Drones for Live Streaming of Visuals for People with Limited Mobility

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***Abstract*—Robotics is the field currently taking its place as a leading candidate for dramatic changes in everyday life. Advances in the past 10 years in sensing, actuator and power technologies have fuelled an explosion of opportunities in this exciting, and surprisingly affordable domain. Small Unmanned Aircraft Systems (drones) are being rapidly developed for research, public service, and commercial applications, all around the globe. Drones offer a number of unique affordances to mobile technology research for community empowerment and 'extreme user' access: they are relatively inexpensive, easy to operate and to fit with alternative interfaces for people of all abilities, and are readily available. Furthermore, they can carry a payload of light, inexpensive, and off-the-shelf sensors that can be used to support a wide range of research efforts. A potential helping application has been developed in UCD for live streaming of visuals for people with limited mobility. The aim is to use drones and virtual reality as surrogates to provide access to visual information to differently-abled people. This paper will summarize the state of the art in drones research in terms of the affordances to assistive technology. Imagine being able to take any sport or imagine any far-away and otherwise inaccessible cultural heritage or educational site and to bring these rich assets to life within an immersive environment. The paper proposes a system to integrate virtual reality (VR) with a low-cost unmanned, semi-autonomous quad rotor. This quad rotor with a VR headset would allow for first-person vision and manipulation using the Robot Operating System. The system would enable the user to move the quad rotor remotely using natural head movements, which could be tracked by the VR headset and translated into six degrees of freedom commands that would then be sent to the quad rotor. This would facilitate operation when compared to commercially available controller methods, as it would immerse the user in the robot's environment. The paper presents the software components that will allow people off site to strap themselves into a virtual reality headset (i.e. Oculus Rift at the top end of technology, or one of the many emerging affordable VR headsets such as Google cardboard) and then - via footage taken from drone flights and other digital media – to be able to participate virtually, in real time, with other users who are all synchronously immersed in these environments. From the point of view of the camera on the plane overhead, the viewer can get a very good impression of a site, seeing things that you would not normally be visible even during a 'real' walk of the same terrain. Overtime, the aim is to facilitate people with limited mobility to have access to live streaming of visuals and thus to experience the sense of empowerment and inclusion that live engagement in physical activity can inspire and support.**

Keywords—Virtual Reality; Distributed Computing; Unmanned Aerial Vehicles, Educational Technology, Social Implications of Technology (Cultural Differences), Technological Innovation, Distance learning, Context-Awareness

I. Introduction

Since the invention of a wireless remote controlled boat by Nikola Tesla in 1898, the area of radio controlled robotics has advanced extensively in most aspects, but the majority still employ a basic stick controller whose design dates back to the early 1900s. This is problematic, as these controllers are not easy to use with more modern robots. Specifically, the natural movements that modern robots try to emulate require more natural inputs than basic stick controllers, triggers, switches, and dials. Another major problem with basic controllers is the required training time. As the inputs are not intuitive, they must be learned. This training time can vary drastically depending on the complexity of the system. Another problem that arises with these basic controllers is in the user-interaction feedback loop. Specifically, a user needs sufficient and timely feedback for optimal robot control and damage avoidance. Such feedback is not available with conventional control systems. Nowhere is this truer than in aerial robotics.

In the last decade, Unmanned Aerial Vehicles (UAVs) otherwise known as drones have gained extensive adoption across the globe in non-military uses such as crop evaluation, parcel delivery, and archaeological documentation. This change has occurred due to a pairing of technological improvements and significant cost reductions. Significant advancements have been made in the functionality and ease of use UAVs such more including simpler controller design, more intuitive controller-aircraft interaction, and better flight management information systems. Yet, most of these UAVs continue to be manipulated with basic stick, trigger, and dial controllers. While great control can be gained through hours of practice, a first person view is required for full functionality and sensor control, which mandates that the operator watch a portable screen to move in the correct area. The operator must rely on "line of sight" visual contact. This precludes effective UAV deployment in many areas, such as enabling users to provide access to visual information to People with Physical and/or Intellectual or other Disabilities..

