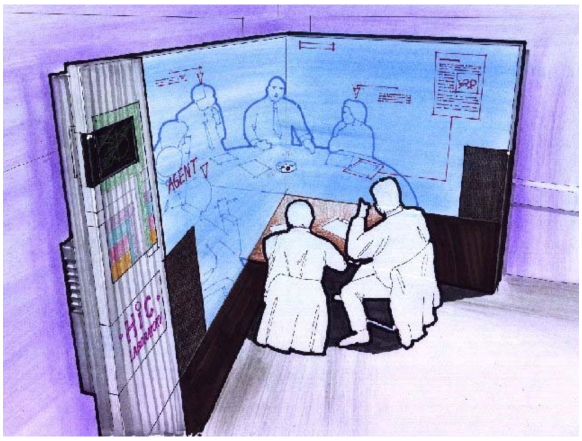
VIRTUE

VIRtual Team User Environment



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Project Title: VIRTUE - VIRtual Team User Environment
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Consortium Partners:

Partner code	Partner name	Short name (as on M1 form)
1	British Telecommunications	BT
2	Heinrich-Hertz-Institut	HHI
3	Sony UK Ltd	Sony
4	Technical University Delft	TUD
5	TNO Centrale Organisatie	TNO
6	Heriot-Watt University	HWU

CONTENTS

1. Introduction

1.1. Preamble

This document is the final report describing progress made with the VIRTUE project. The project commenced at the beginning of 2000 and finished at the end of March 2003. The original intention had been to complete the project at the end of 2002, but it was agreed to extend work by 3 months to benefit from additional publicity CEBIT in March 2003 and to enable further tuning of the final demonstrator to be completed.

1.2. Primary Objectives

The primary objectives were to:

- To develop the innovative technology necessary to produce a convincing impression of presence in a semi-immersive teleconferencing system.
- To integrate and demonstrate a telepresence system incorporating such innovative techniques.
- To investigate the human factors involved in maximising the effectiveness and realism of telepresence, and to use them to drive the design of the system.

1.3. Specific Technology Objectives

Specific technology objectives were to provide efficient and practical solutions to the critical issues for which no current feasible approaches were available, including:

- ***Realistic wide view synthesis for dynamic scenes****:* For a person to appear real and live inside a display, a fast rendering of the moving person's head and upper body from unseen viewpoints was required. This could be achieved without reconstructing a full 3-D model. Instead, the information provided by multiple cameras could be exploited to synthesise new views for a range of viewpoints of other participants. This would be further combined with novel strategies to combat occlusions in the scene, typically created by gestures, e.g. waving a hand in front of one's body. Strategies to be investigated included combining image-based rendering with fast rendering of 3D models of moving body parts including held objects.
- ***Object-based segmentation and motion tracking****:* Robust real-time spatial-temporal object segmentation and motion analysis techniques were to be investigated for object segmentation from an arbitrary office background and tracking different parts of the body based on motion. Object-based segmentation would be combined with disparity estimation to refine segmentation and depth analysis results.
- ***Flexible camera setup****:* An important aspect of VIRTUE was the independence of the system from the camera and display configuration. To allow for a flexible multi-camera set up, registration of camera images was required. Techniques that employed two-view and three-view geometrical constraints would be most important.
- ***Multiple Sensor Fusion***: To produce an efficient representation of the reflectance and depth information extracted from multiple camera views which would be suitable for compression and transmission through the systems layer protocol and for deterministic rendering of arbitrary angles of view at the receiving equipment.

1.4. Specific demonstrator objectives

An advanced real-time demonstration system would be designed and constructed aimed at a 3-way telepresence video conferencing system supporting life-sized upper body video images in a shared virtual environment. The main objectives of the demonstrator were as follows:

- The video would be analysed and rendered at a rate of at least 25 frames per second.
- The 2D display would be mechanically integrated with a real desk, which seamlessly merged into the virtual desk on the display.
- The system would enable eye-to-eye contact, spatial awareness, directed body language and

motion parallax.
- Video streams of a participant would be captured with a multi-camera arrangement allowing a 3D analysis of the scene and tracking of the viewer's head.
- Two remote communication partners would be placed in an integrated visual environment at the same virtual table.
- The demonstrator would include complete spatially dependent audio communication.
- Audio and video would be synchronised to maintain lip synchronisation.
- To conclude the project, a final demonstration virtual meeting would take place across three locations.

