Towards Mobile Embodied 3D Avatar as Telepresence Vehicle

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Abstract. In this paper, we present mobile embodied 3D avatar to shift a rich experience of avatar from a virtual world to our real life with a new style of telepresence. Conventional telepresence research have focused on the exact re-creation of face-to-face communication at a fixed position in a specialized room, so there have been much less research on a life-sized mobile telepresence system despite many off-the-shelf mobile telepresence robots available. We propose various scalable holographic displays to visualize a life-sized avatar in an actual life. In addition, we introduce architecture to control embodied avatar according to user's intention by extending popular architecture for a multimodal virtual human, namely SAIBA. Our primitive prototype system was tested with 5 simple avatar animations to embody with a wheeled platform robot and a life-sized transparent holographic display and proved realistic avatar's movement complying user's intention and the situation at the remote location of avatar.

Keywords: interaction techniques, avatar, telepresence, telework, mobility, transparent display, platforms and metaphors, multimodal interaction, SAIBA

1 Introduction

Thanks to the rapid advancement of core technologies for the telepresence, such as broadband internet, loss-less compression, high-resolution imaging/capturing, robotics, and computer vision, we are at the verge of transition from a classic video-based teleconference service to immersive tele-robotics exploration service in our daily life [1,2,3,4]; simply speaking, our projected body in a distant environment finally gained legs to move around from a fixed place. For instance, Double Robotics proposed iPad-based remote exploration robots at a reasonable cost of $1,999 [2]. iRobot introduced RP-VITA(Remote Presence Virtual + Independent and Telemedicine Assistant) as a "teledoctor" [3]. Willow Garage provided telepresence robot development kits and libraries [4].

Despite of many available resources of telepresence robots, their display size always settles for less than human-face size in order to just represent face expression and gaze direction of operators but not full body expression. Even if the robots deploy mechanical arms, torso, and head with motion capabilities, non-verbal expression from body gesture is limited by the DOF (Degree Of Freedom) of their corresponding

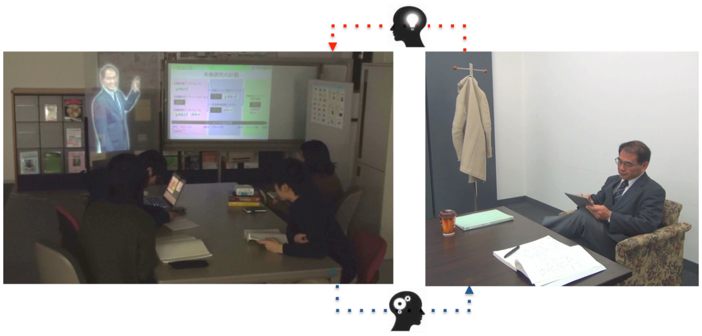


Fig. 1. Sample image of mobile embodied 3D Avatar as a Telepresence Vehicle (left). Sample image of a senior operator manipulates his avatar at home in a long distance (right). Operator watches the remote scene through a view of avatar and inputs his intention by selecting specific action from an interface, while avatar realizes his intention and action based on the surrounding physical space and robot's current body status and gives a feedback to operator's interface system to filter out difficult actions from the action lists. This loop is processed online.

movement, and thus likely become gawky: following the exact same problem as humanoid robots have. Studies about the impact of the human picture size on social telepresence have stated that the smaller the display size, the less realistic presence [5,6]. Furthermore, they warned a head only picture is more harmful to social telepresence. Even though many life-size telepresence display research have been done in a specialized immersive environment at a virtual reality laboratory, there is much less research on telepresence robot with a full-body human image because it is difficult to display such a large realistic image atop mobile robots. Especially, it is important and critical to reduce the occlusion of display itself on the background; otherwise, not only damages the social telepresence but also incites terror toward telepresence robots due to the bulk.

Development of a mobile and immersive telepresence display is one of our goals to tackle in this paper. We present several solutions to this problem with a review of our previous research results along with currently available transparent displays and optical elements at the section 3 and introduce our prototype system at the section 4 (Fig1. shows a sample image).

