Optical Architectures for Augmented-, Virtual-, and Mixed-Reality Headsets

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Bernard C. Kress

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Preface

This book is a timely review and analysis of the various optical architectures, display technologies, and optical building blocks used today for consumer, enterprise, or defense head-mounted displays (HMDs) over a wide range of implementations, from smart glasses and smart eyewear to augmented-reality (AR), virtual-reality (VR), and mixed-reality (MR) headsets.

Such products have the potential to revolutionize how we work, communicate, travel, learn, teach, shop, and get entertained. An MR headset can come in either optical see-through mode (AR) or video-pass-through mode (VR). Extended reality (XR) is another acronym frequently used to refer to all declinations of MR.

Already, market analysts have very optimistic expectations on the return on investment in MR, for both enterprise and consumer markets. However, in order to meet such high expectations, several challenges must be addressed. One is the use case for each market segment, and the other one is the MR hardware development.

The intent of this book is not to review generic or specific AR/VR/MR use cases, or applications and implementation examples, as they have already been well defined for enterprise, defense, and R&D but only extrapolated for the burgeoning consumer market. Instead, it focuses on hardware issues, especially on the optics side.

Hardware architectures and technologies for AR and VR have made tremendous progress over the past five years, at a much faster pace than ever before. This faster development pace was mainly fueled by recent investment hype in start-ups and accelerated mergers and acquisitions by larger corporations.

The two main pillars that define most MR hardware challenges are immersion and comfort. Immersion can be defined as a multisensory perception feature (starting with audio, then display, gestures, haptics, etc.). Comfort comes in various declinations:

- **wearable comfort** (reducing weight and size, pushing back the center of gravity, addressing thermal issues, etc.),
- **visual comfort** (providing accurate and natural 3D cues over a large FOV and a high angular resolution), and
- **social comfort** (allowing for true eye contact, in a socially acceptable form factor, etc.).

In order to address in an effective way both comfort and immersion challenges through improved hardware architectures and software developments, a deep understanding of the specific features and limitations of the human visual perception system is required. The need for a human-centric optical design process is emphasized, which would allow for the most comfortable headset design (wearable, visual, and social comfort) without compromising the user's immersion experience (display, sensing, interaction). Matching the specifics of the display architecture to the human visual perception system is key to reducing the constraints on the hardware to acceptable levels, allowing for effective functional headset development and mass production at reasonable costs.

The book also reviews the major optical architectures, optical building blocks, and related technologies that have been used in existing smart glasses, AR, VR, and MR products or could be used in the near future in novel XR headsets to overcome such challenges. Providing the user with a visual and sensory experience that addresses all aspects of comfort and immersion will eventually help to enable the market analysts' wild expectations for the coming years in all headset declinations.

The other requirement, which may even be more important than hardware, is contingent on the worldwide app-developer community to take full advantage of such novel hardware features to develop specific use cases for MR, especially for the consumer market.

Bernard C. Kress
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Acronyms

3DOF	Three degrees of freedom
6DOF	Six degrees of freedom
AI	Artificial intelligence
AMOLED	Active matrix organic light-emitting diode
AR	Augmented reality
CD	Critical dimension (lithography)
CMOS	Complementary metal–oxide semiconductor
DFM	Design for manufacturing
DLP	Digital Light Processing
DNN	Deep neural network
DTM	Diamond turning machine
EB	Eyebox
EPE	Exit pupil expansion
EPR	Exit pupil replication
ER	Eye relief
ET	Eye tracking
GPU	Graphical processing unit
HeT	Head tracking
HMD	Head-mounted (or helmet-mounted) display
HPU	Holographic processing unit
HTPS	High-temperature poly-silicon (display)
HUD	Head-up display
IC	Integrated circuit
iLED	Inorganic LED (array)
IPS	In-plane switching (LCD)
IVAS	Integrated visual augmentation system
LBS	Laser beam scanner
LC	Liquid crystal
LCA	Lateral chromatic aberration
LCD	Liquid crystal display
LCoS	Liquid crystal on silicon
LD	Laser diode

LED	Light-emitting diode
LSR	Late-stage reprojection
LTPS	Low-temperature poly-silicon (display)
M&A	Mergers and acquisitions
MEMS	Micro-electro-mechanical systems
MLA	Micro-lens array
MR	Mixed reality
MTF	Modulation transfer function
MTP	Motion-to-photon (latency)
mu-OLED	Micro-OLED (panel) on silicon backplane
NTE	Near-to-eye (display)
OLCD	Organic liquid crystal display
OLED	Organic LED (panel)
OST-HMD	Optical see-through HMD
PDLC	Polymer-dispersed liquid crystal
PPD	Pixels per degree
PPI	Pixels per inch
QLCD	Quantum-dot liquid crystal display
RCWA	Rigorous coupled wave analysis
ROI	Return on investment
RSD	Retinal scanning display
SLAM	Simultaneous location and mapping
SLED	Super-luminescent emitting diode
UWB	Ultra-wide-band (chip)
VAC	Vergence–accommodation conflict
VCSEL	Vertical cavity surface emitting laser
VD	Vertex distance
VLSI	Very-large-scale integration
VR	Virtual reality
VRD	Virtual retinal display
VST-HMD	Video see-through (HMD)
XR	Extended reality