1.5. Specific Human Factor Studies Objectives

Specific human factor studies objectives would take user acceptance into consideration from the outset by a continuous line of studies:
- To investigate the effectiveness and unique functionality of a computer-mediated collaborative working system with particular emphasis on the new features and power that a true visually immersive presence such as VIRTUE could bring about.
- A comparative study of a multi-party face-to-face meeting with computer-mediated emerging media and the design of specific tasks to assess the issue of user acceptance in the light of social interactions.
- To incorporate experimental results and requirements into the design of VIRTUE, and improve the possibility of overall system success.
- To promote methodologies and approaches developed in VIRTUE as future standards for assessing telepresence collaborative working systems - with minimum and optimum features related to the tasks and objectives for particular types of conferences.

2. Organisation Of The Project Into Workpackages

The project consisted of five work packages (WPs) defined below. The division between work packages was chosen to group the appropriate combination skill types required to implement the work. Work was progressed using milestones and Deliverables (See Section 3)

WP1; Algorithms (HWU/TUD): The scope of this WP was:
- To identify, research, specify and implement working prototypes of vision and rendering algorithms (modules) matching project requirements.
- To assess the performance of the implemented algorithms and enhance where necessary.

WP2; Real-time Platform (HHI): The scope of this WP was:
- To research and develop an efficient, scalable and modular real-time implementation of the vision and rendering algorithms, porting and further optimising modules developed in the algorithms work package suitable for integration into the complete system.

WP3; System (Sony/BT): The scope of this WP was:
- To research, specify, build and integrate system layer components. This work package included all facilities required to produce an end-to-end demonstrator except the vision and rendering modules defined in the real-time work package.

WP4; Human Factors (TNO): The scope of this WP was:
- To take user acceptance into consideration from the outset by a continuous line of human

factors studies. The proposed research result would be an empirically validated demonstrator (with respect to human factors issues) with the potential for building trust and getting commitment from team members.

WP5; Management (BT): The scope of this WP was:

- To control and manage of the projects progress, as well as the planning of publicity, publication, and dissemination activities.

3. Progress Made Against Milestones And Deliverables

Ref:	Deliverable	Date due	Status
D01	Requirements Specification Document	April 1st	Completed and issued 17/4/00.
D02	Systems layer design document and MPEG4 review.	Month 6 30/6/00	Completed and issued 12/7/00.
D03	Vision and rendering platform architecture document.	Month 8 31/8/00	Completed and issued 7/9/00.
D04	Research report describing the algorithm review including calibration, rectification, segmentation, disparity estimation, depth map combination strategy, head position tracker and rendering.	Month 10 31/10/00	Completed and issued 16/11/00
D05	Working software for the rendering algorithm optimised to run on the target hardware. Documentation and performance assessments.	Month 16 30/4/00	Completed and documentation issued, 7/5/01.
D06	Demonstration of platform for view rendering and head position tracking.	Month 21 30/9/01	Completed and demonstrated at IST 2001.
D07	Working software for the vision algorithm optimised to run on the target hardware. Documentation and performance assessments.	Month 22 30/10/01	Completed and documentation issued 17/10/2001.
D08	Complete systems software, hardware and documentation.	Month 24	Completed and documentation issued 22/02/2002.
D09	Final research report on human factors experiments.	Month 24	Completed and documentation issued 01/03/2002.
D10	Demonstration of complete system.	Month 36	Completed (2D) with CEBIT demonstration 12/03/2003
D11	Future algorithms research report.	Month 36	Completed and documentation issued 21/03/2003.

Ref:	Deliverable	Date due	Status
D12	Report on Human Factors assessment of the complete system.	Month 36	Completed and documentation issued 30/12/2002.
D13	Quality plan.	Month 3 31/3/00	Revised and re-issued 12/03/2002.
D14	Dissemination and use plan	Month 36	Completed and documentation issued 08/04/2003
D15	Project presentation.	Month 3 31/3/00	Completed – on VIRTUE website March 2000.
D16	Input to standards bodies.	Month 36	Completed and documentation issued 30/12/2002.

Ref:	Milestone	Date due	Status
WP5 – MS1	Initial meeting	Month 1	Completed February 2000.
WP5 – MS2	Web site set-up	Month 2	Completed February 2000.
WP4-MS1	Requirement Specification Document	Month 3	Completed Apr. 2000.
WP5 – MS4	Quality Plan	Month 3	Completed May 2000.
WP3 – MS1	Design documents complete	Month 7	Completed July 2000.
WP5-MS3	Audio conferencing tools set up	Month 8	Completed Oct. 2001.
WP4-MS2	Spatial audio experiments complete	Month 9	Completed Apr. 2000
WP1 – MS1	Research report(s) see D04	Month 10	Completed Nov. 2000.
WP4-MS4	Task environment for experiments	Month 11	Completed Dec. 2000
WP4-MS5	Prototype system for HF experiments	Month 12	Completed Jan. 2001

