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Mobile Robot tele-guide based on laser sensors

TESI DI LAUREA

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Chapter 1. Introduction

1.1 Telerobotics

"If every instrument could accomplish its own work, obeying or anticipating the will of others . . . If the shuttle could weave, and the pick touch the lyre, without a hand to guide them, chief workmen would not need servants, nor masters slaves." Aristotle wrote these words over two thousand years ago. He envisioned what we today call "robots" [1].

Robotics is the science and technology of robots, their design, manufacture, and application.

A robot according to is “any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner”.

A typical robot will have several, though not necessarily all of the following properties:

- is not 'natural' i.e. artificially created
- can sense its environment, and manipulate or interact with things in it
- has some ability to make choices based on the environment, often using automatic control or a preprogrammed sequence
- is programmable
- moves with one or more axes of rotation or translation
- makes dexterous coordinated movements

Robots can be placed into roughly two categories based on the type of job they do:

- Jobs which a robot can do better than a human. Here, robots can increase productivity, accuracy, and endurance.
- Jobs which a human could do better than a robot, but it is desirable to remove the human for some reason. Here, robots free us from dirty, dangerous and dull tasks.

Robotics was born as science to develop machines, destined to factories. Jobs which require speed, accuracy, reliability or endurance can be performed far better by a robot than a human. Hence many jobs in factories which were traditionally performed by people are now robotized. This has led to cheaper mass-produced goods, including automobiles and electronics. Robots have now been working in factories for more than fifty years.

Nowadays, there are endeavours to use these technologies in new environments that are dangerous or unreachable to humans. There are many jobs which a human could perform better than a robot but for one reason or another the human either does not want to do it or cannot be present to do the job. The job may be too dangerous, for example exploring inside a volcano. Other jobs are physically inaccessible. For example, exploring another planet, inspecting areas with very high level of radiations, cleaning the inside of a long pipe or performing laparoscopic surgery.

Looking at these new perspectives robots are going to be more complex than factories enabled ones, because we need to consider the presence of many new variables.

Different kind of operations are not easy to automate, and nowadays it is hard to develop autonomous robots, so it is necessary to drive them "by hand".

A new branch of Robotics is gaining importance as we can see in literature: *telerobotics*.

Telerobotics is based on the idea to control a robot to support operation at a distance. The robot may be in another room or another country, or may be on a very different scale to the operator, where for an example a surgeon may use micro-manipulator technology to conduct surgery on a microscopic level. The goal of bilateral telemanipulation is to allow a human user to manipulate and interact with a remote environment via master and slave robotic devices. Typically, there is a master robotic device designed to detect the user's commands by being directly held and manipulated by the user. At the remote location, a slave robot tries to mimic the motions of the master.

Successful manipulation inherently requires some form of perception of the remote site and the response to the requested actions, necessitating closed loop interaction.

The computer network services have broadly used in our daily life, such as e-mail, FTP, Telnet, the World Wide Web, e-mail, etc. and, it could be convenient to use Internet to telecontrol intelligent robots.

In recent years, many research centres and laboratories have developed methods for the networked robots. We will introduce successful telerobotics applications classified in relation to the field of application.

The aim is to introduce the reader to typical tasks, problems and solutions proposed in Telerobotics. This will be useful to better understand the potential and application possibilities of the proposed investigation.

Medical robots

Additionally, a lot of telerobotic research is being done in the field of medical devices, and minimally invasive surgical systems. The medical robots can provide high-accuracy operation and precise action on surgery interventions. The design requirements for the teleoperation controllers are significantly different from classical teleoperation applications. With a robot system a surgeon can work inside the body through tiny holes just big enough for the manipulator, with no need to open up the chest cavity to allow hands inside.

To many the idea of robots performing open-heart surgery sounds like science fiction but recently this idea has become a reality. Remote surgery (also known as telesurgery) is the ability for a doctor to perform surgery on a patient even though they are not physically in the same location. It is a form of telepresence. With the invention of the da Vinci Surgical System, introduced in 1999 by the California Company Intuitive Surgical, surgeons can operate on patients while sitting at a computer council from across the room where they control a robot much like playing a video game.

Figure 1.1: A laparoscopic robotic surgery machine

The da Vinci Surgical System comprises three components: a surgeon’s console, a patient-side robotic cart with 4 arms manipulated by the surgeon (one to control the camera and three to manipulate instruments), and a high-definition 3D vision system. Articulating surgical instruments are mounted on the robotic arms which are introduced into the body through cannulas. The surgeon’s hand movements are scaled and filtered to eliminate hand tremor then translated into micro-movements of the proprietary instruments. The camera used in the system provides a true stereoscopic picture transmitted to a surgeon's console.

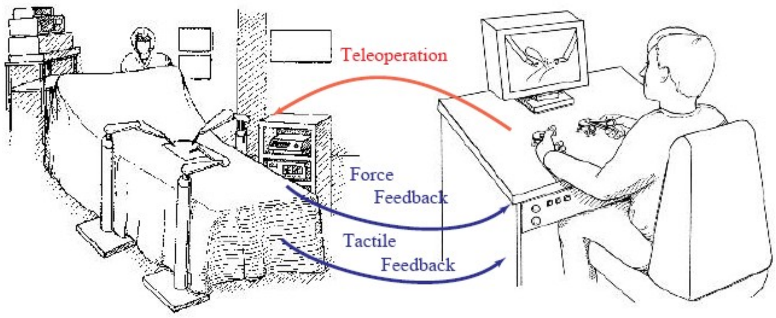

Figure 1.2: Telesurgical system concept

The da Vinci System including surgery for prostate cancer, hysterectomy and mitral valve repair, and is used in more than 800 hospitals in the Americas and Europe. Remote surgery is essentially advanced telecommuting for surgeons, where the physical distance between the surgeon and the patient is immaterial. It promises to allow the expertise of specialized surgeons to be available to patients worldwide, without the need for patients to travel beyond their local hospital [3], [4], [61].

Undersea and space applications

As mentioned before, in telerobotics field the robot can provide operations in environments that are dangerous or unreachable to humans. For this reason, we will give attention to the undersea and space applications.

To minimize the inherent risk and cost involved in human space travel and space walks there is growing interest in using robotic devices to perform much of the satellite and space station maintenance work currently conducted by astronauts. Teleoperation is well suited for these maintenance task as it allows a human operator to control the motion of the robotic device from the safety of the shuttle, space station, or a ground based command center without the need for extensive pre-programming.

Most space exploration has been conducted with telerobotic space probes. Most space-based astronomy has been conducted with telerobotic telescopes. Recent noteworthy examples include the Mars exploration rovers (MER) and the Hubble Space Telescope.

In and NASA’s Jet Propulsion Laboratory (JPL) designed a prototype Mars rover named Field Integrated Design and Operations (FIDO). FIDO rover hardware and software architecture is the most mature and field-tested of the current NASA technology rovers.

FIDO operators use the Web Interface for TeleScience (WITS), a web-based toolset for collaborative, geographically distributed robotic science operations.

Mission scientists can command the rover remotely via WITS and receive telemetry data coming from the rover and its scientific instrumentation (Figure 1.3).

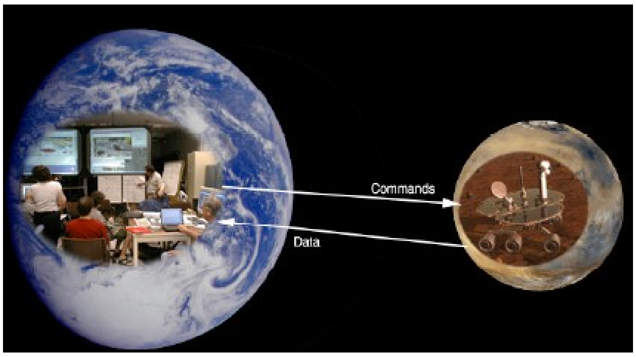

Figure 1.3: Satellite between FIDO and JPL

The Mission Operations Team at the JPL can communicate with the rovers via WITS every day by using a satellite link.

Marine remotely operated vehicles (ROVs) are widely used to work in water too deep or too dangerous for divers. They repair offshore oil platforms and attach cables to sunken ships to hoist them. They are usually attached by a tether to a control center on a surface ship. The wreck of the Titanic was explored by an ROV, as well as by a crew-operated vessel.

Romeo was designed like an operational test-bed. Its aim is to perform research on intelligent vehicles in the real subsea environment and to develop advanced methodologies for marine science.

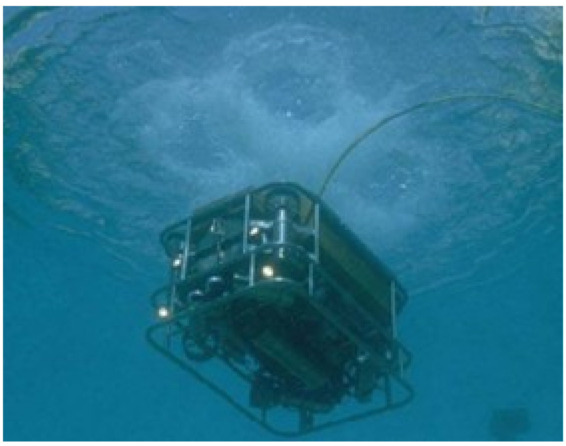

Figure 1.4: Romeo

Romeo is intended as a prototype demonstrator for robotics, biological, and geological research.

1.2Telepresence and stereoscopic visualization

Teleoperation, telepresence and Synthetic Telepresence are some important aspects on telerobotics. The teleoperation is the most standard term for referring to operation at a distance; instead, the telepresence refers to a user interacting with another remote place than your current place, and is distinct from Synthetic Telepresence, where the user is given the impression of being in a computer simulated distant environment

Mostly, feedback from robot is transmitting to an operator and then displaying on a screen. In order to do that, it is common to use common 2D display systems. The use of 2D displays brings many limitations in performing tasks in 3D environment.

Viewing at mono images we lose one of the best properties of our visualization (eyes-brain) system: the depth perception.

We use VR technologies to make the user feel more immersed and present in the virtual environment. This often helps to improve the user skills in performing various 3D tasks.

Everybody seems to agree that stereoscopic visualization presents the necessary information in a more natural way, which facilitates all human-machine interaction Errore: sorgente del riferimento non trovata. The use of stereo vision in teleoperation is expected to improve navigation performance and driver capabilities , , . A user can more easily adapt to new environment and plan his task. An important benefit is that the stereo visualization facilitates the spatial localization of the objects and the obstacles. This is a key feature in interaction jobs to avoid errors or collisions, caused by wrong estimation of a distance.

Parameters connected to the robot motion can be easier estimated when using stereoscopic view; a user can, for example perceive more precisely speed and acceleration of an object .

1.3The proposed investigation

Works in the literature have demonstrated how stereo vision contributes to improve perception of some depth cues, but it hard to find work specially addressing mobile robot teleguide [47].

The study considers two different kinds of robot workspace reconstruction modalities: Synthetic Telepresence (Laser based teleguide) and Video Telepresence (Video based teleguide).

In the Video based Teleguide, the visual feedback is provided by the on-board camera images sent through the network link.

In Laser baser Teleguide, the visual feedback is generated by the computer, based on 2D maps constructed by the on-board laser sensor.

In the Laser based teleguide, the user looks at the synthetic images, driving and interacting with them in real-time.

Instead, in the Video based teleguide, the real images are shown to the user with a delay.

The aim of this work is to investigate the advantages of the Laser based Teleguide and compare this teleguide with the previous results obtained of the students at the Aalborg University. In the previous work these students have studied the Video based Teleguide and the Laser based Teleguide. The Laser based teleguide only used a Robot Simulator.

In this project we made a systematic study, which involve several users. Each participant is asked to teledrive, using a laser based Teleguide, a remotely located mobile robot on two different 3D visualization technologies. The mobile robot 3MO.R.D.U.C., is available at the Robotics Lab of the University of Catania in Italy. The test user will be sitting on different 3D facilities at the Aalborg University in Denmark.

The results support that the stereo visualization helps the capability of the drivers in robot teleoperation.

1.4Thesis outline

The Chapter 2 is relative to the State of Art and the background knowledge. We will talk about: the mobile robots, the mobile robot teleoperation using different visual feedbacks: video and laser based, advantages and disadvantages of the stereoscopy and the stereo technologies and devices. Finally, we described a guideline for evaluations of virtual reality devices.

In Chapter 3 at the beginning we will show our goals and core ideas. The previous projects, useful to develop of the new system, will be examined underlining positive and negative features. Particularly we show synthetic teleguide, that is an application based on client-server architecture that works on-line. At the end we will mention about test procedure and result analysis.

Chapter 4 will give some details about the system setup therefore describe a Robotic System, a Visualization System and a Network Connection. On the second section of this chapter, we will analyze our results data collected during the Laser based teleguide. At the end we will compare this results with the date obtained in the previous work

Chapter 2. State of art and background knowledge

2.1Teleguide

Robot teleguide is driving a tele-robot at a distance. Tele-robots may be driven on Mars surface, at Mount Etna near by lava, at bottom of the Marianas Trench or higher regions of earth's atmosphere. Robot tele-guide enables an observer to see through the eyes of a robot.

The sensor-data are sent to an operator, he understands the surrounding environment and he can decides about next actions of the robot. The robot is fully mobile. This means, that it is able to move, turn, change the camera positions, etc. The operator can control robot using one of the input devices, for instance: keyboard, mouse, joystick. Sometimes there is set up tracking system to trace the operator head's position and update camera viewing point.

2.1.1 Mobile robotics

Mobile robots have the capability to move around in their environment and are not fixed to one physical location. In contrast, industrial robots usually consist of a jointed arm (multi-linked manipulator) and gripper assembly (or end effector) that is attached to a fixed surface. Mobile robots are the focus of a great deal of current research and almost every major university has one or more labs that focus on mobile robot research. Mobile robots are also found in industry, military and security environments. They also appear as consumer products, for entertainment or to perform certain tasks like vacuum cleaning or mowing. The three key questions in Mobile Robotics are:

- Where am I?
- Where am I going?
- How do I get there?

To answer these questions the robot has to

- have a model of the environment (given or autonomously built)
- perceive and analyze the environment
- find its position within the environment

- plan and execute the movement

During the last two decades of research in robotics, there have been many different methods and technologies proposed to tackle the problem of a mobile robot localization. In general, the two main aspects to be addressed when designing a location method are: extraction of positional information and word representation.
Both aspects involve the use of sensors to update the motion status of the robot and to observe the surrounding environment.

2.1.1.1 Sensors for Localization

There are different types of sensors proposed in the literature for mobile robots. Sensors for robotic system can be divided in two groups: internal and external sensors.

- ***Internal Sensors***

The internal sensors are mainly represented by odometric system, inertial sensors and compass systems. These sensors measure some internal state of the robot such as: motion based on wheel rotation (odometry); acceleration, orientation, stationary conditions, (inertial); direction\heading (compass).

- **Odometry**

  Most of robotic mobile platforms are wheeled, so that the use of wheel encoders has become popular. Therefore, knowing the size of the wheels and their configuration makes it possible to estimate the robot motion.
  Unfortunately, with this kind of system, error accumulates so that even a small error may lead a large error over time. An error may be due to wheel slippage or bumps.

- **Inertial**

  There are different types of sensors, but the more popular are: accelerometers, gyroscopes and inclinometers.
  The accelerometers measure both liner and angular acceleration; they may also provide position information. Typically these sensors suffer a very poor signal to noise ratio for low accelerations.
  The gyroscopes measure angular and linear motion, they may also provide velocity and position.

The inclinometers measure inclination gradient by electrically sensing gas bubbles moving inside a tube with liquid as effect of the gravity force.

The inertial sensors in robotics system can be complemented by an odometric system. This enable a reduction of the drift problem they are subject to. Inertial sensors represent a basic component of aircraft navigation systems, and they also find application in outdoor robots navigating in uneven terrains.

· **Compass**

The compass was used since over 2000 B.C. when Chinese suspended a piece of naturally magnetite from a silk thread and used it to guide a chariot over land.

The mechanic magnetic compass is the most common and oldest kind of magnetic compass. It used the magnetic field of the earth to find the direction.

The major drawbacks are: weakness of the earth field, easily disturbed by magnetic objects or other sources and not feasible for indoor environments.

However the compass is still a good source of information to estimate the initial robot orientation.

Different inertial sensors can be combined to increase accuracy, reliability, and range of operation.

- ***External Sensors***

The external sensors are mainly represented by vision, sonar, laser, infrared, and radar. They provide information about objects in the workspace surrounding the robot.

· **Vision**

The visual observation is created by arrays of photo-sensitive cells recording light intensities related to a given workspace-portion:

· CCD (light-sensitive, discharging capacitors of 5 to 25 micron)

Figure 2.1: Several kinds of CCD sensors

· CMOS (Complementary Metal Oxide Semiconductor technology)

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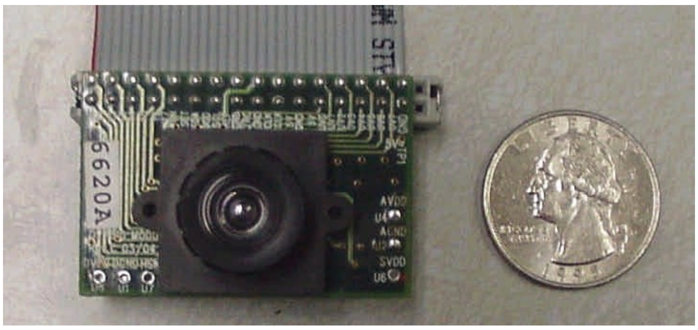


Figure 2. 3: CMOS

Vision is our most powerful sense. It provides us with an enormous amount of information about our environment and enables us to interact intelligently with the environment, all without direct physical contact. It is therefore not surprising that an enormous amount of effort has occurred to give machines a sense of vision (almost since the beginning of digital computer technology!)

Vision is also our most complicated sense. Whilst we can reconstruct views with high resolution on photographic paper, the next step of understanding how the brain processes the information from our eyes is still in its infancy.

When an image is recorded through a camera, a 3 dimensional scene is projected onto a 2 dimensional plane (the film or a light sensitive photo sensitive array). The interpretation of 3-D scenes from 2-D images is not a trivial task. However, using stereo imaging or triangulation methods, vision can become a powerful tool for environment capturing.

· **Laser**

The Laser sensor (standing for Light amplification by Stimulated Emission of radiation) is used to measure distance.

The sensor by a mechanical mechanism with a mirror sweeps transmitted and received beams coaxial.

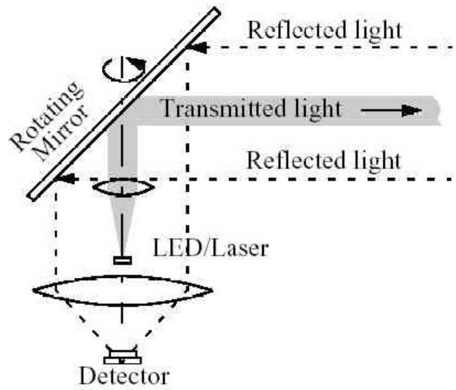
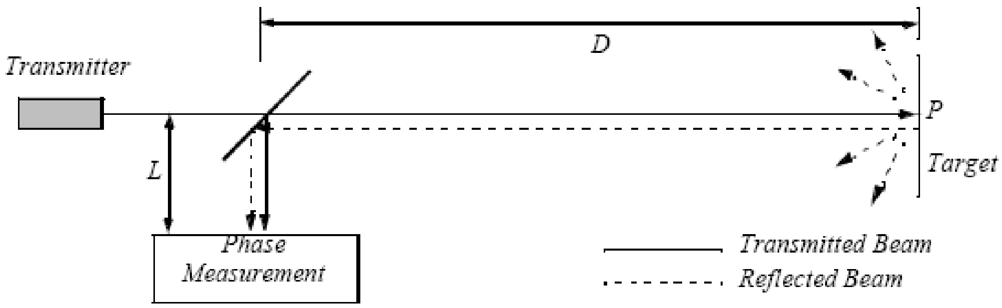


Figure 2.4: Laser sensor with rotating mirror

The transmitter illuminates a target with a collimated beam and it received the reflected beam detects the time needed for round-trip.



The distance to an object can be achieved by measuring the time of flight or the phase shift.

The time of flight is the time between transmission and reception of the light pulse. This time is directly proportional to the distance between the scanner and the object.

If you indicate with L the distance between the laser and the obstacle and with c the light speed:

$$t_{flight} = \frac{2L}{c} \quad \Rightarrow \quad L = c \cdot \frac{t_{flight}}{2}$$

The quality of time of flight range sensors manly depends on:

- Uncertainties about the exact time of arrival of the reflected signal
- Inaccuracies in the time of fight measure
- Interaction with the target (surface, specular reflections)
- Variation of propagation speed
- Speed of mobile robot and target (if not at stand still).

The Phase-Shift measurement produces a range estimation.

We can indicate with:

f the modulating frequency,

c the light speed,

$\lambda = \frac{c}{f}$,

D′ is the distance covered by the emitted light

$$D' = L + 2D = L + \frac{\theta}{2 \cdot \pi}\lambda$$

D distance between the beam splitter and the target

$$D = \frac{\lambda}{4 \cdot \pi}\theta$$

where θ is the phase difference between the transmitted and the reflected beam.

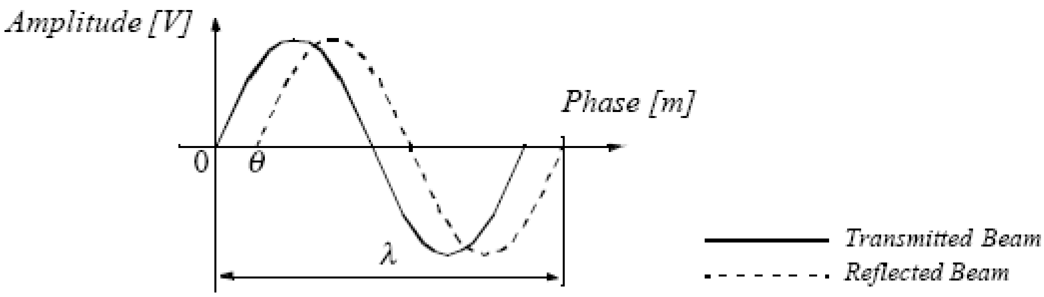


Figure 2.5: Transmitted and Reflected beam

Confidence in the range (phase estimate) is inversely proportion to the square of the received signal amplitude.

In the Figure 2.5 is possible see a typical range image of a 2D laser range sensor with a rotating mirror. The lengths of the lines through the measurement points indicate the uncertainties.

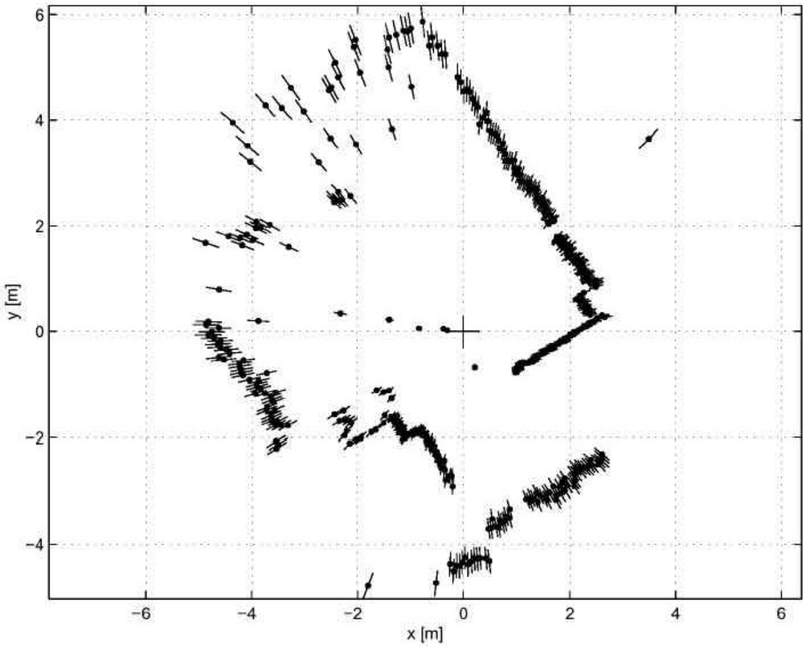


Figure 2.6: Range image of a 2D laser range sensor

· **Sonar**

The sonar sensors measure the distance from an obstacle using the flight time of an ultrasonic signal produced by means of a vibrating piezoelectric sensor.

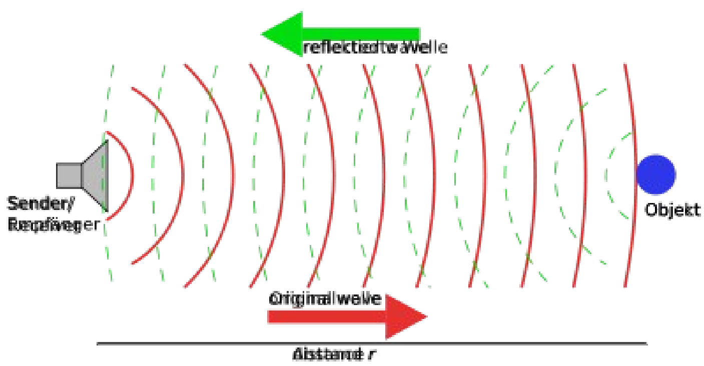


Figure 2.7: Sonar sensors

Active sonar creates an ultrasonic pulse, often called “ping", then listens for reflections, “echo” of the pulse (Figure 2.6). The ultrasonic pulse is electronically generated using a Sonar Projector composed of a signal generator, a power amplifier and an electro-acoustic transducer/array. The received signal is commonly processed by measuring the time of flight. This time is depending on the speed of the sound in air, and thus the temperature, humidity, air pressure, etc, may effect measurements. The knowledge of time of flight enables the computation of the distance to the target, which reflected the pulse.

The sonar field of view is a cone and the sensitive area increases proportionately with the distance. It is necessary to introduce an inhibition time to avoid the false obstacles due to the ping signal. The inhibition time does not allow reading distance too short.

The main drawback with the sonar sensor is its wide beam of perception, which causes the fact that it is impossible from on reading to identify the object position within the beam. Some of the other sonar drawback are; specular reflection, the possibility of a crosstalk when using multiple sensors or multiple robot.

Nevertheless, the sonar is the sensor most commonly used in Robotics, because widely available, cheap, and easy to controller.

· **Encoder**

A digital optical encoder is a device that converts motion into a sequence of digital pulses. The pulses can be converted to relative or absolute position measurements, by counting a single bit or by decoding a set of bits.

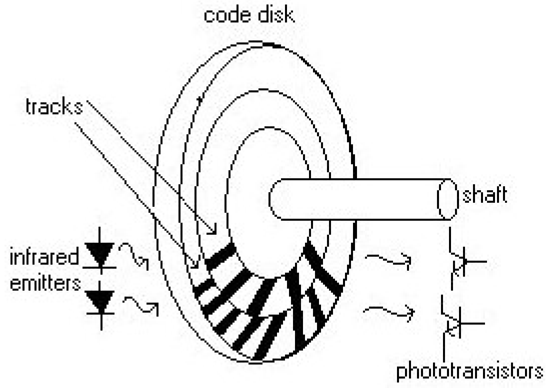
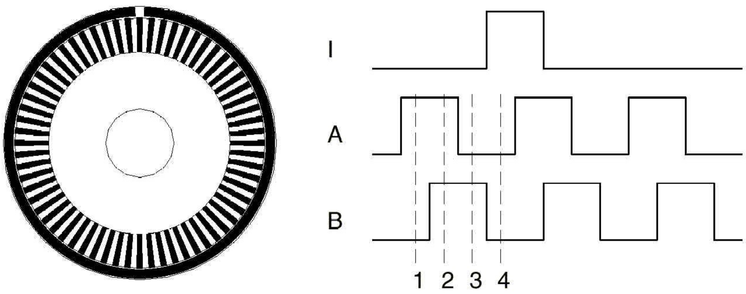


Figure 2.8: A rotary optical encoder

Encoders can be in linear or rotary configurations, but the most common type is the second one (Figure 2.7). The rotary encoders are manufactured in two basic forms: the *absolute encoder* where a unique digital word corresponds to each rotational position of the shaft.

The *incremental encoder*, which produces digital pulses as the shaft rotates, allowing measurement of the shaft relative position.

The incremental encoder, sometimes called relative encoder, is simpler and cheaper than the absolute encoder. It consists of two tracks and two sensors whose outputs are called channels A and B.



State	Ch A	Ch B
S_1	High	Low
S_2	High	High
S_3	Low	High
S_4	Low	Low

Figure 2.9: Incremental encoder disk track pattern

As the shaft rotates, pulse trains occur on these channels at a frequency proportional to the shaft speed and the phase relationship between the signals yields the direction of rotation. The code disk pattern and output signals A and B are illustrated in Errore: sorgente del riferimento non trovata8.

The angular motion can be measured, by counting the number of pulses and knowing the resolution of the disk. The A and B channels are used to determine the direction of rotation by assessing which channels "leads" the other. The two encoder channels are quadrature signals, it means that the signals are a 1/4 cycle out of phase with each other .

- **Bumpers**

These sensors have to recognize and reduce damages in a collision. The bumpers are simple switches pushed when there is a collision.

Different external sensors can be combined to increase over a single sensor accuracy, reliability, range of operation, etc.

2.2 Navigation in unknown environments

During the past, a significant body of research has been dedicated to mobile robotics with a number of studies that have focused on the problem of navigation and map building in unknown environments. The robot navigates itself towards a goal position while avoiding obstacles. During the entire navigation process the robot must specifically collect certain information about its environment (i.e. a map of the locations of obstacles, walls, etc) and update the resulting map. Using images or other sensors we can understand the surrounding environment and interact with the workspace with better accuracy.

An interesting question in our study was what kind of visual feedbacks could guarantee a better performance for the teleoperation.

In this work two different visual feedback typologies are studied: video and laser based.

There more we discuss about the telepresence and virtual telepresence, according to [44]:

- Telepresence is a spatially distant real environment, e.g. a remote space viewed through a video camera.
- Virtual telepresence is a computer simulated distant environment.

