Virtual reality for the effective communication of numerical data

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Self-Introduction



Editing with GoArt

- Hiroaki Ohtani (大谷 寛明)
- Department of Physics, Keio University, Japan
- Ph.D on "Theoretical Study on Metal-Nonmetal Transition in Liquid Chalcogens" from Keio University in 2000.
- Research Student on "First-Principles Study of Structure and Electronic States in Condensed Systems" at The University of Tokyo from April 2000 to June 2000
- Joined the National Institute for Fusion Science (NIFS), Theory and Computer Simulation Center, as an Assistant Professor from July 2000.
- Present position: Associate Professor, Sensing and Intellectualizing Technology, National Institute for Fusion Science (NIFS).
 - Plasma Physics Research through Simulation:
 FRC, magnetic reconnection, dynamo effect
 - Research on Visualization Techniques and Analysis Using Virtual Reality (VR) Visualization

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Outline

- Virtual Reality system
- Introduction of research achievements
 - Collision points of High-energy tritons and plasma-facing walls
 - Dust particle orbit
- Summary

What comes to mind when you hear the term "virtual reality"?

Virtual-reality?

This word was first used by VPL Co. Ltd. in US in 1989.

Three elements of VR

Presence	The objects exist in the space
	\rightarrow Stereoscopic view
Interaction	The objects are interactively controlled.
	\rightarrow The images moves by the operations.
Autonomy	The objects are autonomously controlled.
	\rightarrow Simulation of virtual-reality world

2016=The First Year of VR(VR元年)



XR

When you hear about virtual reality, what best represents their worldview?

We see, hear, smell, touch, and taste the reality through five-sense organs.



Virtual-reality in "The Matrix"



By the virtual-reality system,



What is the virtual-reality?

• "Virtual" is explained in The American Heritage Dictionary as "Existing in essence or effect though not in actual fact or form"

 \rightarrow Our awareness of the "reality":

We "feel" the reality through the five senses as "windows", and "reconstruct it" in our brain.

→ The research of virtual-reality technology is how to give the virtual parts of the real world to the users.

How does the human being feel the reality?

Why do we use VR system for scientific investigation.

