Collaborative Environment supported by Virtual and Augmented Reality

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--- Outline ---
- Virtual Reality
- Collaboration of Virtual and Real World
- Correspondence between Virtual and Real
- Augmented Reality
- Studies on Augmented Reality
- Summary

Virtual Reality
- Computer-generated world which is different from real physical world.
- Shape and appearance are not completely the same as real ones, but its effect is essentially the same.
- Beyond physical limitation to expand human ability

Focuses on “Artificial World”

VR Applications
- Various VR applications have been introduced to operation & maintenance of Nuclear Power Plant (NPP) field.
- Examples by IFE (VR Applications)
  - Training System for Nuclear Fuel Exchange

VR Applications
- Design of MCR
- Dose rate prediction & procedure planning for decommissioning

CREATE
VRdose
Collaboration of Virtual and Real World

Virtual World
- 3D CAD data, Maintenance data, Functional model
- Design
- Procedure planning
- Training
- Tele-operation

Real World
- Actual plant
- Construction
- Operation
- Maintenance
- Decommissioning

Augmented reality
- Procedure reconfirmation
- Work instruction
- Record of modification

Virtual reality

Correspondence between Virtual and Real
- Virtual world should be always essentially consistent with real world.
- It is difficult to correspond virtual world to real world.
- Troublesome to create and maintain virtual world
- Design changed, expanded, appended, updated and decommissioned
- AR (or Augmented Virtuality) is one of the solutions.
- To realize close linkage between virtual and real world.

Augmented Reality
- Augmented Reality (AR) expands the surrounding real world by superimposing computer-generated information on the user’s view.

Focuses on “Real World”

Virtual Objects
Head-Mounted Display

Example (Indication of a nut)

AR Applications

Under development
- Navigating workers to the workplace
- Indicating dangerous locations
- Viewing plant parameters
- Visualization of the radiation map
- Viewing virtual information in real world
Problems to Apply AR to Plant Field

Elemental technologies to realize AR applications must provide higher performance than conventional AR applications
- Tracking Technology (measures position and orientation)
  - Wide area, High accuracy, High reliability
- Display Technology
  - Safer, Light weight
- Cultural custom of workers
  - Workers are typically conservative about new technology
    - Not enough only better than the best current practice
    - Must prove and show that the new technology is sufficiently superior
  - Appropriate evaluation method for AR systems

Tracking Technology for AR

- Tracking
  - Measure position and orientation of user’s view in real time to superimpose virtual objects at correct position.
- Many kinds of tracking technologies are developed
  - GPS
    - Indoor
  - Ultrasonic/Magnetic Sensor
    - complex obstacles
  - Infrared Sensor
    - Magnetic source/object
  - Inertial Sensor
    - Wide area tracking
  - Marker-less
    - Accurate/stable

  can not be used in plant field

  Artificial marker technique has a possibility to be used in plant field

Studies for Solving Problems

Various fundamental studies have been conducted for 5 years with IFE and Fugen NPP (Japan)
- Improvement of Tracking Technology
  1. Tracking method using line markers and circular markers
  2. Hybrid tracking method
  3. Marker arrangement optimization
- Selection of Suitable Hardware
  4. Comparison of display devices
- Prototype System Development
  5. Decommissioning work support system
- User-Centered Evaluation of AR System
  6. Heuristic evaluation of AR system

Artificial Marker Technique

Calculate the position and orientation using positional relationship between camera and markers pasted in the environment

1. Paste plural markers in the environment in advance
2. Measure 3 dimensional position of markers in advance
3. Capture the markers with a camera mounted on the user
4. Recognize more than 3 feature points on the markers and calculate the position and orientation of the camera
Available Distance of Conventional Marker

- Maximum distance between camera and marker
  - ARToolKit (VGA, f=4mm)
    - 80mm : 1 m,
    - 250mm : 3 m,
    - 400mm : 5 m

- Problem
  - There are many objects in plant.
  - Surface of the objects is not flat.
  - It is difficult to paste large markers.

It is necessary to make the markers smaller or make it easier to be pasted in a complicated environment.

(1) Tracking Method using Line Marker

- Design of line marker
  - Code "0" Code "1" Gap
  - 40mm 80mm 20mm

- Feature point
- ID of marker (7 bits)
- Humming code (4 bits)

- In plant, there are many pipes which shape is “line”
- Easy to paste line-shaped markers on the pipes

Example: Tracking in Plant

- Evaluation of the maximum available distance
  - Condition: Camera Dragonfly B&W XGA, f=6.37mm
  - Marker Width: 3cm Length: 52cm

- Maximum available distance is much longer than the conventional tracking methods

- Maximum Available Distance

- Maximum Available Distance

- Maximum Available Distance

- Available Distance of Conventional Marker
Disadvantage of Line Marker

- More than 2 markers must be recognized at the same time (At least 3 feature points need to be recognized).
- It is difficult to recognize enough markers if the distance between the markers and the user is very short.

Tracking Method using Circular Marker

- Design of circular marker
  - Center white circle
  - Outer black circle
  - Middle code area circle which consists of black or white fans
  - Corner circles used for 2 layer tracking

- Features
  - 99 unique markers
  - 2 layer recognition

Centers of circles are used for the tracking calculation.

