解説
Explanation

Ship Design Review and Collaboration with Virtual Reality Tools

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1. Introduction

Visualisation is the ability of people to form images in their mind. This skill is required to support spatial problem solving in the course of developing the design of a ship, for example, arranging an engine room or routing pipework around structure. People's ability to visualise complex designs and engineering issues varies widely [3]. Although designers and engineers will probably be quite skilled in visualisation, there are many people involved in the design of a vessel that may not have comparable abilities.

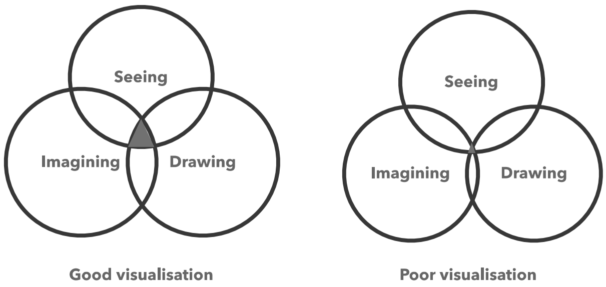

Fig.1　McKim's visualisation model

Studies have proven that problem solving is much better if people can see the design in natural way instead of applying cognitive load to imagining the design by reading drawings that show views, elevations, and sections [1]. Furthermore, CAD systems with screen displays for understanding complex three-dimensional or 3D models are useful but have many limitations. The application of consumer Virtual Reality (VR) hardware with collaboration software like ShipSpace™ can provide a powerful visualisation and communication medium for design and engineering review.

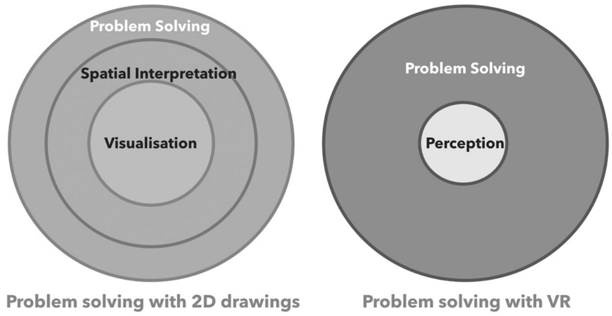

Fig.2　Cognitive load – spatial problem solving

2. Limitations of CAD Systems for Review

With the increasing power of digital computing in the last decades, the ability to create more realistic digital virtual representations of the real world and design has developed tremendously. From using computers as a simple drafting tool for traditional drawings, to the ability to created 3D true geometrical forms that can be viewed from any perspective, CAD has replaced the traditional drawing board in less than a decade.

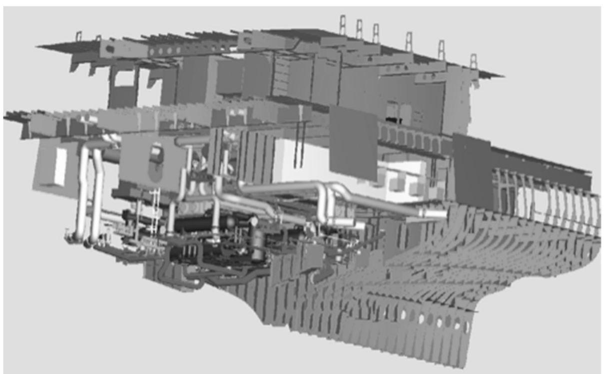

Fig.3　ypical CAD ship 3D model

Today there are dozens of modelling and

engineering CAD programs that can create realistic 3D objects and complex virtual environments such as a ship with all its design details. While these CAD systems are good at creating the 3D models, a computer screen display with mouse and keyboard interface have significant limitations that prevent them from being a useful design communication and collaboration platform.

2.1 Navigation in 3D

The change between designing in two dimensions to designing in three is quite profound. In 2D design, the concept of up, down, left and right is well established. Most computer based tools such as the computer desktop and mouse all are optimised for two dimensional navigation.

When working in three dimensions, using traditional tools designed for two dimensions becomes clumsy and time consuming. New devices such a 3D mouse can help, but simply navigating around a 3D digital environment can be complicated and confusing. The difficulty of working in 3D is often reported as a barrier for expanding its use in engineering design.