Simulation and experimental observation results: numerical data

 1.1913
 0.0035
 0.932E+00
 0.303E+00
 0.123E-03
 0.312E+00
 0.317E+00
 0.812E-08
 0.826E-08
 20

 12.9641
 0.0381
 0.927E+00
 0.303E+00
 0.148E-03
 0.311E+00
 0.312E+00
 0.811E-08
 0.813E-08
 220

 24.7097
 0.0726
 0.923E+00
 0.303E+00
 0.149E-03
 0.311E+00
 0.308E+00
 0.811E-08
 0.803E-08
 420

 36.5124
 0.1072
 0.922E+00
 0.305E+00
 0.163E-03
 0.311E+00
 0.306E+00
 0.810E-08
 0.797E-08
 620

 48.3488
 0.1420
 0.923E+00
 0.309E+00
 0.189E-03
 0.311E+00
 0.304E+00
 0.809E-08
 0.791E-08
 820

 60.3060
 0.1771
 0.930E+00
 0.317E+00
 0.229E-03
 0.311E+00
 0.302E+00
 0.808E-08
 0.786E-08
 1020

 72.080
 0.2121
 0.943E+00
 0.329E+00
 0.303E+03
 0.312E+00
 0.302E+00
 0.809E-08
 0.782E-08
 1220

 84 1703
 0.2472
 0.965E+00
 0.347E+00
 0.357E-03
 0.315E+00
 0.303E+00
 0.303E+00
 0.303E+00

A sequence of numbers

Visualization is important

U4535 U115FTU1 U470FTU1 U355F-U3 U353FTUU U375FTUU U875F-U8 U805F-U8 164.8953 0.4843 0.119E+01 0.499E+00 0.364E-03 0.360E+00 0.328E+00 0.885E-08 0.808E-08 2820 175.0677 0.5142 0.122E+01 0.526E+00 0.365E-03 0.366E+00 0.332E+00 0.895E-08 0.811E-08 3020 185.0871 0.5436 0.126E+01 0.555E+00 0.352E-03 0.372E+00 0.334E+00 0.903E-08 0.811E-08 3220 195.0345 0.5728 0.130E+01 0.588E+00 0.348E-03 0.378E+00 0.336E+00 0.910E-08 0.809E-08 3420 205.0297 0.6022 0.135E+01 0.625E+00 0.359E-03 0.384E+00 0.338E+00 0.917E-08 0.807E-08 3620 215.0114 0.6315 0.140E+01 0.666E+00 0.383E-03 0.390E+00 0.341E+00 0.924E-08 0.806E-08 3820 225.0278 0.6609 0.145E+01 0.711E+00 0.442E-03 0.398E+00 0.344E+00 0.932E-08 0.806E-08 4020 235.0636 0.6904 0.151E+01 0.758E+00 0.541E-03 0.406E+00 0.348E+00 0.943E-08 0.809E-08 4220 245.0407 0.7197 0.158E+01 0.808E+00 0.625E-03 0.416E+00 0.354E+00 0.956E-08 0.813E-08 4420 255.0293 0.7490 0.165E+01 0.859E+00 0.700E-03 0.427E+00 0.360E+00 0.972E-08 0.819E-08 4620 265.0108 0.7784 0.172E+01 0.912E+00 0.740E-03 0.440E+00 0.368E+00 0.990E-08 0.828E-08 4820 274.8972 0.8074 0.180E+01 0.965E+00 0.773E-03 0.453E+00 0.377E+00 0.101E-07 0.839E-08 5020 284.6304 0.8360 0.187E+01 0.102E+01 0.784E-03 0.467E+00 0.387E+00 0.103E-07 0.852E-08 5220 294.2310 0.8642 0.195E+01 0.107E+01 0.793E-03 0.480E+00 0.396E+00 0.105E-07 0.865E-08 5420 303.6541 0.8919 0.203E+01 0.113E+01 0.796E-03 0.492E+00 0.406E+00 0.106E-07 0.878E-08 5620

Analysis of numerical data





Ion: The reconnection electric field is maintained by pressure tensor terms by particle meandering motion. Electron: The reconnection electric field is maintained by the wavy components generated by drift kink instability.

Analysis of numerical data ex. Magnetic reconnection





Problem of visualization on 2D display



It is important to analyze the 3D data in 3D space!

[1] Cruz-Neira, C. et al: Comm. ACM (1992) Vol.35, No.6, pp.65-72.

CAVE type VR system CompleXcope @ NIFS

- Univ. Illinois at Chicago invented CAVE type VR system in 1992[1].
- NIFS installed it in 1997.
 - VR visualization of LHD plasma equilibrium solution
 - VR visualization of simulation data
 - Application of stereophonic sound
 - VR visualization of medical data
 - Application to psychology
 - Integrated VR visualization of simulation, device, and experiment data
 - VR visualization of engineering design data



When a viewer with liquid crystal glasses comes into the room, he is surrounded by 4 screens.

He can see the stereo and immersive view through the liquid crystal glasses.

When he moves his head, walks in the room or moves the object by Wand, the images on the screens are reconstructed rapidly according to his movement by tracking system.

Viewer feels himself being in the simulation model with <u>high immersive feeling</u>, and he can watch the objects with any size and from any direction.

Why can we see in 3D vision?

Parallactic displacement

- Positions of left and right eyes are different.
- Left and right eyes see different figures from each other.
- Brain recognizes the difference, and then the depth information is also recognized.
- You can see the subjects in 3D vision.
- Human being has other mechanisms for recognition of the depth information:
 - vergence angle
 - change of thickness of crystalline lens
 - experience (how to shade the object)
 - motion parallax
 - and so on.



 →There are multiple methods to obtain depth information, and then combining these factors, the depth length is recognized. Inconsistencies in this information can cause VR sickness.

CAVE system case

- Parallactic displacement
 Liquid-crystal glasses has a Bluetooth, which
 synchronizes the opening of shutters with the
 demonstration of figure on screen.
 Frequency of changing the figures is 128Hz.
 Viewer can feel left and right figures being
 shown on the screen at the same time.
- Tracking system
 This system can detect the position and
 direction of glasses and Flystick2 by the red-ray
 cameras.

→ Regeneration of objects on the screens according to the movement of head or control by Flystick2



Head mounted display (HMD) Case

- Parallactic displacement HMD is equipped with separate displays for the left and right eyes.
- Sensor for 3DoF or 6DoF HMD is equipped with an acceleration sensor or gyro sensor. It detects head direction and rotation, head position and movement.
- Tracking
 The camera integrated into the VR device captures the user's hand movements, including the orientation of the palm and the degree of finger bending, in real time.





