SUDHIR DIXIT
RAMJEE PRASAD

# Human Bond COMMUNICATION

## THE HOLY GRAIL OF HOLISTIC COMMUNICATION AND IMMERSIVE EXPERIENCE

WILEY

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The Holy Grail of Holistic Communication and Immersive Experience

*Edited by*

*Sudhir Dixit*
*Ramjee Prasad*

WILEY

This edition first published 2017


*Registered Offices*
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA

*Editorial Office*
111 River Street, Hoboken, NJ 07030, USA

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*Library of Congress Cataloging-in-Publication Data*

Names: Dixit, Sudhir, editor. | Prasad, Ramjee, editor.
Title: Human bond communication : the holy grail of holistic communication and immersive experience / edited by Sudhir Dixit, Ramjee Prasad.
Description: Hoboken, NJ : John Wiley & Sons, 2017. | Includes bibliographical references and index.
Identifiers: LCCN 2016046268 (print) | LCCN 2017002987 (ebook) | ISBN 9781119341338 (cloth) | ISBN 9781119341468 (pdf) | ISBN 9781119341413 (epub)
Subjects: LCSH: Telecommunication systems. | Human-computer interaction. | Digital communications. | Information technology.
Classification: LCC TK5102.5 .H86 2017 (print) | LCC TK5102.5 (ebook) | DDC 621.38201–dc23
LC record available at https://lccn.loc.gov/2016046268

Cover design by Wiley
Cover image: © dem10/gettyimages

Set in 10/12pt Warnock by SPi Global, Pondicherry, India

Printed in United States of America

10 9 8 7 6 5 4 3 2 1

*नैव किञ्चित् करमीति युक्तो मन्येत तत्ववित् ।*
*पश्यन् शृण्वं स्पर्शम् जिघ्रन्नश्नन् गच्छन् स्वपञ् श्वसं ॥*

*प्रलपं विसृजन् गृहणं उन्मिषण निमिशन् अपि*
*इंद्रियाणीन्द्रियार्थेषु वर्तन्त इति धारयन् ॥*

*Naiva kinchit karmiti yukto manyeta tattvit-vit*
*Pashyan shunvan sparshan jigrhrann asnan gacchan svapan svasan*

*Pralapan visrijan grihnann unmishan nimishann api*
*indriyaanindriyaarthesu vartanta iti dhaaryan*

*One who knows the truth is always certain that it is the senses that are engaged in observations, like seeing, hearing, smelling, touching, and tasting and is the involuntary participant of the actions happening around, just like opening and closing of eyelids. Such observations are not the part of the ultimate knowledge, but, when a seeker looks beyond them, finds the ultimate truth.*

*—The Bhagavad Gita (5.8 and 5.9)*

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Dr. Sudhir Dixit recently joined the CTIF Global Capsule (CGC) as the Director of Home for Mind and Body, an international centre for peace, located in Rome, Italy. Additionally, he is a Fellow and Evangelist of basic Internet at the Basic Internet Foundation in Norway. He has also been the CEO and Cofounder of Skydoot, Inc., a start-up at San Francisco Bay area in the content sharing and collaboration space. From December 2013 to April 2015, he was a Distinguished Chief Technologist and CTO of the Communications & Media Services for the Americas region of Hewlett Packard Enterprise Services in Palo Alto, CA, and prior to this he was the Director of Hewlett Packard Labs India from September 2009. From June 2009 to August 2009, he was a Director at HP Labs in Palo Alto. Prior to joining HP Labs Palo Alto, Dixit held a joint appointment with the Centre for Internet Excellence (CIE) and the Centre for Wireless Communications (CWC) at the University of Oulu, Finland. From 1996 to 2008, he held various positions with leading companies, such as with BlackBerry as Senior Director (2008), with Nokia and Nokia Networks in the United States as Senior Research Manager, Nokia Research Fellow, Head of Nokia Research Center (Boston), and Head of Network Technology (USA) (1996–2008). From 1987 to 1996, he was at NYNEX Science and Technology and GTE Laboratories (both now Verizon Communications) as a Staff Director and Principal Research Scientist.