Ref:	Milestone/Deliverable	Date due	Status
WP3-MS4	Design and Construction of Prototype desk and display.	Month 13	Completed Jan. 2001
WP3-MS2	Synthetic Elements. Implementation complete.	Month 15 31/3/01	Completed Mar. 2001
WP3-MS3	Compositor. Implementation complete.	Month 15 31/3/01	Completed Apr. 2001
WP1-MS2	Optimised rendering algorithm available.	Month 15 31/3/01	Completed May 2001
WP2-MS1	A description of the hardware architecture including interfaces between the components	Month 15 31/3/01	Completed May 2001
WP4-MS3	Experiments complete on the effects of a shared virtual background and on social asymmetry.	Month 18 30/6/01	Completed June 2001.
WP4-MS6	Selective gaze experiments complete.	Month 18 30/6/01	Completed December 2001.
WP4-MS7	Delays/synchronisation experiments complete.	Month 19 30/7/01	Completed December 2001.
WP2-MS2	A prototype of the view rendering real-time platform is available to enable simulation tests on the receiver side.	Month 21 30/9/01	Completed October 2001.
WP3-MS5	Demonstrator of dynamic view rendering and head position tracking.	Month 22	Completed October 2001.
WP4-MS8	Experiments complete on the value of stereoscopic visualisation and motion parallax.	Month 22 30/10/01	Completed December 2001.
WP4-MS9	Pilot Long term adaptation experiments complete.	Month 23	Completed August 2002.
WP1-MS3	Optimised vision algorithms available.	Month 24 31/12/01	Completed October 2001.
WP3-MS6	Compression algorithms. Implementation complete.	Month 24	Completed March 2002.
WP3-MS7	Delivery Layer (networking). Implementation complete.	Month 24	Completed May 2002.
WP4-MS10	HF Experiments complete.	Month 24	Completed February 2002.
WP2 - MS3	A prototype of the platform for segmentation, 3D analysis and motion tracking is available.	Month 28	Completed October 2002.
WP3-MS8	Complete system integrated (2D; CEBIT)	Month 33	Completed March 2003

Ref:	Milestone/Deliverable	Date due	Status
WP1-MS4	Research report(s) on algorithm improvements.	Month 36	Completed March 2003
WP5-MS6	Exploitation plan produced	Month 36	Completed April 2002
WP4-MS11	Assessment of final system complete.	Month 36	Completed December 2002.
WP5-MS5	Meeting of the PMC	Month 1, 6, 12, 18, 24, 30, 36	Month 1, 6 &12, 18, 21, 27 and 33 PMC held. Completed.

4. Project Achievements

4.1. Introduction

Progress made has been grouped under the individual Workpackages responsible for the work undertaken. However, as the project progressed, collaboration tended to cross Workpackage boundaries so that achievements described under one Workpackage may have involved participation with others.

4.2. WP1: Algorithms (HWU/TUD)

The definition of software architecture and specified techniques through experimental feasibility studies was completed. Additional algorithmic requirements needed to meet performance needs were identified. There was close interaction with the Real-Time workpackage to define real-time architecture. A number of publications were produced and initiatives undertaken to raise VIRTUE's visibility with potential users, the press and the research community.

The compositor was completed in the first year with some enhancements added during the second year allowing the synthetic objects of the VIRTUE office to be combined seamlessly with the real video objects.

HWU set up a living document on the project web-site (partners access only) to contain notes on the limitations of the current design, and of desired features to be implemented in future VIRTUE work (commonly referred to as VIRTUE++). HWU started on the last task of WP1, identification and design of future algorithms (task "algorithms improvement" in the Project Plan) and information on this was located in the live document.

System module algorithms were studied for calibration, rectification, figure-background segmentation, disparity estimation, view synthesis, depth layer processing for occlusions, and head position tracking. Prototype algorithms were designed and tested in non real-time to identify the most suitable candidates for development, and real-time working. Algorithms and software were tuned to meet real-time specifications, especially view synthesis and head tracking.

Algorithms were adapted to meet quality, real-time and operation requirements, especially:

- User-friendly 4-camera calibration package,
- Hand and head detection,
- Head tracking,
- Elimination of artefacts from synthesised video images.

Investigations were made into future algorithms on the basis of a combined evaluation of prototype performance and Human Factors tests.

The work on advanced imaging algorithm research carried out at BT, aimed at either reducing the operational restrictions of current VIRTUE stations or towards consideration of a future collaborative working system in the sense of pervasive computing, basically fell into two areas; an indoor conferencing environment and an outdoor conferencing environment.