On the contrary to telepresence in an actual world, it is more popular and ordinary activity in the general public to beam their bodies to "avatars" in a virtual world, such as Second Life, MMORPG (Massively Multiplayer Online Role-Playing Game), SNS space at game consoles (e.g. Xbox Kinect Avatar, Nintendo's Mii space, PlayStation Home), and etc. Avatar can be any form of virtual creatures and virtual objects, so the potential diverseness and richness of expressions and activities are much beyond the ones realized by tele-robots in a conventional telepresence research. For example, a small boy can not only play a role of a matured dandy or an attractive woman to enjoy an adult life socializing with other people in a virtual space, but also gain a new experience with flying a sky with a form of a bird, swimming a deep sea with a form of a fish, or pretending his favorite animation characters. Such an endless possibility and creativity have inspired our goal to bring the avatar in a virtual world into our actual and physical world. To accomplish this goal, we propose a mobile embodied 3D avatar as a new telepresence style. Our research goal consists of the following three sub-themes:

- Mobile full-scale holographic display system

- Architecture to realize avatar's behavior with a dynamic robot display
- Framework to map an operator's intention and trait onto embodied avatar

It is essential and difficult part to re-create avatar's visual appearance and unique motion in a real world. Successfully embodied avatar should enable operators to explore in a building, a city, or even a sky and communicate with remote inhabitants without losing their chosen avatar's form and personalities. Thus, our research focus is not to reconstruct face-to-face communication as many existing telepresence research do but rather to bridge the gap between avatar in a virtual world and telepresence robot in a physical world to fuse respective advantages: e.g. rich expression and animation, mobility and sensory interface with the real world. It is quite important issue how remote inhabitants see and judge the appearance and behavior of telepresence robot in terms of creating "self" images [7]. If it shows poor appearance with a small display and miss-matched mechanical motion, there will arise a huge gap between operator's "self" image and reaction by remote inhabitants; for instance, tele-doctor and tele-teacher need friendly and faithful "self" image to work with remote patients and students smoothly. To avoid such a mismatch, we propose an architecture to grasp operator's intention, plan action based on the available animation of avatar, context of robot, and the remote situation, following a popular virtual agent's framework, so called SAIBA (Situation, Agent, Intention, Behavior, Animation)[8]. We review a SAIBA framework and present our extended version of SAIBA at the section 4 along with our primitive prototype system.

It is predictable that if we embody many existing avatars from a game or a virtual space, people shift their favorite avatars from a virtual to a real world and enjoy limitless exploration and interaction with actual inhabitants through avatar's eyes. We can think this new telepresence as a novel vehicle to explore 2nd life in a real world.

At the next section, we review related research on a single full-body telepresence display and a mobile telepresence, and then discuss several methods with pros and cons analysis to develop scalable mobile telepresence display for a various form of full body avatar. After that, we introduce our primitive prototype system to pretest our architecture for avatar control according to user's intention and situation. In conclusion, we summarize our work and propose the next task to refine the system for more intuitive operation.

2 Related Research

Full-Body Telepresence. Whille most of conventional life-sized telepresence research have been studied at a large scale like a wall-screen or a specialized immersive shared space, there is a trend to develop a minimum-sized stereoscopic display to re-create a single-person in a life-size at a distant location. For example, Tachi et al. have developed TELEsarPHONE (Telesar II) to realize a mutual telexistence system for face-to-face telecommunication via slave robots [9]. In order to make a motion parallax image, they deployed retro-reflective materials atop of the robot's upper body and projected multi-view images of the pilot from multi angles; remote people can see a single-view of the pilot image projected from a corresponding projector close to their position because retro-reflective materials have very narrow range of reflection angle. Even though they successfully re-created precise 3D upper body image of a pilot in real time, it is designed for the fixed position and not scalable for mobile full-body telepresence. On the other hand, Michihiko et al. presented U-Tsu-Shi-O-Mi, which is an overlaid humanoid robot with virtual human (VH) in a video see through display [10]. U-Tsu-Shi-O-Mi nicely fuses advantage of rich expression of VH into a physical body of a humanoid to create embodied avatar; however, users can't see the augmented full-body telepresence image with their naked eyes and furthermore this system is not scalable to non-human avatar. Kim et al. proposed TeleHuman, a cylindrical 3D display portal for life-size human telepresence [11]. They deployed 6 kinects and a 3D projector to realize full-scale motion parallax image of a human in 360 degree-views with a correct gaze direction. The system can be applied to any avatar form as long as the size is within the cylinder, but likewise they have not considered the mobile telepresence at all but only static teleconference application.