Intuitive Control System: Controller tracking / Gesture controller (hand tracking)



Tracking of the controller



Detecting of the degree of finger bending and the direction pointed by the index finger ²³



Detecting of the palm of user's hand

How to develop VR software

- CAVE-type
 - Marketed software (AVS/Express MPE, and so on)
 - Programming by yourself.
 - CAVE library
 - Interface of CAVE hardware
 - Managing of screen, tracking, projection, and so on.
 - OpenGL (Graphic library)
 - Managing of subjects, optical features, position and so on.
 - C/C++
 - Open software and commercial software
 - Unity + MiddleVR (Middle software between Unity and CAVE system)
- HMD-type
 - Open software or commercial software
 - Unity: Game development engine (C#).
 - Useful user interface
 - Correspondence to various output system (HTC VIVE, Meta Quest, PICO, WindowsMR, zSpace)
 - Various assets



GUI of Unity

INTRODUCTION OF VR VISUALIZATION ANALYTICS AT NIFS

Collision points of High-energy tritons and plasma-facing walls Dust particle orbit

COLLISION POINTS OF HIGH-ENERGY TRITONS AND PLASMA-FACING WALLS

Fusion reactor and fuel system



Tritium inventory and plasma facing wall

Open divertors First wall of vacuum vessel **Closed divertors** Dome structure

Inside of Large Helical Device (LHD), National Institute for Fusion Science (NIFS)

Material probes



Material probes 15mm x 42mm x 7mm



- Tritium inventory: Amount of accumulated tritium which stays in the shadow area and do not circulate in the tritium circulation system.
- One of the shadow areas is the plasma facing wall where the tritium approaches directly.
- We investigate the triton accumulation in the wall.
- By putting material probes on the vacuum vessel of LHD.
- Necessary to find the appropriate positions to put the probes on the wall.

Purpose of this study

- For determining the positions of probes, the researcher should check the distribution of the intersection points of the tritons and the plasma facing wall.
- We evaluate 1MeV triton trajectory by collisionless full-orbit calculation code, and we calculate intersection points of tritons and plasma facing wall.
- We VR-visualize the intersection points with the plasma facing wall.

Trajectory and intersection point 1

Trajectory calculation : LORBIT[1]

$$- m\frac{d\boldsymbol{\nu}}{dt} = q(\boldsymbol{E} + \boldsymbol{\nu} \times \boldsymbol{B})$$

- No collision effect
- Magnetic field in vacuum. Electric field is ignored.
 - Because of energetic particles, it is assumed the effect of electric field can be ignored.
- Initial position: Generation distribution of triton is determined based on the neutron generation distribution calculated by FIT3D-DD[2].
- Initial velocity: Isotropic distribution along parallel and perpendicular to the magnetic field
- Collision detection
 - The divertor plate and the vacuum vessel are represented by the triangle and polygons, respectively, based on the design data which was used in the installation of the divertors and construction of the real LHD.
 - We calculate whether the triton trajectory exists inside or outside the polygons, and we detect the intersection point of the triton and the plasma facing wall.
 - The coordinate point of the intersection point is stored in the Cartesian coordinate system.



Generation distribution of 1MeV Tritons

[1] M.Isobe, et al.: J. Plasma Fusion Res. SERIES, 8, 330.[2] R.Seki, etl al.: Plasma Fusion Res., 14, (2019), 3402126.

VR visualization

- Input data of intersection points is recorded in Cartesian coordinate
 - Number of original point data : 583,695
- CAVE VR software: modified virtual-LHD(vlhd)[1] based on C++, OpenGL and CAVELib library.
 - Interface program of reading the positions of particles
 - Point Sprite method[2] visualizes the intersection position as a sphere[3]
- Inside of the LHD vacuum vessel with the divertor plates is rendered by Unity [4] based on the design CAD data of the real LHD.
- FusionSDK[5] superimposes and displays the OpenGL images generated by vlhd and Unity in one VR space.

[1] A.Kageyama, et al., Proc. ICNSP, 138 (1998).