TUD developed and improved a calibration package for simultaneously calibrating the four cameras at each station. A GUI was provided by HHI. Research for further optimisation of the calibration was conducted leading to the proposal of the MSSMCC algorithm. Self Calibration issues were also investigated.

The View Synthesis for full CCIR images was implemented by TUD on the VPS board by dividing the images into four overlapping stripes and works in real time. The full CCIR View Synthesis was integrated with the disparity estimation and segmentation and interfaced to the compositor.

A representation of all four image sequences into one description has been proposed and investigated for future improvement of the system.

4.3. WP2: Real-Time (HHI)

The real time component of the project, collaborated with the systems and algorithms work packages. Investigations of vision and platform rendering considered options including dedicated VIRTUE hardware using the TriMedia processor board and Pentium III chip for real-time applications. Segmentation, head tracking, viewpoint interpolation and interfacing would be designed on the TriMedia, with vision algorithms on the Pentium III.

The design, manufacture and test of the VIRTUE hardware called VPS (VIRTUE Processor Station) was completed. Each VPS package contained a multi-TriMedia board and an interface board. The package was faster and contained twice the amount of SDRAM than currently available products. TriMedia multi-processor board to host PC communication was established. The TriMedia board provided digital video interfaces satisfying ITU Rec.601 allowing the transfer of video data without loading the PCI bus of the host PC. Algorithms on the TriMedia processor could be implemented in C++, so that simulation software could be easily ported onto new hardware. The different algorithm modules running on several VPS boards were then implemented in the final system.

A module, segmentation of hands, was designed and implemented at HHI. This module localised accurately the speaker's hand in each frame of the sequence, contributing substantially to improving the quality of disparity maps. It was integrated in the real-time platform in order to support the disparity estimation module in terms of an improved quality. The segmentation of hands included an automatic initialisation of the hands without any specific task or gesture. The user could sit in front of the display and the module recognised the hands by itself. The hand mask was encoded in a specific data stream, which was downstreamed to the other modules. This information was used in the disparity estimation module and the dense field interpolation.

The calibration procedure required that image capturing, feature detection parameter estimation and verification by rectification was necessary. The different algorithms were developed by TUD and have been integrated in a common GUI. With this GUI, the whole calibration process could be easily handled and a simple test of the captured images and the calibration result provided good feedback to the user. Faulty image pairs could be recaptured.

The foreground/background segmentation was improved by a shadow detection scheme, which made the segmentation process more robust against shadows in the background and on the table.

The final VIRTUE hardware called VPS (VIRTUE processor station) was applied successfully in the integration phase of the whole system. There were 4 VPS boards containing 16 TriMedia processors in the analysis PC. In the synthesis PC, 3 VPS boards containing 12 TriMedia processors were located. The driver software provided by Philips was modified as it was only designed for a maximum number of 10 TriMedias.

A detailed test strategy has proven the stability and given confidence in the VPS board. It functioned correctly in different PC's and with other PCI cards. Communication between the TriMedia multi-processor board and the host PC was implemented and different methods of transferring data to the PC were identified. A minimum of four video streams and additional data such as disparities and segmented masks of the hands were transmitted between various processors. Transmission occurred between different TriMedia processors on a single VPS board, between TriMedia processors on different VPS boards and between TriMedia processors and the host PC, the Pentium IV processors of the dual Pentium system. A ModuleManager and a BufferManager, which were part of the HHI TriMedia-Library, were developed to simplify access to shared memory on the local VPS board and host PC.

Integration of algorithm modules on different boards was started and rendering was successfully implemented. The foreground/background segmentation and the head tracking algorithm modules were integrated in the rendering PC, which composed a virtual conference scene containing 2D life video objects.

During the hardware development, the importance of an additional interface for the developed VPS TriMedia boards became apparent so a flexible SDI interface card was developed in order to connect arbitrary cameras with the video input of the VPS board. This additional SDI interface provided

- 4 x SDI In/Outputs (SMPTE 259M standard Serial Digital Video)
- 4 x Channel Link In/outputs like the Channel Link Interface board
- 4 x Video In/Out (parallel data) to connect to the VPS board

The main difference between the SDI interface board and the Camera Interface Unit was that arbitrary cameras could plug directly onto a VPS package comprising the SDI interface and the VPS board.

Whilst completing the real-time optimisation it was found that some specific capabilities of the TriMedia processor had to be used in order to achieve the necessary speed of the algorithms requiring modifications to the C++ code running on the TriMedia.

