Technical feasibility report

Collaboration Spaces

Building Blocks

Item, NTNU

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Project: Collaboration Surfaces

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DMP = Collaboration Spaces + Real-time Internet

REALINT - Real Time Internet - supports 40 Gbps data rates to all European citizens and institutions. REALINT provides service quality guarantees through five classes for the future collaborative society.

A. Guaranteed real-time requirements, content packets are dropped in a controlled way, the probability for loss for certain control packets shall be ultra-low (TBD).
B. Moderate real-time requirements, packets shall be delivered in a correct sequence
C. No real-time requirements, but packets shall be delivered in correct sequence
D. No real-time requirements, all packets can be delivered out of sequence
E. No real-time requirements, packets can be delivered out of sequence or even lost

REALINT gives the European society, ICT industry and service-providers outstanding new opportunities for secure public management and business through a new IPSec-based authentication and security scheme. A novel distributed system assures reliability and availability with graceful degradation of quality with increasing errors and traffic load. An integrated mobile and fixed network supports all kind of mobile devices and futuristic collaboration spaces.

All this is enabled by the clean slate DMP (Distributed Multimedia Plays) [RON11] system and network architecture, which includes two main parts, REALINT and Collaboration Spaces. The concept of Quality Shaping was introduced to obtain full control of quality over the European-wide network and end systems. Only one IPv6-based protocol, the AppTraNetLFC protocol, is needed for link flow control and the network-, transport- and application layers. This novel protocol handles setup and release of multi-party collaborations, Quality Shaping and network operation and management, in addition to controlled and guaranteed content transfer. PCIe is applied for the physical layer and link framing.

Collaboration Spaces

An important application of DMP is networked musical collaborations. Such collaborations have been tested for many years, and in the 90-ths the interest of reducing artificially introduced delays close to the natural delays increased. Lately, a project aimed at testing the perception of networked musical collaborations was carried out with participants from NTNU, Uninett, Nidaros Domkor and the Norwegian College of Music. Figure 1 shows the configuration where a conductor is conducting a small choir over a network without delay (direct wired connection).

Figure 1. Conducting of Choirs, [CON12].

To reduce the end-to-end user delay we have to take camera and display frame rates into account. A normal transmission frame rate is 60 fps progressive. In [CON12] it is shown that 60 fps is too low to display a smooth movement of an object. Normal HDTVs now have a screen update rate of 200 fps or even 400 fps, but with the input only 60 fps or 30 fps interlaced, interpolation has to be performed in the TV set by delaying the presentation of the video several frames. Tests [CON12] have shown that for conducting a choir via cameras, network and displays, 60 fps is not sufficient. Other tests have shown that at 50 fps a moving ball is smeared out over the background, and if the shutter is fast the movement becomes jerky. At least 300 fps are required to reduce the smearing and jerkiness to a nearly invisible level [BBC08]. But it is obvious that frames of videos that do not change from one to the next frame do not represent any new data, and objects should therefore not be sent out from the camera, but just be stored and repeated at a high frame rate in the receiver. But to be able to react to optical events say within 5 ms, a camera shooting frame rate of 240 fps (4.12 ms) or higher is required. Therefore, a high frame rate and fast processing of object segmentation and decision making is necessary. The sub-objects representing the temporal resolution can also be dropped in the network according to prioritizing rules.

Figure 2. 'Fighting the riders', advanced, all surfaces are Collaboration Surfaces [RON07a]

Figure 3. Virtual Working Lunch [RON07b]

Other collaborative systems and applications

SISCO and Polycom telepresence

These companies are the leading vendors of telepresence systems for professional use. Their systems are in use all over the world, and of course restrained by the available networks and standards. The video is of HDTV quality, the sound is good, and setting up conferences has become quite user-friendly. The existing standards and networks constrain the optical end-to-end delay to several hundred milliseconds. But in many cases this is not critical, for example in standard networked meetings.