This paper proposes such a controller for improved UAV control, and argues that this improvement could make an important contribution to the fields of Ability Studies and Applied Inclusive Design, as well as to the field of Drone research.

The affordances to assistive technology which the targetted use of lightweight drones could make are potentially huge. Drones can reach remote terrain, whether at height or below ground level, and can thus enable people who require the use of wheelchairs or other mobility devices to experience the real-time sensation of engaging in sports and other cultural activities which would otherwise be impossible for them.

Whilst there have been research projects focussed on the engagement of people who use wheelchairs in mixed ability dance (Goodman, McKeown, Deveril, O'Kennedy, et al 2013-16) [1] and Goodman, Perlin et al: 2012 [2], for instance, and in participation in music and other cultural activities (Goodman, Donegan, et al, research conducted in 2005-16 and published in the documentation of SMARTlab [3]), as shown in Fig. 1, Fig. 2 and Fig.3, these studies have focussed primarily on the live experience of movement when assisted by either mechanical controls or by other movers and musicians in a shared space. Attention has also been paid in the research community of Video Modelling and Social Robotics [5] and in Computer Vision, Social Robotics and Visualisation to the uses of robots and robotic interfaces to virtual worlds and visualisation systems to support full and self-directed co-creation of integrated closed loop learning systems for people with differences in ability of all kinds: intellectual, cognitive, developmental, and physical (Goodman, Sudol, Duffy, et al [6], [7], [8], [9] and [10].

However, relativley little attention has been paid to date to the affordance which drone technology could offer to the experiential learning and remote learning and 'shared experience' of sports and cultual activities taking place on mountains, hills, in ravines etc: in other words, on the potential uses of drones to extend the reach of the person with a mobility issue so that they can view and engage in activity taking place at height or at a remote location, but in real-time, including the synchronous changes in orientation which camera angles and virtual reality perspectival options can simulate.

We therefore argue that drones can become much more than glorified, extremely long/flexible 'selfie sticks' for the mounting of digital cameras and virtual reality headsets, but can additionally create the visualisation and experiential sensory impact of a much more substantial kind.

The application of drones as an assistive technology extends from research designed to apply mobile robotics to aid social engagement and accessibility [11], [12]. The practical challenges to drone use for applied assistance can limit use for many cases outside of the laboratory or closely controlled setting. These challenges include difficulty using the remote system to control the aircraft, limited battery life that requires frequent operator intervention during the use case, potential safety issues resulting from loss radio connection to the operator and the difficulty of a fully autonomous takeoff and landing sequence that can be executed without direct human intervention. Each of these barriers is being addressed by the commercial drone industry and considerable changes have been implemented [13].

Fig. 1. Blair Wing and James Brosnan in rehearsal for Streets Called Home mixed ability dance/technology performance, Tunis World Summit: SMARTlab 2009

Fig. 2. Lizbeth Goodman, Blair Wing, Bobby Byrne, James Brosnan and JulieAnna Facelli rehearsing for Streets Called Home, Tunis World Summit, 2009.

Fig. 3. On stage at the Tunis World Summit, 2009

This paper will explore the potential to develop a VR enabled drone that will be an assistive technology to support social engagement for people with high end autism spectrum disorder (ASD). The use case will be an alpine expedition to a culturally relevant location. The study participant will coordinate with the full expedition team during planning phases and will participate virtually through the VR interface and body worn and drone mounted cameras during practice hikes and the eventual expedition. Although the commercial drone technology is not mature enough to support a full implementation of this case study, we can test the VR interface in combination with an onsite pilot in command to manage launching, safety, and battery life barriers. The expectation is that this will provide the participant with a greater sense of inclusion, empowerment, belonging, and achievement. We also expect the participant to achieve increased fine motor control, increased eye gaze focus, increased awareness of multiple sensors, and increased ability for group work.

II. VR and Drones Implementation

A. Background

Virtual reality (VR) first began with the United States' military's development of the Link Flight Instrument Trainer in the late 1930s. Current military VR mostly focuses on simulations for air force pilots for improved battleground simulation response and teamwork development [14] [15]. Non-military usage of VR is perhaps most notable for surgical training [16, 17] and other highly delicate tasks needing specialty training. For example, the use of robots can improve surgical accuracy through the removal filtering of small, human-based vibrations [18]. This approach is also used for critical long-distance, tele-operated repairs and maintenance on the International Space Station [19], as well as remote bomb defusing [20]. Despite advances in these fields, VR is most widely adopted in the entertainment and gaming communities where physical presence in real or imagined worlds can be simulated to give a first person view of a character [21].