- [2] http://marina.sys.wakayama-u.ac.jp/~tokoi/?date=20060227 (床井研究室)
- [3] H. Ohtani, et al., Contributions to Plasma Physics, 56, (2016), pp.692-697.

[4] https://unity.com/

32 [5] https://www.fiatlux.co.jp/product/virtual/easyvr/index.html https://www.cybernet.co.jp/ar-vr/products/fusion/



Determination of positions of material probes



Position 3 Not so many strikes





34

Divertor plates

Position 2 Many tritons strike when the toroidal magnetic field is inverted.

Divertor plates



Position 1

DUST PARTICLE ORBIT

Dust particles in fusion plasma





In the LHD experiment, long pulse discharge was successfully sustained for about 48min with plasma density (n_e~1.2x10¹⁹m⁻³) and a plasma temperature (T_{e,i}~2keV).

(Kasahara et al: IAEA2014)

• The plasma was terminated by abrupt increase of carbon emission, which is synchronized with release of a large amount of dusts from a divertor region in the inboard side of the torus.

Shoji et al : PSI 2014.

Physics of dust particle is one of key factors in fusion plasmas.

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Analysis of Dust Trajectories on 2D display



It is very difficult to grasp 3D trajectories of dust particles in 2D projection due to loss of information regarding depth.

3D data should be analyzed in 3D space!!

Purpose of this study

- We visualize the trajectory data of the dust particles observed in the LHD plasma experiment in the VR space.
- We compare the trajectory with the magnetic field structure calculated by MHD equilibrium calculation.

Simulation results in Experimental Device (Integrated VR Visualization)

- Virtual-LHD(vlhd) (Simulation data)
- Unity (Experiment device by CAD data)
- FusionVR (Fusion of several visualization data)

H.Miyachi et al: IEEE Comp. Soc. (2005) 530. H.Miyachi et al: IEEE Comp. Soc. (2007) 536.







H.Ohtani, et al : IEEE Transactions on plasma Science, 2011 H.Ohtani, et al: Plasma and Fusion Research, 2011

Visualization of dust particles

- An interface for reading the time-sequential experimental data of the 3D dust particle positions
- A function for visualizing the dust trajectory in VR space
 - Dust : point-sprite method
 - <u>Trajectory: line</u>
 - <u>The different particles and</u> <u>trajectories are stained with</u> <u>different colors, respectively.</u>
 - First position is colored by white.
 - Transport direction of dust
- Implementation to Virtual LHD.



VR visualization



Ohtani et al: Contrib. Plasma Phys. 2016

ctories and magnetic-field line



From 3-O port

Magnetic

Side view

Top view

- The dusts locate in the periphery region.
- Most particles move along magnetic-field line, and some particles radially across the lines with sharply curved trajectories.
- The transport direction varies from place to place.

SUMMARY

Summary

- Since the implementation of the CAVE-type VR system *"CompleXcope"*, we have been advancing VR visualization research.
- The CAVE-type VR system is an ideal tool for collaborative research. Thanks to its use of transparent liquid-crystal glasses, *CompleXcope* allows multiple participants to view the same object and engage in discussions.
- We have conducted collaborative research based on visualization.
- By targeting real data from experiments and simulations, we integrated VR visualization with experimental device 3D model data, contributing to experiment preparation and analysis.

Future of VR research

•The shift from VR to XR (VR/AR/MR) has already begun.

•"Visualization for Viewing": Converting numerical data into information accessible through senses such as vision, hearing, and touch.

•"Visualization for Exploration": Utilizing data science and data-driven science to immerse oneself in the data space and perform iterative data analysis.

•"Visualization for Presentation": Researching methods of presenting analysis results to humans for gaining scientific knowledge.

•The focus of visualization research is now shifting from visualization for viewing to visualization for exploration and presentation.

•Collaborative, interactive, immersive information analysis methods will be key concepts moving forward.

•The transition from research using CAVE systems to those using HMDs is underway.

•It is recently becoming possible to share a single VR space among multiple HMDs.

•Recently, integration between visualization and machine learning becomes essential.

•Multisensory information transmission and analysis will also gain importance for high-dimensional data analysis.

This research topics will include spatial $3D+\alpha$ representations, dimensionality reduction and so on.

•Efforts are being made to apply haptic devices to VR visualization in NIFS.

Thank you for your attention.

I will demonstrate VR visualization in NIFS tour this afternoon.