Mobile Telepresence. As much as a display size is small, there have been many mobile telepresence robots at academia and markets as we described at Introduction. A robot of mobile telepresence with a display can fall into two principal types: blimps with a portable projector to move in mid air [12, 13] and wheeled carts with a flat panel display to move on the ground [2,3,4,12,]. Although it is possible to make full-body mobile telepresence in both ways, they have corresponding pros and cons. As Paulos et al. [12] pointed out, blimps have difficulty in controlling and staying at a point of space because of its lightweight body susceptible to air disturbance and require a constant maintenance for helium gas to float blimps. However, we can't ignore the fact that blimps can move anywhere in a space without complex calculation to avoid obstacles on the ground and can take any form. We can make use of the flexibility and scalability of blimps to realize flying avatars and a wide gamut of sizes, although we do not discuss a further detail in this paper. On the contrary, wheeled carts are the most popular style for mobile telepresence at the moment because of user-friendliness, high loading power, long lifespan, and accumulation of research and know-how. We chose this basic style for our primitive prototype system to test our concept and architecture because our laboratory owns a couple of wheeled platform robots and related research experience [14].

Nakanishi et al. verifies that a movable display imitating remote operator's movement along a depth direction can enhance a social telepresence more than a fixed display [15]. This result indicates such a possibility that corresponding movement of display for avatar's behavior is essential to actualize a realistic embodied avatar. Recently, Kuster et al. have suggested a concept of mobile telepresence system as the next generation teleconference [16]. They have shown currently available components to realize well immersive 3D telepresence system, such as semi-transparent holographic displays, free-view virtual cameras with kinect, transmission of 3D images with low latency, etc. Although they show a sketch of a mobile full-body telepresence platform, they have not constructed any prototype systems yet. Moreover, since their focus is how to re-create exact face-to-face communication but not how to actualize a life-sized avatar including non-humans, our research goal is different from them. To our best knowledge, there have been much less research to realize a mobile full-body telepresence display and no framework have been proposed to fuse a motion of robotic display, avatar's animation, and operator's intention.

At the next section, we discuss scalable and lightweight holographic display to actualize mobile embodied avatar, and finally introduce our architecture to realize a behavior of avatar with a robotic display according to user's intention based on SAIBA framework [8] at the section 4.

3 Scalable Mobile Telepresence Display

As we stated previous sections, there is less research on a mobile full-body telepresence display even though we can recognize the place to enjoy telepresence is shifting from a specialized laboratory to a public place in our daily life. In order to develop life-sized mobile displays, we have to solve two trade-offs: weight and display size, display size and feeling of oppression. Needless to say, when we install an immersive full-body display atop a mobile robot, we have to balance the weight of the display and a loading power of the mobile robot. In general, we need at least 80-inch display to display a full-scale human body. The weight of 80-inch is more than 50 kg. Taking an example of loading power of typical wheeled carts from Segway RMP 200 series [17], the average loading power is 45 kg; thus, a human-sized display is over the loading power. It is true that the rapid advancement of flat displays like OLED displays are dramatically reducing the weight of displays; however, if we consider a scalability to deal with various forms and sizes of avatar, deployment of a projector is rather practical. Moreover, it is important to make a display frame and a background image as transparent as possible so that a life-sized display is less oppressive and more blended into a real world. There are couples of methods to make such transparent, scalable, lightweight, holographic displays: kinetic display, particle display, and transparent optical element (Fig.2 shows corresponding images).

Kinetic Display. As we know from principle of animation, our eyes have a persistence of vision to integrate all partial images we gained within a short time of human's temporal resolution (50-100ms in general). Thus, it is not always necessary to prepare as large screen as the size to show avatar; we only need a "part" of it to create large screen visible for our eyes. We have developed a scalable kinetic screen based on the persistence of vision (see Fig. 2-(a)) [18]. We called such display a kinetic display since it is not static but dynamically moving to scan a real space for a virtual display. Our propeller-shaped prototype system scans 4m-diameter circle with 6 rotating blade-screens at a speed of 1.5 rotations per a second; the total physical screen area is 4 % of the circle area. The transparency is about 93% with this rotation speed. In spite of the fact that we need a motor to rotate a propeller and a frame to support, the total weight is much less than expected from a large flat display. We can choose any material and size to create proper blades, although we have selected a regular reflective projection screen material with a frame made of light and tough bamboo. We verified the same holographic effect with a much smaller propeller display, whose size is 1/30 of the original.