To replicate these VR concepts in the home-electronics market, major video-gaming companies offer the Microsoft Xbox Kinect, Sony PlayStation Eye/Move, and Nintendo Wii Controller, which monitor the movements of users in front of them using visual and physical sensors. Furthermore, some movie theatres and televisions have stereoscopic technologies, such as the Fusion Camera System developed by Cameron and Pace [22] with its polarized 3D effects. There are now also smart phones capable of giving haptic feedback [23]. Pfeil et al. [24] created a project exploring upper body 3D spatial interaction metaphors for control and communication with the Augmented Reality Drone (AR Drone) where the user's spatial proximity to an Xbox Kinect 3D camera is interpreted and converted into movements, which are then sent to the AR Drone. This allows control with no physical controller. The user sees the AR Drones movements from their perspectives, not from the AR Drones' frontal camera. This non-physical control method has proven easy to use and accelerated the learning cycle.

Natural, human-based commands improve control with minimal effort to enhance immersion and proprioception. This allows the user to interact with the environment to a much higher degree for navigation and manipulation. Research has shown that users want these kinds of controllers, despite greater task-specific durations and lower precision (when compared with traditional controllers in the hands of experienced users). In particular, head tracking controllers were favoured, because of their higher immersive sense [25].

Higuchi et al. [26] developed a head tracking solution for tele-operation of an AR Drone. Using synchronized optical trackers attached to the head and an AR Drone chassis, the quad rotor would follow the user's gaze and change altitude to match that of the user's headset. The project showed successful, nearly real-time drone response using the head and body trackers. Mollet and Chellali [27] also developed a head-tracking system, combined with a VR helmet, which allows the tele-operators to operate in a natural way seeing what the robot sees. They used groups of robots each with its own operator to fly in an environment with features and objects that were pre-registered in a vision library. The system allowed users to see some Augmented Reality features (e.g. virtual arrows to represent points of interest).

The main problem with some of the above trackers is that they require an environment with statically placed colour pads that are used to track motion changes in the image scene. Image analysis is also used to track the user's movements using either regular webcams or hybrid optical and infrared tracking, which requires significant processing power. With the Oculus Rift (OR), only the on-board sensors are used to track the user's movements by fusing the sensor readings. This means that it can track movements efficiently without the need to setup colour markers for tracking in the area in which the user may be using it in. The approaches outlined above have shown that the Oculus Rift is playing a major role in enhancing user immersion for tele-presence and tele-operated robots.

B. Oculus Rotor Implementation

The proposed architecture relies on two integrated architectures: the ROS architecture and the AR Drone SDK's architecture [28]. The AR Drone SDK for Linux has been selected for implementation. The application will be built from OS-specific calls to primarily OpenGL and WiFi drivers. The applications will operate from separate threads detailed below in thread priority. These threads are handled by the ardrone_autonomy ROS library [29].

1. AT Commands - basic function commands.
2. NavData - Contains AR Drone information.
3. Video Management - Contains video information and meta information.
4. Video Recorder - Contains the controls for video recording (on device).
5. Control - Handles thread requests and ACK packets to and from the AR Drone. This is used to synchronize the quad rotor's image stream on initiation.

A ROS node is a process that performs computation. Nodes are combined into a graph and communicate with one another using streaming topics, Remote Procedural Call (RPC) services, and the Parameter Server. These nodes operate at a fine-grained scale, and robot control system will usually be comprised of many nodes (e.g. one to control a laser range-finder, one for the wheel motors, one for localization, one for path planning, and one to provide a graphical system view). All ROS node control will be based in the oculusrotor node. This node will contain the subscribers for the project including open source otl-oculus node, ardrone_autonomy [29], and the rosserrial-arduino nodes, which will contain the head AR Drone sensor and Wii Nunchuck values that will be used in the input system. This node will also provide the publishers to the quad rotor an input command channel and an OR monocular first-person viewer. The images will be modified by overlaying a flight "heads up display" to allow the user to know the direction of flight, any existing tilt, yaw, or rotation of the head, and some basic AR Drone information.