CAVE, RAVE

Represent some of the first realisations of practical, usable 3D visualisation rooms. The basic concepts were developed at the University of Illinois at Chicago, and industrialised by the company Fakespace Systems, now merged with Mechdyne Corporation [MEC12]. The latest version is RAVE 2.

Muscade

Multimedia Scalable 3D for Europe, is an EU project funded by ICT 7FP. Focus is on 3DTV production and transfer facilities and rendering on 3D displays. See [BER12] and http://www.muscade.eu/.

Other

Since the introduction of the concept of telepresence by 1980, many companies and research groups around the world focus on telepresence, videoconferencing, virtual reality, etc. A Google search with ‘telepresence’ returns about 34 800 000 answers. The e-book ‘’3D Videocommunication: Algorithms, concepts and real-time systems in human centred communication’’, edited by Oliver Schreer, Peter Kauff and Thomas Sikora reviews the history of telepresence [SCH12].

DMP basic concepts

For a more detailed description of the DMP basic concepts such as Quality Shaping, the AppTraNetLFC protocol and the DMP network topology see [RON07b], [RON11]. Here we go through the concepts used for Collaboration Space.

Scene Profiles are introduced to describe in detail the limitations and possibilities of any collaboration space.

In DMP projects several coding methods have been proposed. The first approach developed before 2007 [RON07b] divides a scene object into four, nine or more spatial sub-objects which are processed independently, in true parallel if necessary. Sub-objects can be dropped by any network node in a controlled and prioritized way, depending on traffic load, and reconstructed by interpolation in the receiver. This guarantees the maximum delay through the network and a minimum spatial resolution. To reconstruct edges of objects (including textures), a special sub-object containing edge intensity values (a few bits wide) and elsewhere zeroes in each pixel address is sent in parallel. When edges are sparse, run-length compression can be applied efficiently to the sub-object. Edge values are written over the reconstructed object pixels in the receiver.

Later, the kriging concept [PAN10] was introduced and found to give excellent results for the color components Cb and Cr, but not for the Y component. To handle this, more advanced techniques where features of images are classified and can be coded and dropped according to importance in the network, are needed [PAN12].

Scene Profile Specification of the Collaboration Space used throughout the text

For short, in the text the actual collaboration space has got the name CollSpace. Gross size of CollSpace, height x width x depth: 3 x 4.5 x 3.5 meters. The net size will be approximately 2.50 x 4.0 x 3.0 meters, due to pico projection and camera arrays and sound equipment.

Own experience, perception and assessment indicate that screen pixels of 1.3 x 1.3 mm are individually visible from viewing distances less than approximately 1 meter **{Research tasks}.** This is important for deciding the lens element size of the lens array to be used for display. Since we intend to integrate small camera lenses in the display lens array, the visibility of those has to be considered. Non-formal tests with small black dots of one mm diameter on a white PC screen show that the dots are quite visible. Vice versa, 1 mm white dots on a black screen are also visible, but not that disturbing as black on white. 1 mm grey dots in natural images are visible but not much disturbing, while in synthetic images they are quite annoying. Formal tests on this should be carried out. For now we use a pixel size of 1.3 x 1.3 mm in the displays for the CollSpace **{Research tasks}**.

All four walls will have multi-view cameras and displays. In addition, the floor and the ceiling will have multi-view displays. Figure 4 depicts how a CollSpace Building Block, CSBB, (see Figure 7 below) can shoot video in nine slightly overlapping space sectors, three horizontally and three vertically, assuming a FOV of 50 x 50 degrees for each sector image **{Research tasks}**.

To avoid the 'Mona Lisa effect' [NGU09] and to obtain continuous 3D viewing, the CSBB shall be able to shoot views 6.5 cm apart horizontally and 13 cm vertically **{Research tasks}**. To reduce the total data rate not more than 20 views horizontally and 3 views vertically simultaneously should be sent **{Research tasks}**. However, which views out of the total generated views, 154 ((2*300 + 400)cm/6.5 cm) and 9 respectively **{Research tasks}**, should be selected adaptively.