While it is not distant idea to deploy propeller-shaped kinetic displays for a terrestrial mobile telepresence robot due to the risk of injury, it is reasonable to build airborne avatar with kinetic display since they likely stay over human's hand reach: e.g. birds, dragons, angels, and so on. Nowadays, we can buy many remotely operable flying robots with a wifi camera installed as with AR Drone [19]. Besides, a size and a weight of portable projector is dramatically decreasing along with the cost, so it is practical to build mobile embodied avatar with a kinetic display. If we control multiple airborne robots of kinetic displays, it is even possible to create a dynamically deformable large avatar from combination of them

Particle Display. We define a particle display as a screen consisting of many light diffusive particles such as fogs, mists, dusts, smokes, water droplets, and so forth. Since a particle display is scalable and easy to form a large transparent holographic display, it is popular and practical mid-air screen as with fog screens [20]. However, since fog screens are not originally intended for mobile application, current off-the-shelf fog screens are very susceptible to air disturbance while screens are in motion.

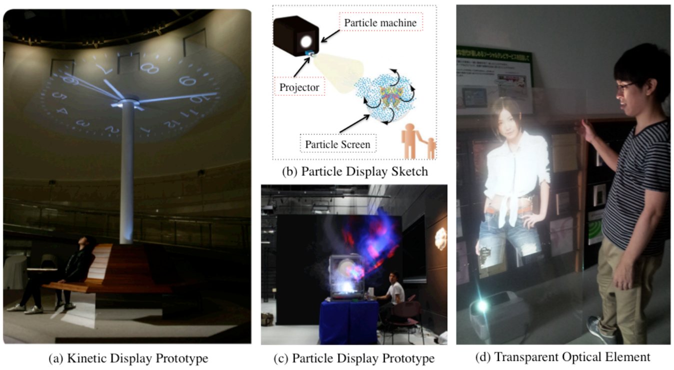


Fig. 2. (a) Kinetic Display Prototype showing a clock deploying 6 blade screens of 1.7m length rotating at the speed of 1.5 rotations per second [18] (b) Particle Display Sketch (c) Particle Display Prototype based on vortex ring fog screen, showing a flying dice more than 4.0 m at a constant speed [21] (d) Transparent Optical Element demo showing a full-scale human figure with a short range projector [22]

To break through such a low sustainability, we have proposed vortex ring based particle display [21]. Vortex ring (smoke ring) has attracted a lot of attention from fluid dynamics researchers because it has a high stability together with a great transportability to deliver any particles inside of it toward remote location at a constant speed. We have utilized vortex ring to build a stable particle display with a scalable depth range (see Fig.2 - (b) (c)). We verified vortex ring can function as a moving flat projection screen in a mid air and project avatar in a depth range for a short time (3 seconds per once). Current prototype has a quite low refresh rate (~ 0.5 Hz) to project mid-air image because currently available fog machines have small production capacity and also very slow are off-the-shelf piston-actuators to emit a vortex ring screen, so we are refining these bottle necks to enable 3D scanning of the space with high speed vortex ring screen in the same way as X-Ray scan. When we project a corresponding 2D sliced image with respect to a vertical position of a flying vortex ring at the speed faster than our temporal resolution, our eye should recognize full-body 3D image of avatar. In addition, vortex ring is expected to function as a multimodal display since it can transport odor and chemical particles together. We have not utilized a particle display for mobile telepresence yet, but we plan to do.