Sudhir Dixit has 21 patents granted by the US PTO and has published over 200 papers and edited, coedited, or authored seven books (Wireless World in 2050 and Beyond: A Window into the Future (2016), Wi-Fi, WiMAX and LTE Multi-hop Mesh Networks by Wiley (2013), Globalization of Mobile and Wireless Communications by Springer (2011), Technologies for Home

Networking by Wiley (2008), Content Networking in the Mobile Internet by Wiley (2004), IP over WDM by Wiley (2003), and Wireless IP and Building the Mobile Internet by Artech House (2002)). He is presently on the editorial boards of *IEEE Spectrum Magazine*, Cambridge University Press Wireless Series, and Springer's *Wireless Personal Communications Journal* and *Central European Journal of Computer Science* (CEJS). He was a Technical Editor of IEEE Communications Magazine (2000–2002 and 2006–2012). He is a two-time winner of the MIT's Technology Review India Grand Challenge Award (2010).

From 2010 to 2012, he was an Adjunct Professor of Computer Science at the University of California, Davis, and, since 2010, he has been a Docent of Broadband Mobile Communications for Emerging Economies at the University of Oulu, Finland. A Life Fellow of the IEEE, and a Fellow of IET and IETE, Dixit received a Ph.D. degree in electronic science and telecommunications from the University of Strathclyde, Glasgow, UK and an M.B.A. from the Florida Institute of Technology, Melbourne, Florida. He received his M.E. degree in Electronics Engineering from Birla Institute of Technology and Science, Pilani, India, and B.E. degree from Maulana Azad National Institute of Technology, Bhopal, India.

Dr. Ramjee Prasad is a Professor in multi-business model and technology innovation in the School of Business and Social Sciences, Aarhus University, Denmark. He is the Founder President of the CTIF Global Capsule (CGC). He has been a Founder Director of Center for TeleInFrastruktur (CTIF) since 2004. He is also the Founder Chairman of the Global ICT Standardisation Forum for India, established in 2009. GISFI has the purpose of increasing the collaboration between European, Indian, Japanese, North-American and other worldwide standardization activities in the area of information and communications technology (ICT) and related application areas.

He was the Founder Chairman of the HERMES Partnership—a network of leading independent European research centers established in 1997, of which he is now the Honorary Chair. He is a Fellow of IEEE (USA), IETE (India), IET (UK), and Wireless World Research Forum (WWRF) and a member of the Netherlands Electronics and Radio Society (NERG) and the Danish Engineering Society (IDA).

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He is the Founder Editor in Chief of the Springer International Journal on Wireless Personal Communications. He is a member of the editorial board of other renowned international journals including those of River Publishers. Ramjee Prasad is Founder Cochair of the steering committees of many renowned annual international conferences, for example, Wireless Personal Multimedia Communications Symposium (WPMC) and Wireless VITAE and Global Wireless Summit (GWS).

He has published more than 30 books, 1000 plus journal and conference publications, and more than 15 patents and over 100 PhD graduates and a larger number of master's students (over 250). Several of his students are today worldwide telecommunication leaders themselves.

# Preface

Applications today have been enriched with multimedia content consisting of audio, video, augmented reality and consistently progressing toward multidimensional rendering, such as stereo, 3D, ultrahigh definition, and fidelity. In parallel, the user interaction with the devices and applications is delivering engaging experience through voice, gestures, gaze, touch, and so on. Wearable devices and body sensors are continually being integrated with applications and user devices, such as a smartphone, remote control, and finding useful applications in healthcare and remote monitoring. Humans interact with applications and consume content through optical and auditory senses. But the understanding is incomplete in the absence of information from and about the other three sensory inputs, namely, olfactory (smell), gustatory (taste), and tactile (touch). This is because all five senses interestingly interact among themselves and the environment, such that being able to sense them, transmit them, and render them at the receiver can potentially deliver powerful experiences. This book on human bond communication (HBC) is about utilizing all five senses to allow more expressive and holistic sensory information exchange through communication techniques for more human sentiment centric communication. The overall outcome is for the human brain to be holistically cognitive of the subject of interest. This complete perceptive information is well exchanged among humans through these senses and, when collectively agreed, becomes knowledge. This is the first book of its kind to motivate research and innovation in holistic communication and to launch a new era of novel products and services to disrupt the status quo of contemporary applications and services that only deal with aural and optical capture, transmission, and rendering of information.