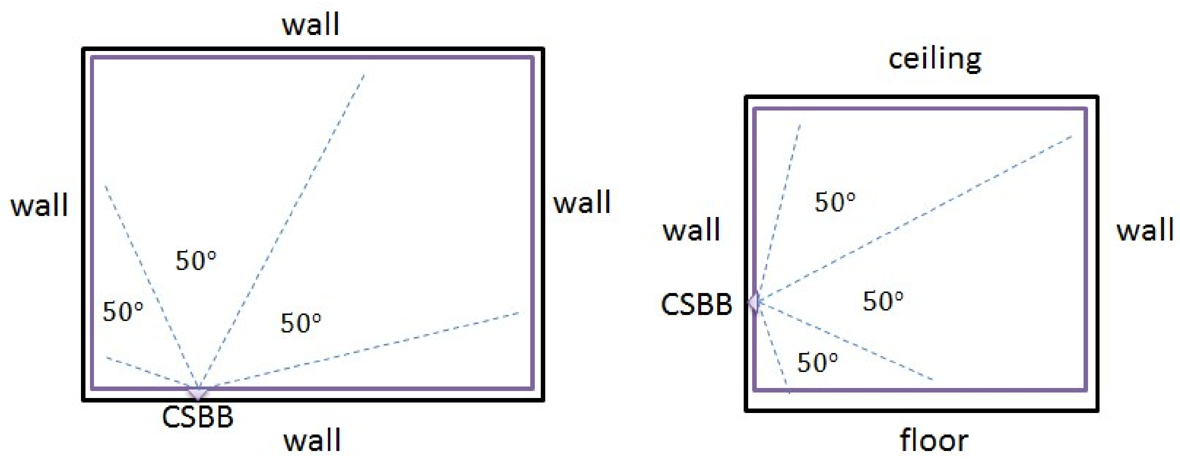

Figure 4. Each CollSpace Building Block, CSBB, can shoot and cover the space in nine sectors. Walls are 300 cm and 400 cm wide, respectively, the height is 250 cm.

An example of a collaboration using CollSpace is following. CollSpace A is a travel bureau marketing and selling boat trips to the fjords of Norway. The surroundings in CollSpace A can be shot from a third place, let it be the stunning view of the waterfalls of the Hardanger fjord shot live from a tourist ship passing by. The travel bureau seems to be moved to the deck of the ship. Potential customers in CollSpace B have face-to-face contact with the salespersons in CollSpace A and the background from the fjord. Multi-view and views from walls, ceiling and floor, are extremely important in this scenario. Maybe an airplane is crossing over the customer's heads while a small boat is passing by at their feet. And of course, the visual quality should be of highest class. The customers in CollSpace B shall feel as if they were present on the tourist ship, watching the fjord with the waterfalls.

CSBB – the CollSpace Building Block

To avoid the 'Mona Lisa' effect the cameras are integrated into the display. The intention is to build a small unit that can shoot multi-view video and show multi-view video, and which can be used as a flexible building block for building collaboration surfaces and spaces of varying qualities, forms and sizes. Such collaboration space examples are outlined in the previous section. To be modular and flexible, two versions of the unit are proposed. One combines a multi-view display and camera array, the other is a multi-view display. Both are based on the laser projection technique described below. In this way, large display walls with few cameras, small display walls with dense camera arrays or anything in between can be built.

The display approach is based on Microvision's laser projection techniques [MIC12]. In Figure 5 the principle is shown. An image is generated by mixing read, green and blue laser beams optically and temporarily together, and scan a rectangular display area line by line using a tilting mirror, MEMS **{Research tasks}**.