The two intensive weeks of integration at TNO in September and October 2002, enabled a 3D version to be run, when the main issues were identified to improve the 3D processing and to provide a full running system with acceptable and convincing rendering quality. It was decided to provide a 2D demonstrator with much enhanced quality compared to the system demonstrated a year before at the IST event. The main achievements were robust and stable head tracking and a convincing integration of the video objects in the virtual scene. The missing functionality compared to the 3D system was the rendering of the remote participants on the screen according to the head position of the viewer in front of the display.

4.4. WP3: Systems (Sony/BT)

The definition of the VIRTUE system architecture was investigated in collaboration with the corresponding real time studies. Test sequences with the correct body views, actions and environment (e.g. background) were made available by Delft to evaluate and test the algorithms developed. Calibration procedures and software for calibrating the four cameras were also developed.

Suitable state-of-the-art progressive scan colour cameras and large displays for the VIRTUE terminals were ordered. A camera interface unit was developed in the second year to synchronize and perform format conversion for easy integration into the VIRTUE terminal. The camera interface unit was also used for test sequence capture for real-time algorithm simulations. All other hardware was assembled to build the three complete VIRTUE terminals e.g. speakers, microphones, PCs and lighting. Each terminal also incorporated a large Plasma display (61” or 50”), a semi-circular desk, and four colour progressive scan cameras.

Methods for communicating between different processes running on the three computers were investigated. Prototype code was produced, for example systems network layer software was developed allowing audio-video synchronisation, adaptive bandwidth control, seamless connect/disconnect and high speed multiple peer-to-peer data transfer between the three VIRTUE terminals. A detailed review into MPEG-4 in the first year concluded that the VIRTUE system would use MPEG-2 video object compression. An MPEG-2 codec was developed, in the second year, using a custom chip set together with a general purpose PCI base card. This offered a flexible low latency MPEG-2 solution for VIRTUE.

The system allowed a three-way conference to be performed without the benefit of the 3D processing that offered eye-to-eye contact and motion parallax.

The major Systems WP modules of VIRTUE were integrated to provide a fully functional 2-D three-way demonstrator. This included the following modules:

- 4 Colour Progressive Cameras
- Camera Interface Unit
- Head tracker (part of WP2)
- MPEG-2 Codec
- Network Software
- Video object foreground/background segmentation (part of WP2)
- Compositor
- Audio (mono) with echo cancellation
- Software control of modules

A demonstration of the prototype station at IST2001 incorporated the multi-camera calibration package made available by Delft. A camera interface unit synchronised the four camera inputs and reformated data to transmit to the VPS card developed by HHI. Issues on rectification, distortion and calibration were resolved. The compositor was integrated with the head tracker, developed by BT, allowing the user to adjust the view of the virtual world using moving head movements.

4.5. WP4: Human Factors (TNO)

A pilot study on long-term use of videoconferencing and a number of experiments were completed with respect to:

- Spatial audio
- Synchronisation and transfer delays,
- Effects of 3D visualisation and motion parallax on telepresence,
- Selective gaze,
- Effects of a shared virtual background and on social asymmetry.

Progress with Human Factors was subsequently made with:

- Long-term adaptation experiment completion,
- Assessment of final system with respect to:
    - Development of customer questionnaire,
    - Development of expert assessment questionnaires,
    - Reporting to the project, e.g. during the Basingstoke meeting,
    - Co-ordination with partners on receipt of VIRTUE terminals at TNO,
    - Development of new user tasks and behavioural measurements,
    - Provision of an integration and experimental infrastructure for partners at TNO,
    - Set-up of terminals at TNO: together with partners (HHI, Sony, BT, TU Delft) to provide a 2-D version of the final system,
    - Final system assessment with Human Factors experts,
    - Final system assessment with a panel of 18 users,
    - Data collection and analysis.

4.6. WP5: Management (BT)

Directly after project start a quality plan was produced that described rules and conventions for the co-ordination and co-operation within the project. A project management committee was established that consisted of one senior representative from each partner. The committee met about 2 times per year in conjunction with the regular technical and exploitation meetings. Tasks of the management committee were to review the progress achieved compared to the work plan, deciding on changes to the work plan and reallocation of resources, planning of publication and publicity activities, as well as the dissemination of the results, planning for the next 6 months.

The management committee also discussed related and relevant developments outside the project that might have an influence on the project results or may require changes to the work.

A Web Site was created for providing the project with a public window and for providing a common area where internal project documentation could be securely located.

5. ICOB And Assessment of Auditors

The demonstration of the VIRTUE project at the ICOB workshop in Berlin, was mainly organised by HHI, Dr. Oliver Schreer and Peter Kauff . The main objective of this workshop was to bring together experts from many different areas related to tele-immersion, to discuss concepts of immersive communication and broadcast systems, to discuss results of real-time communication tests and to demonstrate to a wider audience the potential and feasibility of immersive media. The assessment of the project by the auditors was made towards the end of ICOB after demonstrations of the VIRTUE workstations had been given.