Transparent Optical Element. It is a beginning of a craze for a plat panel industry to produce a transparent flat panel display as the next trend. Especially, we can find many applications at digital signage and smart phone. On the other hand, there are more semi-transparent projection films obtainable at reasonable costs and with various optical properties: e.g. anisotropy, directional refraction, total internal reflection, and so on. We have selected highly diffusive semi-transparent film [22] for our prototype system because we can flexibly customize the shape and size of screen. This transparent film has well enough viewing angles (90 degrees in horizontal and vertical direction) and resolutions (50 lines/mm) to test the reality of mobile full-body avatar with our action framework without any display driven concerns (Fig.2 (d) shows sample full-body human image with the film). Microsoft research group proposed wedge shaped semi-transparent optical elements to guide projection image from the near side of the wedge screen to viewers in front of screen so that they can dramatically reduce the projection distance [23]. Inspired by such smart optical elements, at the next prototype system, we are going to investigate and develop more intelligent optical elements than now. At the first trial, we are currently experimenting with fast photochromic material [24] which responds to violet light instantly to change a color so that we can make contrast higher and as a result enhance visibility of avatar; though, it is not a topic to share further in this paper.

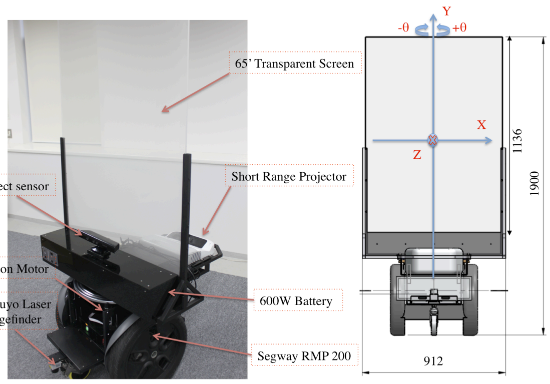
We have not discussed about a method of multi-view stereoscopy for all displays listed so far. If we can project multiple images with multi angles to a display without mixing each image, we can theoretically realize multi-view stereoscopy; this is possible, as long as we deploy directional refraction material as a screen component. Regarding kinetic displays and transparent optical elements, wedge shaped optical element is one of such solutions because it can work as a transparent directional lens. As for particle display, it is rather easy to realize direction refraction at particle screen, since small particles refract light in a quite narrow range because of Mie scattering property. Yagi et al. have developed a 360-degree fog display utilizing this advantage [25].

4 Prototype System and Architecture

We have developed our primitive prototype system for a proposed mobile telepresence system to embody avatar (see Fig.3). Our prototype system consists of three key components: transparent holographic display, wheeled platform robot, and architecture for action control of embodied avatar according to user's intention.

Transparent Holographic Display. As we stated at the section 3, we have deployed a highly diffusive transparent projection film [22] atop a 65-inch acryl panel to make immersive life-sized telepresence display. We have decided the size to make a total height of prototype system less than 1.9 m, which can range the height of most of people, especially in Japan. Furthermore, if we make the height too large, it is difficult to go through a standard door and exit and also more likely to be swung. We have deployed an ultra short-range projector, Epson EB-485W, which can project 80 -inch image from a 0.56m distance with 3100 lumens brightness. The net projection area is 1.136 m x 0.912m, which can include life-sized upper body together with an upper thigh for a height of 1.7m people. The projector and screen is fixed with an aluminum frame.

Wheeled Platform Robot. As we discussed at the section 2, we have decided to use a wheeled platform robot for our prototype because it is well studied and has great transportability with a high power. Since we own a Segway RMP 200 in our laboratory and have know-how to control, we used Segway for our experiment with a few modifications to reduce the weight and to mount holographic display on the top. Our wheel platform robot consists of a kinect to build virtual view similar to human's eyes' position and direction, two Hakuyo compact laser rangefinders, URG-04LX, at front end and back end of the robot, for a collision detection and 600w battery as a portable main power and a Maxon motor and a driver to rotate the upper body. All robot controls and graphics rendering are processed by one linux pc of 2.4 GHz Core-i7 CPU, 16 GB RAM, and Geforce GT650M 2GB GPU. The integrated mobile telepresence system can move about 1.5 hours without any external power supply.
We have chosen the left-handed coordinate system for our local coordinate, following the convention of ROS (Robot Operating System)[26].