When applying these two technologies to teleoperation, they will produce significantly different results in addition to the difference in their image originalities. Their main differences are summarized in the following table:

	Telepresence	Virtual Telepresence
image	real	synthetic
interaction	real world	3-D model
viewpoint	fixed	controlled by operator
view-field	limited	up to 180 degrees
image quality	visibility-dependent	visibility-independent

Table 2.1: Difference between telepresence and virtual telepresence

2.3Visual Sensor

The use of visual sensor in telerobotics is very common. The visual sensor provides very rich and high contrasted information, which strongly improve user's comprehension of remote environment features. The above makes the use of cameras irreplaceable in many tasks which need accurate observation and intervention.

It is possible to improve the performance of a teleoperated system increasing the presence level using the stereoscopic visualization.

There are several works in the literature which focus on stereoscopic visualization, typically assessing stereoscopic versus monoscopic visualization.

Students at Aalborg University developed several semester projects dealing with telerobotics. Projects about telepresence and teleoperation, were implemented and tested, using VR facilities to examine the advantages of stereo vision.

The topic of these works was the robot teleoperation using 3D visualization.

In [45] and [46], the test user focused the attention on the advantages of the 3D Vision for the telepresence comparing mono and stereo vision in robotic field, examining the immersion level of the users. The authors developed a "3D Mobile Robot Simulator" by using OpenGL library. The application builds a 3D environment with a static map and it allows the navigation in this environment with a robot.

The focus was to evaluate the difference between mono and stereo robot guide using different technologies, to understand the advantages and disadvantages of each technology. Very important is to underline that this study lead to a characterization between 3D technologies by using parameter such as immersion, cost and portability.

In [44], the authors realized a network connection between Aalborg University in Denmark and the robot at the University of Catania, Italy. This network connection allows sending the images or sensor data coming from the robot and the movement commands.

In particular, the data sent by the robot are images coming from two on-board cameras; the client simply shows the real environment trough a video rendering.

In the last project developed at Aalborg University, the authors to take advantage of this network connection, they developed a new client for robot teleoperation using the existing network libraries. This network connection allows sending the images or sensor data coming from the robot and the movement commands. This data exchange is necessary to develop the Video based teleguide.

In the first project version the images acquired in the video based teleguide were small. In the new project version, the images are stretched before the visualization. This operation is useful on the technologies where the screen used is large, such as the flat wall. Furthermore they have deleted the flicker in video based visualization. The previous application cleared every time the buffer for the images; as a result, there was a flicker effect on the screen. They solved this problem overwriting the previous data on the video buffer.

They compared different VR facilities in the video based teleoperation.

The experiments have demonstrated that the use of stereoscopic video images provides a higher depth perception of the elements in the remote environment. Monoscopic images, instead, give a vague idea about the real distance of the elements on the scene and consequently decreases the teleoperation performance in common tasks like teleguiding. In other tasks where the operator only supervises, without monitoring, the monoscopic vision could be sufficient.

2.4 Laser Sensor

The teleoperation by using synthetic environment requires that mobile robot have the capability of terrain of reconstruct the workspace.

The rich information provided by a camera may require a large bandwidth to be transmitted at interactive rates. This often represents a challenge for transmission to distant locations or when the employed medium has limited communication capabilities. The large bandwidth represents a main issue in video-based robot teleoperation because of the requirements in terms of bandwidth, information loss, etc., [28]. For example, autonomous underwater vehicles, robots for planetary exploration or long distance robot telecontrolled via the Internet, are all applications where a large bandwidth in communication is not possible.

Several video compression techniques have been developed which may reduce or solve the transmission delay problem. In case of stereo images, the information to be transmitted is larger (double, in principle). However, this can greatly be reduced, e.g. based on redundant information in stereo images, while specific networks for streaming video have been proposed, [11].

The bandwidth constraint may lead to transmission delays. Remote intervention is still possible with delayed images, but a delay affects interaction performance, e.g. response speed and accuracy. Up to three seconds of delay a robotic system can still be teleoperated with minor problems, [16]. The price to pay is a slower operation and user interaction.

Therefore, the need to improve the synthetic teleoperation system is obvious.

In literature there are some papers describing the possibility to reconstruct 3-D environments starting from the data coming from the sensors: sonar, laser etc. but none of this talk about the teleoperation.

In “Virtual Teleoperation of Underwater Robots” , the authors describe a research work which attempts to overcome the problem by introducing virtual telepresence operation approach. This virtual telepresence interface takes robot's position and orientation data from a sonar navigation system, and generates 3D synthetic images of the worksite based on its CAD model using virtual reality technology. It provides the robot operators with a full perception of its spatial location, flexible options of viewpoints and functions for teleoperation of underwater robots.

The virtual telepresence interface project is an extension of the sonar navigation project . In this project the proposed procedure consists of two main steps. In the first step, the sonar sensor measurements from the robot surroundings are mapped into a two-dimensional occupancy grid map. In the second step, the Radon Transform is used to extract the line parameters from the occupancy grid map.

These parameters are subsequently used to represent the profiles of the detected objects as a representation of the robot environment. Applying a wall extension process to the resulting line map completes the process within the limits of resolution of the grid map.

The presented experiments in this work have confirmed that the proposed line map construction approach is able to reconstruct the unknown indoor environment in spite of the uncertainty in sensor measurements.

In “Virtual Teleoperation of Underwater Robots” the main aim of the research is to improve the efficiency of subsea intervention work by devising an effective and practical virtual telepresence interface for use in support of the ROVs (remotely operated vehicles) operation. The approach of the interface is to generate a synthetic 3D underwater environment based on CAD model of an offshore structure. This virtual telepresence interface will provide the pilot with a 3D virtual representation of the underwater environment and facilities for assisting navigation and preventing collision/ tether entanglement.

The main conclusion of this paper is that the virtual telepresence incorporated with robot safety domain concept, not only can improve the efficiency of underwater robots operations, but also forms the basis for supervisory control and fully automated control of the robots.

In the last project the student have developed a Laser based teleguide based on client-server architecture that works on-line. The client side reconstructed the 3D remote environment based on 2D maps constructed by the Robot Server Simulator.

They compared different VR facilities in the laser based teleoperation and the results confirmed the advantages of a depth enhanced mobile robot teleguide. But using the robot simulator we unknown the real friction parameters (e.g. ground-wheel contact coefficient).

2.5Remote robot teleoperation

The communication between two computers can be implemented by using a Transmission Control Protocol/ Internet Protocol (TCP/IP) socket or the User Datagram Protocol (UDP). In general, when the teleoperation is performed over a great distance, such as in undersea or outer space operations, a time-delay problem happens in the transmission of information from one site to another. The time delay can lead to instability on closed loop teleoperation. In the literature, many experts proposed various methods to solve these problems -.

In recent years, many research centre and laboratories have developed some methods for the networked robot. As mentioned above, Internet can be used to control intelligent robots remotely.

The following is an overview of networked intelligent robot systems, .

In general, the networked intelligent robot can be classified in relation to four different control architectures:

- *One to One:* most systems provide one user control for one robot, the system permits remote user control of the mobile robot, and it also provides real-time sensors feedback to the user (Figure 2.9).

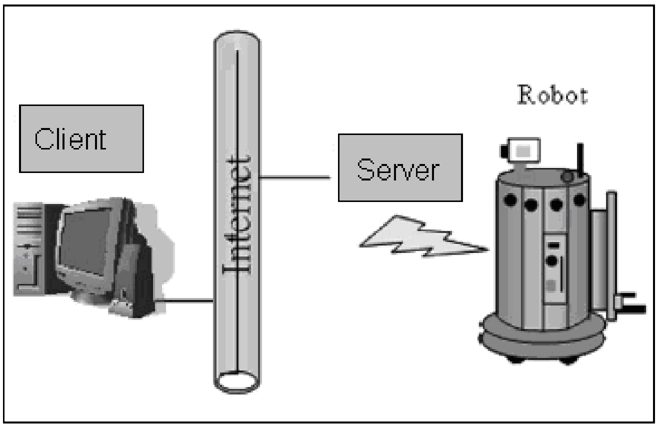


Figure 2.10: One to one network

- *One to Many:* the networked intelligent robot systems permit one user control for multiple robots. Each user monitors different sensors and submits control inputs based on the different sensor information. Finally, the *Server Collector* receives the data sequence and it sends to each robot the right command (Figure 2.10).

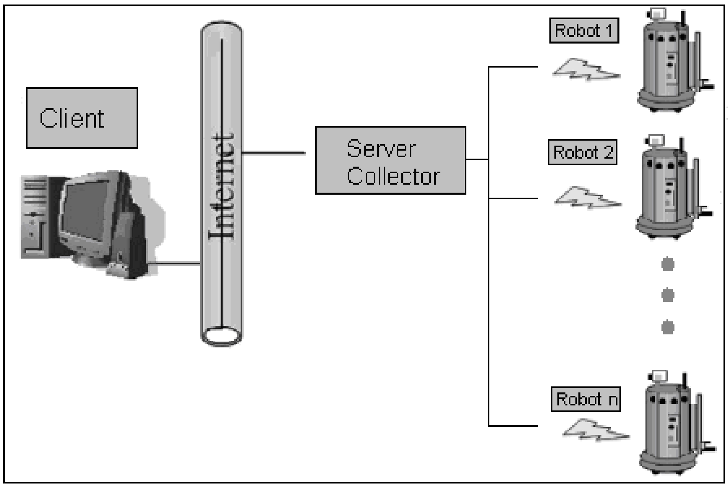


Figure 2.11: One to many network

- *Many to One:* the idea is that many people are working together to control a robot. All control inputs must be combined to a single control signal for the robot or there is a user hierarchy (Figure 2.11).

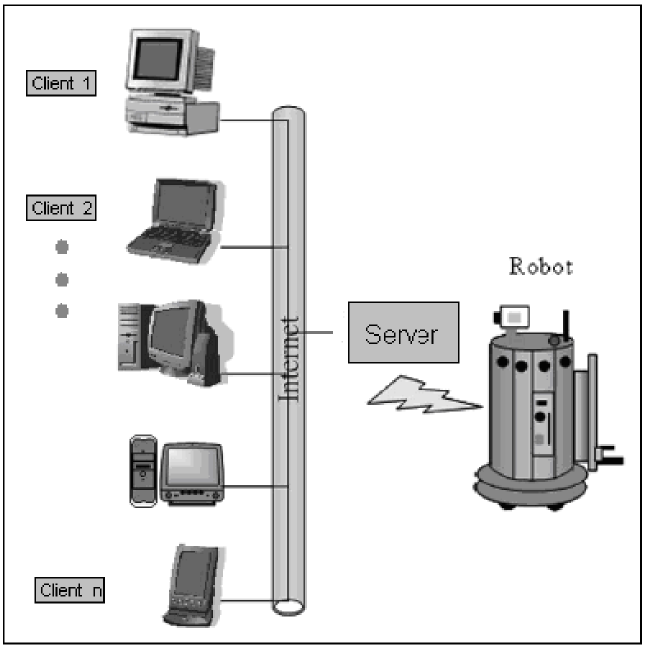


Figure 2.12: Many to one network

- *Many to Many*: in this case many users can control several robots (Figure 2.12).

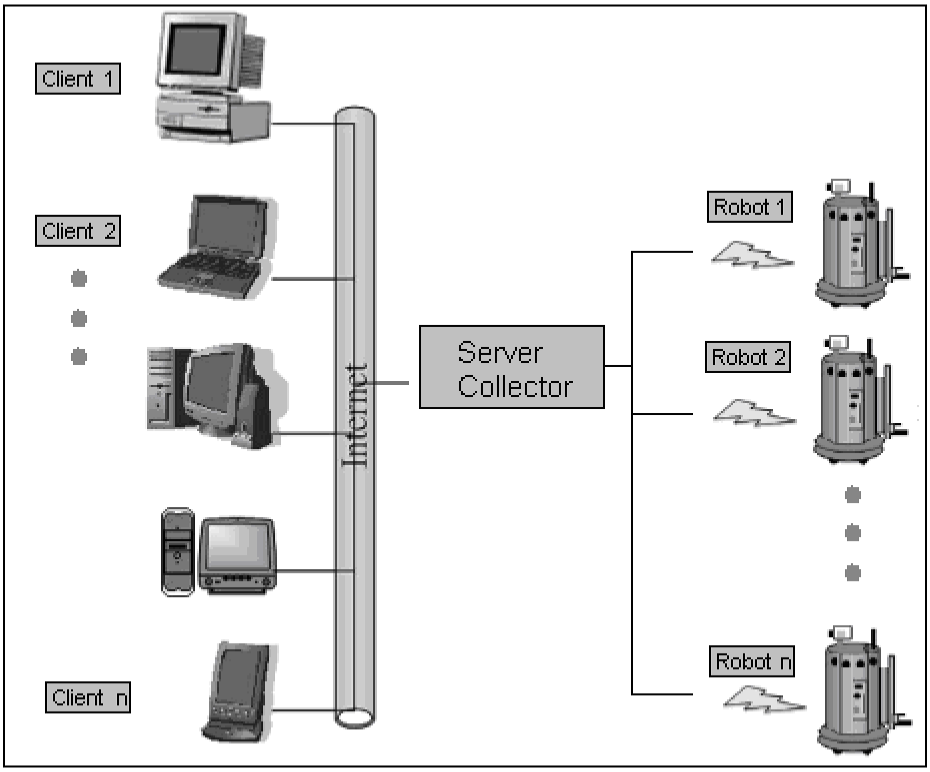


Figure 2.13: Many to many network

2.6Stereo Visualization

Leonardo da Vinci realized that to truly capture reality in a painting we should have two paintings, the views seen by each of the artist's eyes.

Euclid the philosopher and father of classical geometry laid the foundations of stereoscopic "art" almost 2000 years earlier when he wrote "To see in relief is to receive by means of each eye the simultaneous impression of two dissimilar images of the same object" [29].

We see the world stereoscopically and so, presumably, we should endeavor to recreate the visual experiences to which we are accustomed in other images.

Stereoscopy is a visualization technique gives an impression of depth. That is why we can see, not only shapes and colors of the objects, but also we are able to see spatial relationships between those objects.

This technique requires delivering to the brain two images, which are taken from two slightly different points of view (from left and right eye). Those two images are almost

identical and the only difference is a viewing angle of the objects and the way of objects interposition in the scene. Those differences give us information about third dimension.
It has been early discovered that we can see 3D world in a common plane 2D screen. The phenomena that help us to perceive depth on 2 dimensional displays are called monocular cues. Images which are rich in monocular depth cues will be even easier to visualize, when the binocular stereoscopic cue is added.

2.6.1 Depth cues

3D world can be displayed in 2D screen by using the monocular depth cues which tricks to improve the depth perception in visual displays. There are few different techniques, which help user to feel 3D impression.
The *perspective* is the strongest depth cue (Figure 2.13). It is based on the relationship between foreground and background objects. When the perspective is present we feel as all the parallel lines converge on a point, the vanishing point, situated on the horizon line. The perspective deforms the object shape, in fact, the closer parts become bigger and the further parts become smaller then the objects closer to the horizon seem more distant.
Similar to the perspective depth cue is the *relative size* (Figure 2.14). It is based on the knowledge that closer object are bigger than those which are in the second plan.
We talk about the *interposition depth cue* (Figure 2.15) if an object standing over another object partially covering it, then we evaluate the covering object closer to us than the covered one. If we want to show a landscape in natural way, we should use an aerial perspective (Figure 2.16). This depth cue makes distance object more hazy and closer more clearly.

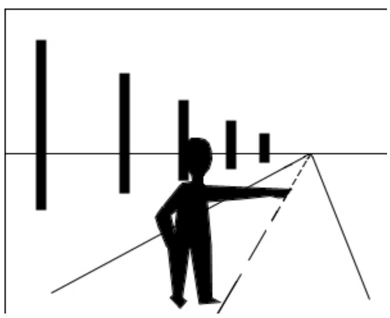


Figure 2.13: Depth cue: perspective

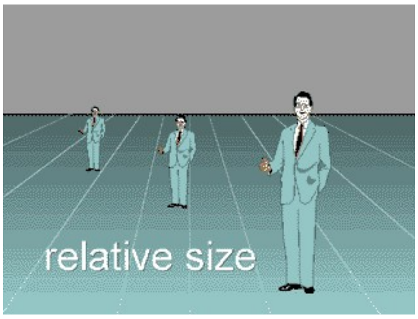


Figure 2.14: Depth cue: relative size

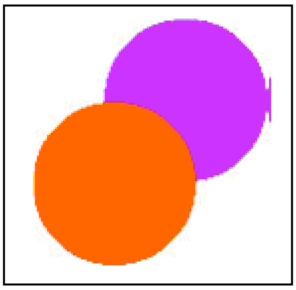


Figure 2.15: Interposition

Figure 2.16: Depth cue – Arial perspective

Figure 2.17: Depth Cue – Light and shade

Very important technique is the *light and shade* (Figure 2.17). This allows seeing an object shape and relative size to other objects by shading and brightening particular parts of a scene.

The *motion parallax* depth cues (Figure 2.18) is available only for motion pictures. Objects, which are further, are moving slower, than the objects, which are closer to the viewer. For instance, it could be easy observed, during travelling by a car and watching changes on the side of the car. Trees, which are situated near to the road, are moving faster than mountains, which are far away from the car.

Those depth cues are very helpful for making 3D impression. However, they are insufficient in many applications. Sometimes, it is much more convenient to use stereoscopic images, instead of mono images.

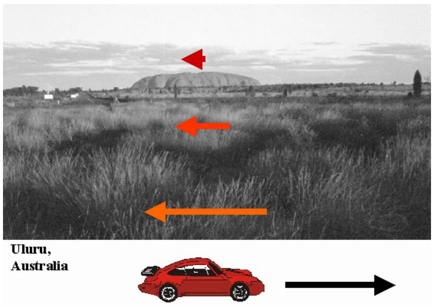


Figure 2.18: Depth Cue – Motion Parallax

2.6.2 Perceiving stereoscopic images

According to a perception of a stereoscopic image there exist several issues, which require more complex explanation. In the following section we will describe them step by step.

One of the basic issues is retinal *disparity*.

"Disparity refers to the difference in images from the left and right eye that the brain uses as a binoculars cue to determine depth or distance of an object."

It is defined by:

"The distance, in a horizontal direction, between the corresponding left and right image points of the superimposed retinal images."

Disparity causes, that a user's brain has to combine two different, but similar, images into one image. This phenomenon is called fusion, and as result, the user perceives a sense of depth, which is called stereopsis.

The *parallax* is the distance between two corresponding points, one from the right image, and second one from the left image, which are displayed on the same screen. The parallax concept is similar to the disparity one but while disparity is connected with the user's eye and retina, the parallax is measured on the display screen. We can say that disparity is caused by parallax and then disparity produces stereopsis.

There are four different types of parallax:

- *Zero parallax*
- *Positive parallax*
- *Divergent parallax*
- *Negative parallax*

The **zero parallax** (Figure 2.19) is obtained when two corresponding points from both images lies on the same place on the screen. Both eyes are accommodate and converged on the same point of the screen.

Positive parallax occurs when the axes of the left and right eyes are parallel or almost parallel (Figure 2.20). In this condition, the observer sees the given object in a further distance than the plane of the screen.

The **divergent parallax** is a special kind of positive parallax. It occurs, when the distance between corresponding points is greater than distance between eyes. It should be noticed, that it will never occur in real world.

The last type is the **negative parallax** (Figure 2.21). In this situation, the observer can see objects, which seem to be closer, than the plane of the screen.

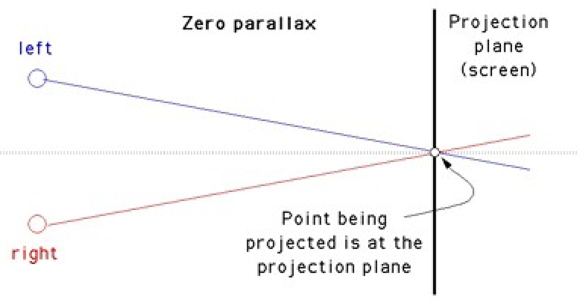


Figure 2.19: Zero parallax

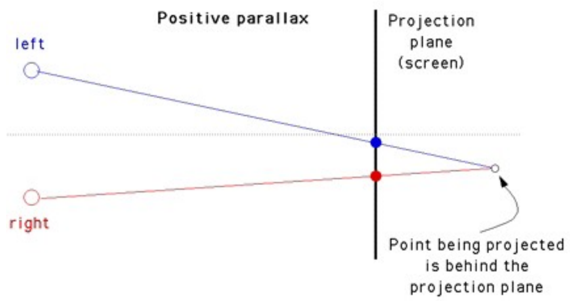


Figure 2.20: Positive parallax

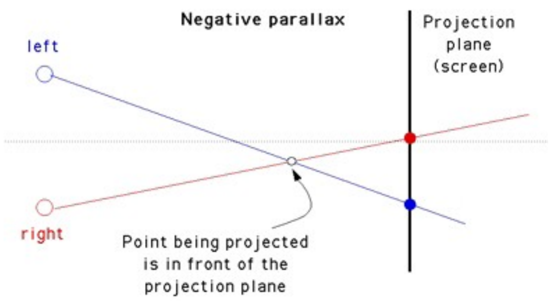


Figure 2.21: Negative parallax

2.6.3 Stereo parallax

Stereo parallax is actually a physical condition that refers to the apparent displacement of a point or a feature of some height in a photo or image caused by a shift in the position of observation. The stereo parallax can be measured as angular or linear parallax:

Angular parallax is the degree of convergence needed to fuse an object. In other words, angular parallax (stereo angle) is the angle between lines running from two camera lenses to the nearest object. (Figure 2.22) (In human vision, it is the angle between lines running from eyes to the nearest object.)

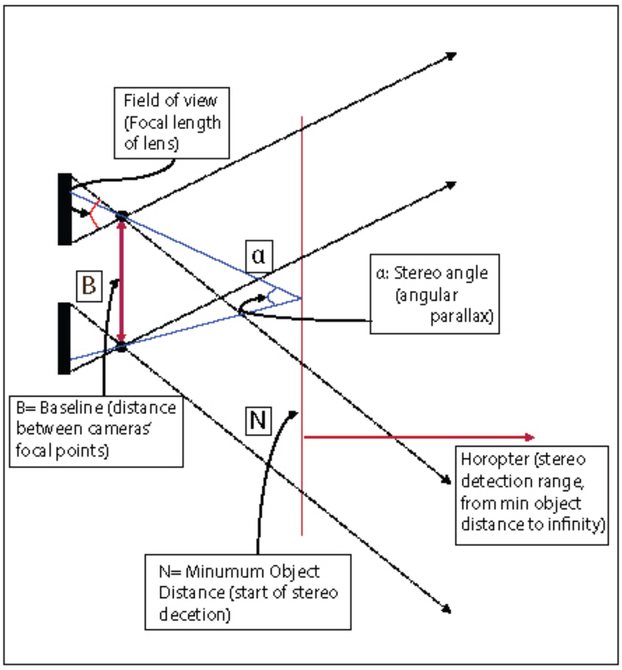


Figure 2.22: Stereo Angle, angular parallax

The angular parallax can be obtained using the following equation:

$$\alpha = 2 \cdot arctg\left(\frac{\frac{B}{2}}{N}\right) \qquad (1)$$

The angular parallax can be absolute or relative and it is measured in degrees or radians. The absolute angular parallax of an object at infinity stereoscopy is zero. The angular parallax increases when the object gets closer. A ghost effect occurs and it is hard to fuse the object when the point is too much close. The limit for angular parallax differs depending on the application. In stereo photography and robot tele-operation tasks, the suggested maximum angular parallax is 2°; in the computer games it is often limited to 1.5°; Videredesign, *stereo camera manufacturer, advises to keep angular parallax below 5°.*

Linear parallax *is the difference in distance between homologous points on a stereo pair. The linear parallax is a relative measure and it can be measured in mm or inches.*

In the following section we will describe the pinhole camera model useful to explain the stereo capturing and linear parallax.

2.6.4 Stereoscopy advantages and disadvantages

The stereoscopy is the most natural way of perceiving 3D reality. Stereoscopy gives a more natural way of perceiving 3D, structure's depth and the details not observed before become evident. The combination of two views can provide more useful information in a scene than a single view, or two views that are taken from different viewpoints .

There are several benefits of using stereoscopy; it helps the users to perceive the structure layout in visual complex scenes. Moreover the users can more easily adapt to new environment and better plan his task. Next benefit of stereoscopy helps in better perceiving of spatial localization. This characteristic is very important in interaction jobs to reduce the number of mistakes, which are caused by wrong estimations of distances. The stereoscopy helps users to estimate several attributes connected to the motion. For instance, the user can better perceive the speed and the acceleration of an object. The improvement in concentration on different depth planes is a great advantage, in fact, it allows user to fix his eyes on the most important part of the scene. At last, the stereoscopy has a big influence on perceiving of surface materials.

There are many benefits on using stereoscopy, but, there are disadvantages related to this technique.

First of all, there is an issue due to the accommodation convergence breakdown. This problem is strictly connected with the nature of viewing 3D images. In the accommodation convergence breakdown, the eyes converge at the point in space where the virtual object appears while still focused to the screen. This effect troubles the learned coordination between the muscles moving the eyes and the ciliar muscles focusing the lenses. The result of this discrepancy is inconvenience of the viewer when looking at stereo pairs with big vertical parallaxes. Therefore stereo visualizations should inhabit only a limited volume in front of and behind the screen. For instance, when we have big positive parallax in small screen, it could produce discomfort for observer.

The crosstalk is another problem that occurs on the stereo images. This problem depends on the 3D display technology. The crosstalk happens, when the image from one eye appears by chance to the other eye. This could cause unwanted flickering and ghosting. Those problems have negative influence on the user viewing; for instance they might cause eye strain, double images perception and depth distortion.

2.6.5 Approaches to Stereo Visualization

In 1838 Charles Wheatstone builds the first stereoscope to study human binocular vision. Two pictures, taken from two slightly different viewpoints are used to "fool" human brain, because when observing through the stereoscope the two pictures merge into a 3D environment in our brain. We can consider it as the first VR (Virtual Reality) instrument for stereo viewing.

Since this first temptative, stereoscopy's instruments evolved but they are based upon the same principle of the stereoscope.

The 3d stereo visualization can be classified as: *Passive*, *Active*, or *Autostereoscopic*.

Passive stereo visualization is based on multiplex images in space. There are three different kinds of space multiplexing:

- *Anaglyph Stereo* (Figure 2.23). This technique produces a depth effect by applying two colour filters to the images typically red and green. This two filtered images are superimposed with a small offset. The anaglyph glasses, containing filters corresponding to the colors of the two images, direct the appropriate image to each eye. When this image is viewed through the anaglyph glasses, it visualizes a stereoscopic image because the visual cortex of the brain fuses this into the perception of a three dimensional scene.

This approach is probably familiar to most of us, having been used many times in the cinema, TV, and in print.

A major disadvantage of the technique is that the use of differently colored filters causes retinal rivalry. Furthermore, it is not possible to display color images, because there are the "false colour" problems.

The main advantages of this approach are that its relative simplicity makes it economical and portable.

Figure 2.23: Anaglyph glasses and a filtered coloured image

- *Polarized method* uses polarized filters. The users have to wear special polarized glasses (Figure 2.24), which create the illusion of three-dimensional images by restricting the light that reaches each eye.
- Two images are projected through orthogonal polarized filters and superimposed in a silver screen. Each filter, on the glasses, passes light, which is polarized in the same way and blocks the orthogonally polarized light. Each eye can see one of the images and the stereo effect is performed. This kind of stereo technique must be viewed on a projected screen and there is no way to use it with common computer monitors.

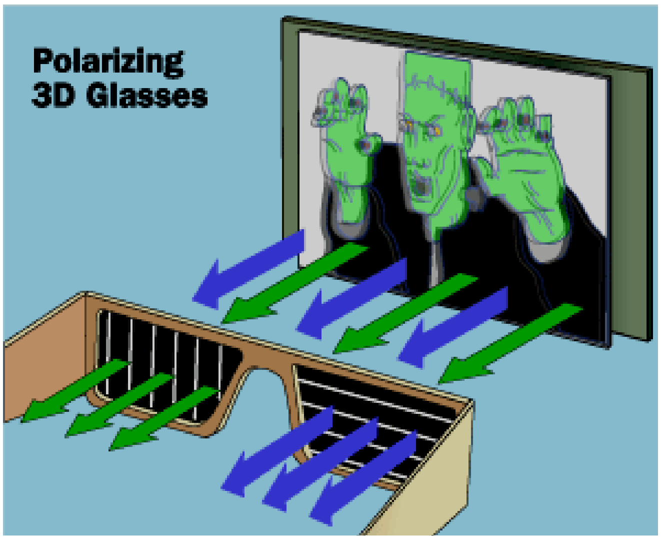


Figure 2.24: Polarized System

Also this technique has some issues: it is expensive to implement; crosstalk or channel interference because the not ideality of the two filters; the final image is shown in a subdued way due to the presence of two filters.

Figure 2.25: Polarized glasses

- *Separated Displays* is based on different displays very close to the user eyes. This is used in HMDs (Head Mounted Displays)

The main advantage of this system is the lack of crosstalk, it is easy to implementhead-tracking capabilities, but only one user at time can use it and it is often really expensive.

The **Active Stereo** technique is based on multiplex images in time: the left and right images are displayed in a screen, in alternative sequence.
A sync device separates the video flows for each eye, a special glasses alternately darkens over one eye, and then the other, in synchronization with the refresh rate of the monitor, while the monitor alternately displays different perspectives for each eye (Figure 2.26)

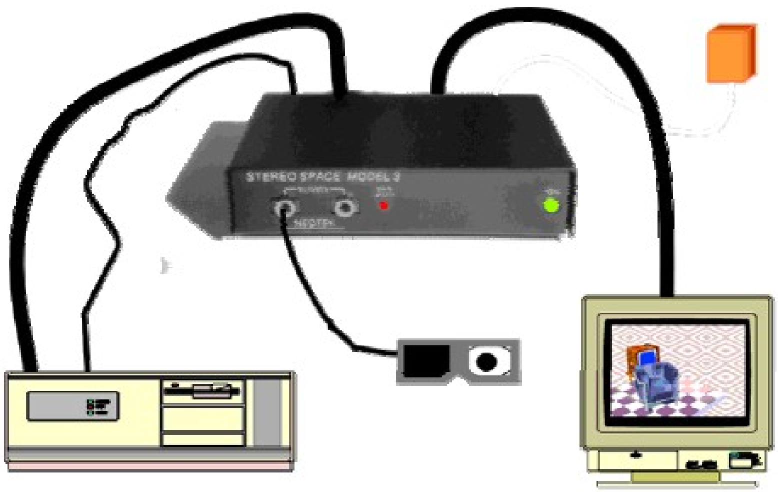


Figure 2.26: Active Stereo

This method uses LCD shutter glasses in conjunction with the desktop to create the illusion of a three dimensional image. The device consists of liquid crystal glasses. The liquid crystal has the property that it becomes dark when a voltage is applied.
The main problem of this technique is the image flickering, this disturb can be decreased by using projectors or CRT with a minimum refresh rate of 80 Hz.