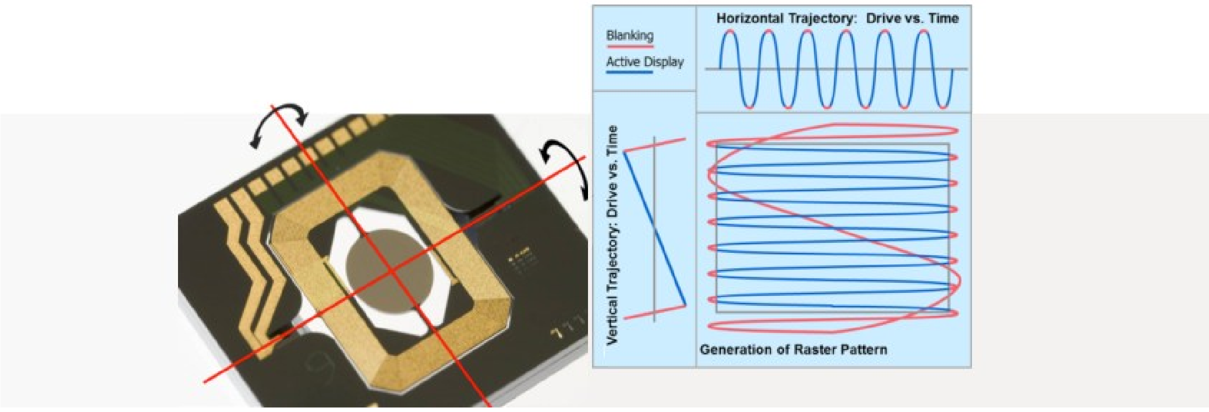

Figure 5. Projection of images using RGB lasers and a tilting mirror.

Source; Macrovision 2012. http://www.microvision.com/technology/picop.html

Figure 6 shows how the PicoP projector is embedded in a mobile device. The current PicoP projector supports 720p resolution at 60 Hz, which do not satisfy the requirements for conduction choirs.

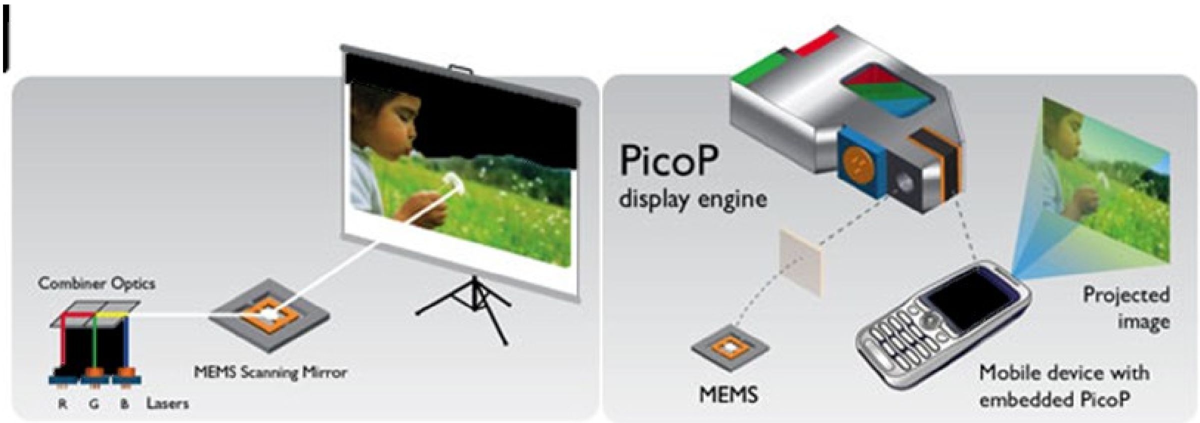

Figure 6. Principle and application of the PicoP display engine.

Source; Macrovision 2012. http://www.microvision.com/technology/picop.html

How to obtain 20 views?

Figure 7a shows a back-projection system using laser scan and a plano-concave lens array to spread the pico laser pixel rays into views. As shown in Figure 8, 20 pixels from the projector contribute to 1 display pixel which can then be viewed from 20 directions. Assuming a 1k x 2k pixel projector, it will support 1k/20 x 2k/20 = 50 x 100 display pixels each with 20 views **{Research tasks}**. Using display pixels of diameter 1.3 mm (one lens element) we may have a building block module of 65 x 130 x 100 mm. The depth is set to 100 mm for mechanical reasons. Note that to perceive depth when viewing the display the left and the right eye must see different views. It is evident from Figure 8 that when each pixel is represented by the diverged laser beam and the scanning is static, at very short viewing distances the viewer will see two views that are not neighbours, and at long distances he will see only one view and loose the depth. This can be improved using adaptive scan (see below) **{Research tasks}**.