2.2 Observation in 3D

The usual practice of rendering a 3D virtual environment onto display monitor is can be likened to looking at a picture in a book or on a wall. Understanding the scale and size of objects in a complex environment such as a ship's engine room can be difficult. Furthermore, when using a CAD system with a screen display the field-of-view (FOV) is generally limited to 30-45 degrees horizontally compared to human eye sight which has a FOV of about 180 degrees.

Projecting a 3D image onto a flat 2D screen distorts the view and limits the useful FOV that can be displayed. If the user changes the zoom or FOV, this alters the 3D image and how it needs to be interpreted. As with pictures a book, a person viewing images on a computer screen need some prior understanding of the elements in the picture and context since the picture could be smaller or larger than how they would look in reality. Furthermore, how the objects are positioned will also affect their size in the picture. There is also no possibility to use human stereoscopic vision when using computer monitors to help understand size and distances.

2.3 Rendering a Virtual 3D Environment

A complete 3D virtual model of a ship with all its internal and external details is an enormous amount of geometric data, even for modern computing hardware. Most CAD users will be familiar with the lengthy time it takes for the computer to redraw a complex 3D scene when the virtual camera or view point is moved. Generally, CAD software is optimised for fast editing of the 3D model geometric database. This often makes CAD systems poor at changing the displayed images with the fluidity necessary to create the illusion of motion.

3. The Art of Virtual Reality

3.1 What is Virtual Reality

Virtual Reality is a computer-generated visual experience that tricks your mind into reacting as if you are in a real physical environment, even though you are just seeing a digitally created image.

Key aspects of achieving this immersion include:

- Immersive vision – Wide field-of-view, you do not feel you are looking through a window or camera.
- Stereoscopic vision - Both your eyes are used together to gauge size and distance.
- Vision tracking - The image seen is coordinated and with your head movement and changes without noticeable lag.
- Graphical stability - The image animation is smooth, without jerkiness, stutter or drop-out.
- Real world concepts - Notion of up and down is preserved, simulated gravity constrains you onto a surface, etc.
- Interactive - You can interact with the virtual environment.

3.2 Theatres

Theatre type single large screen front projection is often used when many people need to view the virtual world. A three-dimensional effect is sometimes provided using shutter or polarised glasses. This is often proclaimed as VR; however, it is the least immersive because the field-of-view is limited and cannot be controlled by individual observers. While this form cannot be considered proper VR, it is included so the reader can understand the limitations of the technique.

Fig.4 VR theatre

With theatre projection the perspective is only correct for a single observer position. It is also not possible to understand the size of objects because there are multiple scaling factors such as the size of the screen and distance of the screen to the observer. The technique also usually induces a high degree of motion nausea among the observers because of navigation in the virtual world is controlled by a third person and the aforementioned inaccuracies of the projection. All other observers are 'along-for-the-ride' which can quickly lead to motion nausea. Typically 10-15 mins is people's threshold, or even less if motion is frequent. This makes theatre type VR very limiting as a design collaboration tool.

3.3 Caves and Domes

Projection caves and domes are also used provide a VR-like experience, but they are very expensive to set up and have significant limitations. In particular, objects in the virtual environment that are close to the observer cannot be displayed or approached as they are removed from the image projection when they 'enter' the cave or dome. This make them particularly unsuitable for human factor engineering which is primarily interested in direct human interaction with the environment.

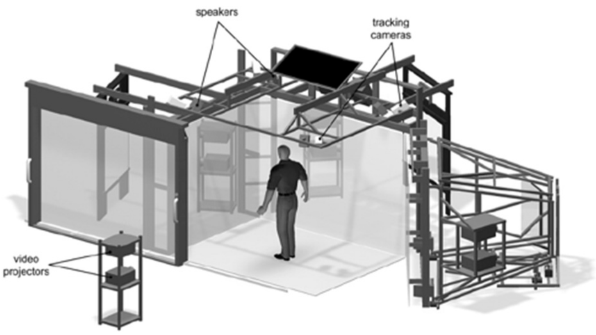

Fig.5 VR cave

Another limitation is that the view in a cave or dome is correct only for a singular position. If the observer inside the cave or dome moves, leans to the side or bends down, the view the observer sees will no longer be accurate. This also means that the effectiveness of design collaboration by having multiple observers inside the cave or dome is compromised by inaccurate visuals.