The **Autostereoscopic Stereo** method takes the name by the main characteristic to make possible to view stereo images without using glasses. Separates images based on special reflecting layers laying on visualization display, typically sub-divided in: Parallax Barrier and Lenticular Sheet, [20], (but more approaches are available, [18]).
This approach is one-user audience because the user has to stay into a limited area
of use. This kind of technology has not been lucky until now, few implementation and advantages have been done.

2.6.6 VR Display Technologies

Virtual Reality (VR) is a three-dimensional, computer generated, simulated environment that is rendered in realtime according to the behaviors of the user. An artificial world is created by computers and designers, using special software and hardware.
The VR has three main features; the primary feature of VR is immersion in the environment provided by a computer, the feeling of being inside that space. The second main feature is interactivity with objects in the space; you can move things, open doors, etc. The third main feature is the ability to navigate through that space, to go in any direction you want. A major immersion and presence in the virtual environment often helps to improve a user skills in performing various 3D tasks and in our case improve the immersion means to have a better drive of the robot. 3D vision can guarantee a major precision in the teleguide and good performances on the obstacles avoidance.
Different stereoscopic approaches can be used coupled to different display systems among them we describe, which are listed below:

- 3D Laptop Small Powerwall
- Head-mounted display
- 3D Desktop with shutter glasses
- 160-degree Panorama
- 6-sided Cave
- 1-sided Cave

According to [54] the main characteristics, which are important to characterize different 3D Display Technologies, are:

Display Size: describes the geometric dimension of the screen (From tiny HMD monitors to large 360deg.).

Display Structure: describes the shape of a screen (E.g. flat, curved, table-like, cubic shaped, head mounted).

Projection Modality: refers to type of projection (E.g. monitors type: LCD/CRT, front/back projected screens).

Image Quality: characterised by several parameters such as: the resolution, the brightness, the contrast, the colour range and refresh rate.

Observation Condition: Observer field of view, isolation from surrounding, stereo technology, etc.

Now we will show each device and a comparison between them.

3D Laptop

Figure 2.27: 3D Laptop

The 3D laptop (Figure 2.27) uses an ordinary laptop with a 15 inch flat LCD (liquid crystal display) for displaying passive stereo. Anaglyph (stereoscopic) images are viewed, using contrasting color filters in simple glasses (anaglyph glasses). These glasses combine images from two slightly different viewpoints into a single image. This 3D display technology cannot use active stereo because of low refresh rate (minimum refresh rate to use active stereo is 80 Hz). Image quality depends on the laptop screen, but usually they have a high-resolution and a good image quality. The 3D Laptop is the low-cost version of a very portable virtual reality device.

The main advantages of 3D Laptop are:

- High portability.
- Low cost of the device.

No need to use special devices.

Main disadvantages of 3D Laptop are:

- Small display
- Low refresh rate.

Flat Wall

The Flat Wall (Figure 2.28) is a front projected 1.5 m × 1.5 m silver screen with two high resolution projectors and a computer with two video output.

To achieve optimal results, modern graphics hardware is needed. The system uses passive stereo with polarized filters. The resulting image quality is very high, especially since a high frequency and true color are used. Altogether the system is not portable and expensive.

Main advantages of the Flat Wall are:

- Large screen to increase the immersion
- Low cost of the polarized glasses
- Large audience.

Main disadvantages are:

- High cost of the devices (two projectors and a silver screen)
- Low image brightness.

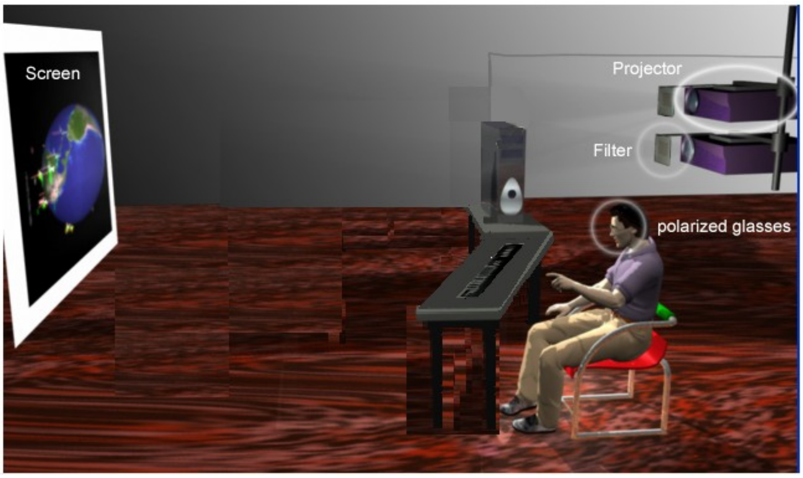


Figure 2.28: Flat wall

HMD

The Head-mounted display (HMD) (Figure 2.29) is a graphical display device, such as a pair of tiny LCD screens worn like glasses. Often they are combined in a single helmet and used with position tracking sensors and earphones for 3D sound. The displays are very small and according to the size of the displays, the field of view is also very small (60 degree on diagonal).

This 3D Display Technology cannot use active stereo, because of very low LCD refresh rate (50-60 Hz; minimum refresh rate to use active stereo is 80 Hz).

Figure 2.29: Head-mounted display and HMD in use.

Since the image is displayed directly to the eyes of the user, only passive stereo can be used. The maximum resolution is 1024 × 768 × 3 pixels which results in very high image quality, high contrast and full brightness. The main advantages of HMD are:

- Portability
- Image brightness
- High contrast
- Perfect stereo channel separation (no crosstalk)
- Special display hardware is not required
- Head tracking.

Main disadvantages are:

- High cost
- Limited field of view (less than 60 degree)
- Cumbersome cables
- Weighty
- The user can't see his hands.

3D Desktop with shutter glasses

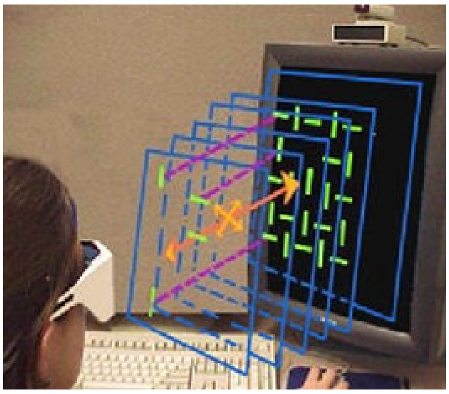


Figure 2.30: 3D Desktop

The 3D desktop (Figure 2.30) consists of a common desktop PC with a flat CRT (cathode ray tube) monitor (e.g. 21 inches), a computer with two video output and shutter glasses.
The 3D desktop uses the active shutter glasses technique for the stereo visualization, because of very high CRT refresh rate. To achieve a correct 3D impression the shutter glasses have to be synchronized with the monitor refresh rate. The glasses employed contain liquid crystals and a polarizing filter. The spectacles become dark when voltage is applied and translucent, when not. In accordance to the refresh-rate of the monitor, the glasses darken over one eye at the time. Therefore the images get rendered differently (from another perspective) for the left and the right eye. This fact allows the user to see stereo.
Main advantages of 3D Desktop are:

- High resolution
- High image quality
- Low cost.

Main disadvantages are:

- Flickering when refresh rate is too low (less than 80 Hz)
- Low portability.

Panorama

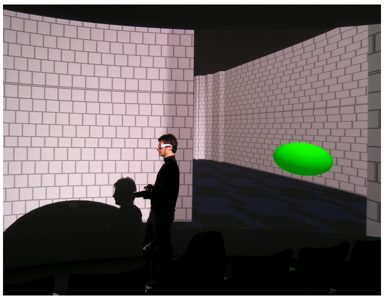


Figure 2.31: 160-degree Panorama

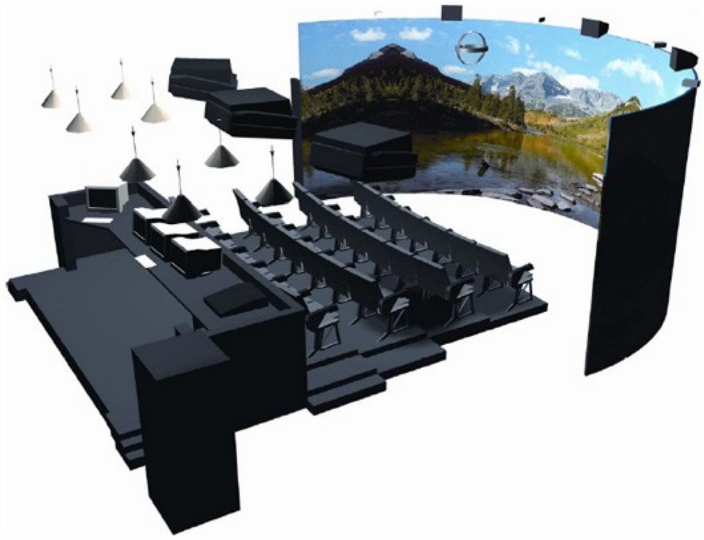


Figure 2.32: The setup of the panorama at Aalborg University

The Panorama (Figure 2.31, Figure 2.32) Panorama is a large front-projected 8 meters curved screen with three, high resolution projectors. For the projection onto this fixed installation 3 high-resolution projectors are used. The main advantages of Panorama are:

- High quality of the images.
- Crispy colours.
- High resolution.
- The shape and size of the screen enables the immersion because the use of the retina peripheral areas.

The main disadvantages of Panorama are:

- High cost of the equipment.
- No portability.

It is for this reason that this kind of device is not suitable in case of robot teleoperation.

1-sided CAVE

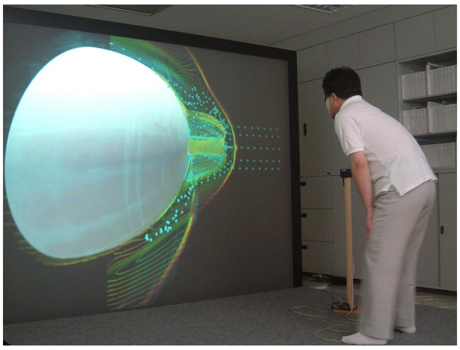


Figure 2.33: 1-sided CAVE

1sided Cave is a large (2.5 m x 2.5 m) back projected screen (Figure 2.33). Images are projected with low resolution and high frequency.

Two different stereo technologies can be applied: passive anaglyph and active shutters.

The main advantages of 1-sided CAVE are:

- Large display
- Low cost
- High frequency
- Large field of view
- More suitable for gestural expression and natural interaction than other technologies and possibility to walk around.

Main disadvantages are:

- No portability
- Low resolution
- Only one person can be tracked.

6-sided CAVE

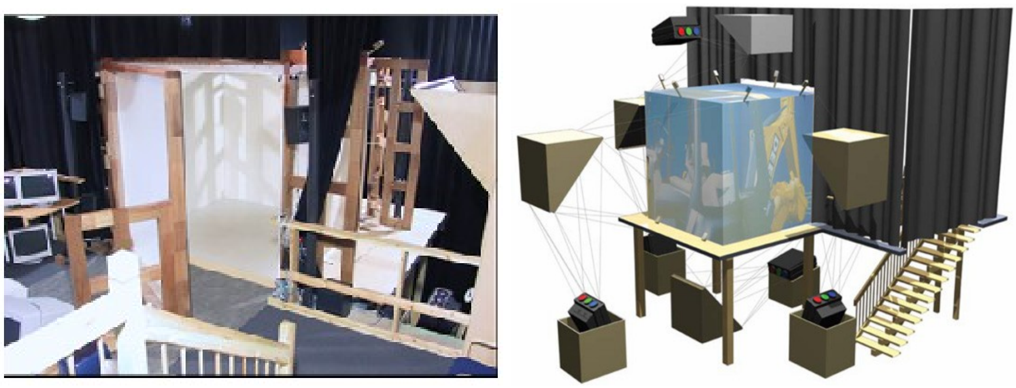


Figure 2.34: The setup of the 6-sided CAVE environment at Aalborg University

The 6-sided CAVE (Figure 2.34) is a cube with display-screen faces surrounding a viewer. When the viewer moves within the bounds of the CAVE, the correct perspective and stereo projections of the environment appears on the display screens. The 6-sided CAVE is composed by 2.5 m x 2.5 m rear-projected screens with 6 high resolution and high frequency projectors and a PC clusters that manages the projectors. These devices need a fixed installation in a large location. It is allowed the Stereo visualization by using active shutter glasses. The main advantages of 6-sided CAVE are:

- Full 360 view (projection on all 6 sides).
- Large multi-display
- High immersion
- Good colour

Main disadvantages of 6-sided cave are:

- High cost
- No portability
- Only one person is allowed (tracking is needed)
- Cumbersome structure.

2.7Usability evaluations

In the [50] was created a guideline for evaluations of virtual reality devices. This guideline is not supposed to help experts in evaluations, but it is meant to give an overview of evaluation of virtual reality devices in general and to help at the first approach of conducting a user study. Furthermore the guideline bases upon a precise analysis on the current state of the art of evaluations in the field of virtual reality.

This guideline was used by Students at Aalborg University. They developed several semester projects dealing with telerobotics. Projects about telepresence and teleoperation, were implemented and tested, using VR facilities to examine the advantages of stereo vision.

Particularly this guideline was used in:

- “3D Stereo Visualization advantages for the mobile robot teleguide” ([45] and [46]), where the focus was to evaluate the difference between mono and stereo robot guide using a Static Simulator.
- “Stereoscopic enhanced robot teledrive based on laser and video sensors” where the aim of this work is to investigate the advantages of stereoscopic vision in mobile robot teleoperation, using two different kinds of robot workspace reconstruction modalities: Synthetic Telepresence (ST) and Video Telepresence (VT).

2.7.1 General Guidelines

A guideline give general indication on how to conduct evaluations on virtual reality devices and combines traditional usability approaches(as presented in [55], [56] or [57]) with the results of the paper research and the authors’ personal experience with conducting usability studies.

The guideline is targeting students and researchers working in the field of virtual reality. During their projects it is often required to evaluate virtual reality facilities and since mostly they are no experts in the field of evaluation, this guideline should help at the first approach on this area.

The following sections include the most important information and facts when conducting usability studies.

Research Question

Before even starting to build a setup for an evaluation one should formulate the research question for the usability study. The research question defines the main subject of the study (for some example research-goals). Therefore it is very important to create a strong and valid research question.

Once the research question is formulated it should be tested of its applicability and practicability. The best research question does not help if the project can not be realized, if the topic does not interest the researcher or if the expected results do not express and benefit anything. Furthermore it is very important that the research question is not formulated too widely so that the focus is on the specific part of the project that is to be tested and that it is possible to solve the question in the given time.

Participants

Target Population

First of all it is necessary to get to know the target population for the usability study. Therefore all necessary skills, demographic facts and other important attributes should be inquired before asking volunteers to come. The following list shows a short overview of the most important facts, when acquiring participants:

- Age.
- Gender.
- Education.
- Experience in virtual reality.
- Computer experience.
- Gaming experience.
- Vision.

Number of Participants

The number of participants depends on the type of usability study which is conducted. Basically there are two main forms:

- Between-subject evaluations.
- Within-subject evaluations.

Between-subject designs or independent group designs, arrange participants to user groups. Each user group is doing only one specific task or a series of tasks on only one virtual environment. The user groups have to consist of users with exactly the same preconditions —for example the experience with virtual reality devices or the age. Between-subject evaluations require more participants (to have an equal number of users in each group) and more work in advance, concerning the background of the volunteers. The advantage of between-subjects is the minimization of possible learning effects and long experiments are easier to conduct, because one user has a limited task. Using within-subject designs, each participant gets to do each task on each virtual reality device. This setup allows to get significant results by employing less participants. In order to not bias the results, "counterbalancing" has to be applied. Counterbalancing mostly randomizes the sequence of users doing tasks to minimize the learning effect. In [57] the employment of 4 to 12 participants is suggested. Furthermore it is stated that 10 to 12 participants cover about 80 percent of all possible error cases. Taking into account that virtual reality devices are very different from commonly used computer interfaces, especially treating the possible errors, these numbers should be reconsidered.

Thus, it is recommended to test between 16 and 46 participants in order to receive significant and valid results. Everything above 33 participants is considered to be meaningful and the more participants, the more accurate the result. Furthermore the between-subject designs need to employ about 44 percent more participants than within-subject studies.

Forms

Concerning the forms handed out to the participants; this guideline conforms to the traditional approaches introduced in the state of art of evaluations in the field of virtual reality. The following section provides a short introduction into the most common utilized forms.

Information Sheet

The information sheet or also called test script provides an overview of the entire testing process. This form should be handed to the participants at the very beginning—before testing. The information sheet should include the following points:

- Title of the project.

- Names and contact information of the researchers.
- Name of the supervisor(s).
- Introduction to the project.
- Purpose of the evaluation.
- Duration of the user study.
- Tasks to be completed.
- Possibility to withdraw for the study at any time (voluntary participation).
- No effects on the participants' courses or grades.

Together with the information sheet the participants should be introduced to the project. This should be done by the test monitor, who also explains the most important tasks and shows, if required, some examples.

Consent Form

The consent form states that the researchers are allowed to use the data collected during the user study. This may also include eventually taken pictures or videos. It is a reassurance for the participant that his/her data will not be used for any other purpose than the one explained in the consent form and/or in the information sheet. For the researcher this form is a legal reassurance that he/she is allowed to use and publish the obtained data.

Background Questionnaire, Device Questionnaires and Post-test Questionnaire

Background Questionnaire The background questionnaire provides, as the name states, background information on the participant. This might be necessary to check, if the participant fits into the target group. Therefore the background questionnaire should answer the items listed in section relative to "Target Population".

Furthermore the background questionnaire could answer some specific and relevant research questions, like the number of usability studies participated so far or the current employment.

Device Questionnaire Device questionnaires are typically used when comparing different devices or applications to each other or if some information has to be obtained during test sessions. Usually the questionnaires are handed to the participant's right after finishing a task session on a specific device/application.

The questions usually contain the participants' impressions and feeling regarding the facility just tested. It is important to hand the user the device questionnaire right after conducting the study on the device, since the impressions are quite fresh and there is no overlay from other experiences.

Post-test Questionnaire Post-test questionnaires collect data about the users' feelings and preferences during the evaluation. Typical content of post-test questionnaires could be:

- Ranking of the devices/applications tested.
- Preferences and specific feelings.
- Physical conditions before and after the user study.
- Personal opinions.
- Suggestions for improvement.

It is also possible to combine the different kinds of questionnaires.

Questionnaire Design

It is very important to design the questions clearly so that they can not be misunderstood or misinterpreted. Generally it is easier to tick check-boxes than to write the information required. There are different ways on how to create answering possibilities:

- "Binary" check boxes that are either yes or no.

  Likert scales that allow to express the participants level of agreement (usually 5 scale, from disagree to agree).
- Semantic differentials are usually 7-scale answer possibilities reaching from 0 to 3 on both sides, helping the participant to express his/her preferences.
- Fill-in questions where the user can write statements with his/her own words.
- Branching questions that allow adding a second question to an already answered question (typical if yes—question).
- Check boxes where the participant is able to tick either one ore more list items.

Schedule

To avoid chaos in the evaluation a schedule is highly recommended. This schedule should include the timing of the single tasks, the completion time for one task, the overall completion time, the sequence of the tasks per participants, eventual breaks, time needed for introduction and debriefing and availability of the rooms.

Test Plan

The test plan includes every necessary knowledge for the user study. The test plan describes the main content of the usability study. It serves as the basic document for communication to other people that might be involved in the user study. Furthermore the test plan describes the resources needed (rooms, virtual reality facilities, ...) and gives an overview of the milestones already accomplished.

Formal Study

The following list shows the most important facts that have to be considered before conducting the formal study:

- Technical facilities should be working
- Rooms should be booked.
- Test plan should be designed.
- Schedule should be made.
- Forms should be designed and ready.
- Roles of present persons should be defined.
- Participants should be acquired and informed.

Tasks

The number of possible tasks which users are asked to complete during an evaluation is high.

Moreover the tasks can be further distinguished into between-subject and within-subject tasks.

In order to avoid negative side effects (such as motion sickness) and fatigue long enough breaks between should be held between the single task sessions.

Results and Presentation

Another very important part of conducting usability studies is the evaluation of the collected data. The processing of the results can be very complex and time consuming since most of the time there is a lot of data collected.

Statistical Evaluation

The following list includes the currently most frequently employed statistical methods for evaluations:

- ANOVA;

- t-test;
- Mean;
- Median;
- Standard deviation.

Usually these methods are employed to show the error rates and significant differences of the data collected.

In figure 2.35 the frequency of the used statistical tools is shown. ANOVA (analysis of variance) in its various forms (one-way, two-way, three-way and multifactorial) was used most in the researched papers. Furthermore also the mean was calculated very often.

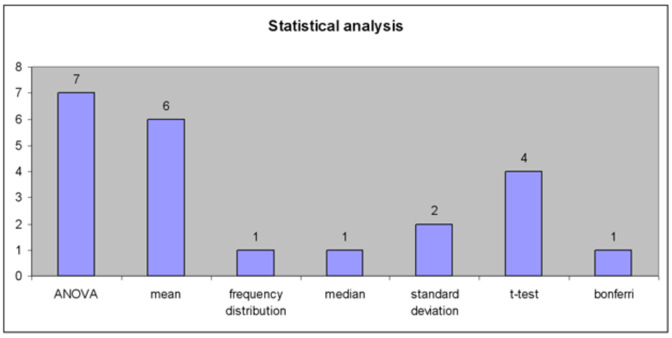


Figure 2.35: The frequency of the statistical methods employed in the papers

Graphical Evaluation

There are several ways on how to display the results of an evaluation. The graphical displays were most frequently used in the researched papers.

For the graphical display of the gained data, frequency distributions (in form of histograms) are mostly employed. Their main purpose is to display error rates and time. The results of ANOVA’s are frequently displayed in tables.

Chapter 3. The proposed approach

3.1 Core idea and argumantation

The aim of this work is to investigate the advantages of stereoscopic visualization in mobile robot teleguide. The proposed work focuses on the use of the laser sensor and on a comparison with the use of the video sensor. The performed experiments ran on different VR systems and stereo visualization approaches.

In both cases, Video and Laser based, the user can remotely drives the robot relying on visual feedback. In Laser based teleguide, the visual feedback is computer generated, based on 2D maps constructed by the on-board laser sensor. In the Video based Teleguide the visual feedback is provided by the on-board camera images sent through the network link.

The VR technologies give to the user the sensation of being present in the remote environment. The sense of presence improves the user's skills in performing different 3D tasks. One aim of the project is to evaluate the system performance with different stereo viewing techniques. In particular, we will take into account the following approaches to stereo viewing:

- Anaglyph
- Polarized

In the previous work, tests have been made with Video based teleguide and Laser Based teleguide. In case of Laser based teleguide tests were performed on a robot simulator. The robot simulator was only using on estimate friction parameters (e.g. ground-wheel contact coefficient).

Therefore we unknown the real friction parameters and the real efficiency of the Laser based teleguide in the unknown environment. In the proposed studies we run an actual experimental session we make the systematic testing of robot teleguide with laser sensor using a real robot. We experiment robot teleguide on two different VR facilities: Laptop and FlatWall.

Furthermore compare the laser based teleoperation with the previous results:

- compare video based and laser based teleoperation using different VR facilities.

  In the Laser baser teleguide, the image size, sent through the network link, is small. The network can transfer these data fast enough for real time performance. While in the Video based teleguide there is network delay because the images provided by the on-board camera are big. Delay means slow operation and interaction.

Therefore we compare image quality versus delay:

- compare laser based teleguide using a real robot and laser based teleguide using a robot simulator, using different VR facilities .

  It's important to compare the dates of the real laser with the dates of laser simulated so that we can know if the results of the laser simulator based teleguide are truthful and we can choose to use the robot simulator to reproduce situations that cannot be created in the real world because of cost, time and the single resource.

3.2 Strategy

3.2.1 Develop from previous work

As we mentioned, this project is a continuation of previous works done by Students at Aalborg University.

In , the authors realized a network connection between Aalborg University in Denmark and the 3 MO.R.D.U.C. robot at University of Catania, Italy. The connection allows to guide a remote robot (teleguide) in real time using virtual reality instruments. The authors of the last project to take advantage of the network connection, and they developed a new client for robot teleoperation.

This network connection allows sending the images or sensor data coming from the robot and the movement commands. This data exchange was necessary to develop the Video based teleguide. The date sent in the video based teleguide are jpeg images of 1280x480 pixels that are two images of 640x480 provided by the left and right on-board camera.

In this project we used this network connection to exchange sensor data for the Laser based teleguide. The data sent in the laser based teleguide are jpeg images of 200x200 pixels that represent the 2D map of the environment. In order to obtain this map, the server uses a map-building algorithm and it produces the floor-map image elaborating data coming from laser scanner and the odometric model of the robot.

Since the image size sent from the server to the client in the laser based teleguide is small, the network can transfer these data fast enough for real time performance. Therefore the laser modality reduces the delay.

In the previous work the authors developed a "3D Mobile Robot Simulator" that builds a 3D environment with a static map and it allows the navigation in this environment with the robot. In this project we reuse the reconstruction techniques used in the 3D Mobile Robot Simulator to build a virtual environment in order to build the synthetic environment in the laser based teleguide.

Some improvements and corrections were necessary to project. The main problems were:

- Errors in the floor-map. The odometric model of the robot wasn't exact, as a result, the server rebuilt a wrong floor-map. Then we have corrected the odometric model so we have the exact ambient where a robot navigates.
- Flicker in laser based visualization. The previous application cleared every time the buffer for the synthetic environment; as a result, there was a flicker effect on the screen. We solved this problem deleted only the more old walls those aren't necessary for the navigation and overwriting the previous data on the synthetic environment buffer.

In order to test the client in a simple way, in the last project the students developed a Robot Server Simulator (RSS). A robotics simulator is used to create applications for a specific robot without be dependant of the 'real' robot. The RSS allows to reproduce situations that cannot be created in the real world because of cost, time and the single resource. In addition, the simulator can be used to create fast robot prototyping. Many robot simulators feature physics engines to simulate the robots dynamics.

This RSS includes the following features:

A physics engine simulating the robot's dynamic.

A sensor model engine simulating the behaviour and the noise of the sensors.

3.2.2 Approach to robot teleguide

When considering the main aspects of the system is possible identify three main actors which need to interact and to exchange feedback from and to every end point:

- a robot, operating in a remote place;

- a driver, using VR facilities;
- an internet connection.

The robot is a mobile platform equipped with two CCD cameras of 320 _ 240 pixel, a laser scanner, bumpers on the sides to detect collisions and so stop the engine, sonars and odometric sensor on the directional wheel.

The robot goes in all the directions and one can (locally) set the linear velocity (to go forward/backward) and the angular velocity (to turn left/right). The robot is not autonomous, in fact it is incapable of self-motion and it has not artificial intelligence features.

The robot driver is a human, sitting at a remote location from the robot, that interacts with visual software. This software will be capable of rendering 3D scenes and to send commands over internet to the robot. Every command consists of sequence of messages and it uses the internet connection as a means of transportation.

The robot receives a command, execute it, and send feedback to the driver. The driver through feedbacks can "understand" how the surrounding environment looks like and so that is able to perform tasks by sending commands to the robot. Robot and driver are in different locations so commands have to pass through the network, this implies a time delay in the communication for delay in signals propagation.

The proposed system has classical client-server architecture (). The two modules are usually located on different computers, linked together by an Ethernet link. The main advantages of this architecture are the cheap and accessible resources. In fact, this model is based on a Network Protocol (3rd ISO/OSI Level).

Figure 3.14: Client-Server system

The server processes a lot of data and it offers services to client. The client executes simple operations such as managing the human interface and sending the requests to the server (Figure 3.15).

Moreover, it manages the local resource as keyboard, monitor, CPU, and others devices.

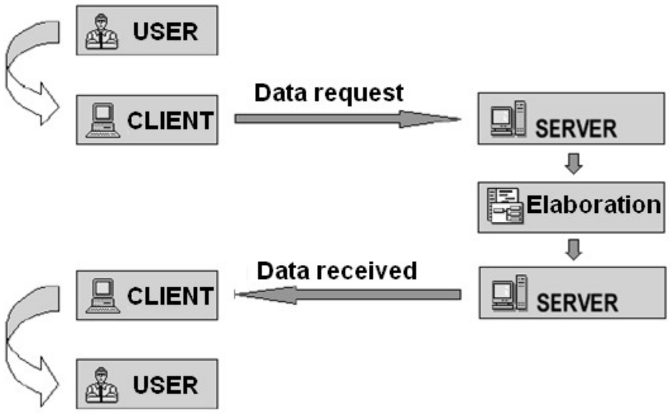


Figure 3.15: Data Exchange between Client and Server

The Robot Server Application (RSA) manages the robot motion and processes the data sensors.

The main tasks accomplished are:

- Receiving the requests from client.
- Processing the requests.
- Sending answer to client (sensor data).
- Managing the robot sensors.
- Control the robot movements.
- Implement the map building algorithm.

A simple program runs on the client and it executes three main tasks:

- It enables the user to send request to server. These requests specify the motion command for the robot.
- It shows in a proper way the data sensor coming from the server.

In order to allow the interaction between client and server, it is necessary to use the same protocol. Internet uses different Application Protocols (7^{th} ISO/OSI level), in relation to the specific network services (SMPT, FTP, HTTP, etc.). Each Application Protocol is based on the TCP/IP and/or UDP Network Protocol and it manages the data exchange.

The UDP Network Protocol is not recommended in case of large network environments because no error detection strategy is implemented. Moreover, in the Aalborg University network, there is a problem with UDP because of the firewalls and proxy systems. In particular, no communications through logic ports, different from standard ones, are allowed to take place. This politics is actuated to increase security control and to prevent the use of dangerous or illegal software.