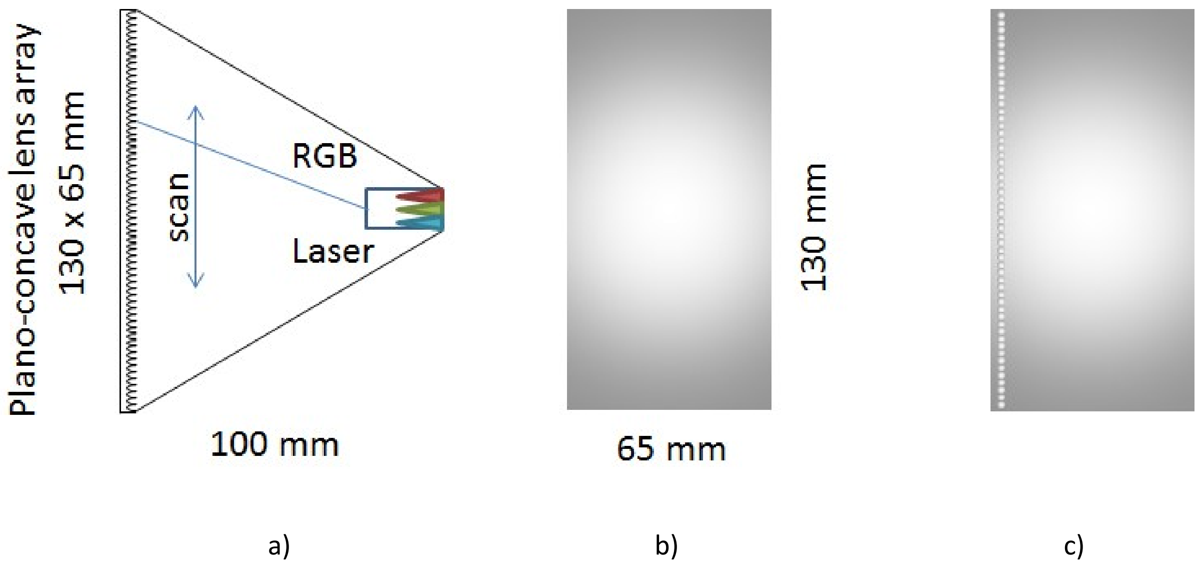

Figure 7. CSBB - the CollSpace Building Block. a) Side view of the display unit. b) Front view of display unit (without camera). c) Front view of display with a camera array on left edge.

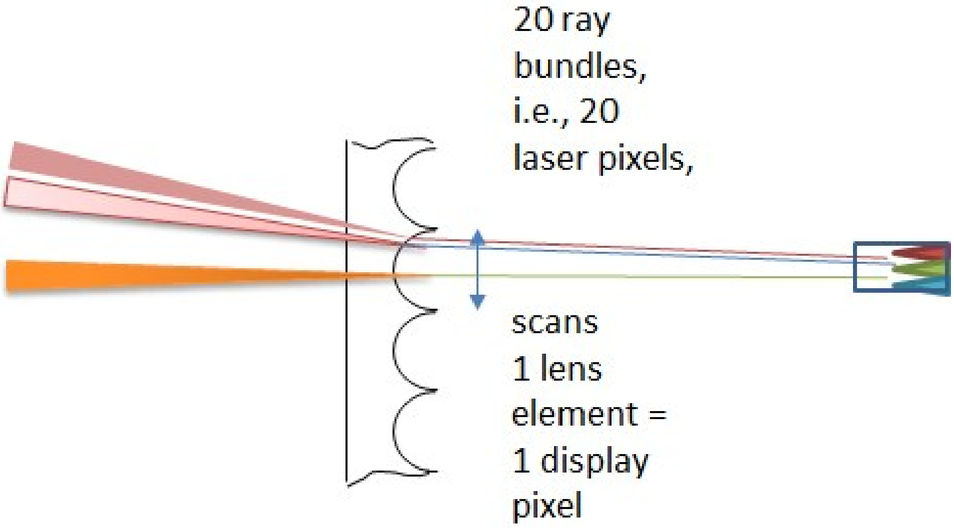

Figure 8. The principle of using a plano-concave lens for spreading laser light into views. Three separate views are shown **{Research tasks}**.