3.4 Head Mounted Displays

Virtual Reality is currently best achieved with a Head Mounted Display (HMD) with an accurate positional tracking system and computer software that updates the display as the user moves their head.

Table 1 VR implementation pros and cons

VR Implementation	Space required	Equipment cost	360 view	Close object	View accuracy	Wearable	Motion nausea
Theatre	Medium	Low	No	Yes	Low	Glasses	High
Caves & domes	High	High	Yes	No	Medium	Glasses	Medium
HMD	Low	Medium	Yes	Yes	High	HMD	Low

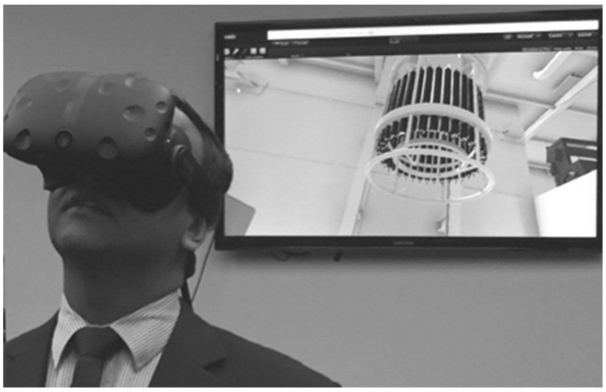

Fig.6 VR Head Mounted Display

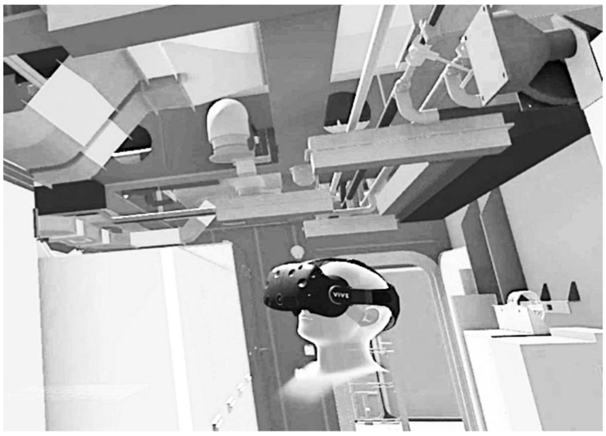

Fig.7 ShipSpace ™ VR tool

The viewed image must change without noticeable lag and have the fluidity to sustain the illusion for the user so that they are immersed in the virtual environment. The high precision tracking of HMDs allows the observer to study objects in VR up close and peer around or under objects. With a HMD the observers' perspective of the virtual environment will always be correct regardless of where the objects are or where the observer is looking.

3.5 ShipSpace ™ Collaboration Tool

ShipSpace™ is a design visualisation and collaboration tool developed by Stirling Lab for use in the maritime and naval design, engineering and construction process. ShipSpace™ reads industry standard CAD files such as Revit, STEP and JT directly and displays the 3D model using consumer grade computer and virtual reality hardware, without any loss of detail and at very high fidelity. Other CAD formats can be handled if required. Proprietary software graphics techniques are used to maintain rendering latency of less than 11ms with 90 frames per seconds for each eye so that immersion is maintained. Surfaces and light are treated carefully to create a strong sensation of presence.

While the graphical load on the computer can be carefully optimised when making a Typically designers of VR games or training simulations will remove or simply 3D objects to keep the video display fluent so immersion can be maintained for the user.

Such manual attention would be both time consuming and could remove important details from the 3D model which would limit the use of VR as a design collaboration tool. The ShipSpace™ application can handle massive amounts of 3D information and perform graphical optimisations automatically to keep the video display fluent without losing any detail.

ShipSpace™ provides a range of sophisticated tools to interrogate the model in various ways, such as reading metadata, x-ray vision, controlling object layer visibility, measuring distances and many others. The tool enables up to 64 users to collaborate in the same virtual space and session.

4. ShipSpace™ Applications in Shipbuilding

4.1 Sales

The purpose of using VR for sales should not be underestimated. It is often a well executed artist impression or a scale model that has been the driving vision for a new project and often the key to garner support and funding. The use of computer based 3D models has largely replaced the traditional work of artists and model makers.