For this reason, our Client application uses a socket TCP/IP on the standard port 80 to communicate with the Server.

In order to test the client in the previous work the students developed a Robot Server Simulator (RSS).

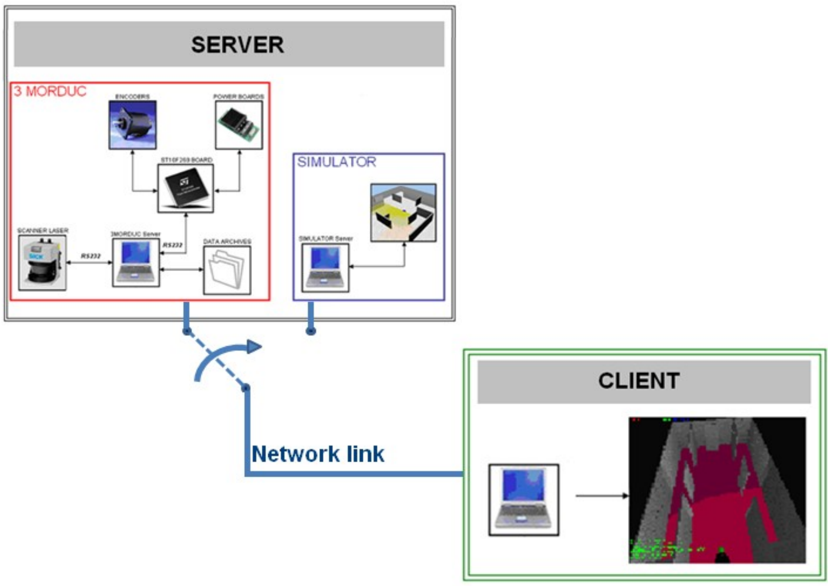


Figure 3.3: Client-Server architecture

3.2.2.1 Laser based teleguide

The synthetic teleguide is an application based on client-server architecture that works on-line. Among the others, the aim of the client side is the reconstruction of 3D remote environment (Figure 3.4). The virtual workspace showed on client should be close to real world.

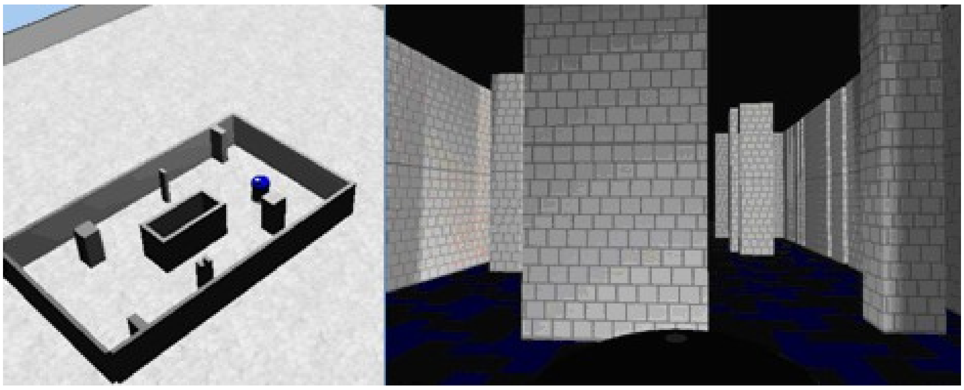


Figure 3.4: Server workspace and Client scene

The server uses a map-building algorithm and it produces the floor-map image elaborating data coming from laser scanner and the odometric model of the robot (Figure 3.5). The client side application implements a technique that renders the virtual scene based on the map coming from robot server. The map represents a 20m x 20m environment and its resolution is 100 cm^2/px.

Using this map the application can cover an area of 400 m^2, which is the size of a typical industrial environment. Every black pixel on the map represents an obstacle in real environment (Figure 3.5)

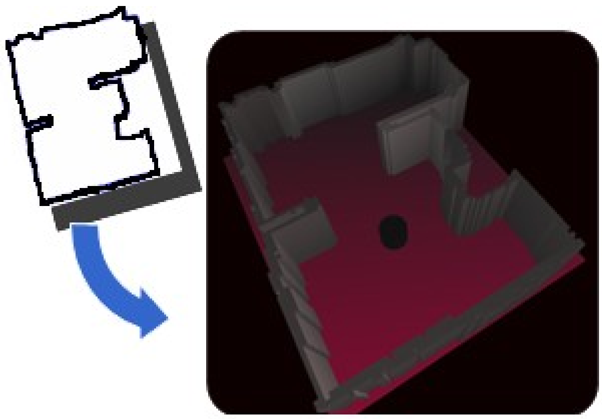


Figure 3.5: Laser map and environment recostruction

The typical indoor environment is composed by straight walls and plane floor. The application applies texture map to the object surface (Figure 3.6). User drives the robot within the boundaries of the virtual scene.

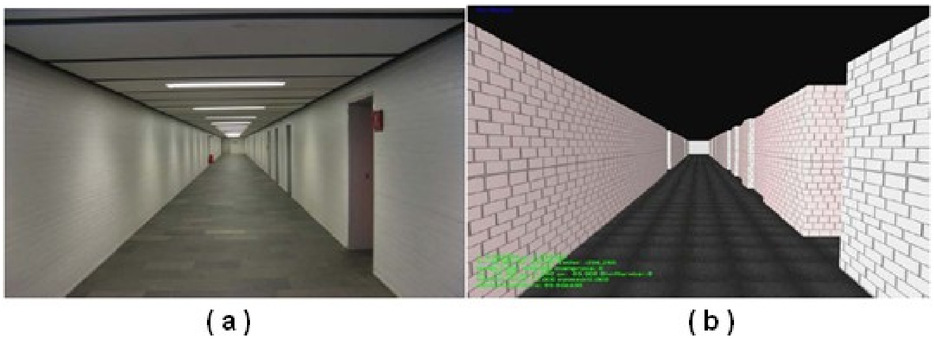


Figure 3.6: (a) indoor environment (b) textures

The scene illumination can be changed using different kind of light model. Also the texture can be modified according to different environment.

The texture can be with bricks or uniform, the light can be diffuse, directional or punctiform (Figure 3.7) and the simulator shows also the object shade.

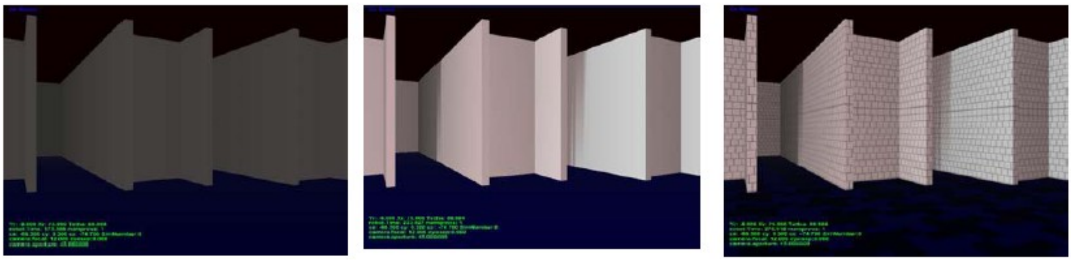


Figure 3.7: Light and texture

The client continuously requests the map data from the server side application. The robot navigates in the real workspace, acquiring new sensor data and elaborating them continuously.

The client renders a robot with the same characteristics of the real robot. Users can drive that robot through the client interface by using keyboard arrow keys (Figure 3.8).

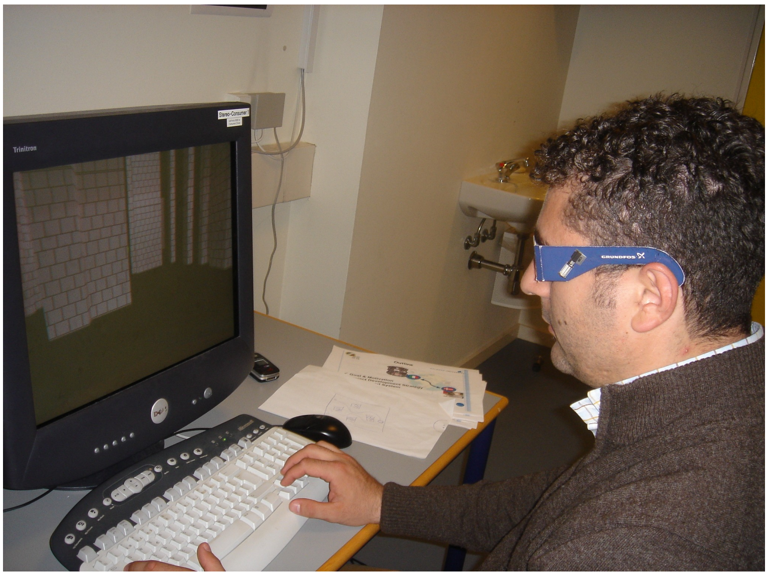


Figure 3.8: Robot navigation

On the client mono and stereo visualization modalities are available and the user can observe the scene using VR facilities. The stereo visualization could improve user's drive performance in term of better evaluating distances between objects and between the robot and the obstacles.

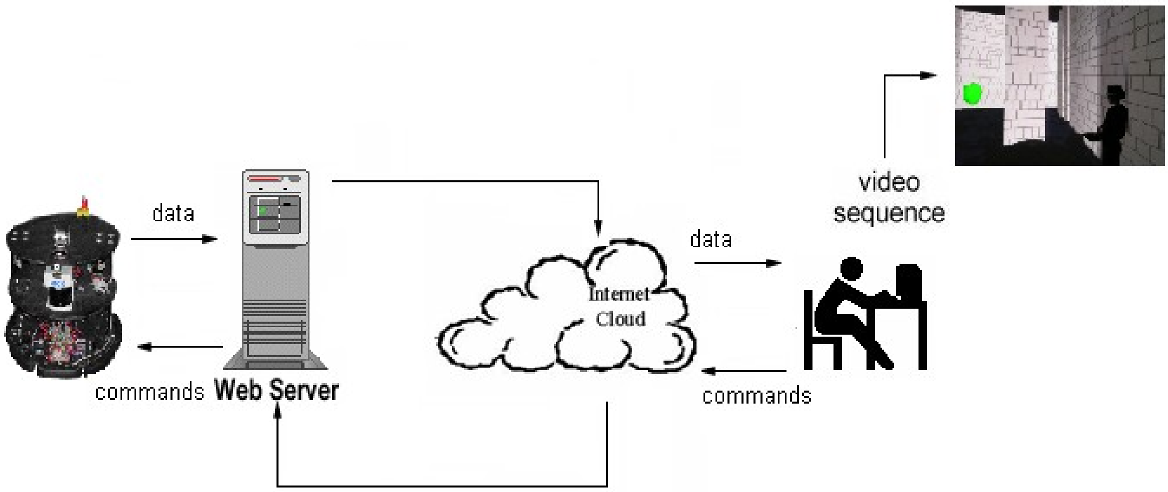


Figure 16.9: Data exchange between client and server

Among the advantages of this kind of teleoperation:

The virtual environment is simpler than the real environment and the client shows all obstacles in the same way. The robot does not recognize small details in the workspace.

The image size, sent from the server to the client, is small. The network can transfer these data fast enough for real time performance.

The illumination related to the visualized environment can be set as one wish.

The client renders a 3D workspace using 2D sensor information.

Disadvantages:

The robot does not detect small obstacles in the workspace. These objects could obstruct robot navigation.

The real workspace and virtual scene could be inconsistent.

The object shape and colours are different from the real ones.

3.2.2.2 Robot Server Application

The *Server* was developed in Borland Delphi 7, an object oriented language derived by Pascal. Several classes are wrapper of the windows A.P.I. making really simple to develop efficient code in fast way.

The choice of this programming language come from the necessity to include it as part of the control system designed in Catania for the 3 MO.R.D.U.C. robot.

- The RSA performs the communication protocol with the ST10F269 motor control board:
  - Tuning the control parameter.
  - Setting the speed of the robot.
  - Getting the encoders measures.
- In this work in the laser based teleguide we use a real robot, there more is important the communication with scanner laser to set its parameters and to obtain the measures, for that purpose inside the RSA we created a module that implements the RS-232 communication protocol with scanner laser.
- Another server module manages the communication with bumpers and sonars by using an I^2C protocol. A stereo camera server module allows changing the cameras settings. There is also a section that shows the images coming from the cameras.
- Furthermore there is a thread to exchange data over internet. The server implements two kind of replies depending from the request received:

Acknowledge to an image and command request or image request;

Acknowledge to command request;

There are two kind of images that we send to the Client: one is a jpeg of 200x200 (map of the environment) for the laser-based, the other is a jpeg 1280x480 pixels(two images of 640x480, left and right) for the video based.

On the RSA a Map-Building algorithm based on the laser scanner sensor, was implemented to create a workspace map.

The Map-Building algorithm produces a black/white image map, where each pixel represents a square area 10cm x 10cm. A black pixel corresponds to an obstacle otherwise the space is free.

The Map-Building algorithm used is a classical Occupancy Grid based on the laser row data and the kinematic model. The algorithm includes the sensor model for the map reconstruction. In this way, it is not possible to create an obstacle between the beam end point and the robot. This algorithm is very simple and permits to avoid inconsistence map problems.

The interface (Figure .10) of the Server application presents four sections dedicate to:

Log communication (1);

Sensors communication (2);

Stereocam (3):

Control movement (4);

In the log section, the communication data with the client are visualized to check if the connection working. The sensors section allows the communication handling with: laser, encoder, sonar and bumpers. The data coming from these sensors are visualized, with a graph of the end beam point, in the case of the laser scanner, using edits on the other cases.

In the Stereo camera section, it is possible to modify the cam setting: brightness, contrast, colours, etc. and it is allowed to display the images captured. At last, there is the control movement section that allows to communicate with the motor drivers and to set the parameters for the axes control.

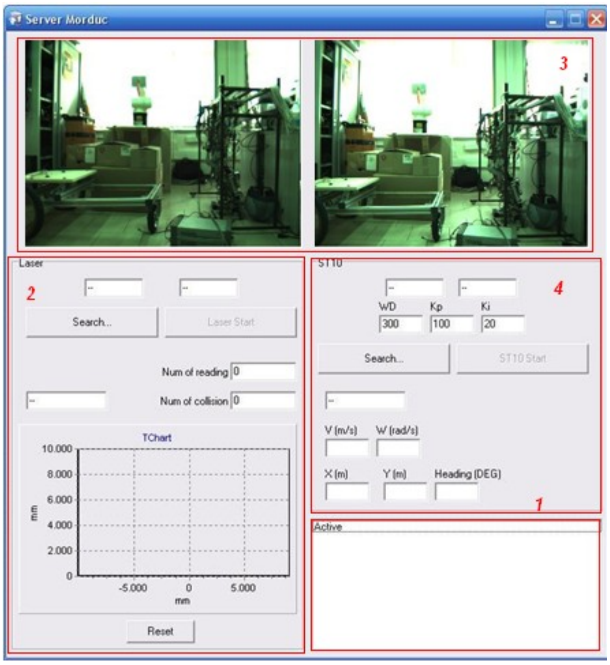


Figure 3.10: Robot Server interface

3.2.2.3 Client

The *Client* was developed using MFC, Microsoft Foundation Classes in Visual C++ (Visual Studio 2005). It is an extension of the robot simulator ; it uses OpenGL libraries to create 3D synthetic images and to handle the different kinds of used VR instruments.
The Client Application allows to user the robot teleoperation from a remote site. The Client's graphic interface represents the robot workspace in different modalities, using a synthetic world or a visual feedback.
The Client also includes the 3D Mobile Robot Simulator developed in ; while the Client operates in this modality the Server is not needed.
The other two modalities need the Server; in particular, in ST mode, the artificial world is built by using the maps coming from the Map-building algorithm. The Client, on VT mode, renders the real images coming from the stereo cameras.
Summarizing, the client is available in three different versions:

- Simulator (stand-alone)

Simulator is a 3D virtual environment generator that works stand–alone without server application running. It loads a static map and renders the environment.
The robot can navigate inside this static workspace.

- Laser based teleguide (with server side)

  Laser based modality uses the "*map-building*" algorithm to render the environment. The client version of the laser based works on-line and it continuously receives the reconstructed maps coming from the 3MO.R.D.U.C. server.

- Video based teleguide (with server side)

  In this modality, the client receives real images sent by 3MO.R.D.U.C. server. Stereo cameras capture the real world images. The client shows the environment through the VR facilities.

Finally, the Client permits to choose between two different devices to show the scene in stereo mode (3D Laptop System and Flat Wall).

Client: Application flow diagram

The Flow diagram shows the sequence of the executed operations and it allows to describe the main functions. A flow diagram is a graphical means of presenting, describing, or analyzing a process. This is done by drawing small boxes, which represent steps or decisions. These boxes are connected together by lines and arrows, which represent sequence and dependency relationships.
The entire application flow diagram is showed in Figure 3.11. In the following sections we will describe its main blocks.

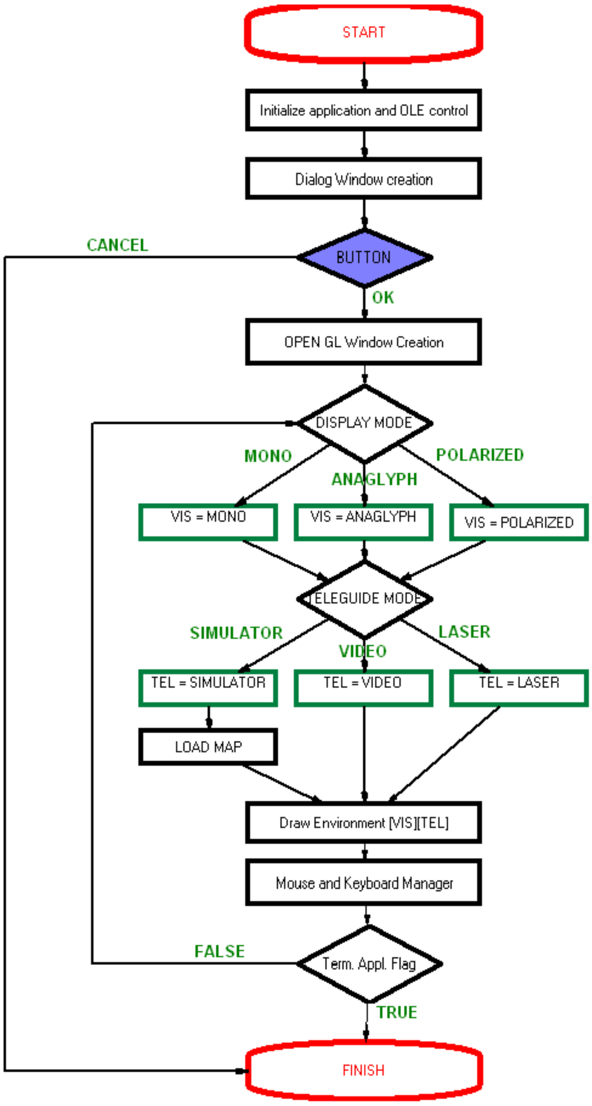


Figure 3.11: Main flow diagram

The first block of the flow diagram is relative to the initialization phase and it could be divided in two steps:

Initialization of the global variables;

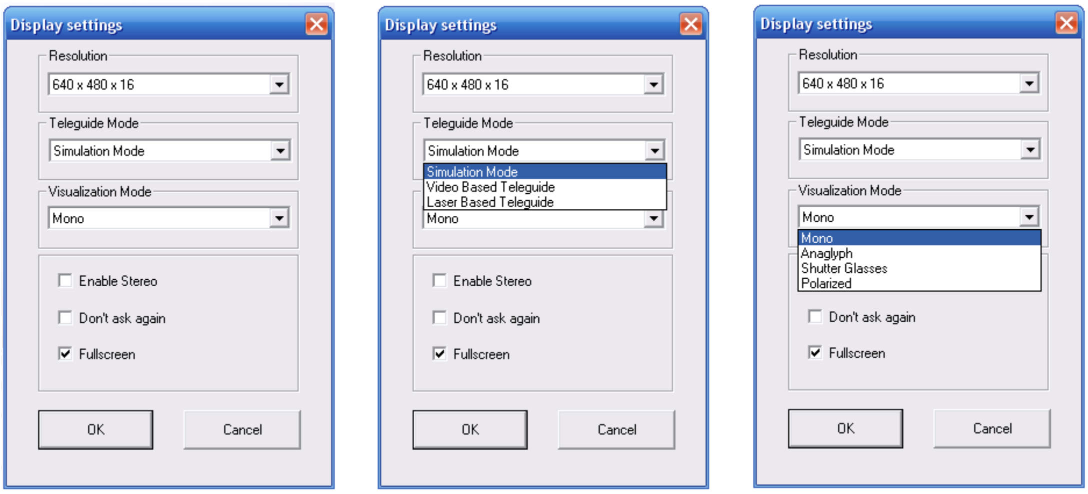
Graphic objects creation;

After this phase, the window dialog is created (Figure 3.12). It allows to the users:

The choice of the right screen resolution;

The choice of the technology used for the teleguide;

The choice of the visualization: mono or stereo;



(a) (b) (c)

Figure 3.12: Window dialog

The check box "Full screen" allows to show the OpenGl window, described below, in full screen mode.

Therefore, the user should choose the right configuration and, after the press of the "OK" button, an OpenGl window will be created. In this window, the image of the environment will be drawn.

The user can choose among three different display teleguide modalities:

- Mono.
- Stereo mode by using Anaglyph glasses.
- Stereo mode by using Flat Wall.

On the OpenGL window, the application will draw, in relation to the teleguide modality:

- The simulated environment, which does not need a server connection and for this reason, it is a stand-alone application. It is based on the Simulator developed by F. Privitera. In this case, we load the environment from a black/white 'jpeg' image, where the black pixels are obstacles.
- The images coming from the stereo cameras mounted on the robot (video-based teleguide).
- The reconstruction of the environment through the images coming from the Server (laser-based teleguide).

In the video-based and laser-based modalities, it is necessary to initialize and to run, respectively, the video and the laser thread. These threads allow the data exchange between the robot and server.

The handling of the events coming from the keyboard and the mouse is given to the following block: Keyboard and Mouse Manager.

Actually, the close event of the Opengl window or the pressure on the 'ESC' key determines the end of the application.

- ***Draw environment***

The Figure 3.13 shows the flow diagram which allows to draw the environment for the different teleguide modalities.

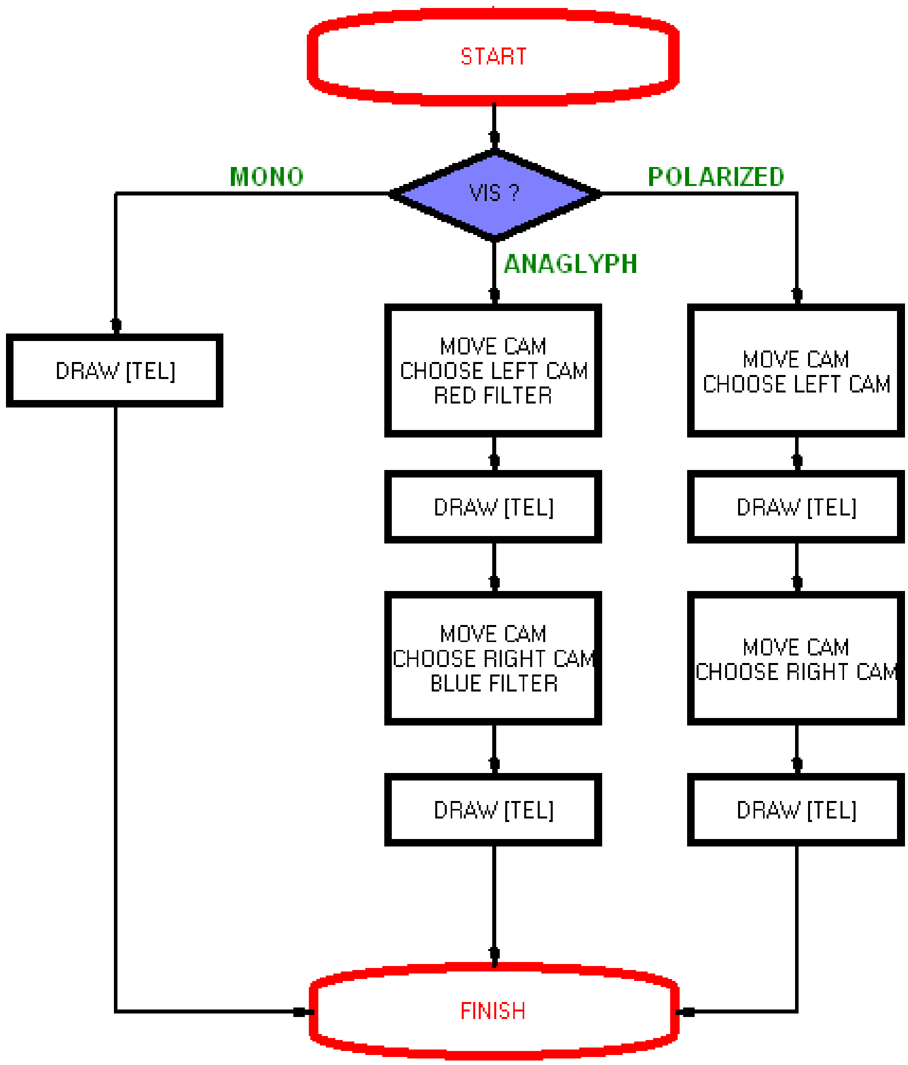


Figure 3.13: Draw environment diagram

The visualization mode is checked and depending on this choice the "Draw" blocks could be interpreted like:

- Draw simulator
- Draw video
- Draw laser

If the visualization mode is "mono", it will be performed just the Draw function. When the visualization mode is on "Anaglyph", it is necessary to move the camera in the virtual environment on the left eye pose, then, load the left image applying on it a red filter and, put it in the buffer visualization. In fact, to achieve a stereo rendering, the left and right images are gathered as one from the robot (Figure 3.14), using some functions they are divided and, then, stored into separate buffers. After, the program will execute the same operations but the selected image will be the right one and the filter will be blue.

Figure 3.14: Images coming from the server (left and right)

In the last case, polarized mode, it will be necessary to move properly the cameras, like in the Anaglyph mode, but it is not necessary applying any filter.

Draw laser

The diagram in Figure 3.15 shows the operations regarding the Draw Laser function:

First, there is the initialization phase for the environment light, background and effects on the scene.

The following step is the HDI creation (Human Display Interface) where the most important teleguide parameters are shown, for example:

- Collisions number
- Execution time
- Robot position
- Robot heading
- Linear and angular speed of the robot

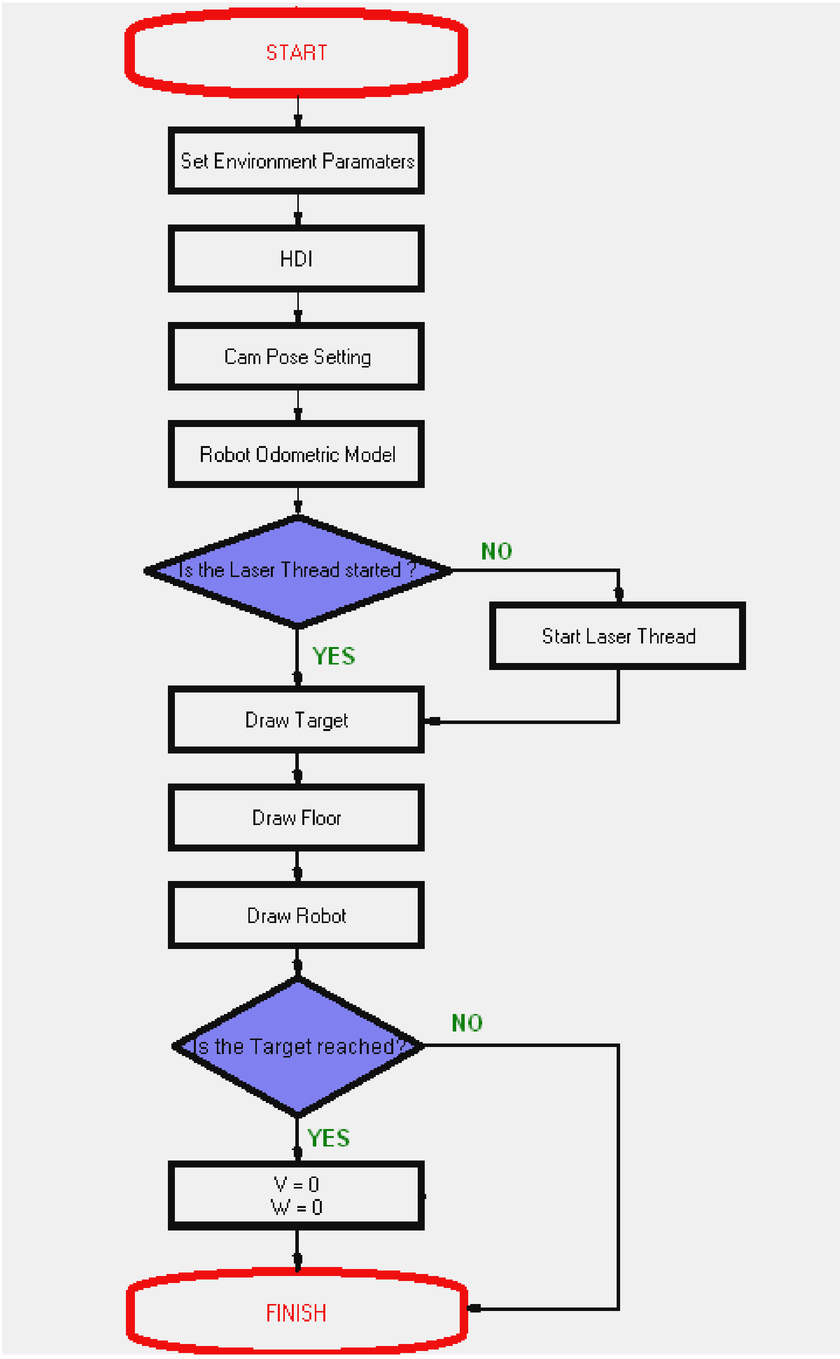


Figure 3.15: Draw laser function

The camera pose is fixed and the robot kinematic model (necessary to the robot movement) is calculated. The next part is relative to the laser thread creation. Then, the target, the robot and the floor are drawn in the scene.

The robot shape is similar to the real one as shown in the Figure 3.16.