Why 20 views? If we take a look at CollSpace outlined in the previous section, and let a viewer move along three walls looking at an object in front of the fourth (long) wall, about 154 views with 65 mm (distance between human eyes) separation is needed. Still we have not included vertical views and views in the ceiling and the floor. We easily come up with more than 1000 views in total. A wall of 2.5 x 4 meters will according to the CSBB specification have about 5.9 M pixels each consisting of 40 bits to be updated at 120 Hz (240 Hz or higher could be required). This means a total data rate of 28 Gbps for each view, for 1000 views it will be 28 Tbps. It seems that we somehow need to reduce the total data rate **{Research tasks}**.

If we reduce the number of simultaneous views per CSBB to 20 views horizontally and 3 views vertically, we need to make the views adaptive, and adapt according to the position and gaze of the viewers in the space **{Research tasks}**.

If we are able to detect all viewers in the space, their positions and also in which direction they gaze, we may send this information over to the shooting CollSpace and in most cases reduce the number of sent views dramatically **{Research tasks}**. Let's assume two static viewers in the space looking at two different objects. Then we need to send say in all 6 – 10 views at a time. If the space is filled up with moving viewers looking in all directions the number of views needed could be a few hundreds. Normally, many viewers in a room look at each other or they watch the same object. Then we may be down to less than one hundred views. And if the objects on the walls do not change very much we may reduce the update rate for the static parts down to 1 Hz, for some moving objects down to 30 Hz, and only a few objects need 120 Hz. Then the data rate could be reduced by a factor of 10. We are down to a total data rate below 30 Gbps before any type of compression. But as we see, we must be prepared for a huge variability in the data rate from let us say 30 Gbps to 30 Tbps, however most of the time much closer to 30 Gbps than 30 Tbps. Since the optical end-to-end delay in many cases is very important (see the example in the text), we cannot spend more than a few milliseconds on video shooting, coding, compression, buffering, decompression, decoding, presentation and other scene processing. We cannot do anything with the propagation delay.

Instead of having an array of cameras for every 65 mm horizontally (and maybe vertically) we can apply CSBB without camera arrays, and use depth maps to produce missing views **{Research tasks}**.

Multi-view display processing

The processing of the display part of CSBB needs to be performed by specialized integrated circuits. To start with, FPGAs for flexibility, and in volume production VLSI for minimum power consumption, maximum performance, and low cost. In a recent study [WAN12], an optimized parallel/pipeline FPGA design can display two views using a depth map close to 100 fps for a 1920 x 1080 spatial resolution. With the most advanced FPGAs today processing 10-20 views at 120 fps with 2k x 1k pixels per frame should be possible **{Research tasks}**. In addition, when the scenes are object and sub-object based the performance can be in many cases increased dramatically. To be studied is the quality of using two views shot by cameras say 50 cm apart and a depth map to synthesize 8 views in between.

When sub-objects either in space or time or both are dropped intentionally by the network, missing sub-objects have to be regenerated by some interpolation technique. To handle this is an important task for the display FPGAs.

The AppTraNetLFC protocol [RON11a] handles the addressing of surfaces, CSBBs and views, and gives the route to the actual collaboration space (using the IPv6 address part).