This book focuses on all technologies and issues related to HBC. It also includes the use cases and business opportunities emanating from human-to-machine and machine-to-machine applications, interactions, and communication. The chapters have been authored by the experts in the various fields, which collectively would make HBC possible.

This book is intended for graduate students, academic teachers, scholars, researchers, industry professionals, and software developers interested in the design and development of more engaging and holistic interaction experiences. This book will also be of great interest to casual readers not necessarily familiar with sensor and communication technologies. Therefore, the content is more descriptive and qualitative than theoretical in style of writing.

We thank the contributors of this book for their time and effort to make this book possible in a short period of time. We particularly acknowledge their patience and for always responding promptly to numerous requests for revising their chapters.

Sudhir Dixit
Woodside, California
January 2017

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## Abbreviations

| | |
|---|---|
| AAA | Anytime, anywhere, anything |
| AAL | Ambient Assisted Living |
| AD | Auxiliary data |
| AI | Artificial intelligences |
| ANN | Artificial neural networks |
| App | Application software to perform tasks for computer/terminal |
| APT | Advanced persistent threat |
| APs | Access points |
| ARPA | Advanced Research Project Agency |
| ARPANET | Advanced Research Project Agency Network |
| B2B | Brain to brain |
| BBI | Brain-to-brain interface |
| BBU | Broadband unit |
| BCC | Body channel communication |
| BCI | Brain-to-computer interface |
| BIRCH | Balanced iterative reducing and clustering using hierarchies |
| BMI | Brain–machine interface |
| ByN | Body as a node |
| CBD | Convention on Biological Diversity |
| CBI | Computer-to-brain interface |
| CCI | Capture, communicate, and instantiate |
| CDR | Computing device recognition |
| CERN | Conseil Européen pour la Recherche Nucléaire (European Council for Nuclear Research) |
| CPS | Calculations per second |
| CR | Cognitive radio |
| CRN | Cognitive radio networks |
| CRNSP | Cognitive radio network service provider |
| CTIF | Center for TeleInFrastruktur |

| | |
|---|---|
| DARPA | Defense Advanced Research Projects Agency |
| DBSCAN | Density-based spatial clustering of applications with noise |
| DNA | Deoxyribonucleic acid |
| DoD | Department of Defense |
| DOI | Dolev–Yao intruder |
| DoS | Denial-of-service |
| DR | Dead reckoning |
| DSP | Digital signal processor |
| DSS | Decision support system |
| DSLM | Dynamic spectrum leasing methodology/Model |
| E&Y | Ernst and Young |
| ECG | Electrocardiogram |
| EEG | Electroencephalogram/electroencephalography |
| eHealth | Electronic health |
| EHR | Electronic health record |
| EMG | Electromyography |
| EMR | Electronic medical record |
| EPC | European Patent Convention |
| EPO | European Patent Office |
| EPR | Einstein, Podolsky, and Rosen |
| ETSI | European Telecommunication Standards Institute |
| FCN | Fog computing node(s) |
| FDM | Frequency division multiplexing |
| fNIRS | Functional near-infrared spectroscopy |
| FP7 | Framework program |
| FP-growth | Frequent pattern growth |
| F-RAN | Fog computing-based radio access network |
| FRAND rates | Friendly, reasonable, and nondiscriminatory rates |
| F-UE | Fog-capable user equipment |
| FUS | Focused ultrasound |
| GDPR | General Data Protection Regulation |
| GIS | Geographical information system |
| GPS | Global Positioning System |
| GSP | Generalized Sequential Pattern |
| H2H | Human-to-human |
| H2M | Human-to-machine |
| HBC | Human bond communication(s) |
| HBCI | Human bond communication(s) interface |
| HBP | Human Brain Project |
| HBS | Human bond sensorium |
| HCS | Human-centric sensing |
| HCS-N | Human-centric sensing-network |
| HCS-NF | Human-centric sensing-network federation |