The project was considered to have a good record with respect to the following:

- The project was very ambitious and achieved an impressive amount of work.
- The demonstrator is very valuable.
- The consortium has managed to establish a positive team spirit.
- Reports were well structured and well written.
- Algorithms and hardware developments were of high quality.
- System engineering (in particular Multi-processor programming) is of high quality.
- The work had solid foundations and rested on a good State-of-the-art and requirements analysis.
- The fact that human factor specialists have been involved in the project from the beginning was very positive.
- The open attitude and the fact that answers given throughout the Q&A session were honest was much appreciated.

A number of shortcomings were observed:

- The work originally envisaged had not been completely finalised and the project achieved less than was intended.
- The project management may have been too optimistic with respect to integration issues.
- A more precise feedback (e.g. simulation, mock-up) could have been provided at an earlier stage to partners responsible for the evaluation of the system.
- Testing could have been better planned to adapt to system integration delays.
- End to end delay was a problem. Since this was known from the beginning, more thinking should have been given to finding solutions.
- Some deliverables were delayed.
- Exploitation plans were not convincing although some of the ideas expressed were interesting.

A number of recommendations were observed:

- The project should produce a roadmap on how to exploit the system and/or on how to make use of some of the components in order to maximise the exploitation of the results.
- The project was strongly encouraged to organise a demonstration at CeBit and, if necessary, to take suitable measures to simplify and/or improve the system and this was undertaken.
- On this occasion, partners should be marketing –oriented and should be prepared to answer customer's questions.
- A final evaluation should be carried out in order to compare the final demonstrator with the originally intended system.
- The results should be reported in remaining deliverables or in the final report.
- Project partners were encouraged to explore other applications of the system, possibly involving content creators, artists or other potentially interested users.
- Partners were also encouraged to explore possibilities for further testing of the system on a real network.
- The project was encouraged to participate and contribute to standardisation activities related to transmission of 3D or 2D + depth representations.

- Finally, the reviewers drew the attention of partners to the importance of a proper documentation of the system components in order to ensure the durability of the system and to prevent difficulties in re-using components in the future.

6. Final Demonstration At CEBIT 2003

CEBIT 2003 took place in March 2003 where the VIRTUE stand and demonstrator reflected recommendations made by the auditors at ICOB in Janiuary 2003.

There were many VIP's and journalists visiting the stand which was filmed by NTV, Euronews and an Iranian TV station. There was also very good press visibility. On the first day, a short article appeared in the daily fair journal. The most convincing aspects were the stability of the segmentation and the improved compositor. It started every morning with a short set-up time and was absolutely stable, although the conditions at CEBIT were far from perfect. People crossed the background and people in front of the display were changed frequently to give visitors the opportunity to experience telepresence with the VIRTUE stations.

Often, people from the same group sat at both stations. There was also high level representation of people from research and politics. For example, the science minister of the county Brandenburg talked to his personal referent by using the two terminals, and was strongly impressed. We had situation like this with a lot of other people.

Some feedback from potentially specialist users was obtained, e.g. from consultants working in different areas. They emphasised the use of a VIRTUE-like system for situations where it was not so important to exchange information or to work jointly on common applications, but where it was necessary to obtain personal and social impressions from the other participants, e.g. lawyers speaking to clients, negotiations between tradesmen special teaching situations, etc.

7. Overall Conclusion

VIRTUE successfully completed research in algorithms, real-time and systems. This work has provided a sound base upon which hardware and software components could be integrated with the VIRTUE stations. A number of experiments in the human factors have also been successfully completed. There were no significant changes in scope of the project although some deliverables were re-scheduled. People on the project enjoyed the demanding work and maintained a working identity with good social interaction at the project meetings. Overall:

- The development of novel image processing algorithms for telepresence videoconferencing was completed and ported to the real-time platform,
- Algorithm improvements involving research into improved methods for integration into the final demonstrator, and for any commercial products were developed,
- Compositor/rendering integration was completed.
- The compositor combined remote natural and local synthetic elements of the conference onto large screen displays. Intelligent merging of the participants and the virtual world were considered in critical areas such as the boundary between the synthetic table and each participant.
- Systems implementation test and debug of all the system components excluding the compositor, vision and rendering algorithms was undertaken.
- The integration, final testing and debugging of all the component part took place with associated documentation (user manuals, source code documents etc).