A platform with PCIe switching and FPGA boards with development tool for the VHDL/C-languages is available for testing CCBB solutions [RON11b], [MAS12] **{Research tasks}.**

Camera array processing

Luminance camera imagers are generally much more sensitive to light than color imagers. Especially in case of RGB Bayer imagers that filter away 2/3 of the incoming light, and reduces the spatial resolution for colors to 50% for green, and to 25% for red and blue. CCD imagers are more sensitive, have better resolution per pixel, and have a better signal to noise ration than CMOS imagers. But CMOS imagers are much cheaper, and several units can easily be integrated into one chip. However, we do not disregard the CCD as a candidate for the white camera **{Research tasks}**.

In our case we need excellent luminance resolution in time and space and good sensitivity, in addition to excellent colors. We therefore propose a camera array consisting of the camera type LRGB (L-luminance) [STA12]. For a given section of the space two cameras shoot images, a luminance camera and a RGB Bayer camera [RON12a] **{Research tasks}**.

Due to the desire for small camera lenses and to maintain image contrast we apply the principle of sparse apertures with following wiener filtering [Fiete10]. This means we substitute one big lens with several smaller lenses that contribute to the same image. For details, see separate report [RON12b] **{Research tasks}.**

A platform with PCIe switching and FPGA boards with development tool for the VHDL/C-languages is available for testing CCBB solutions [RON11b], [MAS12] **{Research tasks}.**

An important task to perform is object recognition, tracking and segmentation. The object can be any object in the space. A special case is to recognize and track faces and eyes in order to inform the collaborating CollSpace that a viewer is focusing on a specific object. A large number of publications are available, see [SON08] for a review of sota **{Research tasks}**.

To minimize the delay when an event occurs or an object moves, the luminance camera shall have a frame rate of at least 240 fps (TBD) and the RGB Bayer camera at least 120 fps (TBD) **{Research tasks}**.

In our CollSpace example the background is exactly known, this is what is displayed by the walls, ceiling and floor. Finding the objects in the space is therefore just to take the difference. Segmentation is then fast (TBD) **{Research tasks}**.

Using two views, depth maps can be constructed [Wang12]. Another approach is to use the laser light reflected back from the objects to the cameras to measure the depth and construct depth maps. This is probably quite complex with so many (known) sources and cameras (TBD) **{Research tasks}**.

Still another approach would be to include extra lasers in the CSBB that produces IR or UV light of various frequencies, and utilize either reflected light or blocked light for segmentation and reflected light for depth measurements **{Research tasks}**.

Practical tests {Research tasks}

In the following tests we use color cameras and displays capable of 120 fps (8.33 ms) and luminance cameras at 150 fps only. The color camera has a rolling shutter, while the luminance camera has a global shutter. In the worst case, due to asynchronous (realistic) camera shutter and display operations, the delay of an optical event can be 2 x 8.33 ms plus network delay (constant propagation plus buffer delays of a few ms in nodes in the path). With a total propagation delay of say 10 ms, the optical user-to-user delay could be about 30 ms worst case, and about 15 ms best case.

The intention is to start testing before SCBB is available. Then we have to emulate the small sparse apertures. This can be performed by using the smallest aperture of the camera and by shooting from all actual positions and poses in turn and store the videos and process offline.

Testing of the perceived quality of fast moving objects will be accomplished at 120/150 fps and lower, by shooting falling balls in a controlled slope. To increase accuracy, a large number of trials will be carried out and the median will be used as the valid measurement (to avoid effects of outliers).

As we see, eventually it is desirable to increase the camera and display frame rate capacity to say 480 fps, but of course use a much lower object update rate most of the time. The maximum update rate will be necessary only for a short interval just after certain important changes in the scene (TBD). In this case the example shows an optical user-to-user delay of about 17 ms worst case, and about 13 ms best case.

Identification of other research tasks

Test if the perceived change of temporal movement of edges from one frame to the next is a good measure for testing the actual temporal change in consecutive video frames.

Test if fast changes of color of an object when no object of the scene is moving spatially, is a good measure for temporal change.

Test when rapidly changing texture of an object in a video becomes visible. Change test? Yes, assuming that that there are not too many edges to be compared, and using a mask to address edge pixels, a comparison of the current frame with the previous is fast to process.

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