| | |
|---|---|
| HGP | Human Genome Project |
| HMI | Human–machine interface |
| GNSS | Global Navigation Satellite System |
| HPN | High power node |
| HPT | Human perceivable transposer |
| HTML | Hypertext Markup Language |
| HTTP | Hypertext Transfer Protocol |
| IAF | Interdisciplinary analysis of functions |
| IBM | International Business Machines |
| IC | Integrated circuit |
| ICN | Information-centric networking |
| ICT | Information and communication technologies |
| IdM | Identity management |
| IEEE | Institute of Electrical and Electronics Engineers |
| IGW | Internet gateways |
| IOD | Intraoral device |
| IoE | Internet of everything |
| IoH | Internet of humans |
| IoT | Internet of things |
| IP | Internet Protocol, intellectual property |
| IPR | Intellectual property right |
| IR | Information retrieval |
| ISDN | Integrated Service Digital Network |
| KDD | Knowledge Discovery in Databases |
| k-NN | k-nearest neighbors |
| LAN | Local area network |
| LDA | Linear discriminant analysis |
| LSI | Large-scale integration |
| METIS | Mobile and wireless communications Enablers for the Twenty-twenty Information Society |
| ML | Machine learning |
| M2M | Machine-to-machine |
| MALDI | Matrix-assisted laser desorption/ionization |
| MEG | Magnetoencephalography |
| MEMS | Microelectromechanical systems |
| mHealth | Mobile health |
| MMS | Multimedia message(ing) service |
| MOS | Metal–oxide–semiconductor |
| MPEG | Moving Picture Experts Group |
| MRI | Magnetic resonance imaging |
| mRNA | Messenger RNA |
| MVNO | Mobile virtual network operator |
| NFC | Near-field communication |

| | |
|---|---|
| NFV | Network Function Virtualization |
| NIRS | Near-infrared spectroscopy |
| NSA | National Security Agency |
| NLP | Natural language processing |
| OC | Oral cavity |
| OCN | Oral cavity as a node |
| OPTICS | Ordering points to identify the clustering structure |
| OTO | Old telecom operator |
| PA | Protected area |
| PAN | Personal area network |
| PbD | Privacy by design |
| PC | Personal computer |
| PCM | Pulse-code modulation |
| PH | Partial human |
| PHR | Personal health record |
| PI | Pseudoidentifiers |
| PN | Personal network |
| PN-F | Personal Network Federation |
| POTS | Plain old telephone service |
| POV | Point of view |
| PrefixSpan | Prefix-projected sequential pattern mining |
| PU | Primary user |
| PWA | Physical world augmentation |
| PWS | Partial wave spectroscopy |
| QoS | Quality of service |
| R&D | Research & development |
| RET | Rare, Endangered, and threatened species |
| RFID | Radio frequency identification |
| RNA | Ribonucleic acid |
| SAR | Structure–activity relationship |
| S-BAN | Smart body area network |
| SDN | Software-defined networking |
| SELDI | Surface-enhanced laser desorption/ionization |
| SEP | Standard-essential patent |
| SF | Science fiction |
| SMS | Short message service |
| SoC | System on chip |
| SPADE | Sequential PAttern Discovery using Equivalent Class |
| STEM | Science, technology, engineering, and mathematics |
| Stethics | Standardization and ethics |
| SU | Secondary user |
| SVM | Support Vector Machine |
| TCP | Transmission Control Protocol |

| | |
|---|---|
| TFEU | Treaty on the Functioning of the European Union |
| TMS | Transcranial magnetic stimulation |
| TPMs | Technological protection measures |
| TRIPS | (Agreement on) Trade-Related Aspects of Intellectual Property Rights |
| UHF | Ultrahigh frequency |
| URI | Uniform Resource Identifier |
| URL | Uniform Resource Locators |
| UWB | Ultra-wideband |
| VANETs | Vehicular Ad-hoc Networks |
| V2V | Vehicle-to-vehicle |
| VHF | Very high frequency |
| VLC | Visible light communications |
| VM | Virtual machine |
| VR | Virtual reality |
| WBAN | Wireless body area network |
| WSP | Wireless service provider |
| WWII | World War II |