Typically any existing 3D models built for exterior renders with programs such as Rhinoceros™ and 3D Studio Max™ can be viewed in VR using ShipSpace™. Often some additional interior rooms of interest such as the bridge will also be modelled to provide a more interesting experience for the viewer. These models are accurate in layout and arrangement but lack any proper engineering details such as the structural elements, piping and so forth. Even equipment arrangements such as navigation consoles and furnishings will be notional as opposed to accurate or final.

Fig.8 Concept model of a patrol vessel bridge

The purpose of the sales model is to give an overall impression of the vessel with realistic looking details without the actual details being fully resolved at that stage. This is also a fundamental aspect of the concept design which will be discussed next.

4.2 Concept Design

While the 3D models built for sales use are based on the concept design, implementing ShipSpace™ in the actual process of developing the concept design is challenging. The concept design phase is a very fluid process with arrangements, superstructures and hull lines changing constantly. Good concept designers have a very high level of ship knowledge are already highly adept at understanding how various design changes will affect other aspects of the design without needing better visualisation tools. Currently the methods and tools for creating 3D models can be too time consuming to be useful for concept design.

Where ShipSpace™ has proven useful in the concept design phase is in validation of the design. For example, utilisation of spaces where the waterlines change rapidly in the fore and aft hull can be easily evaluated in ShipSpace™ once the hull stability model has been developed. Sightlines from the bridge to working deck areas and be quickly validated or tweaked once the external 3D model has been developed. This tends to come later in the tender and contract phase of the project, when it is important to check carefully all arrangement aspects of the design for practicality.

4.3 Basic Design

In the basic design phase of a vessel, the general arrangement of the vessel is agreed and the design process focuses on the development of the structure of the vessel and final arrangement of equipment. In this phase structure and equipment often need to either carefully connect or avoid one another. Equipment such as engines and shaft-lines need to marry to structural foundations while having sufficient clearance for access and maintenance. Piping and ductwork need to snake through girders and deck penetrations to be sure the design can be made to work when it comes to the detail design. Many of the experience based dimensioning and space estimations need to be verified in the basic design.

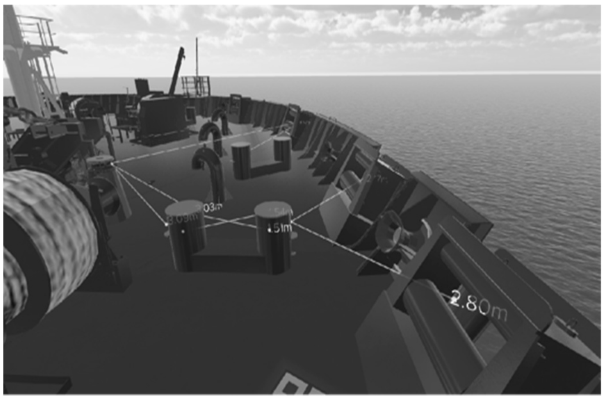

Fig.9 Checking layout of deck equipment

In this phase of the project the benefits of the ShipSpace™ tool are obvious. As the structural model is being developed in 3D, equipment can be easily added to the model. Naval architects and engineers then can experience the developing design in VR to better resolve interface and clearance issues. Arranging equipment and reticulating piping in an engine room is a complex three-dimensional puzzle. The benefit of using VR is that it is easier to use intuition since the design is experienced as if it was already built. Testing has shown the advantage of naturally changing your view point in ShipSpace™ by moving your body and head as you would in real life makes evaluating the design much easier, quicker and more thorough. Users also appreciate that everything they see is correct in scale and perspective.

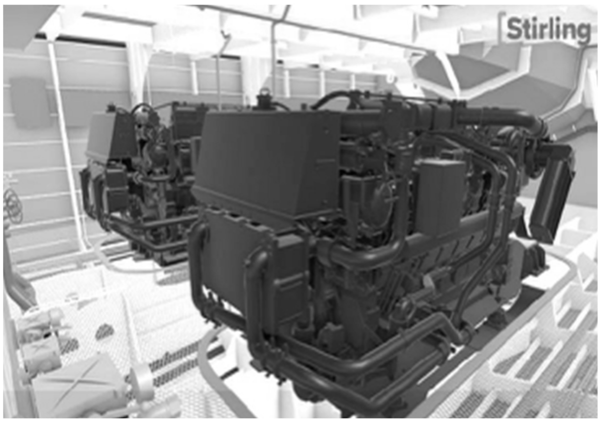

Fig.10 Modelling of engine rooms

Class Societies are moving increasingly towards using 3D models in the approval process. The use of VR tools and the natural way the design can be understood and communicated can only aid the approval process. Furthermore, the ShipSpace™ collaboration system enables up to 64 simultaneous users in the same VR session. As a designer, being able to collaborate with Class experts inside the 3D model, as if it was already built, could lead to faster and easier resolution of many design issues.