Figure 3.16: Robot shape

If the robot reaches the target, the linear and angular speed of the robot will be set to zero and the task is accomplished.

- ***Thread communication in the laser-based***

This thread allows the communication between client and server during the laser-based modality, as showed in Figure 3.17:

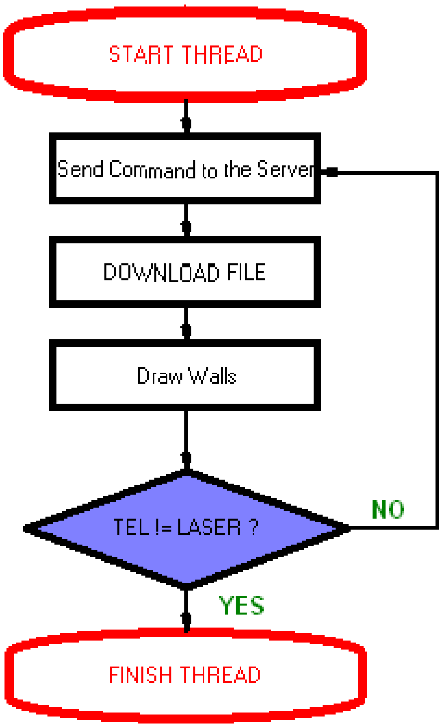


Figure 3.17: Thread laser

The first step concerns the kind of the data sent to the server. These requests are related to the keyboard command. One of the main functions, "Download File" is run, and, as we will see in the next section, it is responsible about the data communication and parsering. When the Client receives the map of the environment from the server, it can create the walls in the scene. The last step is to check if the Teleoperation mode is changed. In the positive case, the thread laser is destroyed, otherwise it is executed as a loop.

- ***Download file***

The main function for the communication with the server is "Download File" (see Figure 3.18).

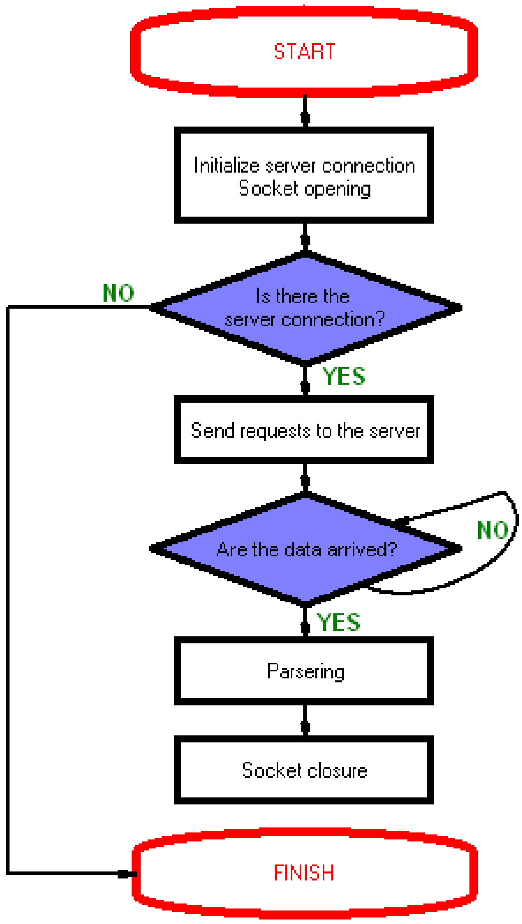


Figure 3.18: Dowload File function

The first part concerns operations related to the socket, necessary for the communication with the server, such as:

Socket creation

Socket opening

If there is the server connection, it is allowed to send and receive requests to/from the server. The server sends an acknowledge for the request reply that has the following command pattern:

Header line	Explanation
HTTP/1.1 200 <CRLF>	The HTTP implemented version is 1.1, the result code of your request is 200 that means everything went fine
Server: Morduc/t/x/y/theta/collision/mindist <CRLF>	The name of the server, t is the time in milliseconds, x and y represent the abscissa and the ordinate in a Cartesian coordinate system in meters, theta is the angle of rotation and , at last, the number of collisions and the minimum distance from the obstacles.
Content-Type: image/jpeg <CRLF>	It tells which kind of images will be sent to the Client. There are 2 images: one is a jpeg of 200x200 (map of the environment) for the laser-based, the other is a jpeg 1280x480 pixels(two images of 640x480, left and right) for the video based
Content length: number of bytes <CRLF>	Image dimension in bytes
<CRLF>	A blank line to hang down the connection

From the Client side, the GET method to retrieve whatever information is identified by a Request URI (Uniform Resource Identifier). The GET method, as described, has many options but we will use only 4 lines that are fundamental in our use:

Header file	Explanation
GET http://<URL> HTTP/1.1 <CRLF>	Retrieve (execute) the object (action identified) by http://<URL> using a HTTP protocol version 1.1 and close line with carriage return and line feed
Host: <HOST> <CRLF>	Used by proxy at Aalborg University to which IP address route the request
User-agent: MorducTeleguide/0.1 <CRLF>	It is used for log purposes
<CRLF>	Close the method

The GET method is the way to retrieve images and to send commands to the robot.
In particular, the Client implements three families of commands:

image.cmd.jpg (or image.cmd.bmp): it could be of four types:

- *stereo.fow.jpg or laser.fow.bmp*: to fetch webcams images or laser image and to move ahead;
- *stereo.bak.jpg or laser.bak.bmp:* to fetch webcams images or laser image and to move back;
- *stereo.rgh.jpg or laser.rgh.bmp:* to fetch webcams images or laser image and to turn right;
- *stereo.lft.jpg or laser.lft.bmp:* to fetch webcams images or laser image and to turn left.

image.jpg (or image.bmp): it used to ask for images fetched by webcams or laser scanner when the robot does not have to move;

command.how: where *command* is which action has to be performed and *how* say in which direction, it uses this schema:

- *step.fow*: to go ahead;
- *step.bak:* to go back;
- *turn.rgh:* to turn right;
- *turn.lft:* to turn left.

After the image is downloaded, it will be used in different ways depending if it comes from the laser or from webcams (as we have seen in the previous sections).

- ***Mouse/ Keyboard manager***

In this section the input events coming from the keyboard and mouse will be described.
The event associated to the mouse is the "Drag and Drop": the camera pan-tilt is updated estimating the distance between the actual position and the position when the left button of the mouse was pushed.
The Manager Keyboard function manages the events associated to the keys pressure.
In the following table, we will show the functionality and layout of each key:

Camera key control	
X	Decrease pitch angle (down)
Z	Increase pitch angle (up)

C	Decrease yaw angle (right)
V	Increase yaw angle (left)
Q	Increase cam z-position (up)
A	Decrease cam z-position (down)
W	Increase cam x-position (left)
S	Decrease cam x-position(right)
E	Decrease cam y-position (front)
D	Increase cam y-position (back)
SPACE	Switch camera on robot/camera fixed
DELETE	Set: camera.phi=0, camera.tetaofs=0, cx=cy=cz=0
F1	Zero eyes separation (If you are in stereo vision)
F2	Decrease Eyes Separation (If you are in stereo vision)
F3	Increase Eyes Separation (If you are in stereo vision)
F4	Decrease camera focal-length
F5	Increase camera focal-length
F6	Zoom in (aperture)
F7	Zoom out (aperture)
Robot key control	
O	Decrease robot radius
Arrows	Move the robot
P	Increase robot radius
Environment key control	
3	HDIEnable (Human device interface)
K	Select the Texture
B	Setup the ambient light (increase the brightness)
N	Setup the ambient light (decrease the brightness)
Log key control	
L	Start log file
F8	Test parameter (egocentric)
F9	Test parameter (relative)
Others	
1	Manage the Teleguide mode (Simulator, Video, Laser)
2	Manage vision mode (mono,anagliph,shutter glasses,polarized)
ESC	Terminate the application

3.2.3 Plan testing activity

The purpose of the testing activity is to obtain tangible proof of user's navigation skills and remote environment comprehension, under different circumstances.

In this work we have delimitated our investigation to two different stereo approaches and visual displays. They are:

- Stereoscopic Approach: Colored Anaglyph and Polarized Filters. These approaches have very different characteristics. Colored Anaglyph is cheap, easy to produce and very portable. However, it has poor colour reproduction and it often generates crosstalk which affects precision and viewing comfort. On the other hand, Polarized Filters nicely reproduce colours, has nearly no crosstalk, and it is very comfortable to a viewer. However, it requires a more complex and expensive setup and it is less portable.
- Visual Display: Laptop and Wall. These displays have very different characteristics. A Laptop display uses LCD technology and it has a relatively small display size, typically up to 19 inches with high resolution. A Wall display is instead typically composed by a projector and a screen with a size up to several meters.

The research question involves the following aspects:

- **Mono versus Stereo**. What are the main characteristics and advantages of using stereoscopic visualization in mobile robot teleguide in terms of navigation skills and remote environment comprehension?
- **Anaglyph Laptop versus Polarized Wall**. How the characteristics and advantages associated to stereoscopic viewing may vary for different approaches to stereo and display system?

The usability study is a within-subject evaluation and it is designed according to recommendation gathered from the literature [57, 58], and authors'experience and previous work on evaluation of VR applications [50].

Each participant is asked to tele-drive a remotely located mobile robot on both the proposed facilities (Laptop and Wall system), using both stereo and mono visualization modalities. This amounts to 4 navigation trials per participant. During a trial several measurements are acquired from the laser and the encoders located onboard the robot platform. These data are collected to support the analysis of user's performance (and are not transmitted to the participant).

We conform to the traditional approaches in terms of forms and questionnaires [58] with few additions [50]. Since experience in playing computer games is also taken into account as experience in teleoperation, the questionnaire will also include questions about the gaming abilities (e.g. hours per week). Initially we provide a participant with an information sheet, consent form and pre-test screening and background questionnaires. At the end of each trial the participant is asked to fill in a questionnaire, and at the end of the entire session there is a conclusive comparative questionnaire and a thank you form.

The schedule for the participant activities includes the timing of the single tasks, the overall completion time (with breaks, form filling, debriefing, etc.), and the task sequence per participant. It is very important to counterbalance the sequence of tasks to avoid fatigue and learning effects. It is also important an initial practise session to get acquainted with task and system.

Finally all the acquired data go through a statistical and graphical evaluation in order to identify precise trends (based on analysis of variance) and potential tendencies (based on average results and specific observations).

3.2.3.1 The quantitative and qualitative parameters

In this section we will give a brief description of the quantitative parameters coming from the data collected during the tasks and the qualitative parameters obtained from the questionnaires.

The quantitative parameters are extracted from the Log files. Among the Log files collected, the data concerning users that did not complete the task, at least in one of the four trials, were excluded from the analysis.

The task is not accomplished when the users hit the obstacles with such a high speed that could be dangerous for the robot.

It is possible to extrapolate important information about the guide efficiency and effectiveness from the analysis of the Log data:

- Collisions Number. The number of collisions registered during a trial. It provides information about obstacle detection and avoidance. The collisions number is an important parameter to measure the guide efficacy.
- Collision Rate. The number of collision divided by the Completion Time. It provides information about obstacle detection which is independent from user speed.
- Mean Obstacle Distance. The mean of minimum distance to obstacles along the path followed during a trial, [59].This parameter is correlated to the Varanoi path [49]. The nearest is the user's path to the Varanoi path, the higher is the parameter.
- Completion Time. The time employed to complete the navigation trial. In particular, we consider the time completion as the time needed to reach the dashed line. It provides information about user's environment comprehension. This parameter may also show user's confidence, (sometime a false confidence). The knowledge of the completion time is also needed to estimate the Collision Rate.
- Mean Speed. The mean speed of each trial. It may show user's confidence.
- Path Length. The length of the robot journey. It may provide information about drive efficiency and obstacle detection.

The qualitative results contain the numbers received from the device questionnaires and the combined background and post-test questionnaire. The device questionnaires were composed of 14 questions and handed to the participants after completing a task session on each virtual reality device. The background questionnaire was to be completed after all testing sessions on all devices.

It is possible to separate the questions into five different categories:

- Sense of Presence. The perceived sense of presence and isolation from surrounding space.
- Depth Impression. The extent of perceived depth when observing different objects.
- Level of Realism. The realism of the visual feedback including objects dimension and general appearance.
- Suitability to Application. The adequacy of the system and stereo approach to the specific task.
- Viewing Comfort. How comfortable the participants felt during the task sessions. The eye strain and general body reaction.

During the evaluation of the data, the questions were grouped into these categories in order to be able to compare the results in each area. Since 7 scale semantic differentials, ranging from 0 to 3 on both sides were used for the answer possibilities, the final results are ranged from 1 to 7, where 1 is the best rank and 7 the worst.
All the acquired data go through a statistical and graphical evaluation in order to identify precise trends (based on analysis of variance) and potential tendencies (based on average results and specific observations).

3.2.3.2 Test procedure

Organization

During the test trials each participant executed the same number of tasks and under the same conditions. Participants were assisted by a test monitor and a technician during the entire test session. The participant task and facility order was given according to a pre-determined schedule in order to counterbalance the sequence of tasks. Table 3.1 shows our schedule. In order to eliminate every possible connection of the sequence of the VR-devices to the performance, the sequence is randomized for each participant. This helps establishing fair conditions for all devices, because there might be a learning effect due to not knowing the map in the beginning.

Participant Number	Learning phase				Formal Study			
	Wall Mono	Wall Stereo	Laptop Mono	Laptop Stereo	Wall Mono	Wall Stereo	Laptop Mono	Laptop Stereo
1	4	3	2	1	1	2	3	4
2	2	1	3	4	3	4	2	1
3	3	2	1	4	2	3	4	1
4	4	1	3	2	1	4	2	3
5	1	2	4	3	4	3	1	2
6	3	4	1	2	2	1	4	3
7	2	4	3	1	3	1	2	4
8	1	3	4	2	4	2	1	3
9	2	1	4	3	3	4	1	2
10	3	2	4	1	2	3	1	4
11	1	4	3	2	4	1	2	3
12	4	1	2	3	1	4	3	2

Table 3.1: The schedule for our experiments

Procedure

Four steps were followed by the participants

Introduction: Before testing every participant will get an information sheet with an overview of the tasks and some information about the project. Then he/she will fill in a consent form, stating that it is their free will to be tested and overall explaining that they can resign from the study at any time without consequences.

A learning phase was then administrated to allow participants to familiarize with the system.

During this phase, the participants drive towards an obstacle, turn around and return to the start position.

Tele-Guide: Before starting the task, the participant receives a map with the outline of the maze. The participant is informed about the starting position and the target position. This step is taken to avoid a possible learning effect by performing the same task on the same area several times, without knowing the map.

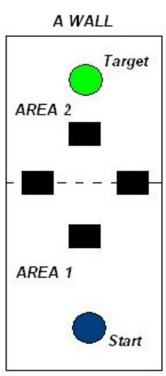


Figure 3.19: Map

The participant is asked to try to be as precise as possible, that means that he/she should try to avoid collisions, but still attempt to finish the task as quickly as possible.
Furthermore, he/she is asked to try to perform the tasks on each VR-system in the same way.
The acquired data referred to a portion of the test trial. This was proposed to increase accuracy and reliability of quantitative measurements. The Figure 3.20 shows the 2D map and the portion of the test trial where data were acquired, (dashed line).

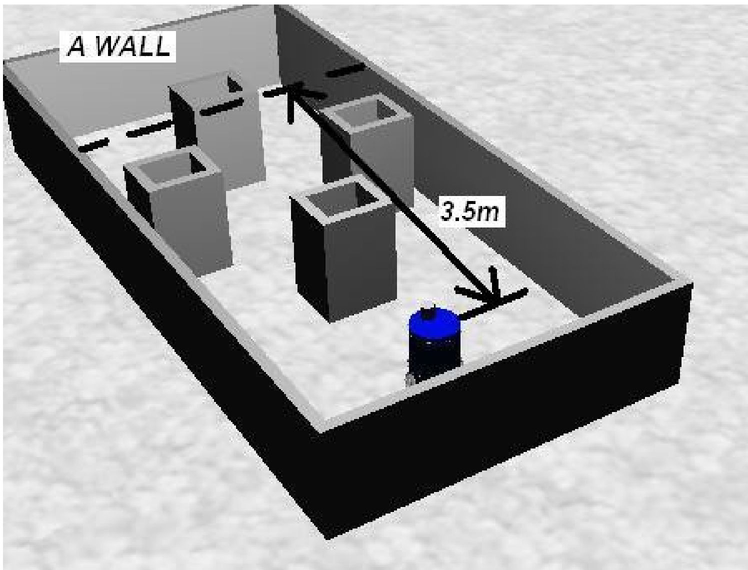


Figure 3.20: 3-dimensional representation of robot workspace

***Questionnaire*:** During the study the participants should fill in two different questionnaires (Appendix B and Appendix C). One contains all feedback information for all devices, which is to be filled after the task on each device and one at the end of the user study. The questionnaires contain questions concerning the background of the users (e.g. age, experience with VR-devices), the overall impression after the test study, the adequacy of the task to the application, the realism of the visual feedback, the sense of presence, the depth impression and the viewing comfort.
***Debriefing*:** Participant's impression was collected, a final questionnaire was also provided together with a thank you form.

3.2.3.3 Results analysis

For show similarities between different data sets often the following techniques are used:

- Arithmetic mean
- Median
- Mode.

Especially the arithmetic mean and the median are often used for evaluation data of user studies connected to virtual reality.
After that the data set were summarized we can examines the data and make predictions and decisions based on the data, especially in situations where we don't know all information that we need to draw conclusions.
The methods used to make this analysis are the following[50]:

- t-test.
- ANOVA.
- Correlation.
- Regression.
- Chi-Squared.
- Probability.
- Distributions.

Particularly in our analysis we have identified:

- Potential tendencies based on average results and specific observations.
- Precise trends based on analysis of variance in particular a one-way ANOVA is applied

Average or Arithmetic Mean

The average or arithmetic mean is one of the mostly used statistical methods.
It measures the average of a data set.
Definition:
If there is a given set of data (list of numbers), the mean is calculated by summing all members of the list and dividing them by the number of entries in the list.

Given that n is the total number of elements in the list, the arithmetic mean is calculated as follows:

$$\bar{x}_{arithm} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{x_1 + x_2 + \ldots + x_n}{n}$$

Analysis of Variance

The analysis of variance—short ANOVA—detects if and how there are differences between the expected values of random variables. Furthermore it tests if the variance between groups is higher than the variance within groups. Therefore significant differences between groups and valid group categorizations can be detected.

One-way ANOVAs are conducted to investigate the difference when there are either three or more independent groups or when the same subjects are used for every treatment.

When conducting an ANOVA, the results are considered to be significant (different) when the p value is below a distinct threshold (usually for $p < 0.5$).

The p-value represents the probability for the null hypothesis that all samples are drawn from the same population (or from different populations with the same mean). The choice of a critical p-value to determine whether the result is judged "statistically significant" is left to the researcher. It is common to declare a result significant if the p-value is less than 0.05 or 0.01, [60].

A typical ANOVA table has six columns.

1. The first shows the source of the variability.
2. The second shows the Sum of Squares (SS) due to each source.
3. The third shows the degrees of freedom (df) associated with each source.
4. The fourth shows the Mean Squares (MS) for each source, which is the ratio SS/df.
5. The fifth shows the F statistic, which is the ratio of the MS's.
6. The sixth shows the p-value, which is derived from the cdf of F. As F increases, the p-value decreases, [33].

The Table 3.2 shows an example of ANOVA table.

Source	SS	df	MS	F	p
Columns	0,00228	1	2,28E-03	4,99	0,0309
Error	0,01916	42	0,00046		
Total	0,02143	43			

Table 3.2 Example of ANOVA table

Display Methods: histogrm

The results of the experimentation are shown in tables and histograms.

In general a histogram can be understood as the graphical or geometrical display of a table which shows the frequency of something. The data can be categorized and combined into differentiable (adjacent) ranges, which are usually not overlapping each other. In statistics a histogram is usually used to display the answers of a questionnaire. It simply counts the replies, results that fall into categories that are also known as “bins”. Histograms can be displayed graphically, but there are other ways to represent it.

Definition:

If N is the total number of results and n is the total number of bins and k is the index over the bins, the histogram h_k is the following:

$$N = \sum_{k=1}^{n} h_k$$

Chapter 4. Experimentation

4.1Experimentation Plan

In the experimentation phase a number of test trials were performed in order to control, via Internet, the mobile robotic platform 3 MO.R.D.U.C. located at the Robotics lab at the University of Catania, in Italy. The test users were sitting on different VR facilities located at the Medialogy lab at the Aalborg University in Copenhagen, Denmark

The test trials were conducted during several days and with different network traffic. This was due to the overall execution time per participant (about 40 min.) and few technical issues, (e.g. battery autonomy up to 50 min. and recharge time up to 1 hour).

The system setup was composed by three main parts which needed to interact and exchange feedback. The three main parts are:

- a Robotic System;
- a Visualization System;
- a Network Connection.

4.1.1 Robotic system: The 3 MO.R.D.U.C. robot

The 3MO.R.D.U.C., “3rd version of the MObile Robot DIEES University of Catania”, shown in Figure 4.181, is a wheeled mobile robot in differential drive configuration. This open robotic platform was successfully used in localization and navigation experiments , .

The movement is accomplished by two 40W DC motors, Maxon F2260, and the motor axes is linked with a gear box (gear ratio 1:19).

Two rubber wheels are linked with the gear box axis and a third castor wheel is free to rotate, facilitating so the execution of the curves.

The robot structure (Figure 4.17 and Figure 4.18) has three shelves linked together.

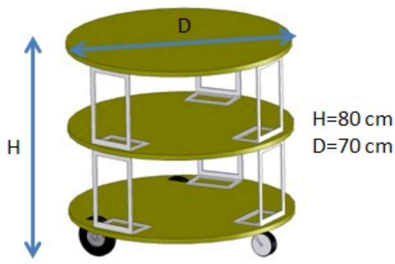


Figure 4.17: Robot structure

On the lower shelf there are two lead batteries (12V/18Ah), which provide the power supply. The robot autonomy is about 30 min. for continuous working.

An on board electronic rack controls the modules of the robot (motion, sensors and communication). On the robot there are several sensors monitoring the workspace and the robot state (bumper, encoder, laser, sonar and stereocam).

The electronic part and sensors on board are analyzed in the following section.

Figure 4.18: 3 MO.R.D.U.C. robot

Finally, on the top shelf there is a laptop where the robot control application is runs.

4.1.1.1 Electronic board rack

The electronic board rack (Figure 4.19) is a modular stacked structure, composed by several electronic boards which accomplish a specific task.

Figure 4.19: Electronic board rack

A standard bus (3MO.R.D.U.C.-Bus) guarantees the system modularity and provides to send the signals to the boards.
The cards on board are:

- *Supply board:* is divided in two parts, the first one provides the power supply for the laser (24 V) to the laser; the second one (12 V/5 V) provides the power supply for the other boards on the rack.
  - *ST10 board:* controls the motor axes of the robot; a firmware allows the communication between the ROBOT and the laptop via RS232 or CAN-bus.
- *Power board:* is composed by two MD03 (H-Bridge), these cards manage the current flow in the motor. The ST10 send the commands to the power-board through the I^2C bus.
  - *Encoder board:* processes the signals coming from the encoders. In particular it provides a differential to single signals conversion, so that the ST10 microcontroller can properly acquire them.
  - *PC Interface board:* allows the communication between the laptop and the boards on the rack; two protocols I^2C and RS-422 were implemented.
  - *Multi I\O board:* interfaces the bumpers and the sonar sensors. It manages 16 digital input/output and provides an expander I^2C connector.

4.1.1.2 Sensors on board

This section will briefly describe the sensors on the 3MO.R.D.U.C.:

- ***Bumpers:*** a belt of bumpers around the entire perimeter of the robot is mounted on the base, over the wheel (Figure 4.20). These sensors have to recognize and reduce damages in a collision. The bumpers are simple switches pushed when there is a collision. They are connected to the same bus of the sonar sensors (I^2C).

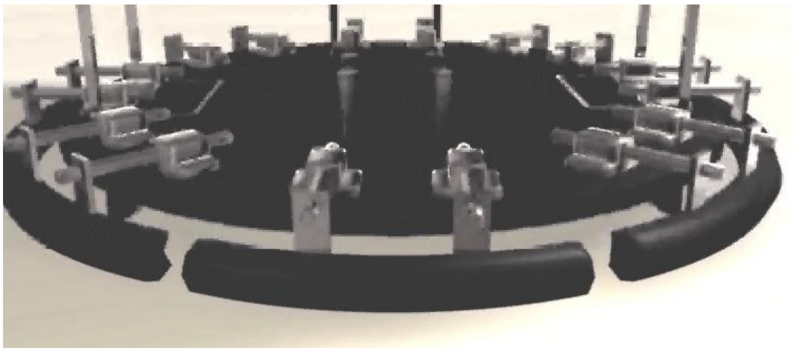


Figure 4.20: Bumpers

- ***Encoders:*** A digital optical encoder is a device that converts motion into a sequence of digital pulses. On the robot there are two incremental encoders with a resolution of 500 pulses/turn.
- ***Scanner Laser:*** The LMS system (Figure 4.5) operates by measuring the flight time of a pulsed laser light beam that is reflected by obstacle. An internal rotating mirror deflects the transmitted pulsed laser beam so that a scan is made of the surrounding area.

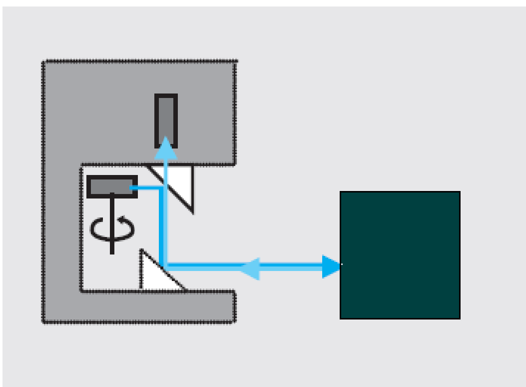


Figure 4.21:Scanner laser and internal rotating mirror

The shape of the target object is determined from the sequence of the received impulses. The measurement data is available in real time for further evaluation via RS232/RS422 serial interface.

Figure 4.22: Scanner laser

The time between transmission and reception of the light pulse is directly proportional to the distance between the scanner and the object (time of flight).
If you indicate with L the distance between the laser and the obstacle and with c the light speed:

$$t_{flight} = \frac{2L}{c} \quad \Rightarrow \quad L = c \cdot \frac{t_{flight}}{2}$$

Automatic fog correction is active in the scanner for outdoor use. Raindrops and snowflakes are cut out using pixel-oriented evaluation. Object blanking is used for suppressing an object that is not to be detected, e.g. a steel cable, that is located within the monitored field. It is possible to configure three separate angular resolutions (0.25°/0.5°/1°) and the maximum scan angle (100°/180°); each scan is in clockwise mode .

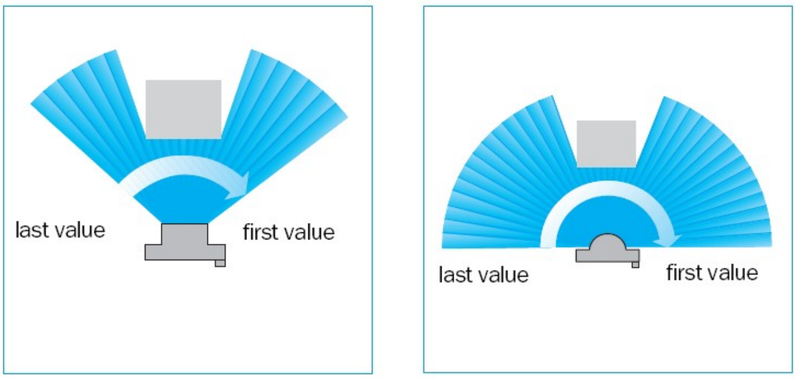


Figure 4.23: MaximumScan Angle (100°/180°)

- ***Sonar sensors***: The sonar sensors measure the distance from an obstacle using the flight time of an ultrasonic signal produced by means of a vibrating piezoelectric sensor.

The sonar on the robot are the SRF08 (8), connected to the I^2C bus.

Figure 4.8: 3MO.R.D.U.C. sonars

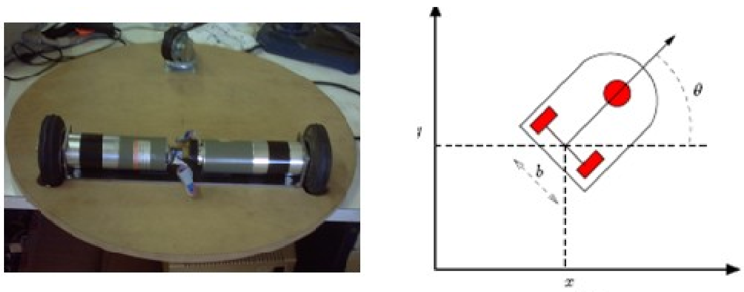
The SRF08 includes also a photo-resistor that allows the environmental brightness sensing.

- ***Stereocam:*** On the robot there are also two high quality stereoscopic cameras; each one has a resolution of 1.3 Megapixel; they are equipped with fixed focus lens of 4.0 mm. The CCD sensors of these cameras have a good noise immunity and sensibility; moreover, it is possible to adjust all the image parameter, e.g. exposure gain, frame rate, resolution. The cameras are mounted on a rigid support; it permits to adjust in a simply way the camera distance in a range 5-20 cm (Figure 4.9).The images come from the two cameras are synchronized with an 8 KHz clock, generated by using IEEE1394 interface .

Figure 4.9: Stereocam system

4.1.1.3 MO.R.D.U.C Kinematic Configuration

Most mobile robots are characterized by a mobile platform with a differential drive kinematic: The mechanical structure of the differential drive platform is composed by two active wheels and one or more passive wheels to give stability (castor wheels).



(a) (b)

Figure 4.10: (a) 3MO.R.D.U.C.bottom part, (b) differential drive configuration

The robot heading is the direction of the translation, θ, is perpendicular to the axis, which links the centre of the two wheels (wheelbase). When the two wheels move with an equal and opposite speed, the robot turns around and changes its heading.

This kinematic system is a non-holonomic constrains and, for this reason, the robot can translate on the plan in a single direction that is identified by θ.

The robot can always reach q_1 (a known final position) starting from q_0 through a series of rotations and translations.