- Human Factors experiments comprised a number of sub-tasks leading to the performance of the experiments.
- Evaluation aspects of the Human Factors assessment were information transfer and psychosocial interactions. The assessment task was focussed at the evaluation of the final integrated prototype with respect to the functionality specified.
- Consideration has also been given to the implications of wide area networking as an attribute to the exploitation data collection.

Appendix: Description Of The Consortium

The six partners in the VIRTUE consortium are two leading industry corporations, two internationally renowned research institutes and two highly regarded research-led Universities. The consortium represents a group of leading institutions in Europe on 3D imaging, telepresence collaborative working, telecommunication and human factors studies. The combined power of research and knowledge would enable them to achieve the far-reaching objectives of the VIRTUE project.

BT (British Telecommunications PLC, UK) is an international telecommunications and Information Technology Group. In order to serve its future core business needs BT Laboratories has been working on the concept and impact of *telepresence* in telecommunications service for several years. Work has included, among many others, through-the-screen video conferencing, audiographic conferencing, virtual humans and wearable computers. BT was the co-ordinator of VIRTUE and so provided its project management; it also contributed to concept development, algorithm research, system integration and testing of VIRTUE.

Key persons involved (Michael Jewell, Li-Qun Xu, Dave Machin):
Michael Jewell is the manager of the Multimedia Design and Development Group within BTexact Technologies. The team carries out research, feasibility and development of services and applications that help people to communicate, providing software development, consultancy and product evaluation in this area of work. Michael joined BT in 1993 having completed a Masters degree in Electronic Systems Engineering at the University of York. He has worked on both research and development projects including the research and development of 3D video-telephony and the use of avatars and virtual worlds in collaborative applications.

Li-Qun Xu joined BT Laboratories in 1996 as a Senior Researcher. For the past two years, he has taken a leading role in working on the core techniques and algorithms in 3-D computer vision and image-based rendering paradigm, with a view to developing an advanced true-view videoconferencing system. Previously he worked as Research Fellow in the Chinese Academy of Sciences, Beijing (88-90), University of East Anglia (90), University of Sussex (91-92) and King's College London (93-94), and as Lecturer at the University of Abertay, Dundee, Scotland (94-96). He received a BSc (Hons) and a MSc in Electrical Engineering, and a PhD in Information Engineering all from Southeast University, Nanjing, China, in 1982, 1985 and 1988, respectively. He has since worked extensively on a range of Research Councils and industry sponsored projects in the areas of speech processing and recognition, computer vision for traffic monitoring, theory and applications of neural networks, multimodal intelligent interface. He is a member of IEEE and British Computer Society.

John Salmon gained a Masters degree in numerical algorithms for control systems in 1983 at the Computing Laboratory of the University of Newcastle. John joined BT in 1988 after having worked for a number of years in UK government and commercial jobs. He is a senior design consultant in the Multimedia Design and Development Group within BTexact Technologies where he has worked on both research and development projects including the implementation of BT's video on demand pilot service. He has also worked on the modelling of both wide and local area networks to evaluate network performance and capacity against the requirements of end user demands. He joined the VIRTUE project in June 2001.

Dave Machin gained a degree from the University of Bradford in 1975, joining BT Laboratories to work on mathematical modelling of transistors for integrated circuits. Subsequently, he spent five years on a collaborative European project, ESPRIT, for automatic design validation of integrated circuits using electron beams. Here he designed high-speed digital and analogue circuitry both for signal averaging and beam scanning. He also designed the motorised stage calibration and control system and much of the user interface for the complete system. In 1990, he worked on subjective testing of telephony services and developed a tool to emulate international telephony networks using digital signal processors. Since 1995, he has worked on both the animation and non-intrusive real-time tracking of facial features using computer vision techniques to implement a practical MPEG4-SNHC system. He is currently investigating active vision techniques for 3D modelling in real time.

HHI (Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH, Germany) is an internationally renowned research institute and has an excellent research track record in image analysis, synthesis and hardware development for real-time solutions for the emerging field of distributed video conferencing in virtual environments. HHI contributed to the algorithms workpackage and led the real-time platform workpackage of the VIRTUE project.

***Key person involved (Oliver Schreer*):**
Oliver Schreer graduated in Electronics and Electrical Engineering from the Technical University of Berlin in 1993. From 1993 until 1998, he was assistant lecturer in Control Theory and System Dynamics Group in the Institute of Measurement and Automation, responsible for lectures and practical courses in the field of image processing and pattern recognition. His research interests were in camera calibration, stereo image processing, 3D analysis, and navigation and collision avoidance of autonomous mobile robots. Since August 1998, he has been a project leader in 3-D vision research group of the Image Processing Department of HHI. In this context he is engaged in research for novel view synthesis, real-time video conferencing systems and immersive TV applications.