(a) Mobile Telepresence Prototype (b) Scale and Coordinate

Fig. 3. (a) Mobile telepresence prototype system (b) Scale and coordinate of prototype system

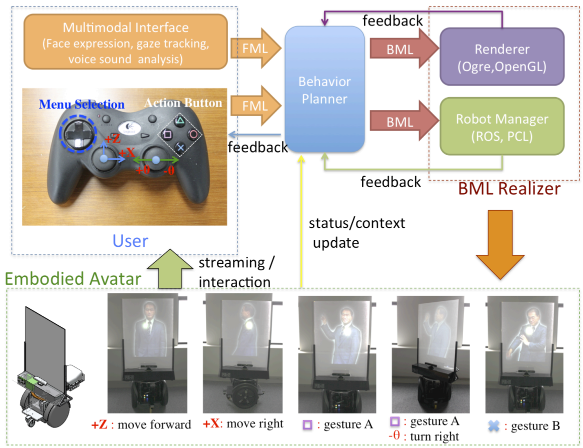


Fig. 4. Architecture for embodied avatar control from user's intention

Architecture. To make an embodied avatar behave naturally, we need a simple architecture to intuitively handle user's intention, robot motion, and rendering of CG avatar at the same time. To build such systematic architecture, we have followed SAIBA[8] as a template since it is one of the most popular architectures to control multimodal behaviors of virtual humans and robots in the same manner. SAIBA simply consists of three components: intent planner, behavior planner, and behavior realizer. Intent planner basically describes user's intention and desire to do in an abstract format: e.g. want to go position A, want to grasp that fruit, etc. Behavior planner integrates all necessary information to make a schedule and logically design blue prints to realize the user's intention. Finally, behavior realizer makes a concrete action based on the blue prints given by behavior planner. All communication between each components are done by exchange of XML- based human readable languages: FML (Function Markup Language) and BML (Behavior Markup Language). You can find a specific form of these XML languages at the website of

Mindmakers [27]. Following this framework, we have built our architecture as shown in Fig. 4. We have chosen a typical joystick game controller as an interface, since it is well designed to control avatar in a virtual reality. Left joystick controls avatar's directional movement in X and Z axis. Right joystick controls avatar's upper body motion. Left cross key buttons can select a menu to configure avatar and action parameters, although we have not utilized yet. User can choose action of avatar from 4 status buttons at the right. Each input into this joystick is translated to FML and passed to behavior planner. Even though we have not implemented yet, we intend to catch user's non-verbal cue from multimodal information such as gaze direction and face expression and pass those information as FML to the behavior planner too in a future. Behavior planner gathers environmental information from a kinect sensor and laser rangefinders to judge the user's intentional action is possible or not at the current status and position of the robot. The planner automatically translates the user's intention in BML format and pass to behavior realizers; that is, renderer to move avatar with animation and robot manager to control robots. If there is error during realization, realizer feedbacks the error to the planner and the user so that user can choose possible actions. When everything goes well, finally embodied avatar can move according to user's intention. After each action, the planner and user received update information of the new state of embodied avatar and interaction inputs by the remote inhabitants around the avatar.

We have tested our framework with simple 5 avatar animations (walk in Z and X direction, turn right, point the right bottom, point the right top) and found it reasonably create corresponding robot motion and synchronized animation according to user's intended action. We also verified the user can't select action which is judged impossible from the behavior planner based on the robot status; for instance, when people cross in front of the avatar, users received error feedback whenever they tried to move avatar forward, pushing a left joystick forward.

5 Conclusion

To shift avatar from virtual to real world, we proposed mobile embodied 3D avatar as a new telepresence style. People can explore a real world with appearance and ability from favorite avatar and also interact with real inhabitants at a remote location in a similar fashion as they do in a virtual world. Even though it is essential to build a scalable mobile telepresence display to actualize a life-sized avatar, we have found there is much less research on the development of such a mobile telepresence system. To break though the current situation, we have proposed 3 methods to make a lightweight and scalable holographic display as key components: kinetic display, particle display, and transparent optical elements. We have presented our primitive prototype system to test a life-sized avatar move realistically according to user's intention. To make a system organized and scalable, we built architecture inspired by a popular framework for a multimodal virtual human namely, SAIBA. We verified our architecture can deal with simple 5 avatar animations according to user's intention and the context and status of the avatar. As a next step, we are going to expand our architecture to handle user's intention from non-verbal cues such as gaze direction and face expression so that we can help senior workers can intuitively use our embodied avatar for their enforced telework.

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