9th International DAAAM Baltic Conference
"INDUSTRIAL ENGINEERING
24-26 April 2014, Tallinn, Estonia

DEVELOPMENT OF VIRTUAL REALITY INTERFACE FOR REMOTE ROBOT CONTROL

Lees, Ü.; Hudjakov, R.; Tamre, M.

Abstract: *This paper discusses different options to apply Virtual Reality for practical industrial applications and provides one of very practical and new example system developed by the authors.*
Key words: Virtual reality, telepresence

1. INTRODUCTION

Virtual reality technologies are one of the fastest developing technologies during last decade. Moreover, technology forecasts predict that virtual reality technologies belong among ten most significant and important technologies changing the world and how humans communicate during next five years. On recent technology trade fairs and Internet sites, all big technology companies demonstrate some new virtual or augmented reality device where some more widely known are Google Smart Glasses, different 3D screen and camera systems. Most of them are still focused for gaming application because this sector is one of the fastest and highest return potential in short term perspective. Despite of this virtual reality applications are starting to find their place for industry too. One of the first sector that attracted virtual reality technology was medical sector because the technology gives to doctors' ability to get more realistic feeling what could happen during an operation or even perform distance operations. Production sector have been careful taking into use virtual reality applications, which is in some extent connected with preconceptions dealing with something that have been used previously mainly for gaming, free time applications, and from the other hand connected with the lack of practical applications and industry suitable virtual reality devices.

Tallinn University of Technology Department of Mechatronics has long experience in developing different machine vision systems and smart algorithms. Rapid development of virtual reality hardware components in the world during some last years have provided a unique and promising base platform to develop new virtual reality applications for industrial robot control. It is well-known that for example the operator of a Explosive Ordnance Disposal (EOD) robot or operator of a precise assembly robot systems or operator of complex processing robotic machine have difficulties in getting real imagination what is happening in 3D in the robots very operating zone. 2D camera pictures or just trust of the machine programming is not enough in many cases. To control the process precisely the operator must interfere it in many cases. Even more, to provide options for remote consultancy for a specific industry processes, it is needed to enable to get real 3D imagination of the process to an engineer remotely.

According to Michael Abrash [1] all following conditions have to be satisfied in order to create sensation of presence:

- Field of view must be more than 80 degrees
- Image resolution must be at least about 1000x1000 pixels per eye
- Pixel persistence less than 3ms
- Refresh rate of about 95 Hz
- Global display - all pixels should be updated simultaneously as opposed to updating line by line
- Optics that allow control of focal length and viewing distance
- Robust angular and positional tracking
- Low latency - reaction from head motion to finishing display update should be below 25 ms

Up until now the limiting device, that has held back virtual reality revolution, has been the virtual reality goggles. The existing models had too small field of view or were too heavy or expensive for wider audience. The breakthrough in virtual reality glasses has been enabled by recent emergence of mobile technologies and advances in computer graphics. Availability of high resolution, small form factor, low power and cheap displays as well of existence of low latency embedded orientation sensors are necessities for building a modern head mounted displays. Advances in computer graphics have enabled to do away with expensive and, more importantly, heavy optics.

One device that relies on aforementioned technological advancements is Rift from Oculus. It puts a single high definition display in close proximity of wearers eyes and renders a stereo image onto the display. The display is too close to the wearers eyes for sharp image, to alleviate the problem a single lense is installed between the screen and the eye. The lense will focus the eye to infinity, and provide 100 degrees field of vision. In addition the lense will warp the image so that there are more pixels in the center of the view area than in the edges which is in line with human physiology - the center of the eye has higher definition than peripheral vision. Unfortunately the single lense will distort the image. The distortion of the lense is compensated by distorting the projected image in opposite direction making the wearer to see orthogonal image.

Most of the cues for spatial vision come from imagery itself - perspective, lighting, etc. For added realism additional cues can be added such as stereo vision and head tracking. Each added cue will increase the realism of the scene. The Rift display is coupled with accelerometer that is used to measure head position. The system is continuously rendering an image based on wearers head position providing head tracking functionality.

For telepresence applications the virtual reality glasses have to be coupled with cameras. Applications such as EOD robot control or remote service benefit from depth perception. For generating stereo imagery a pair of cameras can be used. The pair of cameras must be mounted approximately 65 mm apart, which is about the average distance between human eyes. It would be good if the distance could be adjustable but changing the camera position would invalidate the delicate camera calibration.