In generally we can write:

$$V(t) = \frac{v_l + v_r}{2}$$

$$\omega(t) = \frac{v_r - v_l}{b}$$

Where:

- v_l and v_r are the speeds of the robot active wheels (left and right);
- b is the robot wheelbase.
- $V(t)$ and $\omega(t)$ are the linear and angular speed.

The following equation system describes the kinematic model of the mobile platform in differential drive configuration.

$$\begin{cases} \dot{x}_c(t) = V\cos(\theta(t)) = \dfrac{v_l + v_r}{2}\cos(\theta(t)) \\ \dot{y}_c(t) = V\sin(\theta(t)) = \dfrac{v_l + v_r}{2}\sin(\theta(t)) \\ \dot{\theta}(t) = \omega(t) = \dfrac{v_r - v_l}{b} \end{cases}$$

Where:

- x_c and y_c are the absolute coordinates of the robot;
- θ is the robot heading;

We can apply these equations in a time-continuous system, but, in a time-discrete system, the equations will become:

$$\begin{cases} \dfrac{x_c(k+1) - x_c(k)}{\Delta t} = V\cos(\theta(k)) \\ \dfrac{y_c(k+1) - y_c(k)}{\Delta t} = V\sin(\theta(k)) \\ \dfrac{\theta(k+1) - \theta(k)}{\Delta t} = \omega(k) \end{cases}$$

Assuming:

$u(k) = v(k) \cdot \Delta t$

It is not necessary to consider a partial times Δt which is the time between two encoder data sampling.

The estimated time is often affected by some errors and this measure is important on the accuracy of the equation solving.

Known N_L and N_R, the impulse counter of the left and right encoder, we can consider in left case:

$\Delta N_L(k) = N_L(k+1) - N_L(k)$

Known:

- n : reduction ratio of the gear box
- $Encres$: encoder resolution

It is possible to write:

$$\Delta u_L(k) = \frac{\Delta N_L(k)}{\frac{Encres}{n} \cdot 2 \cdot \pi \cdot r}$$

$$\Delta u(k) = \frac{\Delta u_L(k) - \Delta u_R(k)}{2}$$

For the angular speed, instead:

$$\Delta v(k) = \omega(k) \cdot \Delta t = \frac{\Delta u_R(k) - \Delta u_L(k)}{b}$$

We can place the encoder on the wheel axis or before gearbox (on the motor axis). The advantage of the first method is that we can measure exactly the wheel rotation but with a low resolution.

The second method, instead, does not allow measuring the effect of the errors on gearboxes but has a higher resolution.

We described the kinematic model of the 3MO.R.D.U.C because the Robot Server Simulator was developed so that it followed the same robot' kinematic

4.1.2 Visualization systems

In the Chapter 2 we described advantages and disadvantages of several visualization systems. We chose to use: Laptop PC and Flat-Wall. In this way we compared small displays and large one. Large displays allowed subjects to use an egocentric rather than an exocentric strategy to perform spatial tasks. Hence a large screen involve the peripheral vision areas more than a smaller screens. Furthermore we compared high resolution system and low one.

The Laptop PC, is a standard laptop, 1 GB RAM, 15 inches wide-screen, displaying stereo using the Chromatic Anaglyph approach.

The Anaglyph Stereo (Figure 4.11) produce a depth effect by applying two colour filters to the images red and green.

Figure 4.11: Anaglyph glasses and Anaglyph in use

This 3D display technology cannot use active stereo because of low refresh rate (minimum refresh rate to use active stereo is 80 Hz).

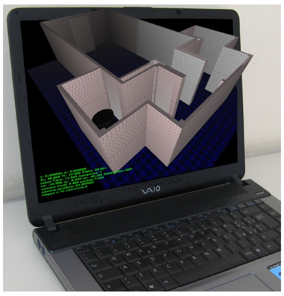


Figure 4.12: 3D Laptop

The second system is a Flat-Wall composed by a computer with two video output, a 2x2 meters front projector silver screen, located approx. 5 meters away by two powerful high resolution projectors equipped with linear polarized filters. Two images are projected through orthogonal polarized filters and superimposed in the silver screen.

The users have to wear special polarized glasses (Figure 4.13), which create the illusion of three-dimensional images by restricting the light that reaches each eye.

Figure 4.13: Polarized glasses and Polarized in use

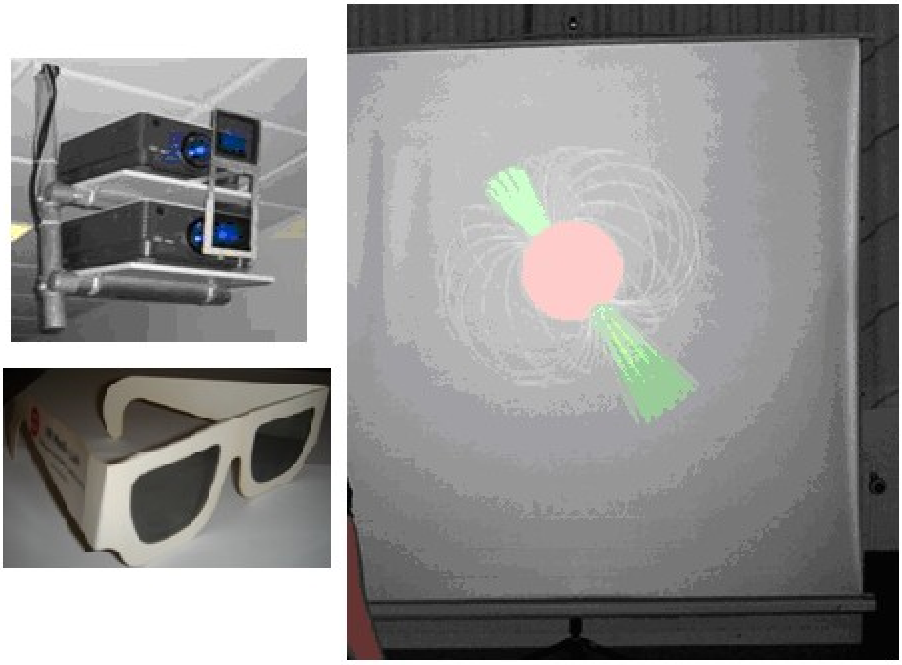


Figure 4.14: Flat –Wall

4.1.3 Network Connection

According to [47], the teleoperation system is implemented as a client-server architecture based on a standard Network Protocol (3rd ISO/OSI Level). The server sits on board the robotic platform. The client runs on the user system. The client and server are connected through an Internet link. We considered the Hypertext Transfer Protocol (HTTP). A protocol developed to transfer information on the World Wide Web. A browser is an HTTP client because it sends requests to an HTTP server (Web server), which then sends responses back to the client. The standard (and default) port for HTTP servers to listen on is 80. This allows us to send packages related to our teleoperation. We have chosen the HTTP because of the presence of firewalls and proxy systems in our local site. Furthermore, the HTTP is quite reliable (it allows for full duplex connection over a TCP/IP channel).

4.1.4 Usability Evaluation

Twelve subjects were tested among students or staff members of the Aalborg University in Denmark. The target population was composed of participants with varying background (e.g. concerning the age) and have none or medium experience with virtual reality devices. This is to guarantee a great internal variance for unbiased and reliable results.

The test trials, that following General Guidelines (listed in chapter 2.5.1) were conducted during several days and with different network traffic. This was due to the overall execution time per participant (about 40 min.) and few technical issues, (e.g. battery autonomy up to 50 min. and recharge time up to 1 hour). Each participant executed the same number of tasks and under the same conditions.

Before starting the task, the participant receives a map with the outline of the maze. The participant is informed about the starting position and the target position.

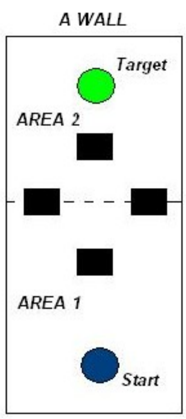


Figure 4.15: Map

The participant is asked to try to be as precise as possible, that means that he/she should try to avoid collisions, but still attempt to finish the task as quickly as possible.

Furthermore during the study the participants filled two different questionnaires, one contains all feedback information for all devices, and the other contain questions concerning the background of the users (e.g. age, experience with VR-devices), the overall impression after the test study, the adequacy of the task to the application, the realism of the visual feedback, the sense of presence, the depth impression and the viewing comfort.

4.2Test Result analysis

4.2.1 Laser based teleguide: results

A formal test with 12 people was conducted to test the Laser based teleguide with the modalities showed in the paragraph 2.5.1.

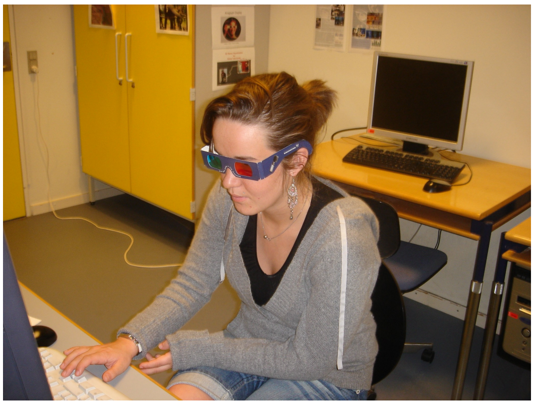


Figure 4.16: An user during the test phase

In this section the quantitative parameters coming from the data collected during the tasks and the qualitative parameters obtained from the questionnaires will be analyzed.

4.2.1.1 Quantitative analysis

Collisions

ANOVA

In the Laser based teleguide the Anova estimated in case of all mono versus all stereo showed a main effect of stereo viewing on the number of collisions per time unit because the stereo support a more realistic navigation and the users drives with more accuracy to avoid the obstacles.

The Anova estimated in case of mono versus stereo in the Laptop facility showed that by stereoscopic viewing the drivers avoid more collisions.

In the Laser based teleguide the improvement between mono and stereo visualization is greater with the wall system, this supports the test participants that have commented that in the Flat-Wall in Stereo is perceived a higher sense of depth, a greater sense of presence and a higher comfort.

This result is demonstrated by the Anova estimated in case of Laptop versus Flat-Wall showed that in case of the wall system the drivers avoid more collisions.

Source	ss	df	MS	F	P
Columns	0,00942	1	0,00942	5,69	0,02
Error	0,07617	46	0,00166		
total	0,08559	47			

Source	ss	df	MS	F	P
Columns	0,00358	1	0,00358	1,57	0,22
Error	0,05027	22	0,00228		
total	0,05385	23			

Source	ss	df	MS	F	P
Columns	0,00599	1	0,00599	5,73	0,025
Error	0,02299	22	0,00105		
total	0,02899	23			

Source	ss	df	MS	F	P
Columns	0,00275	1	0,00275	1,53	0,22
Error	0,08285	46	0,018		
total	0,08559	47			

Table 4.1: The tables represent detail results for the one-way ANOVA estimated in case of "all mono versus all stereo" (1-table), "mono versus stereo in the Laptop facility" (2-table) and "mono versus stereo in the Wall facilities" (3-table),"Laptop versus FlattWall"(4-table).

The Collisions Number is higher in case of monoscopic visualization in most of the cases especially in the wall facility. The higher sense of depth provided by stereo viewing improves driving accuracy.

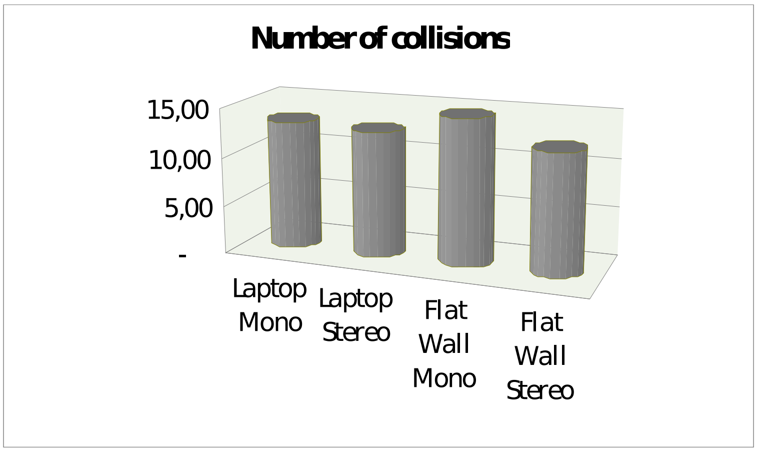


Figure 4.17: number of collision (12 tests)

Mean Obstacle Distance

The next histogram (Figure 4.18) concerns the mean of the minimal obstacle distance. The distances to obstacles are higher in case of stereoscopic viewing especially in the wall facility. This result supports the conclusions gathered in case of collision measurements. The minimal obstacle distance is higher using stereo technologies and in this case the user is generally farther away from the obstacles and drives in a safe way.

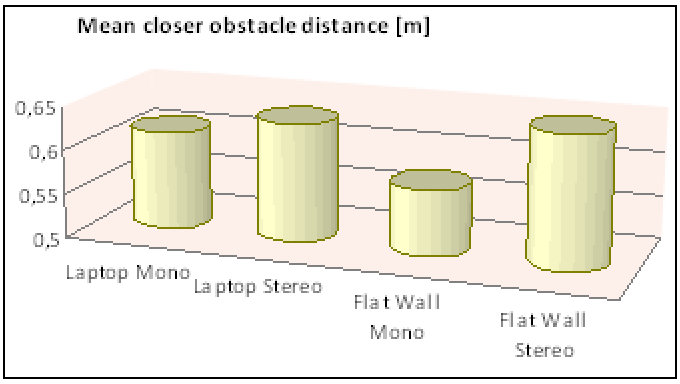


Figure 4.18: Mean closer obstacle distance (12 tests)

Laptop Mono	0,611
Laptop Stereo	0,634
Flat Wall Mono	0,574
Flat Wall Stereo	0,649

Table 4.2: Mean obstacle distance

Execution Time

The mean time employed for a trial is greater in stereo visualization; this result is the same on both the facilities. The test participants have commented that the greater depth impression and sense of presence provided by stereoscopic viewing, make a user spending a longer time in looking around the environment and avoid collisions, but in the Wall facilities the difference between mono and stereo is smaller than Laptop because is more natural drives the robot using the Wall facilities for the higher sense of comfort of this system and the time that the user have spent looking around is recovered by the more security guide. In the state of art some authors attributed the enhanced performance to a greater sense of presence afforded by the large display, which allowed subjects to use an egocentric rather than an exocentric strategy to perform spatial tasks.

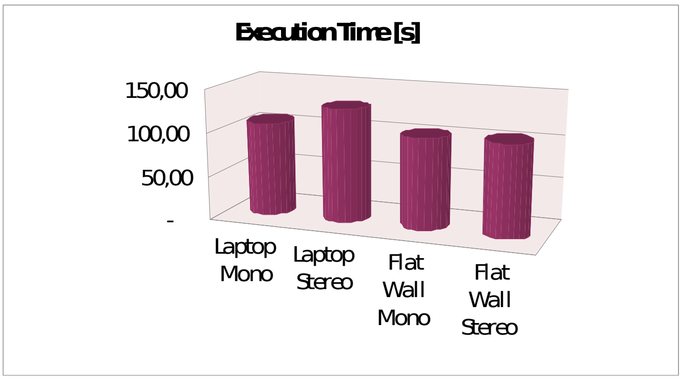


Figure 4.19: Execution time (12 tests)

Laptop Mono	108,23
Laptop Stereo	130,34
Flat Wall Mono	105,17
Flat Wall Stereo	105,17

Table 4.3: Execution time[s] (12 tests)

This result is demonstrated by the Anova estimated in case of mono versus stereo in the Laptop facility showed that by stereoscopic viewing the drivers spending a longer time than the mono viewing.

Source	ss	df	MS	F	P
Columns	2933,01	1	2933,01	3,35	0,08
Error	19287,99	22	876,73		
total	22221	23			

Table 4.4: The tables represent detail results for the one-way ANOVA estimated in case of "mono versus stereo in the Laptop facility.

Path Length

The (Figure 4.20) histogram is relative to the path length in the first area.

In the laser teleguide the path is shorter in the stereo Laptop display than the mono one while in the Stereo Flat-Wall the path is longer than the mono Flat. This because the stereo Flat-Wall support a more realistic navigation and the users drives with more accuracy to avoid collisions hence the distances to obstacles are higher and the paths followed are longer than the mono.

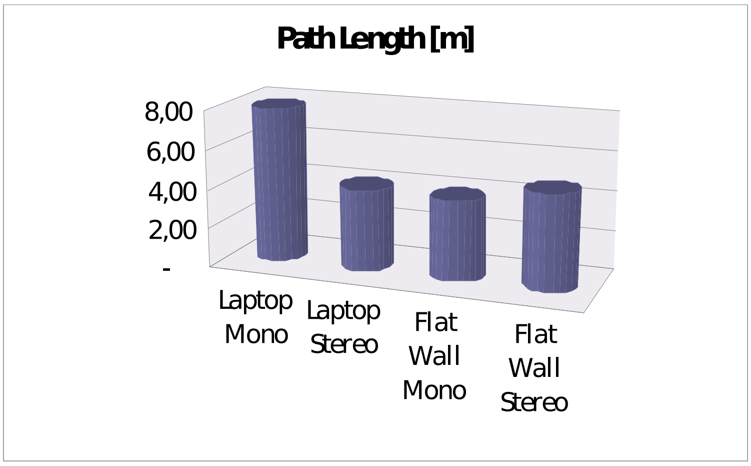


Figure 4.20: Path length (12 tests)

Mean Speed

The Figure 4.21 shows a clear tendency in reducing speed in case of stereo viewing in Laptop facility and reducing speed in case of mono viewing in Wall facility.

In the stereo Flat-Wall the speed isn't smaller than one in the mono Flat-Wall because

Speed=path length/execution time

and in the stereo the paths are longer than the mono.

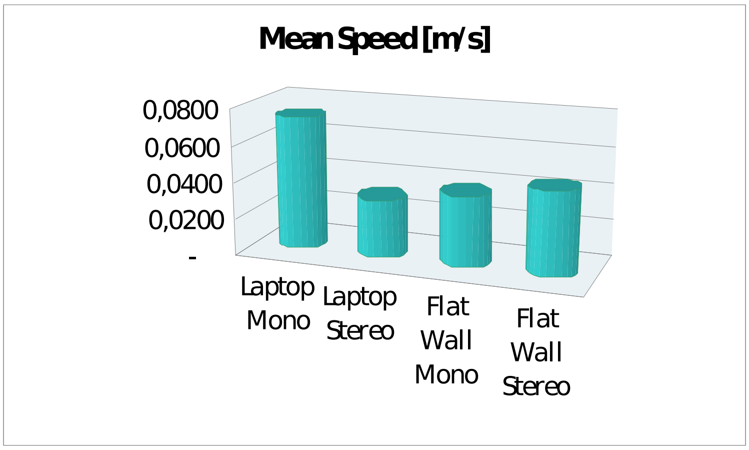


Figure 4.21: Mean speed (12 test)

4.2.1.2 Qualitative analysis

The tables in Figure 4.22 shows that a higher comfort is perceived in case of the Flat-Wall compared to Laptop. This expected result confirms the benefit of front-projection and polarized filters which provide limited eye-strain and crosstalk and great colour reproduction. The passive Anaglyph technology (Laptop stereo) strongly affects viewing comfort and it calls for high brightness to mitigate viewer discomfort. The mean values in Figure 4.22 also show an opposite tendency between the two facilities in terms of stereo versus mono previously commented.

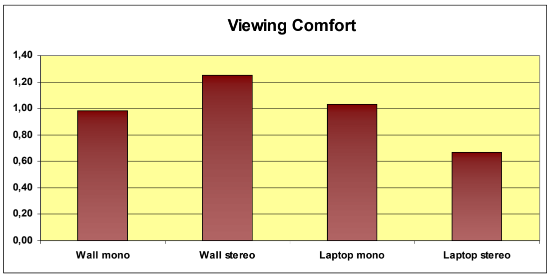


Figure 4.22: Viewing Comfort

The Flat-Wall stereo was considered more suitable for a teledriving task which makes this facility very suitable for training activities.

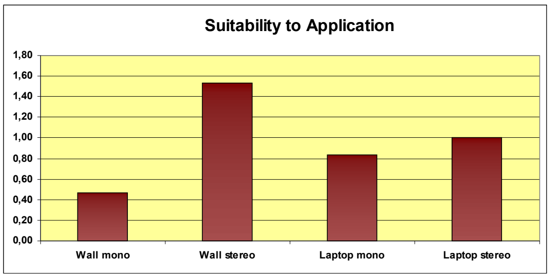


Figure 4.23: Adequacy to application

In case of stereo viewing both the impression of realism and the level of immersion were higher. In particularly the performance in relation to these parameters in the Flat-Wall stereo are better than the Laptop stereo. This may due to the fact that large screens involve the peripheral vision areas more than a smaller screens.

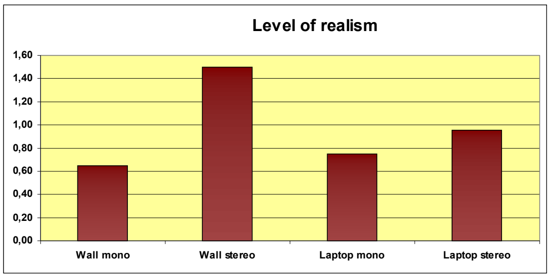


Figure 4.24: Realism

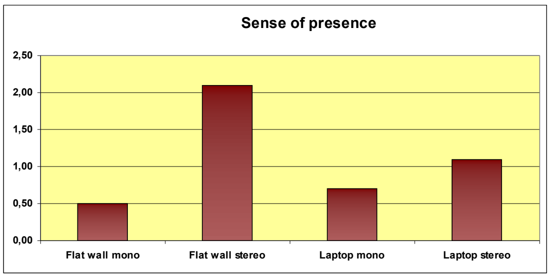


Figure 4.25: Immersion

The stereo visualization provided a stronger depth impression. Results are better in case of a larger screen.

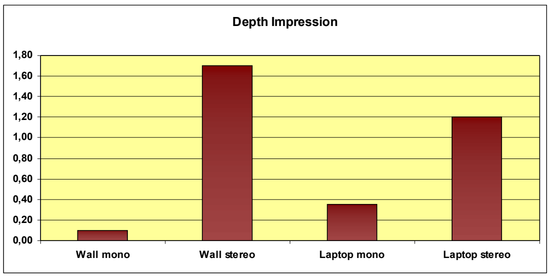


Figure 4.26: 3D Impression

4.2.2 Laser based teleguide vs Video based teleguide

In the previous work tests have been made o the Video based teleguide. In this section the quantitative parameters coming from the data collected during the tasks and the qualitative parameters obtained from the questionnaires, will be compared with the parameters of the Laser based teleguide.

4.2.2.1 Quantitative analysis

Collisions

ANOVA

In the Laser and in the Video based teleguide the Anova estimated in case of all mono versus all stereo showed a main effect of stereo viewing on the number of collisions per time unit because the stereo support a more realistic navigation and the users drives with more accuracy to avoid the obstacles.

Source	ss	df	MS	F	P
Columns	0,00942	1	0,00942	5,69	0,02
Error	0,07617	46	0,00166		
total	0,08559	47			

Source	ss	df	MS	F	P
Columns	0,00228	1	0,00228	4,99	0,0309
Error	0,01916	42	0,00046		
total	0,02143	43			

Table 4.5: The tables represent detail results for the one-way ANOVA estimated in case of "all mono versus all stereo" (1-table laser and 2-table video).

The Anova estimated in case of mono versus stereo on both facilities showed that by stereoscopic viewing the drivers avoid more collisions on both the teleguide.

In the Laser based teleguide the improvement between mono and stereo visualization is greater with the wall system opposite to the Video based teleguide, this supports the test participants that have commented that in the Flat-Wall Stereo is perceived a higher sense of depth, a greater sense of presence and a higher comfort.

Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,00358**	**1**	**0,00358**	**1,57**	**0,22**
Error	**0,05027**	**22**	**0,00228**		
total	**0,05385**	**23**			

Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,00013**	**1**	**0,00013**	**0,25**	**0,06**
Error	**0,02131**	**42**	**0,00051**		
total	**0,02143**	**43**			

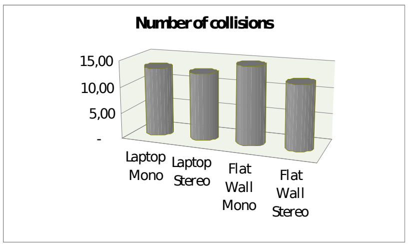
Table 4.6: The tables represent detail results for the one-way ANOVA estimated in case of), "mono versus stereo in the Laptop facility" (1-table laser, 2-table video).

Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,00599**	**1**	**0,00599**	**5,73**	**0,025**
Error	**0,02299**	**22**	**0,00105**		
total	**0,02899**	**23**			

Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,0007**	**1**	**0,0007**	**1,35**	**0,25**
Error	**0,01044**	**20**	**0,00052**		
total	**0,0111**	**2**			

	5	1			

Table 4.7: The tables represent detail results for the one-way ANOVA estimated in case of "mono versus stereo in the Wall facilities" (1-table laser and 2-table video).



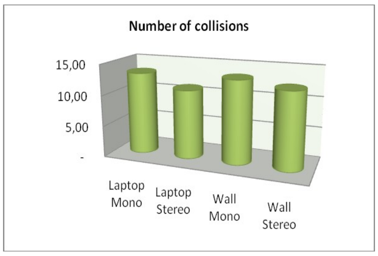


Figure 4.27: Number of collision laser (left slide) vs video(right slide)

Furthermore we have estimated the Anova in case of: "all Laptop" facilities in the video based teleguide versus "all Laptop" facilities in the laser based teleguide, "all Flat-Wall" facilities video based teleguide versus "all Flat-Wall" facilities laser based teleguide and "all Laptop" and Flat-Wall facilities video based teleguide versus Laptop and Flat-Wall facilities laser based teleguide in order to know which between Laser and Video based teleguide improves the performance.

The Anova showed a main effect of Laser based Teleguide on the number of collisions per time because the synthetic environment results more suitable for the teleguide of the robot in a simple map. Furthermore the image size, sent from the server to the client, is small, and then the network can transfer these data fast enough for real time performance

Source	ss	df	MS	F	P
Columns	0,02885	1	0,02885	19,49	0,000069
Error	0,06218	42	0,00148		
total	0,09103	43			

Source	ss	df	MS	F	P
Columns	0,03938	1	0,03938	61,5	0,00000000093
Error	0,02689	42	0,00064		
total	0,06627	43			

Source	ss	df	MS	F	P
Columns	0,06782	1	0,06782	62,24	0000000000049
Error	0,09079	86	0,00106		
total	0,15861	87			

Table 4.8: The tables represent detail results for the one-way ANOVA estimated in case of "all Laptop video versus all Laptop laser" (1-table), "all Flat-Wall video versus all Flat-Wall laser" (2-table) and "Laptop + Flat-Wall video vs Laptop+ Flat-Wall laser" (3-table).

Mean Obstacle Distance

In the laser based teleguide the distances to obstacles are higher in case of stereoscopic viewing. In the video based teleguide in case of stereo viewing the user drives closer to an obstacle compared to mono viewing, because, video images support a more realistic navigation but delay makes the driving unnatural.

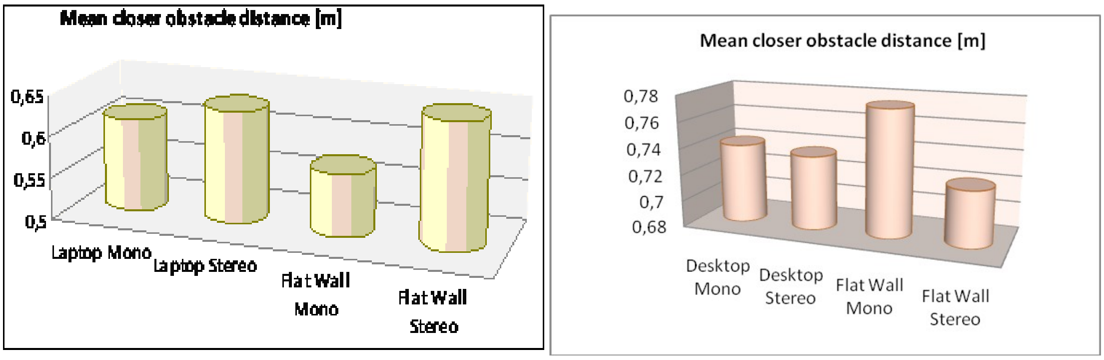


Figure 4.28: Mean closer obstacle distance laser (left slide) vs video (right slide)

Execution Time

The mean time employed for a trial is greater in stereo visualization; this result is the same on both the facilities and on both the teleguide.

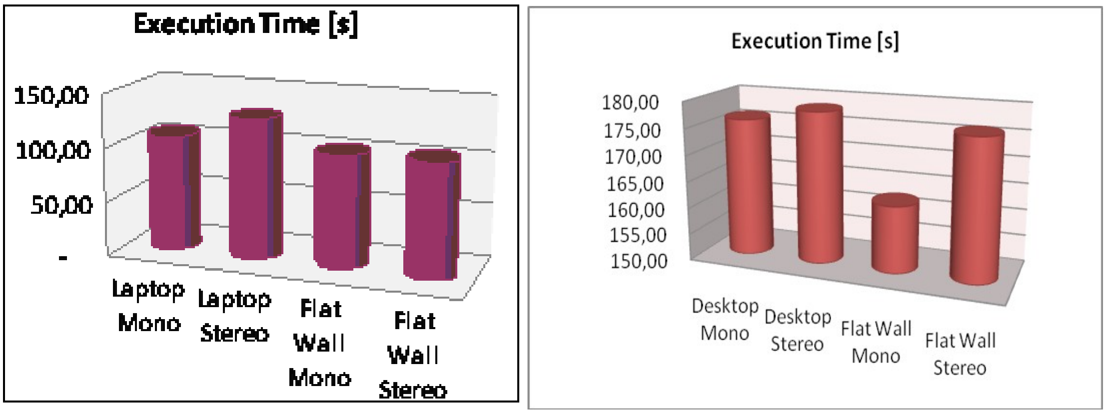
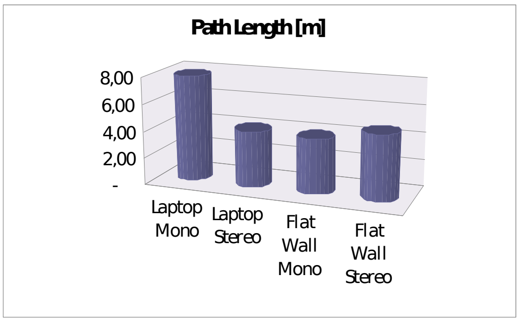


Figure 4.29: Execution time laser (left slide) vs video (right slide)

Path Length

In the video based teleguide the path is always shorter in the stereo than in the mono.