Tracking in a Long Distance

- Recognize more than 4 markers
  - P4P algorithm
- Recognize 3 markers
  - P3P algorithm and use each marker’s shape

Use center of markers as feature points

Tracking in a Short Distance

- Recognize less than 2 markers
  - Use 4 corner circles (P4P algorithm)

Use 4 corner circles of one marker as feature points (Single marker tracking)
Example: 2 Layer Tracking

- Newly designed markers can cover both of short and long distance

(2) Hybrid Tracking Method

- Number of markers which must be pasted in advance affect on the load for introducing the tracking system
- Preparation of AR environment
  - Make markers
  - Paste the markers in the environment
  - Measure 3 dimensional position of the markers
- Number of the markers which must be pasted in the environment should be small
- Extension of the tracking system
  - Using multi camera
  - Sensor fusion

Result of the Evaluation

- Proportion of frames where the tracking is available

<table>
<thead>
<tr>
<th></th>
<th>Single Camera</th>
<th>Multi Camera</th>
<th>With gyro sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracked</td>
<td>21%</td>
<td>49%</td>
<td>69%</td>
</tr>
<tr>
<td>Number of captured markers = 3</td>
<td>3 times</td>
<td>3 times</td>
<td>3 times</td>
</tr>
</tbody>
</table>

- Accuracy of tracking used in plant must be high

- Accuracy of tracking depends on not only the distance from markers but also the arrangement.
- Inappropriate marker arrangement may spoil accuracy.
- It is difficult to decide appropriate marker arrangement without any reference.

(3) Marker Arrangement Optimization

- Development of marker arrangement optimization method

Assumption: Gyro sensor is reliable for 500ms after the tracking by multi camera is not available.
Optimization using Genetic Algorithm

- Various marker arrangements are evaluated and the best arrangement is selected based on a genetic algorithm.

(4) Comparison of Display Devices

- "Water System Isolation Task" was simulated
- Subjects were required to find the specified valve by an AR system
- Measured Indices
  - Task performance (trial time and errors), Mental workload (NASA-TLX), Situation awareness (10-D SART), Eye fatigue (Flicker test), and Usability (Questionnaire)

(5) Decommissioning Work Support

- Development of a prototype system for supporting field work of decommissioning in Fugen NPP.
  - Outline of Decommissioning Work
    - Planning
    - Preparation
    - Pre-work meeting
    - Dismantling work
    - Recording work progress
  - Realizing two functions by AR
    - Confirmation of work procedure
    - Recording work progress as 3D CAD data

Prototype System: Outline

- Small tablet PC, SONY VGN-UX90PS

<table>
<thead>
<tr>
<th>Device</th>
<th>Datagoo 2</th>
<th>SCOPO</th>
<th>Glasstron</th>
<th>Tablet PC</th>
<th>Compact TY</th>
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<tbody>
<tr>
<td>Type</td>
<td>Wearable</td>
<td>Wearable</td>
<td>Wearable</td>
<td>Handheld</td>
<td>Handheld</td>
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<tr>
<td>Model</td>
<td>Shimadzu Corp.</td>
<td>Mitsubishi Electric Corp.</td>
<td>Sony Corp.</td>
<td>Acer</td>
<td>Casio Corp.</td>
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<tr>
<td>Features</td>
<td>One-eye optical see-through</td>
<td>One-eye video see-through</td>
<td>Both-eye video see-through</td>
<td>10.4 inch display</td>
<td>3 inch display</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.8 kg weight</td>
<td>1.8 kg weight</td>
</tr>
</tbody>
</table>

  | CPU          | Intel Core Duo U1400(1.20GHz) |
  | Display      | 4.5 inch TFT Color LCD |
  | Size         | 150.2 mm × 38.2 mm × 95.0 mm |
  | Weight       | 492 g |
  | Camera Resolution | VGA(640 × 480) |
  | Focal Length | 3.8 mm |
Confirmation of Work Procedure

Support marking work for cutting lines and restraint area

Recording Work Progress

Support recording work progress of the day as CAD data

Equipment to be dismantled

Camera Image

Cut 3D CAD data by a stylus pen.

Database can be updated immediately.

Example Video

Target: Ion Tank of Pure Water Facility

(6) Heuristic Evaluation of AR System

- Scenario-based evaluation of prototype system
- Three evaluators (all belong to Fugen NPP)
  - A: a leader of operator group
  - B: belongs to decommissioning team
  - C: an engineer developing decommissioning technology
- Procedure
  1. Explanation of prototype system and scenario
  2. Use prototype system
  3. Answer questionnaires
  4. Group interview
- Questionnaire (5 grade)
  - 14 questions for system function
  - 13 questions for usability
  - Free description (other problems, points to be improved)
Evaluation Results

- Colored display of 3D CAD is comprehensive.
  - More comprehensive if not only colored CAD data but also text information is displayed near CAD data.
- Recording function of work progress is useful.
  - Design of recording function is also appropriate.
- CAD data operation is enough easy.
  - Processing speed of tablet PC is enough fast.

- Display of tablet PC is too small
  - PC is heavy even for small tablet PC (492g)
  - Lighter PC with a larger display is required.

- Others
  - Memorandum should be also input to work record
  - Effective for training of novice workers
  - One of advertisement method to the public
  - May be difficult to understand if work environment is complicated.

Summary of Presentation

- Proposal of collaborative environment supported by VR and AR
- Introduction of five year activities

Future Works

- Improvement of Tracking Technology
  - Reducing the number of markers which must be pasted in advance
  - Simultaneous use of fiducial markers and feature points

- Easy construction and maintenance of virtual world for correspondence between virtual and real world
  - Easy modification of 3D CAD in plant field by AR
  - Application of Augmented Virtuality

- Development of specialized hardware for AR
  - Commercially developed hardware can not meet the requirements
    - Safety, Weight, Viewing angle, Reliability

- Effective collaboration of virtual and real world for integrated plant operation & maintenance