Better depth perception comes from head tracking; to enable that the camera pair must be mounted on a moving platform. In order to avoid image tilting during head movement due line-by-line image scanning the cameras must have global shutter. To avoid depth distortion during head movement the cameras must be synchronized. An object that is at given distance from cameras appears shifted when the images are overlied. The shift or *disparity* between camera images must stay constant during camera movements which in turn requires synchronized image acquisition.

The target of current development project is to create a telepresence application using modern hardware.

2. THE FIRST PROTOTYPE

The emphasis of the first prototype (Fig. 1) was quick development; there was abundance of information about problems of virtual world rendering but not much was known about physical device requirements. The intention of the first prototype was to gather preliminary information about design constraints, it was made of low

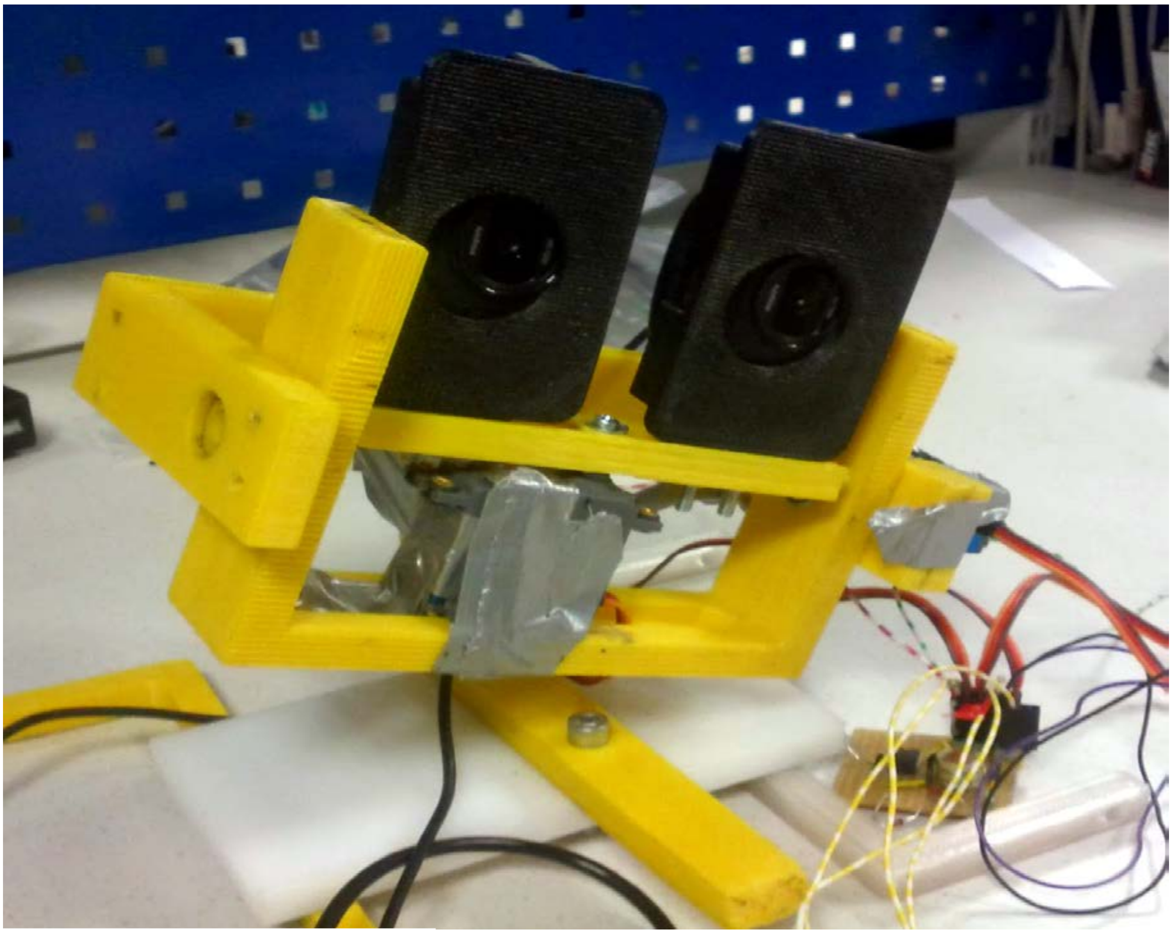

Fig. 1. The first prototype.