The ARDrone is flown using ROS Twist vector messages consisting of linear and angular x-, y-, and z-coordinates. This also ensures that the AR Drone maintains its WiFi connection. Without that connection, the AR Drone would try to reconnect to the user's main node, thereby creating communications problems during operation. The OR head sensors as shown in Fig. 4 collect and store baseline values at the onset of operation. These are compared to the OR headset values. If the change exceeds a certain threshold, then the degree of change can be translated into a 6 degree-of-freedom (DOF) Twist message and sent to the AR Drone. Keeping a baseline position for threshold comparison allows the user to have a neutral zone where head sensor inputs below the pre-specified thresholds do not generate changes in the Twist message. Otherwise in the neutral position, the twist message will be set to make the AR Drone fly in a neutral hover mode.

The altitude and speed controls are implemented using an Arduino Uno board publishing values from a Wii Nunchuck controller. This is connected to an Arduino Uno board with a video game shield, which accepts the Wii Nunchuck controller port. This publishes inputs from the Wii Nunchuck at a speed of 57600 BAUD. The output data are joystick x-, y-coordinate data, accelerometer coordinate data, and Boolean values for the C- and Z-buttons.

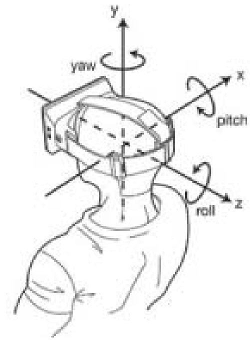

Fig. 4. Oculus Rift Sensor Setup

The system was tested with a mixture of ten experienced and ten novice users. Each participated in two flights: one with the dual stick controller and one with the OR controller. The testing site is shown in Fig. 5. The instructions were to take off, fly the quad rotor to a pre-specified point about 30m away, turn the quad rotor back around, and fly it in a circle back to the point of initial departure . After this, the user was allowed to test the AR Drone by orienting or flying the quad rotor towards themselves through the drone's eyes to get a feeling for the OR system when comparing it against the dual hand controller.

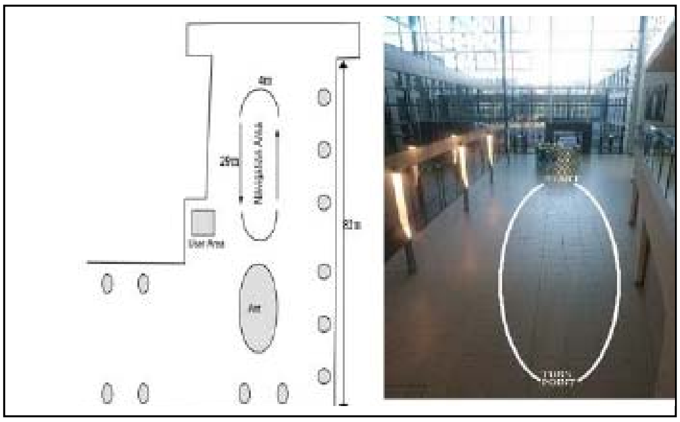

Fig. 5. Flight map and area

To evaluate the effectiveness of the system, multiple approaches were considered. In addition to packet and image performance, the users were visually evaluated as they were flying, and surveyed afterwards. This allowed a comparison of the system operated between control modes and between novice and experienced users. The evaluation considered how stable the user was able to fly the drone and how easily they were able to achieve the assigned tasks. The webcam on the laptop was used to video the users' faces to check for indications of frustration or stress in the operational response as well as verbal requests for assistance in replicating a task were also logged during the testing.

Since the AR Drone uses 802.11n for its Wi-Fi connections, the surrounding environment must be considered. This was quantified with a simple test of the effects of distance on both image stream and command latency. To achieve this, the quad rotor was moved around the room using the OR headset. The AR Drone was then distanced from the laptop at a rate of 1m/s until visual stutter occurred frequently which occurred after exceeding forty meters distance from the laptop. The test ran for 300 seconds in total. A python file was used to plot the ardrone/image_raw, cmd_vel topic successful transmissions, and their bandwidths. The cmd_vel topic contains the commands for the AR Drone's movements emitting from the OR headset, while ardrone/image_raw contains the image stream messages from the quad rotor.