Sony BPE (Sony Broadcast and Professional Europe, UK) was founded in 1978 is a subsidiary of the Sony Corporation. The Sony BPE R&D have had a major influence over the design and development of many new products and technologies within Sony. In recent years, the group has grown a substantial software capability and has developed non-linear editors and multi-media on-line archive applications to product. The VIRTUE team led the systems workpackage and particularly demonstrator physical build, video compression, networking, real-time platform architecture, virtual world build, system integration and testing.

Key person involved (John Stone):
John Stone has worked for Sony Broadcast and Professional Europe for the last nine years. During this time he has been closely involved with the development of algorithms and architectures for video compression and image processing. He has also been involved with the hardware realisation of these systems through VLSI technology. Other work has includes research projects in computer graphics and special effects for the media creation industry. John holds 25 patents mostly in the area of video compression. John has an MSc in Communications and Signal Processing (1986) from Imperial College and a BSc in Electrical Engineering (1983) from Wits University in South Africa.

The TUD (Technical University of Delft, The Netherlands) (group specialises in, among others, creative research on image analysis and visual communication. The former encompasses software and hardware for stereoscopic and 3-D image analysis, image sequence analysis, image understanding etc. The latter covers object-based compression, searching of visual information and wireless multimedia communications etc. The TUD group contributed to the work of algorithmic development and real-time platform.

Key person involved (Emile Hendriks):
Emile Hendriks was awarded an MSc diploma (drs.) in Experimental Physics in 1983 and a PhD (dr.) again in Experimental Physics, both from the University of Utrecht. He was a Lecturer in EE Teaching Laboratory, Delft University of Technology (1987-1994), and an Assistant Professor (1994-1996) and Associate Professor (since 1996) in Information and Communication Group of DUT.

TNO HFRI (TNO Human Factors Research Institute, The Netherlands) specialises in knowledge on human factors and its application in the design of human work and of adequate technical aids. It focuses on some six main research themes, among them the *Perception* and *Group Work* are most relevant to VIRTUE. The TNO-HFRI conducted a continuous line of human factors experiments, user assessments to drive the technical development of the project.

Key person involved (Jan Maarten Schraagen):
Jan Maarten Schraagen joined TNO Human Factors Research Institute, Soesterberg, The Netherlands in 1986 and received his PhD (1994) in Cognitive Psychology from the University of Amsterdam, The Netherlands. He also holds BA and MA degrees in psychology and philosophy from the University of Groningen, The Netherlands. He was a visiting scientist at Carnegie-Mellon University from 1985-1986. He has published more than fifty articles, presentations, and technical reports. His research interests include team decision making, problem solving, and methods for cognitive task analysis. He has been the chairman of a NATO Research Study Group on Cognitive Task Analysis (1996-1998). His applied research at TNO has covered topics ranging from training of fault diagnosis, information presentation in in-car navigation systems, knowledge elicitation techniques for expert systems, the use of simulators in nautical training, to, more recently, distributed decision making in Command & Control teams. Dr. Schraagen is currently program manager of the Distributed Decision Making Group within the Department of Group Work at TNO.

The HWU's (Heriot-Watt University, UK) Department of Computing and Electrical Engineering is one of the largest engineering departments in the UK. Involved in the VIRTUE project are the two well-established departmental laboratories, the Computer Vision Laboratory and Ocean System laboratory that specialise in innovative depth sensors, 3D vision and parallel algorithms and architectures for image interpretation. The VIRTUE team led the algorithms workpackage and contributed to the research and development of 3D video and rendering.

Key persons involved (Emanuele Trucco):
Emanuele Trucco is a Senior Lecturer and an active researcher on 3-D computer vision technologies and their applications. He manages or co-manages research contracts for a total value of 1.2M Euros. Since 1984, he has been involved in vision projects funded by the EU (COST-13, ESPRIT, HCM, FAIR, TMR, MAST, SOCRATES) and national agencies, at the University of Genoa (Italy), the EURATOM JRC at Ispra, the University of Edinburgh, and HWU. Currently, he is the co-ordinator of the RTD partners for project FAIR-CT98-9107, partner (with Prof D. M. Lane) in ARAMIS (MAST-CT97-0083), and host in charge of two Marie Curie fellows. Dr Trucco has published more than 70 papers in international journals and conferences, co-chaired national and international conferences on computer vision (e.g., BMVC'96, SIRS'98, EUROPTO-SPIE’99), and co-authored (with Dr A. Verri) a successful book on computer vision (Prentice-Hall, 1998).