quality 3D printed parts, HobbyKing HK15298B servo motors and Logitech C525 web cameras.
The first problem with the web cameras was that they were not optically aligned and there was no precise mechanism to do so. The cameras were mounted on a loose 3D printed bracket that did not allow fixing them on steady position causing misalignment. Presenting the cross-eyed picture to user of the device induced motion sickness. Even when the optical axes were somewhat aligned the picture was only good for objects that were more than 2 meters away. Evidently there is a need to design an optical axis alignment tools to the second prototype and also do the camera distortion calibration/compensation in software.
The second problem with the web cameras was that they had a rolling shutter meaning that the lines were scanned line by line. While it was not a problem when camera was stationary or even when camera was rotated by hand it significant problem during head movements; turning the head sheared the whole image. Both cameras were working in live mode; image acquisition was not synchronized. This should have caused distortion of depth of objects on stereo imagery during head movements, but none of this was observed. It is possible that the depth distortion was masked by image shearing and motion blur artifacts.
Overall the first prototype failed to produce any noteworthy depth perception through stereo imagery. Significant camera calibration needs to be done for tapping stereo imagery and reducing the sickness. There was, however, definite depth perception from monocular imagery. The effects of motion parallax and occlusion combined produced a much better depth perception than what can be observed on pre-calibrated stereo imagery.
The used servos packed motor, encoder controller and a gearbox into a single unit; they were controlled using pulse-width-modulation (PWM) signal. There were three servos for rotating the cameras over three euler axes. The servos were responsible for major part of the latency in the system; The head movement could be detected within a millisecond, but issuing the PWM positioning signal to servo motor took 20