4.4 Detail Design

Use of the ShipSpace™ tool demonstrates that a valuable benefit of using VR in the detail design phase is the ability to find and resolve clashes. Typically, during the detail design process, many people are involved with developing the piping and cabling routes from schematic or single-line drawings.

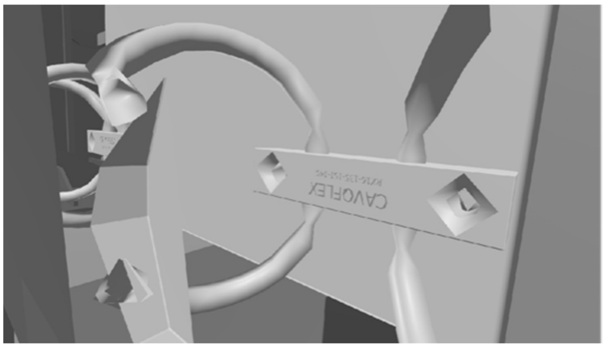

Fig.11 No detail loss with ShipSpace™

A preliminary space reserve or 'space grab' is often modelled by experienced designers as a first step before detail designers follow or trace over with the final pipe spool design complete with joining flanges, valves, filters and other elements in the pipeline.

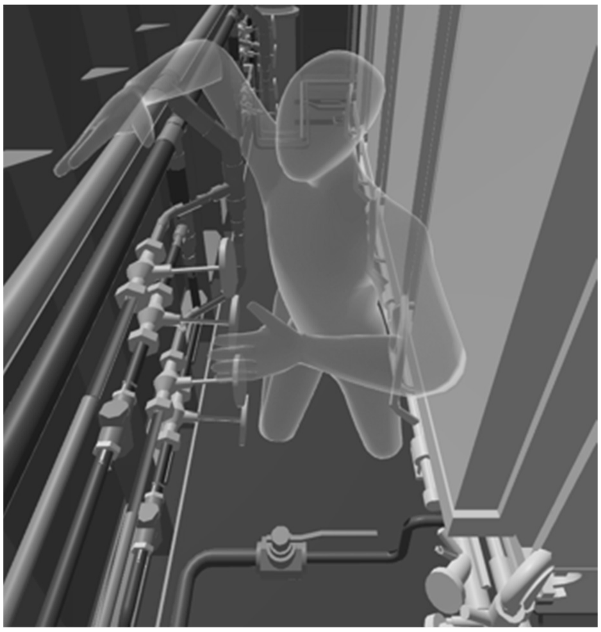

Fig.12 Checking accessibility with ShipSpace™

Despite the initial space reserve planning, invariably clashes (interference between two or more objects), occur in the detail design process that need to be resolved or de-conflicted. Furthermore, even if there are no clashes, the design must be checked for 'build-ability' by experienced production personnel and modified to ensure that design is possible to construct and install easily.

The current method of checking for clashes and build-ability is to use a CAD system or 3D model viewing application on a screen display. Most CAD software has built-in clash detection; however, such checking can often be flawed because many correct instances are flagged as clashes. There is also no capacity to check for build-ability, such as the situation where there is no physical clash, but insufficient space has been allowed for installation or disassembly.

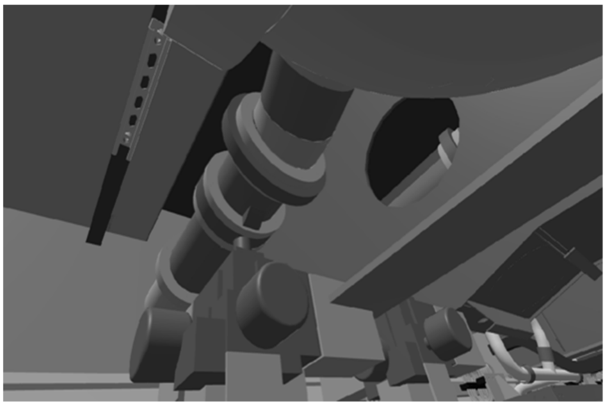

Fig.13 Easier clash detection with ShipSpace™

Testing has shown that finding clashes while examining a model using the ShipSpace™ tool is more effective than using a traditional CAD system and a screen display for two reasons. Firstly, the screen display field-of-view (FOV) is limited to 30-45 degrees horizontally. The Head Mounted Display (HMD) has a FOV of typically 110 degrees. This amounts to 5 to 10 times more viewable area when considering a 2:1 horizontal to vertical FOV ratio [2].