C. *Oculus Rotor Evaluation*

The quad rotor responded well to the published commands. The video latency worked up to a range of 50m. After a distance of about 35-45m between the laptop and drone, visual performance reduced due to the loss in the Wi-Fi signal strength. Decreased responsiveness and image loss hindered user input, as the image feed would stutter as the distance between the laptop and the AR Drone increased.

For the test we simply moved the quad rotor 1m/s away from the laptop in small increments as the rosbag message capture used most of the laptops CPU cycles to capture the messages being passed by ROS and save them to disk. The total time for the experiment was around 268 seconds. As we moved the quad rotor away from the laptop it can be seen in the graphs below that the AR Drone experiences spikes along the way and the further towards the end it fades off faster and faster. This drop in bandwidth especially hinders the visual feedback the user gets. The image bandwidth with respect to time-distance is shown in Fig. 6. The video stream at this point will have dropped to approximately 10-15 frames. This would be classified as visually impairing to the user as the image they being received is more than likely not showing where the AR Drone is currently pointing at. The distance at this point would be approximately 50-60 meters away from the laptop.

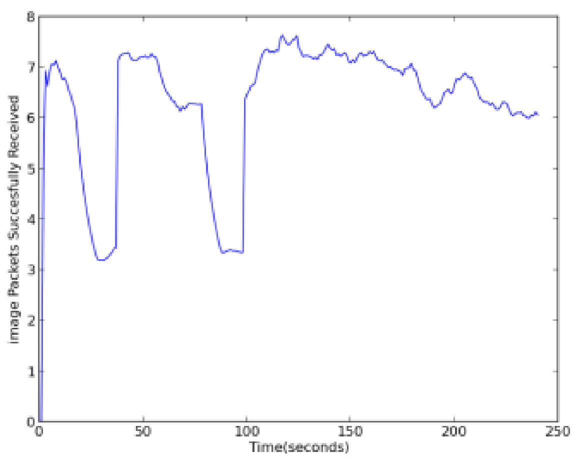

Fig. 6. Image bandwidth/time-distance

About three-quarters of the experienced group were able to use the compass to assist in the return navigation, but the inexperienced users could not navigate back with the visual frame dropout rate. The OR controller was reported to be more intuitive, and the users generally asked fewer questions after the initial instruction while using the controller. However, the OR controller was harder to use in tight spaces due to the monocular to stereo depth conversion problem (i.e. the users lost depth perception when looking through the drone's view). While, the novice user group preferred the OR controller over the traditional dual stick controller, the experienced user group still preferred the dual stick method for its better accuracy.

III. Discussion

We have to date applied our technology innovation tools (eye gaze technologies, alternative interfaces for accessible music and dance communications, and other expressive assistive technology applications) mainly in the context of Inclusive Design and Social Inclusion, as shown in Fig. 7 and Fig. 8. Our aim within the context of the SMARTlab's explicit ethos of 'technology innovation for real social change' has been the innovative use of technology tools to enable enhanced opportunities for communication and self expression of people of all levels of physical and cognitive ability.

Fig. 7. James Brosnan with a new switch to his communications device SMARTlab London 2009

This body of work using drones to extend the reach of assistive technology is a new departure, and one rich in possibilities. In positioning this argument for the enhanced and expanded view of drones as Assistive Technology Tools for cultural and athletic inclusion, we aim to open a debate and to engage in this area in further exploration building upon previous work which has in turn inspired our own thinking in this field [30], [31], [32] and [33]. Our case studies with People with Quadraplegia and Acquired Brain Injury, with Cerebral Palsy, and with Asperger's Syndrome will commence in late September 2016. Analysis of findings, to be co-authored by the participants, will be published separately.

Fig. 8. James Brosnan using Mytobii Eyegaze with Dr Mick Donegan, SMARTlab Dublin 2012

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