In the laser teleguide the path is shorter in the stereo Laptop display than the mono one while in the stereo Flat-Wall the path is longer than the mono wall because the stereo support a more realistic navigation and the users drives with more accuracy to avoid collisions theremore the distances to obstacles are higher and the paths followed are longer than the mono.



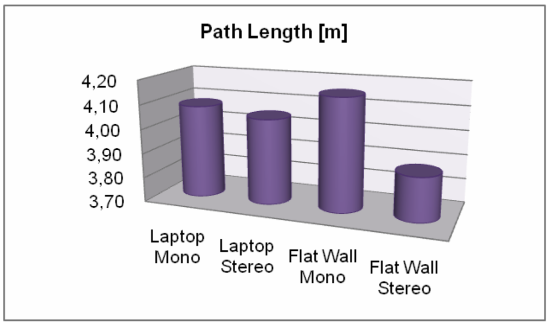


Figure 4.30: Path length laser (left slide) vs video (right slide)

Mean Speed

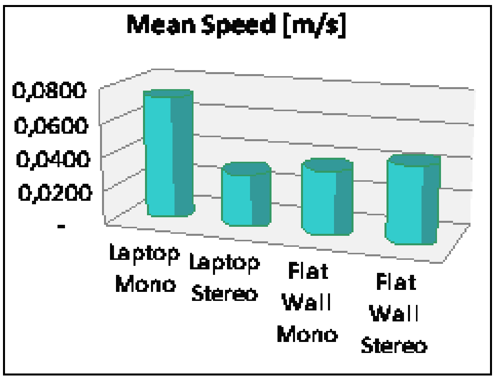
In the laser based teleguide the speed is smaller in case of stereo viewing in Laptop facility and the speed is smaller in case of mono viewing in wall facility.

In the laser based teleguide in the Flat-Wall in stereo the speed isn't smaller than one in the wall mono because

Speed=path length/execution time

and in the stereo the paths are longer than the mono.

Instead in the video based teleguide the speed is smaller in case of stereo viewing on both the display systems because in the Video based Teleguide there isn't significant difference between the use of different displays.



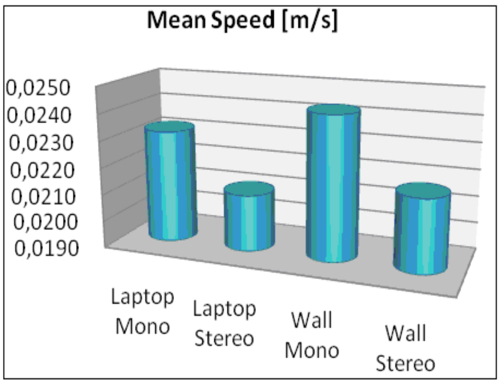
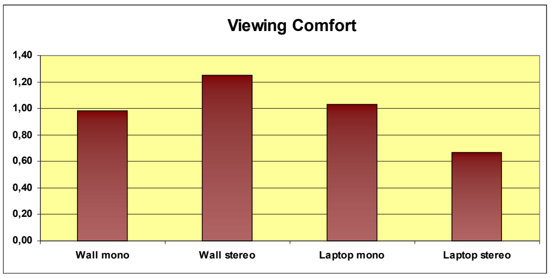


Figure 4.31: Mean speed laser (left slide) vs video (right slide)

4.2.2.2 Qualitative analysis

The tables in Figure 4.32 show that a higher comfort is perceived in case of the Flat-Wall compared to Laptop. This expected result confirms the benefit of front-projection and polarized filters which provide limited eye-strain and crosstalk and great colour reproduction. The passive Anaglyph technology (Laptop stereo) strongly affects viewing comfort and it calls for high brightness to mitigate viewer discomfort. The mean values in Figure 4.32 also shows an opposite tendency between the two facilities in terms of stereo versus mono previously commented.



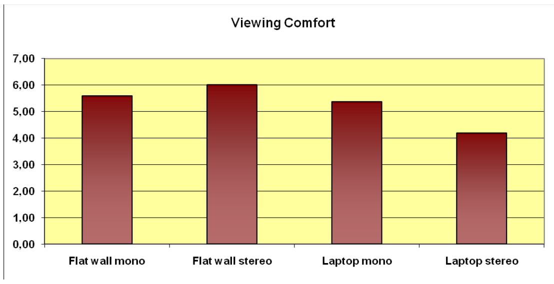
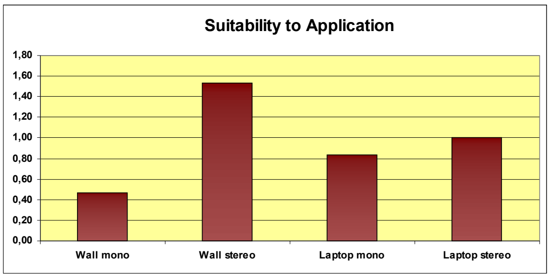


Figure 4.32: Viewing Comfort laser (left slide) vs video (right slide)

In both case, the Flat-Wall stereo was considered more suitable for a teledriving task which makes this facility very suitable for training activities.



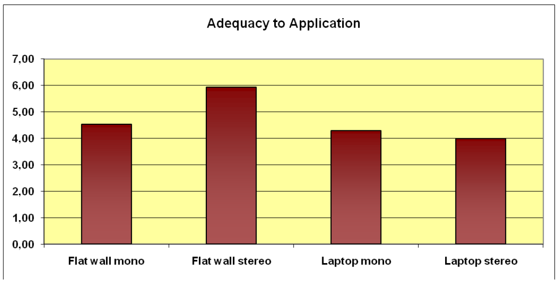
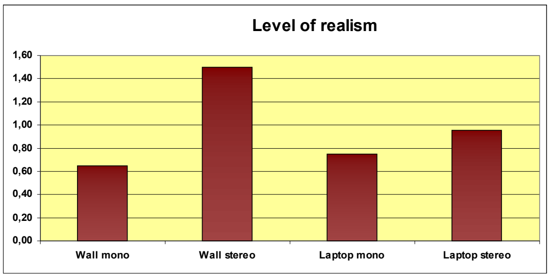


Figure 4.33: Adequacy to application laser (left slide) vs video (right slide)

In both cases, in case of stereo viewing both the impression of realism and the level of immersion were higher.

In the video based teleguide, a large screen improves the performance in relation to these parameters. This may due to the fact that large screens involve the peripheral vision areas more than a smaller screens. The performances in relation to these parameters in the laser based teleguide in the Flat-Wall stereo are better than the Laptop stereo



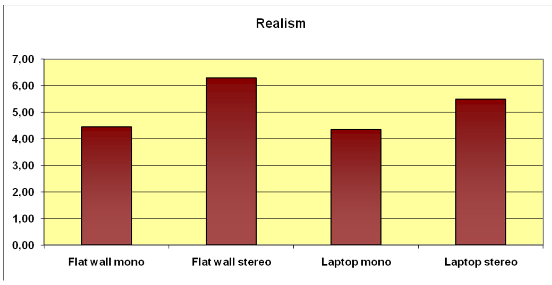


Figure 4.34: Realism laser (left slide) vs video (right slide)

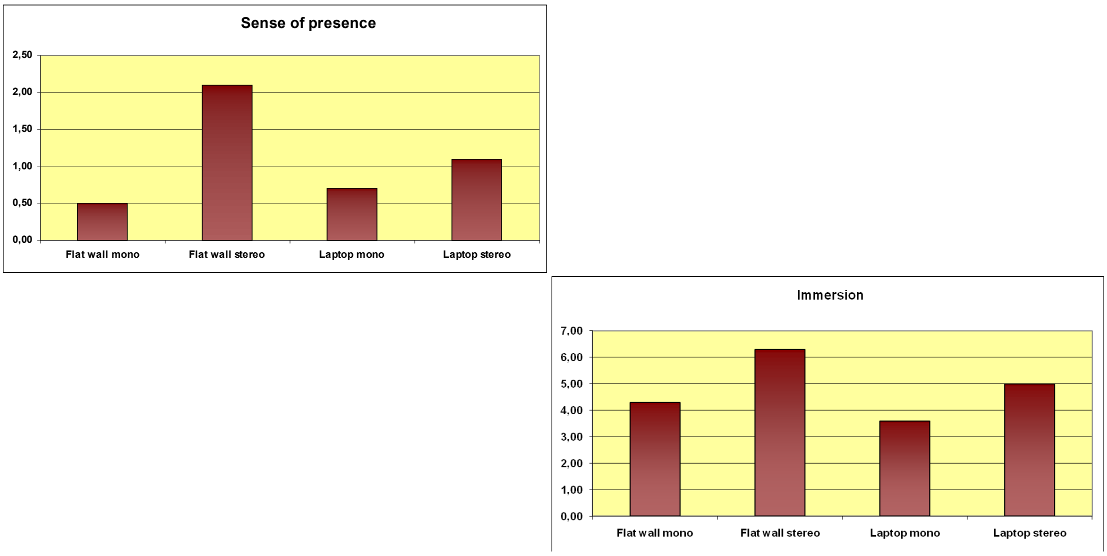


Figure 4.35: Immersion laser (left slide) vs video (right slide)

In both cases, the stereo visualization provided a stronger depth impression. Results are better in case of a larger screen.

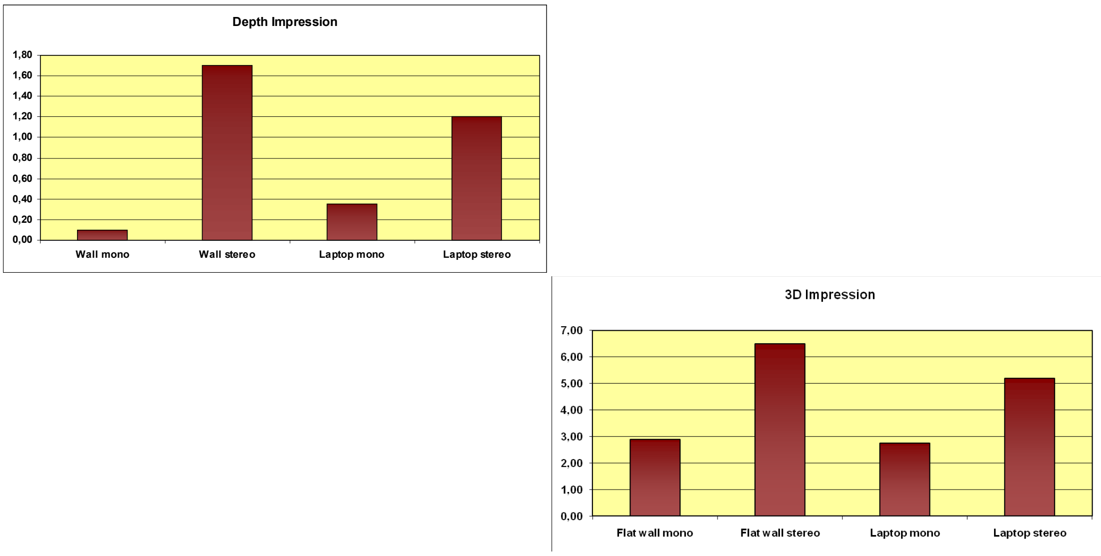


Figure 4.36: 3D Impression laser (left slide) vs video (right slide)

4.2.3 Simulator Laser vs Video

In the previous work has been made tests of the Video based teleguide and the Laser Based teleguide but the second of these only using a robot simulator. In this section the quantitative parameters coming from the data collected during the tasks and the qualitative parameters obtained from the questionnaires will be compared.

4.2.3.1 Quantitative analysis

Collisions

ANOVA

In the Laser simulator and in the Video based teleguide the Anova estimated in case of all mono versus all stereo showed a main effect of stereo viewing on the number of collisions per time unit because the stereoscopy helps in better perceiving of spatial localization. This characteristic is very important in interaction jobs to reduce the number of mistakes, which are caused by wrong estimations of distances. But in the laser simulator based teleguide the difference between mono and stereo is bigger than video.

Source	ss	df	MS	F	P
Columns	0,02391	1	0,02391	6,25	0,015
Error	0,20651	54	0,00382		
total	0,23042	55			

Source	ss	df	MS	F	P
Columns	0,00228	1	0,00228	4,99	0,0309
Error	0,01916	42	0,00046		
total	0,02143	43			

Table 4.9: The tables represent detail results for the one-way ANOVA estimated in case of "all mono versus all stereo" (1-table laser simulator and 2 table video).

The Anova estimated in case of mono versus stereo in the Laptop facility showed that by stereoscopic viewing the drivers avoid more collisions on both the teleguide but in the laser simulator the difference between mono and stereo is smaller than the video.

In the Laser based teleguide the improvement between mono and stereo visualization is greater with the wall system opposite to the Video based teleguide.

Source	ss	df	MS	F	P
Columns	0,00464	1	0,00464	1,07	0,31
Error	0,11307	26	0,00435		
total	0,11771	27			

Source	ss	df	MS	F	P
Columns	0,00013	1	0,00013	0,25	0,06
Error	0,02131	42	0,00051		
total	0,02143	43			

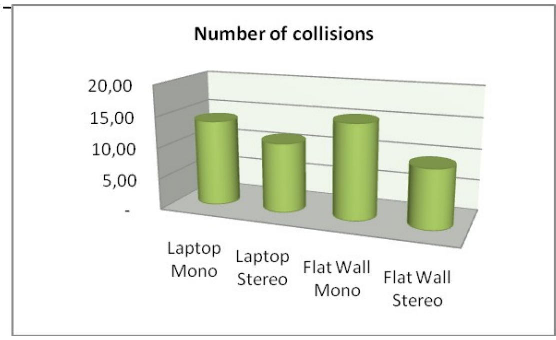
Table 4.10: The tables represent detail results for the one-way ANOVA estimated in case of "mono versus stereo in the Laptop facility" (1-table laser simulator and 2-table video).

Source	ss	df	MS	F	P
Columns	0,02267	1	0,02267	6,58	0,016
Error	0,08952	26	0,00344		
total	0,11219	27			

Source	ss	df	MS	F	P
Columns	0,00599	1	0,00599	5,73	0,025
Error	0,02299	22	0,00105		
total	0,02899	23			

Table 4.11: The tables represent detail results for the one-way ANOVA estimated in case of "mono versus stereo in the Wall facilities" (1-table laser simulator and 2-table video).

The Collisions Number is higher in case of monoscopic visualization in most of the cases. The advantage of stereo visualization compared to mono viewing in the video based teleguide is lower than the laser based case. The higher sense of depth provided by stereo viewing improves driving accuracy.



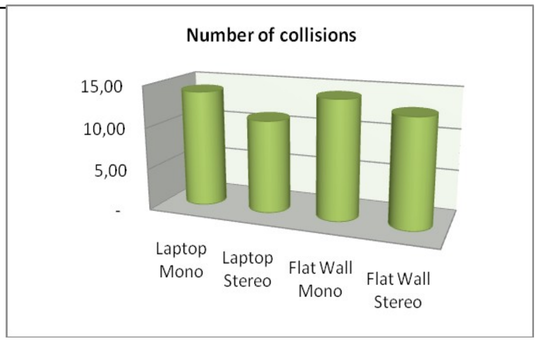
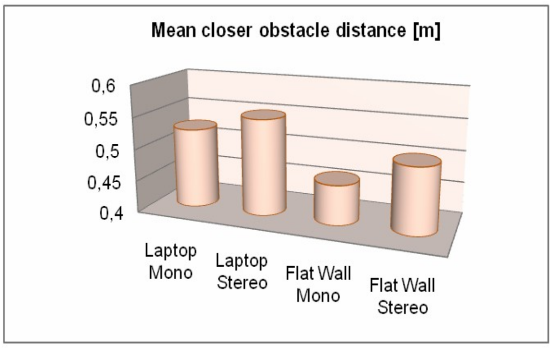


Figure 4.37: Number of collision laser simulator (left slide) vs video (right slide)

Mean Obstacle Distance

In the laser based teleguide the distances to obstacles are higher in case of stereoscopic viewing, this result is the same on both the facilities but this difference is bigger in case of the wall facility. In the video based teleguide in case of stereo viewing the user drives closer to an obstacle compared to mono viewing. In contrast with laser based teleguide the obstacles are in this case unfixed. Therefore a distance to an obstacle changed after a collision. This makes impossible to compare the laser and video based data.



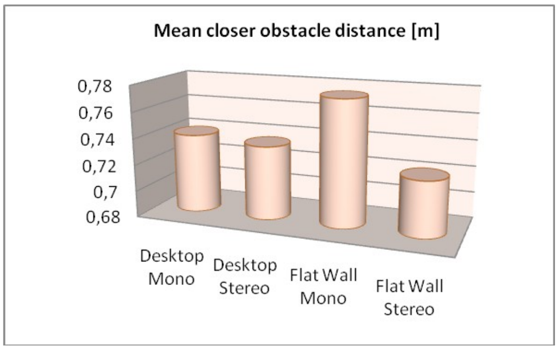


Figure 4.38: Mean closer obstacle distance laser simulator (left slide) vs video (right slide)

Execution Time

In the video based teleguide the mean time employed for a trial is greater in stereo visualization than the mono, this result is the same on both the facilities. The test participants have commented that the greater depth impression and sense of presence provided by stereoscopic viewing; make a user spending a longer time in looking around the environment and avoid collisions. In the laser based teleguide the execution time is lower in a large screen. In the same the time employed for a trial is longer in mono visualization. This because in the laser simulator teleguide the absence of network delay increases operation speed and possible advantages related to stereo visualization.

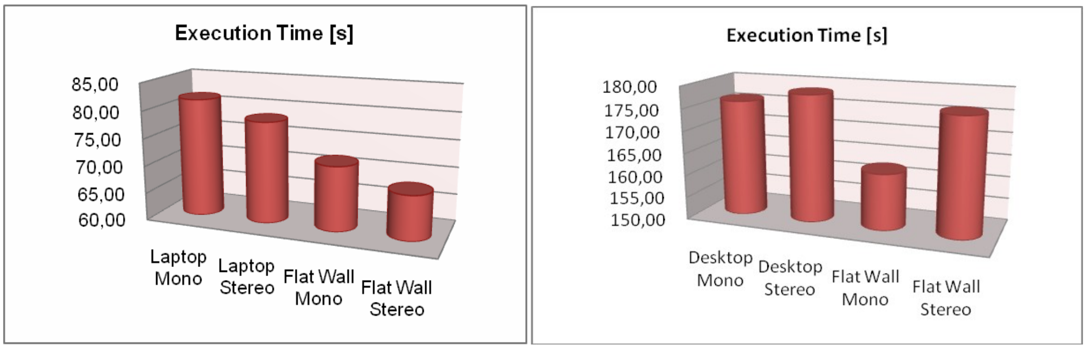


Figure 4.39: Execution time laser simulator (left slide) vs video (right slide)

Path Length

The path is always shorter in the stereo and the improvement of Flat-Wall in stereo compare to the Laptop stereo is statistical significant. In case of the Flat-Wall the stereo visualization technology (polarized stereo) is very comfortable, this leads to a better result in case of stereo viewing. While in case of the Desktop system, the proposed stereo technology is based on the Anaglyph which considerably reduces comfort.

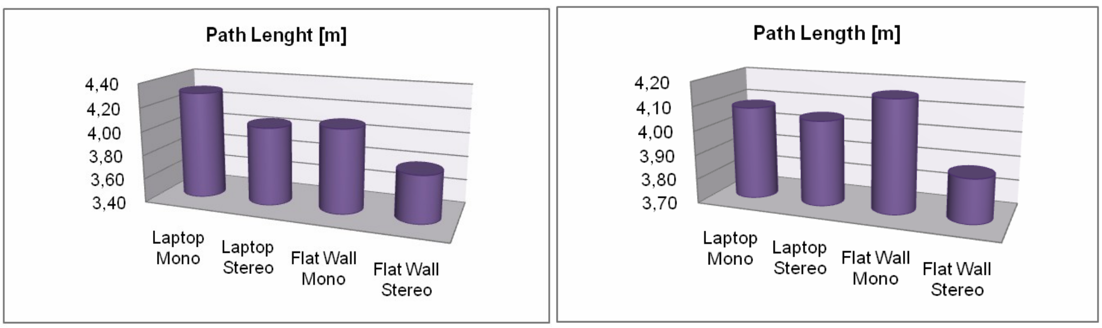
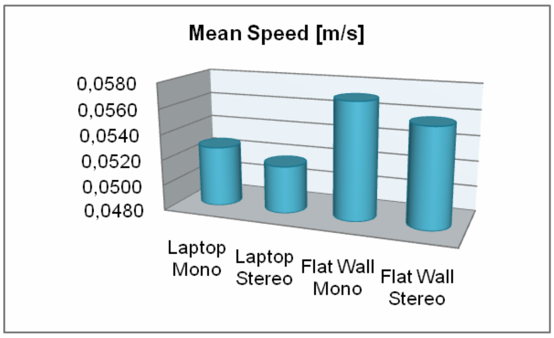


Figure 4.50: Path length laser simulator (left slide) vs video (right slide)

Mean Speed

The figure 4.51 shows a clear tendency in reducing speed in case of stereo viewing on both the displays and on both the teleguide.

In the laser based teleguide a large screen increases the mean speed due to higher presence. While in the video based teleguide a large screen increases the mean speed only in case of Flat-Wall mono. This is because the path length in Flat-Wall is smaller than the Flat-Wall mono.



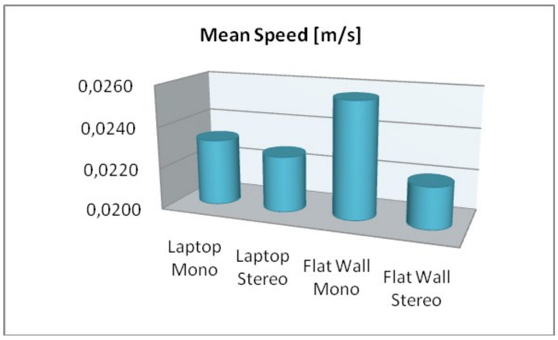
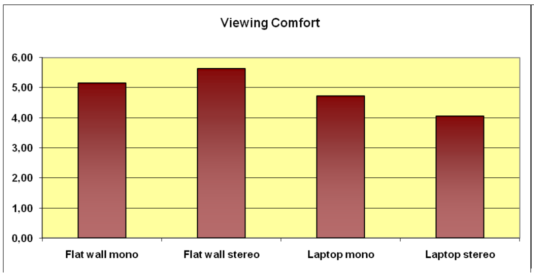


Figure 4.51: Mean speed laser simulator (left slide) vs video (right slide)

4.2.3.2 Qualitative analysis

The tables in figure 4.52 show that a higher comfort is perceived in case of the Flat-Wall compared to Laptop.

In both case, the Flat-Wall was considered more comfortable.



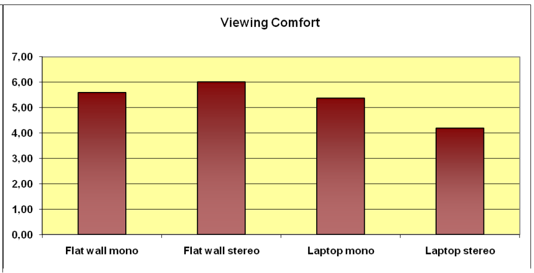


Figure 4.52: Viewing comfort laser simulator (left slide) vs video (right slide)

In both case, the Flat-Wall stereo was considered more suitable for a teledriving task which makes this facility very suitable for training activities.

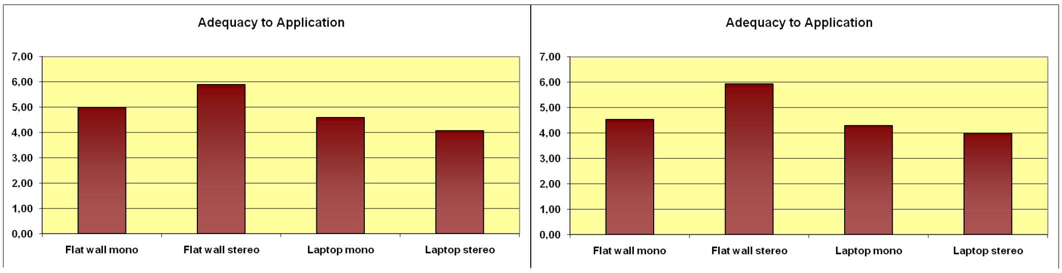


Figure 4.53: Adequacy to application laser simulator (left slide) vs video (right slide)

In both cases, in case of stereo viewing both the impression of realism and the level of immersion were higher.

A large screen improves the performance in relation to these parameters. This may due to the fact that large screens involve the peripheral vision areas more than a smaller screens.

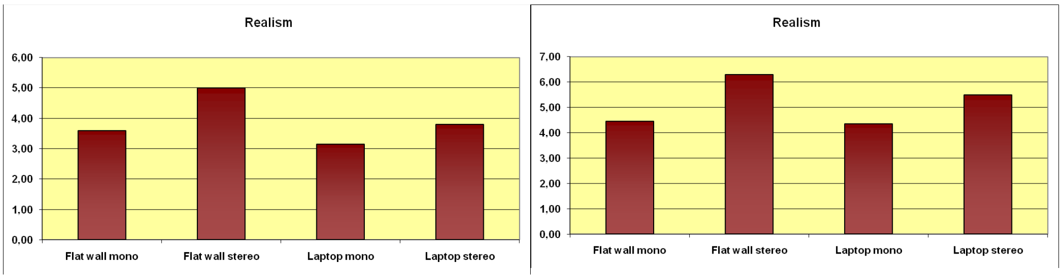


Figure 4.54: Realism laser simulator (left slide) vs video (right slide)

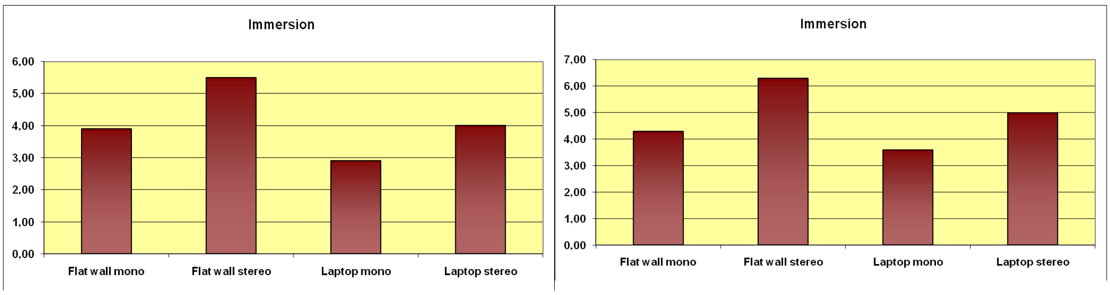


Figure 4.55: Immersion laser simulator (left slide) vs video (right slide)

In both case, the stereo visualization provided a stronger depth impression.

Results are better in case of a larger screen.

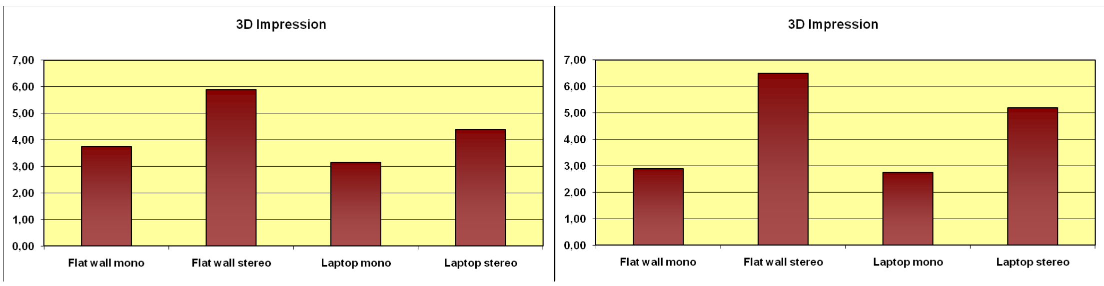


Figure 4.56: 3D Impression laser simulator (left slide) vs video (right slide)

4.2.4 Simulator Laser vs Laser

In the previous work has been made tests of the Simulator Laser based teleguide in this section the quantitative parameters coming from the data collected during the tasks and the qualitative parameters obtained from the questionnaires will be compared with the parameters of the Laser based teleguide.

4.2.4.1 Quantitative analysis

Collisions

ANOVA

The Anova estimated in case of all mono versus all stereo showed a main effect of stereo viewing on the number of collisions per time unit because the stereo support a more realistic navigation and the users drives with more accuracy to avoid the obstacles. But in the laser simulator based teleguide the difference between mono and stereo is bigger than real laser.

Source	ss	df	MS	F	P
Columns	0,02391	1	0,02391	6,25	0,015
Error	0,20651	54	0,00382		
total	0,23042	55			

Source	ss	df	MS	F	P
Columns	0,00942	1	0,00942	5,69	0,02
Error	0,07617	46	0,00166		
total	0,08559	47			

Table 4.10: The tables represent detail results for the one-way ANOVA estimated in case of "all mono versus all stereo" (1-table laser simulator and 2-table laser).

The Anova estimated in case of mono versus stereo in the Laptop facility showed that by stereoscopic viewing in the laser simulator the difference between mono and stereo is smaller than the real laser.

In the Laser simulator based teleguide the improvement between mono and stereo visualization is greater with the wall system opposite to the real laser based teleguide, this supports the test participants that have commented that in the Flat-Wall in Stereo is perceived a higher sense of depth, a greater sense of presence and a higher comfort.

Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,00464**	**1**	**0,00464**	**1,07**	**0,31**
Error	**0,11307**	**26**	**0,00435**		
total	**0,11771**	**27**			

Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,00358**	**1**	**0,00358**	**1,57**	**0,22**
Error	**0,05027**	**22**	**0,00228**		
total	**0,05385**	**23**			

Table 4.11: The tables represent detail results for the one-way ANOVA estimated in case of "mono versus stereo in the Laptop facility" (1-table laser simulator and laser).

