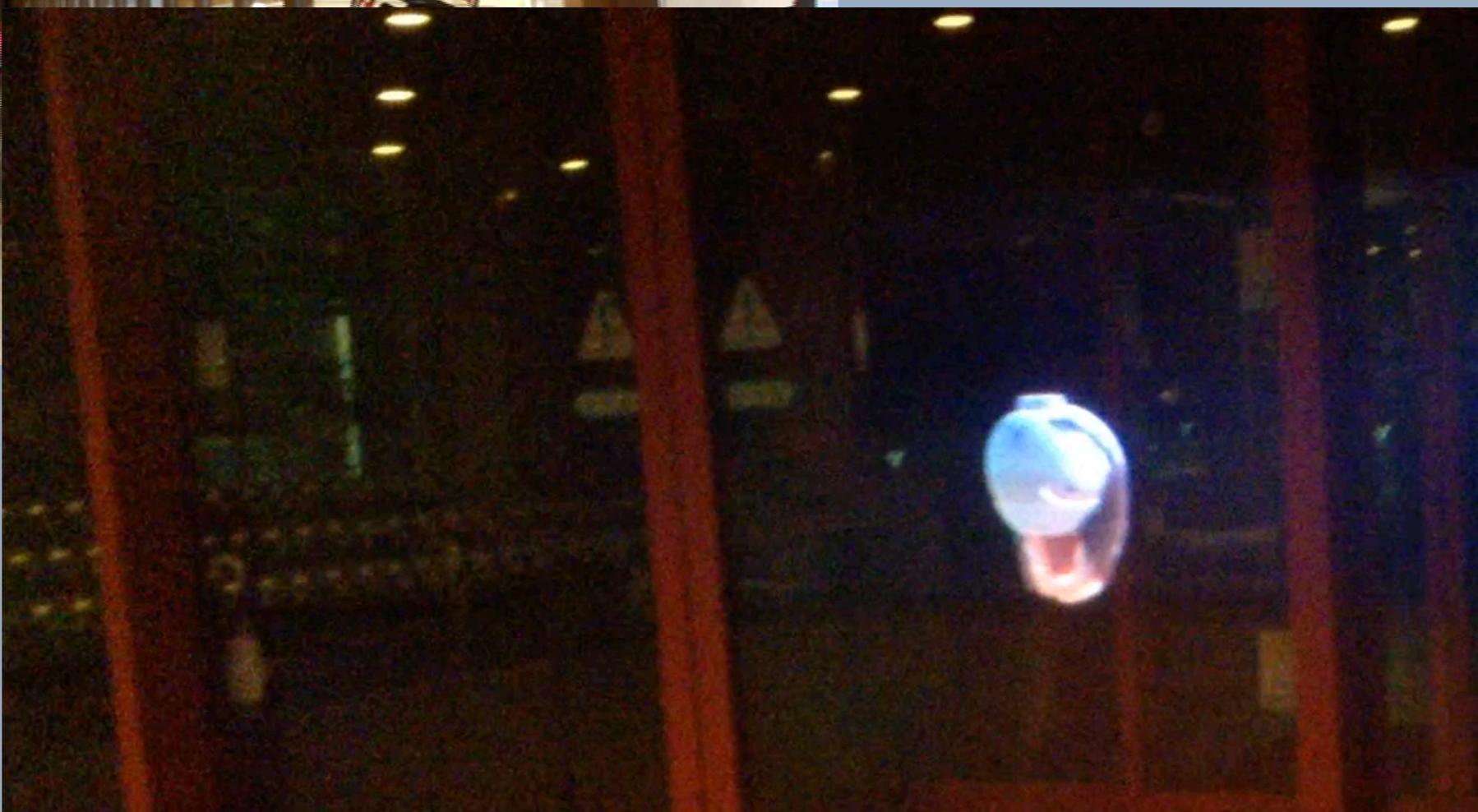
Tengu



Nurarihyon

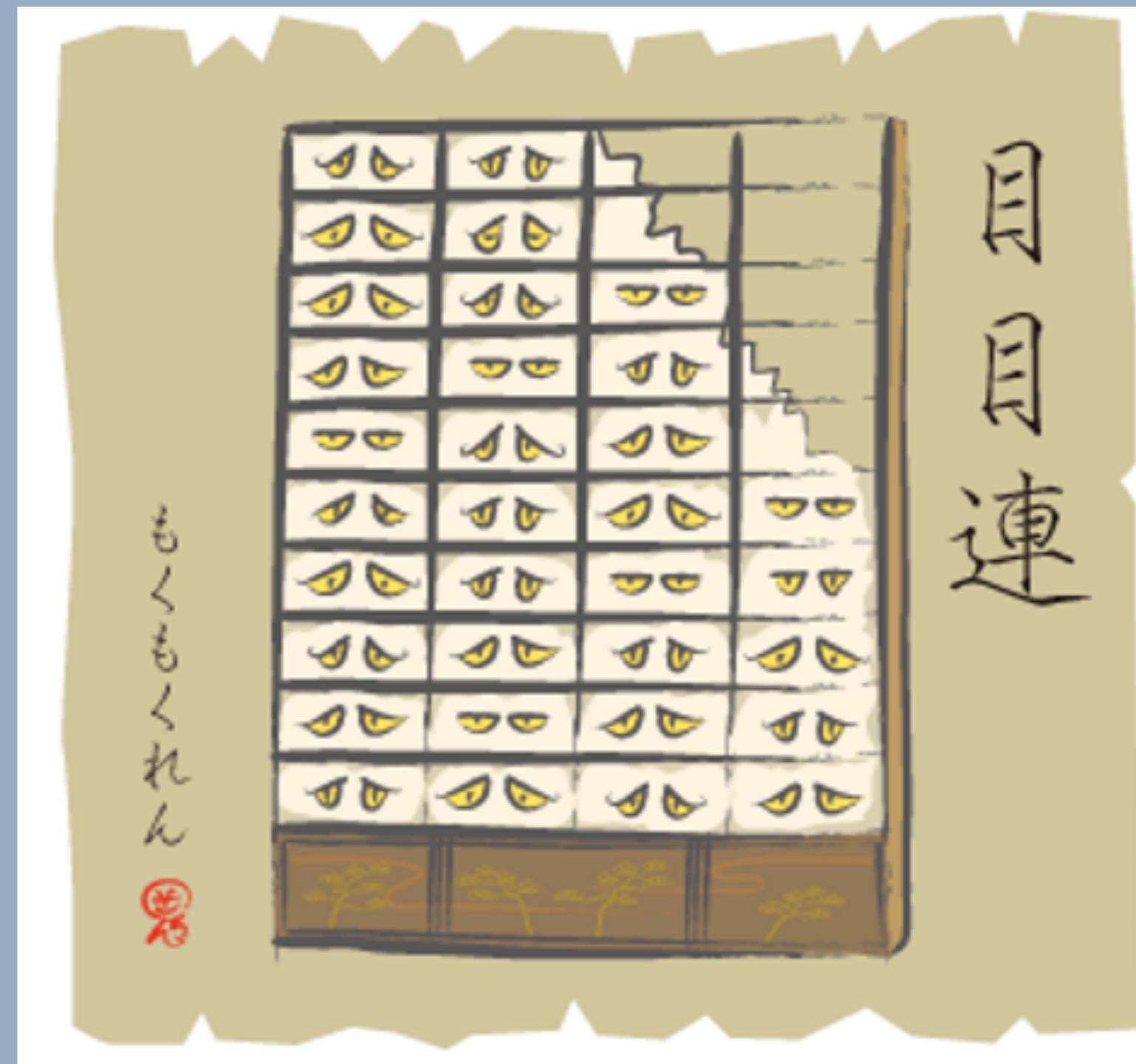


AR YŌKAI(UNPUBLISHED)





Big centipede



Mokumokuren

DISPLAYS

CONCLUSIONS

APPLICATIONS

SUMMARY

AR: EXTREMELY HIGH POTENTIAL (UNLIKE VR)

INTERDISCIPLINARY: COMPUTER GRAPHICS, COMPUTER VISION,
OPTICS, PERCEPTION RESEARCH

Built-in camera
REQUEST

CHAT TO ME AT IDW! LOOKING FOR GOOD COLLABORATORS
CHRISTIAN@SANDOR.COM

EYE TRACKING CAMERA
PHILOSOPHY: TRUE AUGMENTED REALITY

SLIDES WILL BE ONLINE WITHIN ONE HOUR!
[HTTP://WWW.SLIDEShare.NET/CHRISTIANSANDOR](http://www.slideshare.net/Christiansandor)



Approval for an Artificial Retina
The Food and Drug Administration approved a system that allows people with a severe type of retinal deterioration to see patches of light and dark. Camera images are processed and transferred to electrodes implanted in the back of the eye.