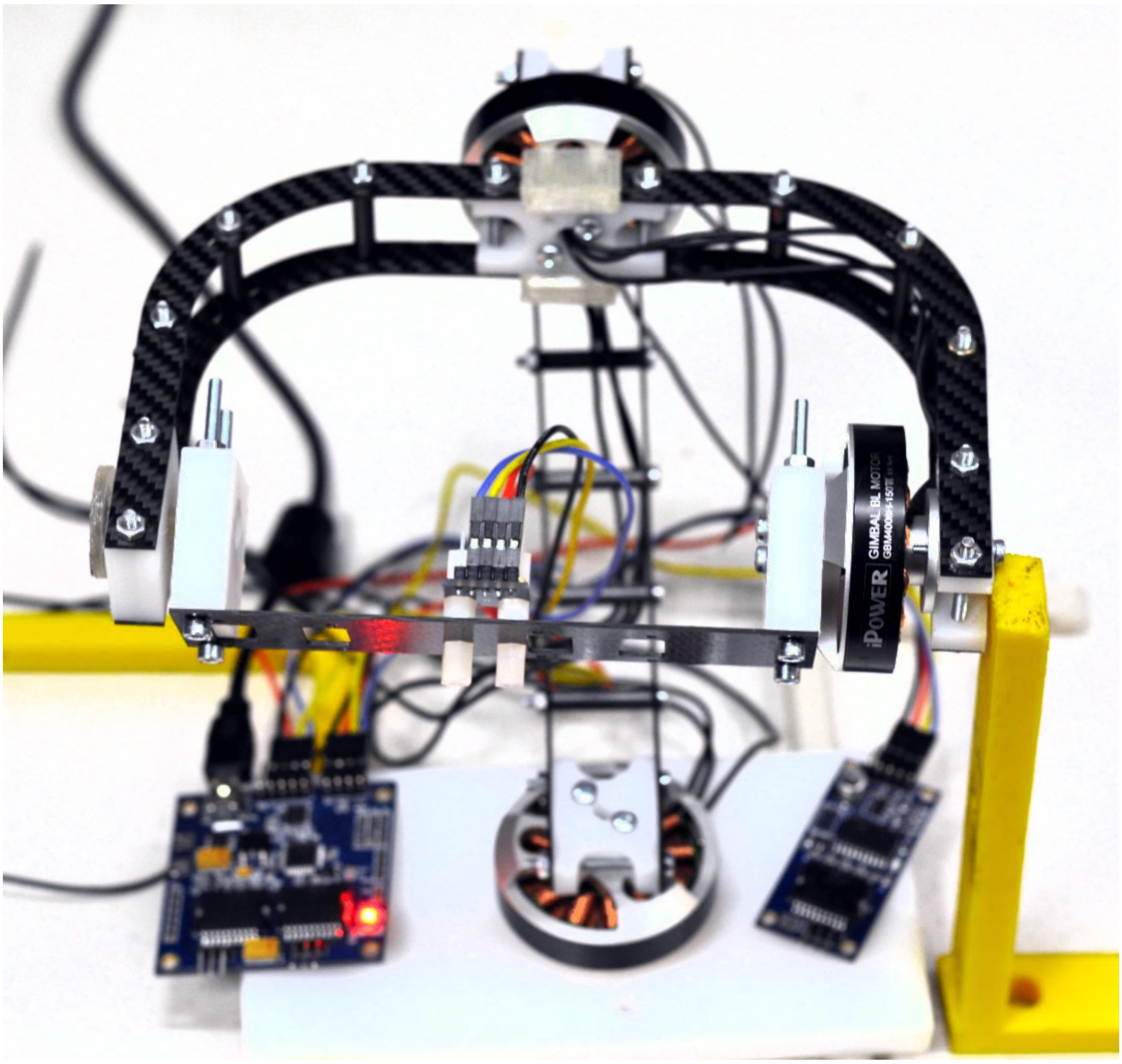

Fig. 2. The second prototype.

milliseconds. The high gearing ratio of the servo added further delays during head movements causing the picture to lag behind head movement - the gimbal system has to be able to achieve angular accelerations of over 900 rad/s² and angular velocities of over 9 rad/s for accurate head tracking [2]. Having a total system latency below 20 milliseconds is important for presence but before the servo latencies are suppressed it is difficult to evaluate the feasibility of the system in a real world scenario.

3. THE SECOND PROTOTYPE

The second prototype (Fig. 2) is in works at the time of writing and will be based on both experiences gathered from first prototype and on further research on the subject. The camera mount will be based on gimbal camera stabilizers that are used together with model helicopters, it will be made of carbon fiber to keep the weight down. The new cameras are designed for stereo imagery applications. The body of the apparatus will be made from carbon fiber in order to keep the weight down and deliver fast reaction times and lower latencies during head movements.

Using light and high torque GBM4008H-150T motors from gimbal stabilizers help to keep the apparatus compact. Instead of connecting the motors directly to encoders it was chosen to use an accelerometer sensor that is directly connected to camera bracket. The main advantage is that it helps to stabilize the camera even when the apparatus is attached to EOD robot - it considers both operator view direction and the position on the carrying EOD robot. The other advantages are the compact size, light weight, easy attachment and easier calibration procedure of such feedback. Conveniently there's a three axis brushless DC motor controller available from BaseCam Electronics that supports accelerometer for feedback. The controller has analog inputs for positioning signal allowing to eliminate most of the PWM delay.

The chosen Leopard Imaging LI-USB30-M021 cameras are of industrial origin; they are designed for monitoring high speed operations and support high resolution imagery. The cameras have global shutter, meaning they acquire all pixels at once, and deliver the frames at rate of 60Hz over USB3 to host device. There is a synchronization input for coherent imagery. Finally the cameras are of compact size helping to reduce the size and weight of the apparatus for lower latency.

4. CONCLUSION

There has been a recent breakthrough in virtual reality technology that enables a whole range of new applications. The article focuses on building a telepresence device and enlists some of the hardware challenges in design of such device together with possible solutions. The major challenges are identified as optical calibration and responsiveness of the robot. The stereo camera imagery needs to be meticulously calibrated in order to provide believable stereo imagery for depth perception and the robot has to be able to perform rapid movements in order to track fast head movements.

5. REFERENCES

1. Michael Abrash, „What VR Could, Should, and Almost Certainly Will Be within Two Years“, Speech at Steam Dev Days, Feb 11, 2014
2. W. R. Bussone, „Linear and Angular Head Accelerations in Daily Life“, Masters Thesis, 2005

6. ADDITIONAL DATA ABOUT AUTHORS

Corresponding author
Robert Hudjakov, robert.hudjakov@gmail.com

Co-authors
Robert Hudjakov, PhD researcher
Department of Mechatronics, Ehitajate Tee 5, Tallinn 19086, Estonia,
robert.hudjakov@gmail.com
+372 5245445

Ülari Lees, Mechatronics student
Department of Mechatronics, Ehitajate Tee 5, Tallinn 19086, Estonia,
ulari.lees@ttu.ee
+372 6203200

Mart Tamre, PhD, professor,
Department of Mechatronics, Ehitajate Tee 5, Tallinn 19086, Estonia,
mart.tamre@ttu.ee
+372 620 3202