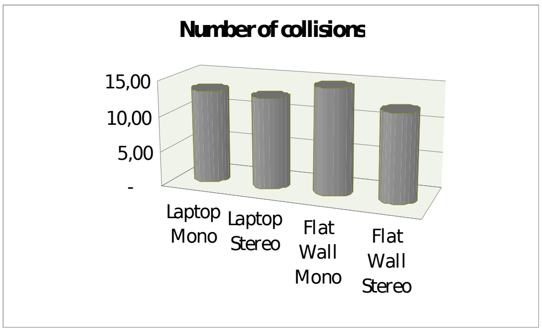
Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,02267**	**1**	**0,02267**	**6,58**	**0,016**
Error	**0,08952**	**26**	**0,00344**		
total	**0,11219**	**27**			

Source	**ss**	**df**	**MS**	**F**	**P**
Columns	**0,00599**	**1**	**0,00599**	**5,73**	**0,025**
Error	**0,02299**	**22**	**0,00105**		
total	**0,0289**	**2**			

	9	3			

Table 4.12: The tables represent detail results for the one-way ANOVA estimated in case of "mono versus stereo in the Wall facilities" (1-table laser simulator and 2-table laser).

The Collisions Number is higher in case of monoscopic visualization in most of the cases especially in the wall facility on both the case. The higher sense of depth provided by stereo viewing improves driving accuracy.



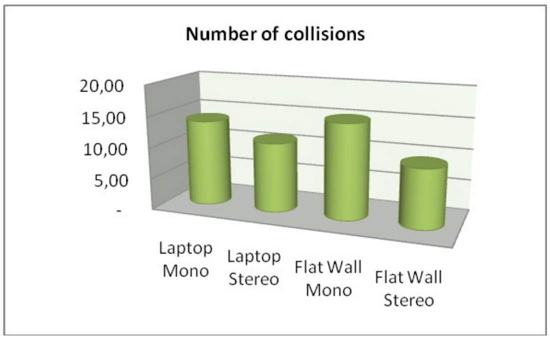
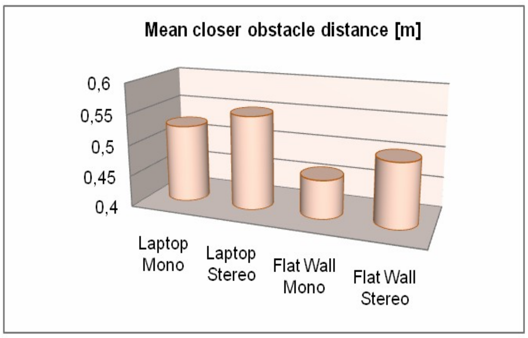


Figure 4.57: Number of collision laser simulator (left slide) vs laser (right slide)

Mean Obstacle Distance

The distances to obstacles are higher in case of stereoscopic viewing; this result is the same on both the facilities but this difference in bigger when they used the wall facility in the real teleguide. This result supports the conclusions gathered in case of collision measurements



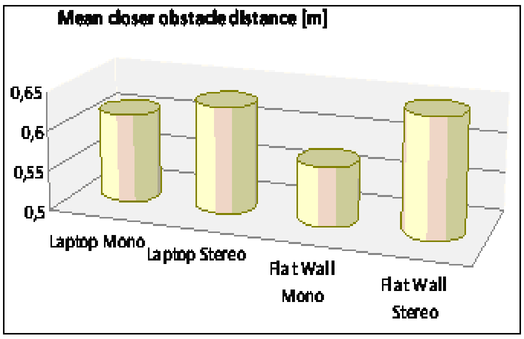


Figure 4.58: Mean obstacle distance laser simulator (left slide) vs laser (right slide)

Execution Time

In the laser based teleguide the mean time employed for a trial is greater in stereo visualization; this result is the same on both the facilities.

The test participants have commented that the greater depth impression and sense of presence provided by stereoscopic viewing in the laser based teleguide, make a user spending a longer time in looking around the environment and avoid collisions, but in the Wall facilities the difference between mono and stereo is smaller than Laptop one because is more natural drives the robot using the Wall facilities and the time that the user have spent looking around is recovered by the more security guide. While in the laser simulator based teleguide a large screen decreases the execution time and the time employed for a trial is longer in mono visualization, because in the laser simulator teleguide the network delay absence increases possible advantages related to stereo visualization and above all large screens.

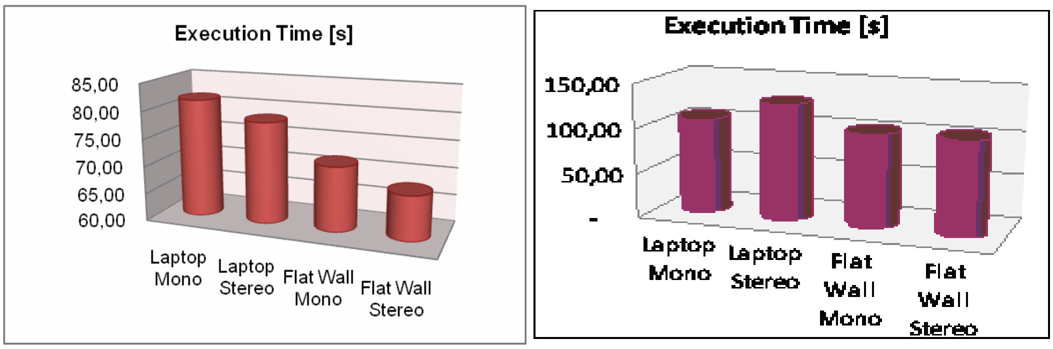


Figure 4.59: Execution time laser simulator (left slide) vs laser (right slide)

Path Length

In the laser simulator based teleguide the path is always shorter in the stereo and the improvement of Flat-Wall in stereo compare to the Laptop stereo is significant.

In the real laser based teleguide the path is shorter in the stereo Laptop display than the mono while in the Stereo Flat-Wall the path is longer than the mono because the stereo support a more realistic navigation and the users drives with more accuracy to avoid collisions hence the distances to obstacles are higher and the paths followed are longer than the mono.

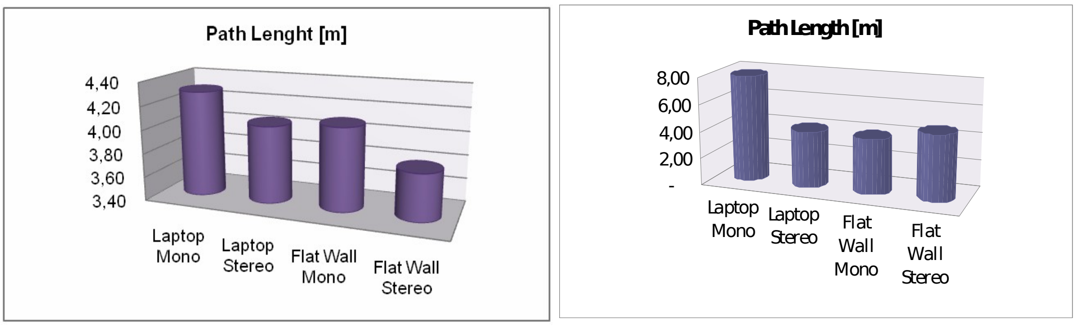


Figure 4.60: Path length laser simulator (left slide) vs laser (right slide)

Mean Speed

In the real laser based teleguide the speed is smaller in case of stereo viewing in Laptop facility and the speed is smaller in case of mono viewing in wall facility.

In the real laser based teleguide in the Flat-Wall in stereo the speed isn't smaller than the wall mono because

Speed=path length/execution time

and in the stereo the paths are longer than the mono.

Instead in the laser simulator based teleguide the speed is smaller in case of stereo viewing on both the display systems because in the Video based Teleguide there isn't significant difference between the use of different displays.

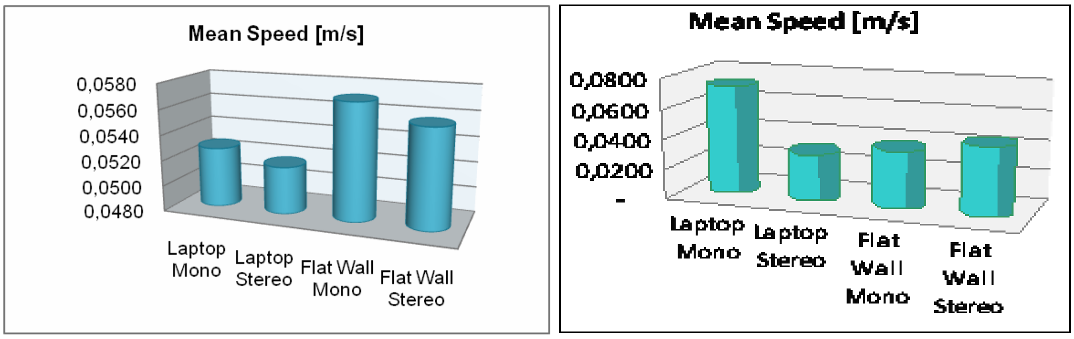


Figure 4.61: Mean speed Laser simulator (left slide) vs laser (right slide)

4.2.4.2 Qualitative analysis

Flat- Wall compared to Laptop. The mean values in Figure 4.62 also show an opposite tendency between the two facilities in terms of stereo versus mono previously commented.

In both case, the Flat-Wall was considered more comfortable.

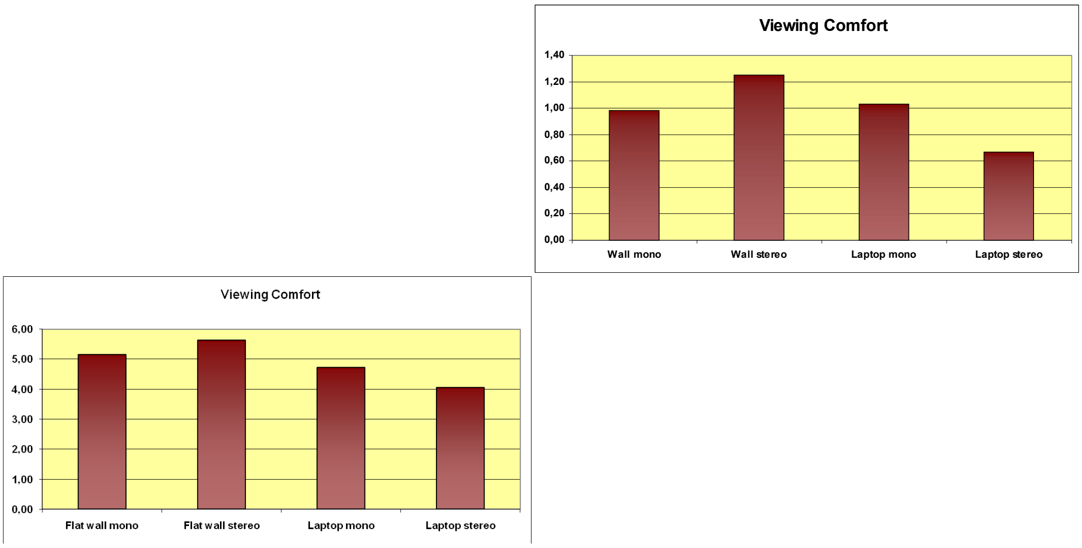
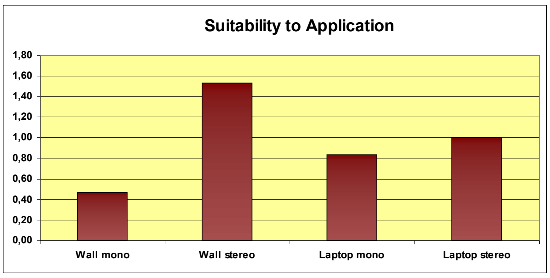


Figure 4.62: Viewing comfort Laser simulator (left slide) vs laser (right slide)

In both case, the Flat-Wall stereo was considered more suitable for a teledriving task which makes this facility very suitable for training activities



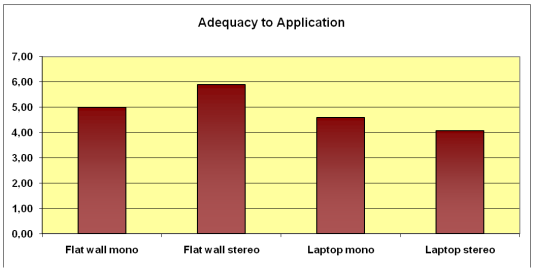
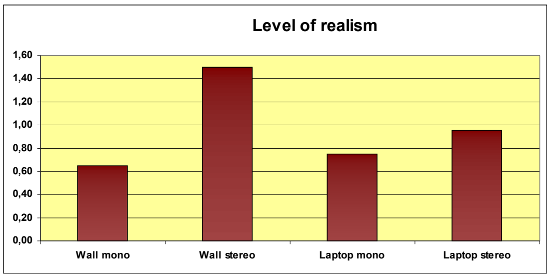


Figure 4.63: Adequacy to application (laser simulator vs stereo)

In both cases, in case of stereo viewing both the impression of realism and the level of immersion were higher.

A large screen improves the performance in relation to these parameters. This may due to the fact that large screens involve the peripheral vision areas more than a smaller screens.



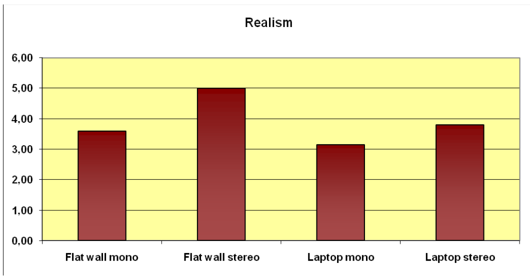


Figure 4.64: Realism laser simulator (left slide) vs laser (right slide)

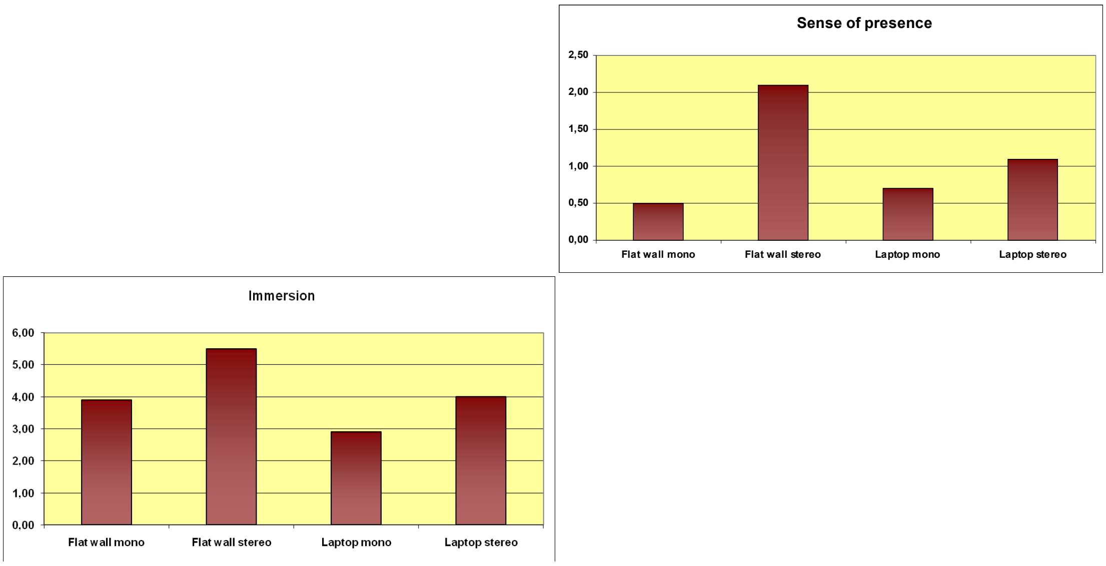


Figure 4.65: Immersion laser simulator (left slide) vs laser (right slide)

In both case, the stereo visualization provided a stronger depth impression. Results are better in case of a larger screen.

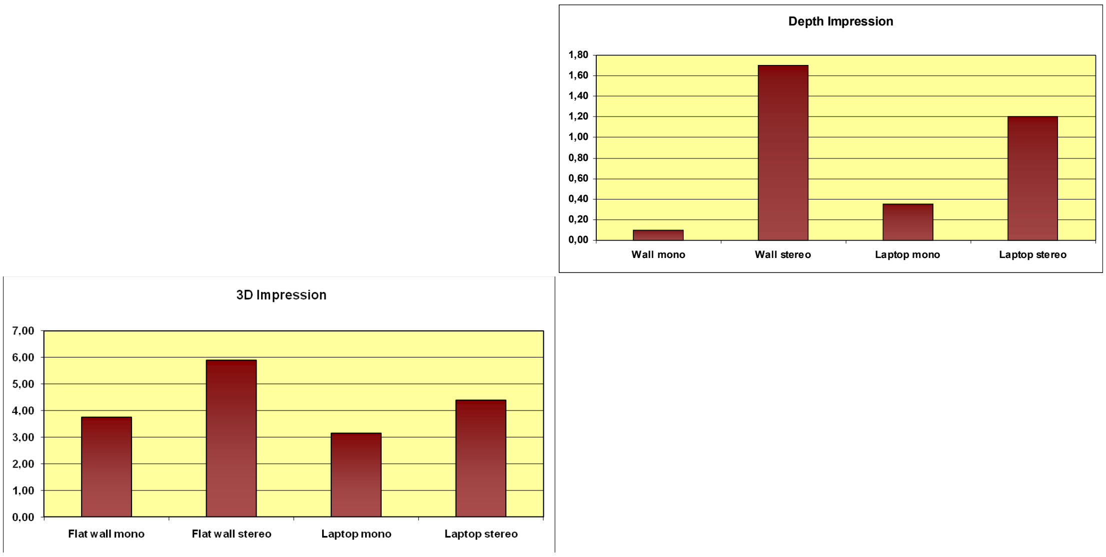


Figure 4.66: 3D Impression laser simulator (left slide) vs laser (right slide)

Resuming the previous results we can say, that:

- The qualitative analysis shows that the testers in the Laser based teleguide consider more comfortable and suitable the Stereo Flat-Wall facility these results agree with the quantitative results. In particularly the Collisions Number in this case are lower and the distances to obstacles are higher. About a level of realism, sence of presence, immersion and 3D impression are higher in the Stereo Flat-Wall, therefore the users keep higher distance from obstacles.
- Comparing laser and video based teleguide, we have found that in both modality the stereo visualization improve user's drive performance in term of better

evaluating distances between the robot and the obstacles, then the number of collisions is lower, especially in the laser modality. Indeed in the laser teleguide the virtual environment is simpler than the real environment. Furthermore in the laser teleguide these improvements are clearer in the FlatWall. This may due to the fact that large screens involve the peripheral vision areas more than a smaller screens. In the Laptop facilities laser based teleguide the user has difficulty to perceive the spatial localization then the path is very long.

- Comparing laser simulator and video based teleguide we have seen that the number of collisions in the laser simulator teleguide is lower than the video teleguide and in particularly the performance in the stereo modality are better than the mono. But in the Laser based teleguide the improvement between mono and stereo visualization is greater with the wall system opposite to the Video based teleguide. This because in the laser simulator teleguide there isn't network delay.
- Moreover we have found that in the laser simulator based teleguide results relative to number of collision and distances to obstacles have the same trend of the real laser based teleguide. Instead in the time of execution and in the path length we can see some differences because in the laser simulator teleguide the network delay absence increases possible advantages related to stereo visualization and above all large screens.

Finally we have seen that the qualitative results agree with the objective parameters obtaining through the analysis of the Log files

Conclusion

This work developed in Denmark, it is a continuation of previous works done by Students at Aalborg University. We studied the teleguide of a mobile robot. The user can remotely drives the robot relying on visual feedback. The feedback is computer generated, based on 2D maps constructed by the on-board laser sensor.
A number of test trials were performed in order to control, via Internet, the mobile robotic platform 3MO.R.D.U.C. located at the robotics lab of the University of Catania, in Italy.
The test users were sitting on different 3D facilities at the Aalborg University.
The experiments involved only 12 test users. This due to the fact that the time test is 45 min, we had problems with the robot's battery and was needed coordination with the remote assistance.
The results of the performed test involving synthetic telepresence (laser based) were presented and discussed. Furthermore these results were compared with the results of previous work. Few conclusions were drawn. The obtained results of the laser based teleguide showed an improvement in user's performance when stereoscopic viewing was adopted. 3D vision guarantees a major precision in the teleguide and good performances on the obstacles avoidance.
The compared results between Laser and Video based teleguide showed improve task performance when we used the synthetic teleguide. These results demonstrated the advantage of a limited network delay.
Finally we have found that in the laser simulator based teleguide some results have the same trends of the real laser based teleguide.
In the feature we want superimpose to the laser based teleguide some other information extract from the video based teleguide to combine the two different modalities. In this way the advantage of the two different modalities could be summed.

Appendix A

Aalborg University Copenhagen

“Robot Teledriving”

Researcher	Valentina Neri	**Supervisor**	Salvatore Livatino

In recent years, applications that allow a user to interact with a computer-simulated environment – also known as virtual reality applications – started to be used more commonly. Nevertheless the full potential of this technology has not been entirely explored by now. One possible application of virtual reality devices could be robot teleguiding, i.e. remotely driving a robot.

In order to get more information regarding the benefit of stereo visualization and large displays for telerobotics applications, a user study is conducted at Aalborg University Copenhagen.

This research is being undertaken as part of our master’s and exchange program at Aalborg University Copenhagen. Volunteers are being sought to participate in this research study. The study consists of four main parts. Firstly, the participants will be given some trial tasks to become familiar with the different virtual reality devices and the driving of the robot. Afterwards the volunteers will be asked to complete a navigation task in a maze. In order to reach the goal, they have to drive a robot. After each driving task on each device, the users will be given a questionnaire, asking specific details about their experience. There will be short breaks between the different tasks.

Finally, they will be given an overall questionnaire asking their preferences (preferred device) and some demographic information. The main goal of this study is to distinguish the optimal conditions for robot teleguiding. During the user study the researchers will be at the participants’ disposal.

Each participant can withdraw from the research at any time without consequence. The study is expected to take approximately 45 minutes to complete. All user testing will take place at the facilities of the Aalborg University Copenhagen. Participation in this user study is voluntary and will not affect the participants’ studies or results in courses that they are currently undertaking.

For more detailed information please refer to the researchers:

Valentina Neri

Appendix B

Questionnaire

"Robot Teledriving"

User Study

The purpose of this questionnaire is to get to know your impressions of the movies you just saw. Please respond to the questions in a candid fashion. All the information you provide is confidential and will remain anonymous. The information you provide will not be used for any other purpose.

1) How comfortable did you feel during this test?

Powerwall mono	very comfortable	3	2	1	0	1	2	3	not comfortable
Powerwall stereo	very comfortable	3	2	1	0	1	2	3	not comfortable
Desktop mono	very comfortable	3	2	1	0	1	2	3	not comfortable
Desktop stereo	very comfortable	3	2	1	0	1	2	3	not comfortable

2) How much did you like driving the robot?

Powerwall mono	liked it a lot	3	2	1	0	1	2	3	did not like it at all
Powerwall stereo	liked it a lot	3	2	1	0	1	2	3	did not like it at all
Desktop mono	liked it a lot	3	2	1	0	1	2	3	did not like it at all
Desktop stereo	liked it a lot	3	2	1	0	1	2	3	did not like it at all

3) How long could you be driving this system?

Powerwall mono	very long	3	2	1	0	1	2	3	not long
Powerwall stereo	very long	3	2	1	0	1	2	3	not long
Desktop mono	very long	3	2	1	0	1	2	3	not long
Desktop stereo	very long	3	2	1	0	1	2	3	not long

4) Do you feel dizzy?

Powerwall mono	no, not at all	3	2	1	0	1	2	3	yes, a lot
Powerwall stereo	no, not at all	3	2	1	0	1	2	3	yes, a lot
Desktop mono	no, not at all	3	2	1	0	1	2	3	yes, a lot
Desktop stereo	no, not at all	3	2	1	0	1	2	3	yes, a lot

5) Do you feel strain in your eyes?

Powerwall mono	no, not at all	3	2	1	0	1	2	3	yes, a lot
Powerwall stereo	no, not at all	3	2	1	0	1	2	3	yes, a lot
Desktop mono	no, not at all	3	2	1	0	1	2	3	yes, a lot
Desktop stereo	no, not at all	3	2	1	0	1	2	3	yes, a lot

6) **How suitable is this system for telerobotics?**

Powerwall mono	very suitable	3	2	1	0	1	2	3	not suitable
Powerwall stereo	very suitable	3	2	1	0	1	2	3	not suitable
Desktop mono	very suitable	3	2	1	0	1	2	3	not suitable

Desktop stereo	very suitable	3	2	1	0	1	2	3	not suitable

7) How strong was the 3D impression?

Powerwall mono	very strong	3	2	1	0	1	2	3	not strong
Powerwall stereo	very strong	3	2	1	0	1	2	3	not strong
Desktop mono	very strong	3	2	1	0	1	2	3	not strong
Desktop stereo	very strong	3	2	1	0	1	2	3	not strong

8) Was the field of view good enough?

Powerwall mono	very good	3	2	1	0	1	2	3	very bad
Powerwall stereo	very good	3	2	1	0	1	2	3	very bad
Desktop mono	very good	3	2	1	0	1	2	3	very bad
Desktop stereo	very good	3	2	1	0	1	2	3	very bad

9) How realistic was the depth of the objects?

Powerwall mono	very realistic	3	2	1	0	1	2	3	not realistic
Powerwall stereo	very realistic	3	2	1	0	1	2	3	not realistic
Desktop mono	very realistic	3	2	1	0	1	2	3	not realistic
Desktop stereo	very realistic	3	2	1	0	1	2	3	not realistic

10) How immersed did you feel (Did you feel that you where actually standing in the application)?

Powerwall mono	very immersed	3	2	1	0	1	2	3	not immersed at all
Powerwall stereo	very immersed	3	2	1	0	1	2	3	not immersed at all
Desktop mono	very immersed	3	2	1	0	1	2	3	not immersed at all
Desktop stereo	very immersed	3	2	1	0	1	2	3	not immersed at all

11) How realistic is the environment?

Powerwall mono	very realistic	3	2	1	0	1	2	3	not realistic
Powerwall stereo	very realistic	3	2	1	0	1	2	3	not realistic
Desktop mono	very realistic	3	2	1	0	1	2	3	not realistic
Desktop stereo	very realistic	3	2	1	0	1	2	3	not realistic

12) How natural is the depth impression?

Powerwall mono	very natural	3	2	1	0	1	2	3	unnatural
Powerwall stereo	very natural	3	2	1	0	1	2	3	unnatural
Desktop mono	very natural	3	2	1	0	1	2	3	unnatural
Desktop stereo	very natural	3	2	1	0	1	2	3	unnatural

13) How natural was the driving?

Powerwall mono	very natural	3	2	1	0	1	2	3	Unnatural
Powerwall stereo	very natural	3	2	1	0	1	2	3	Unnatural
Desktop mono	very natural	3	2	1	0	1	2	3	Unnatural
Desktop stereo	very natural	3	2	1	0	1	2	3	Unnatural

14) Was the visual blind spot between the robot and the visible area disturbing?

Powerwall mono	not disturbing	3	2	1	0	1	2	3	very disturbing
Powerwall stereo	not disturbing	3	2	1	0	1	2	3	very disturbing
Desktop mono	not disturbing	3	2	1	0	1	2	3	very disturbing
Desktop stereo	not disturbing	3	2	1	0	1	2	3	very disturbing

Appendix C

Background-Questionnaire

"Robot Teledriving"

User Study

Thank you for participating in the user study.

The purpose of this questionnaire is to get to know your overall satisfaction with the user study and the devices you just tested. Furthermore we want to collect some demographic data about our participants. Please respond to the questions in a candid fashion. All the information you provide is confidential and will remain anonymous. The information you provide will not be used for any other purpose.

1) **Please rank the devices that you just tested from 1 to 4. The device you liked most should be ranked 1, the device you liked least should be ranked 4. Please only use each number just once.**

___ Powerwall mono

___ Powerwall stereo

___ Desktop mono

___ Desktop stereo

Please explain, why you ranked the devices this way

____

____

____

2) **When using the different Virtual Reality devices, which one made you feel most immersed?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

3) **When using the different Virtual Reality devices, where did you experience the highest viewing comfort?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

4) **When using the different Virtual Reality devices, which one seemed to be most realistic?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

5) **In which case did you perceive the obstacles to be most realistic?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

6) In which case was the depth perception most realistic?

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

7) When using the different Virtual Reality devices, which one seemed to provide the best 3D impression?

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

8) **In which case did you experience the highest physical comfort?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

9) **Which case was most natural concerning the driving?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

10) **In which case was it easiest to orient yourself?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

11) **In which case was best concerning the obstacle avoidance?**

☐ Powerwall mono ☐ Powerwall stereo ☐ Desktop mono ☐ Desktop stereo

12) Do you prefer mono or stereo visualization?

☐ mono visualization ☐ stereo visualization

13) Do you think that 3D impression is important?

☐ yes, it is important ☐ no, it is <u>not</u> important

14) **Have you participated in user studies before?**

☐ yes ☐ no

if yes, in how many user studies did you participate? ______

if yes, Have you participated in user studies concerning Virtual Reality?

☐ yes ☐ no

15) What is your gender?
☐ male ☐ female

16) How old are you?
______ years

17) Are you wearing glasses or contact lenses?
☐ glasses ☐ contact lenses ☐ neither

18) **Do you have any visual impairments (e.g. color blindness)?**
☐ yes ☐ no

19) **Which is your highest finished educational level?**
☐ Primary School ☐ High School ☐ Apprenticeship or trade qualification

☐ University

if you have ticked University please tell us your exact level of (finished) education

☐ undergraduate student (BSc) ☐ graduate student (MSc) ☐ Ph.D

20) Are you working or are you a student?
☐ working ☐ student ☐ both

21) How long have you been using computers?
______ ☐ years

22) How many hours a week are you using computers?
______ hours

23) Have you been using Virtual Reality devices before?
☐ yes ☐ no

if yes, please tell us for how long you have been using them

(please enter a number and tick years, months or weeks)

____ □ years □ months □ weeks

24) Are you playing Computer Games?

□ yes □ no

if yes, please tell us how often you play

____ hours a week

25) Which operating systems are you using?

□ Microsoft Windows □ Linux/Unix □ Mac OS

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