# 1

# Introduction to Human Bond Communication

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## 1.1 Introduction

Information and communications technologies (ICT) have progressed rapidly in this millennium for people to communicate and exchange information using multimedia (speech, video/image, text), and the same has extended to Internet of things (IoT) and machine-to-machine and machine-to-human communication. This trend is only going to accelerate in the years to come with powerful human–computer interaction technologies to deliver engaging and intuitive experiences. But these developments have remained confined to only the sensing and transmission of aural and optical information in the digital domain through the use of microphone, camera, speaker, and display devices. However, the ability to integrate the other three sensory features, namely, olfactory (smell), gustatory (taste), and tactile (touch) in information transfer and replication to deliver "being there in-person" experience, are still far from reality. Human bond communication (HBC) is a novel concept that incorporates all five sensory information from sensing, to digitization, to transmission and replication at the receiver to allow more expressive, engaging, realistic, and holistic information between humans [1] and in some cases between humans and machines such as in remote sensing and robotic control. Lack of inclusion of the other three senses in the digital world of ICT limits the full exploitation of the cognitive ability of the human mind for a fuller perceptive information experience. The five senses and the environment interact in interesting ways to become complete knowledge for human species as its brain has developed and evolved naturally from the time it came into existence on this planet. The profoundness of perceiving an object depends on the incisiveness and extensity

*Human Bond Communication: The Holy Grail of Holistic Communication and Immersive Experience*, First Edition. Edited by Sudhir Dixit and Ramjee Prasad.

of the sense organs. Incisiveness refers to the granularity and minute details or variations an organ can detect, and extensity refers to the range of the physical property that it can detect.

In the traditional world of digital information exchange, the subject is described and presented partially via its aural and optical rendering, which gives a sense of incompleteness and dissatisfaction in fully understanding the subject. In the present era of ever increasing competition through innovation, inclusion of all five senses to deliver complete experience is the holy grail of the research community. Products have begun to appear through wearables and other embedded sensors in the body, but sensors exploiting touch, taste, and smell and embedding them into products remains a distant reality and is an area of intense research today as would become evident from the chapters included in this book.

Auditory and optical sensing is wave based. In audio sound travels through waves and can be sensed and digitized. Similarly, light shining on an object is reflected in electromagnetic radiation, and a part of this spectrum (called visible light in the range of wavelength 390–700 nm) is visible to the human eye and when rendered on the retina becomes a visual formulation of the object in the nervous system. The camera does this nicely to capture an object visually and digitize it for transmission. When rendered remotely on a display device in 2-D or 3-D, a person can see the object as though he or she was seeing it by being physically present at a location where the camera was located. Other human senses (tactile, olfactory, gustatory) utilize particle-based sensing and rely on smearing the object with the sensors. Building such sensors remains a technological challenge for the research community because each type of sensor must deal with large range of parameters and their wide spectrum. Digitization of these parameters is also a major challenge, and even if some finite widely prevalent values can be captured and digitized, their replication from the digital domain to the analog domain and their sensing by a person in an unobtrusive manner is a complex human-sensor interface issue. Figure 1.1 illustrates the HBC system and depicts what is possible today and what is not.

HBC is about understanding the human sensory functionality and works similar to human sensory system, which includes providing a perceptually holistic understanding of an object combining all five senses while incorporating the object's environment.

## 1.2 Human Bond Communication (HBC) Architecture

The HBS architecture extrapolates the contemporary communications architecture to include the missing three senses (or types of sensors): tactile, olfactory, and gustatory, not in use today along with the aural and optic