Secondly, the natural way in which the HMD user changes their view point, by moving their head and body like in the real world, also allows much faster and effective interrogation of the digital environment compared to the typical hand operated mouse interface of a CAD and screen display system.

5. Shipbuilding Take-up of VR

5.1 Poor VR Implementation

Many early adopters of VR using theatre and cave projection have a negative impression of VR due to the aforementioned limitations of such systems. Regardless of the benefits of HMD type VR, poor software implementation can lead to inadequate graphics performance with stuttering and laggy image display, problems that ShipSpace™ is specifically designed to overcome. Many people have been discouraged to use VR as a design tool due to experiencing poor VR implementations. Without the correct computer hardware and optimised software like ShipSpace™ the VR experience can be unconvincing, uncomfortable and can quickly cause disorientation, nausea and headaches for the user.

5.2 VR Success in Sales

The use of ShipSpace™ for sales has been the easiest and most natural implementation of this new technology. Users are almost always keen to experience a new design in VR. Initially this is partly due to the novelty of using VR, which has still only been experienced by a few percent of the general population. However, users are then overwhelmed and astounded by the realism of the experience. In most cases new users are in a state of disbelief at the compelling visual experience of the ShipSpace™ VR system how their brains are being fooled. New users often reach out for handrails that they see in VR when approaching the side of a deck, or duck under low overhead objects. This clearly demonstrates the level of realism provided by the ShipSpace™ VR tool.

5.3 Resistance From Designers

Developing a concept design requires people with good visualisation and imagination skills because they are creating something new. Convincing such people that they need VR tools to help with their concept design can be challenging. The common objection to using VR for concept design is the time consuming need to create a 3D model in the first place.

The concept design is generally developed by individuals whose core competency does not include construction of 3D models and involving additional 3D designers can complicate and slow this fluid design phase. This is changing however, particularly with younger more tech-savvy designers who recognise the benefits and are more willing and adept in working with 3D design.

5.4 Resistance From Builders

Another barrier to using VR in design process is the shipyard. Once in contract, the shipyard is reluctant to make any changes to the design. Some shipyards believe that VR tools like ShipSpace™ that provide the Owner with better understanding of the design increases the risk that Owners will request changes that have the potential to delay the building schedule.

Much of this reluctance is the difficulty of communicating design issues using traditional CAD tools. The ShipSpace™ tool is specifically created to make communication of spatial design issues easier to assess and communicate. ShipSpace™ enables problems and opportunities to be recognised earlier in the design process and ultimately having less impact on the schedule.

6. Conclusion

Good spatial intelligence and high cognitive loads are required for people to interpret drawings and form mental images that are useful for solving design problems or optimising solutions. The limitations of current CAD systems to provide an easy to use and realistic review for 3D environments have been explained.

The concept of virtual reality, its benefits for design and the requirements necessary to effectively deliver a VR experience were presented. VR removes the need to use cognitive load for interpretation and visualisation and allows people to apply their thinking to solving design problems. ShipSpace™ allows subject matter experts and others involved in the ship design process who may not have good visualisation skills to more easily contribute to the vessel design.

A number of case examples demonstrate how naval architects, engineers, designers and operators are using the ShipSpace™ collaboration tool to assist in many phases of the design process. Although the overall benefits of VR is not in question, there are barriers and resistance to using VR tools similar to the introduction of any revolutionary new technology.

7. References

[1] K. Goh and R. J. Spencer, "Virtual Reality for Design of New Warship Concepts," in *RINA Warship 2018: Future Surface Vessels*, London, 2018.

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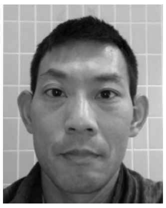

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