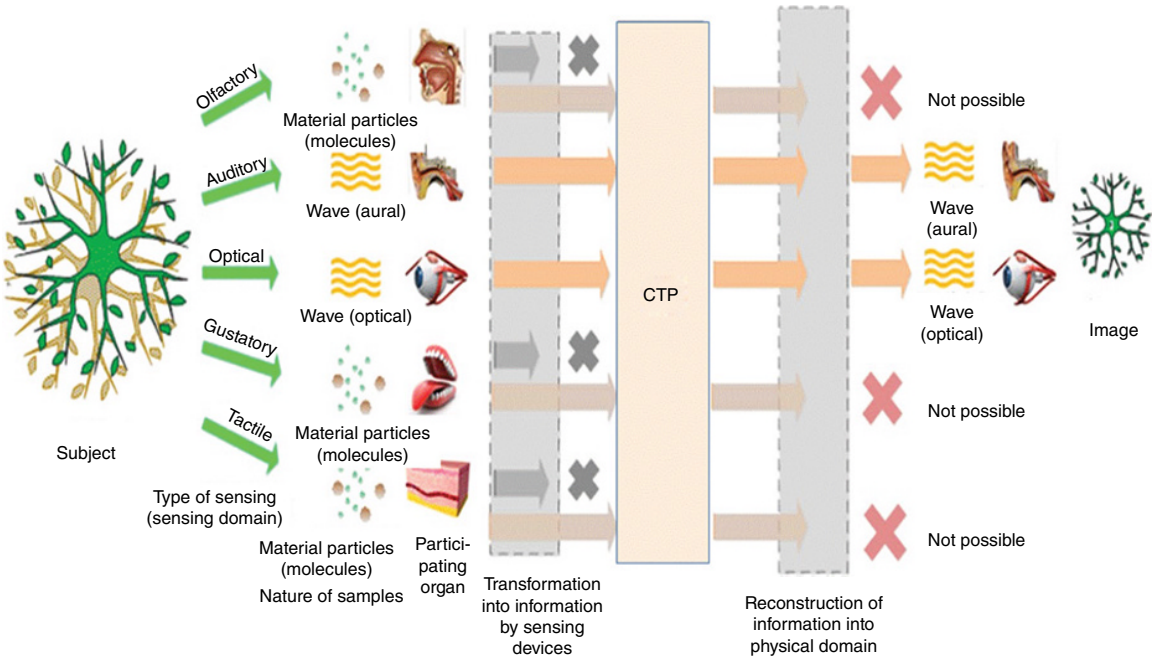


**Figure 1.1** An illustration of human bond communication (HBC) concept. CTP, communication technology platform. Prasad [1]. Reproduced with the permission of Springer.

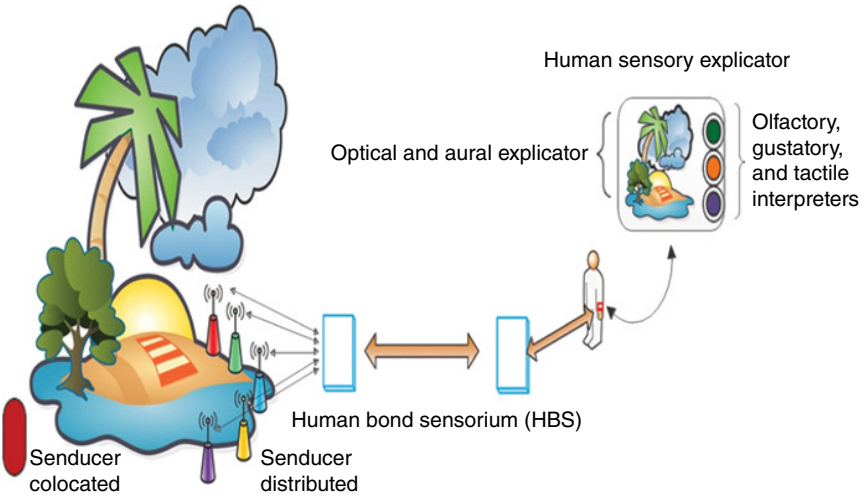


**Figure 1.2** A proposed HBC architecture. Prasad [1]. Reproduced with the permission of Springer.

sensors. Nevertheless, some limited deployments are happening in machine-to-machine and machine-to-human communication use cases where robots are being used, such as in industry, law enforcement, hazardous material handling, and surveillance. A proposed architecture is shown in Figure 1.2 [1]. It should be noted that the architecture goes beyond capturing just a person's senses to also deploying all five types of sensors in any environment to capture smell (e.g., types of smoke, air pollutants), tactile information (e.g., surface roughness, temperature, wind speed), and taste (e.g., liquids, dirt, waste) and learning about an object or its surroundings.

The system consists of the three key building blocks: (i) senducers that sense the characteristic parameters through stimuli and transform those analog values to electrical and digital domain for further processing and transmission, (ii) human bond sensorium (HBS) that collects the data from the senducers, processes them to make them consumable for the human perceptive system (i.e., human consumption) by removing a large amount of nonusable and redundant data and information, transmits it to the far end to the receiver gateway, and (iii) human perceivable transposer (HPT) that transforms the received digital data to human consumable format, which includes replication of the senses to a form that one would expect if the person was physically present at the site where the sensory data were collected through senducers. Until such time the replication solutions are not available, the HPT may prefer to render the non-audio–visual sense data through digital means (such as colors, emoticons, text, other gestures like vibration, pressure, temperature, etc.).