FAIM2017

27th International Conference on Flexible Automation and Intelligent Manufacturing

INSTITUTE OF COMMUNICATION, INFORMATION AND PERCEPTION TECHNOLOGIES

Sant'Anna School of Advanced Studies – Pisa

A Stereo-Panoramic Telepresence System for Construction Machines

Paolo Tripicchio, Scuola Superiore Sant'Anna, Pisa

Emanuele Ruffaldi, Paolo Gasparello, Shingo Eguchi, Junya Kusuno, Keita Kitano, Masaki Yamada, Alfredo Argiolas, Marta Niccolini, Matteo Ragaglia, Carlo Alberto Avizzano

Outline of Presentation

- Context
- Problem Formulation
- Proposed Approach
- System Description
- Hardware Selection
- Camera Calibration
- Reference Frames
- Data Compression
- Visualization
- Augmented Reality
- System in Action
- Conclusions and Beyond

Context

Working machines in construction sites or emergency scenarios can operate in situations that can be dangerous for the operator.

Various operations that require high power and high accuracy (such as panel positioning, plumbing, material handling) are still manually performed by human workers in very inefficient and dangerous ways.

The increase of population density within urban environments is reducing the space available for construction sites.

Governments are introducing regulations aimed at both reducing the environmental impact of construction works and decreasing the amount of work related injuries.

The construction industry could definitely benefit from the introduction of robotic technologies in terms of productivity, human workers safety, and environmental impact.

Problem

- Harsh environments can be dangerous for the operator
- Specialized operators are necessary to operate complex machine with several DOFs
- Construction sites could be far apart and the specialized operators should travel between sites
- Lack of detailed information on the construction sites could generates disasters
- Need of some method to increase the awareness of the operator on the environment
- Reduce physical stress of the operator
- Simplify way of operation of the working machines
- Reduce the ratio between operators and machines
- Reduce costs

Approach

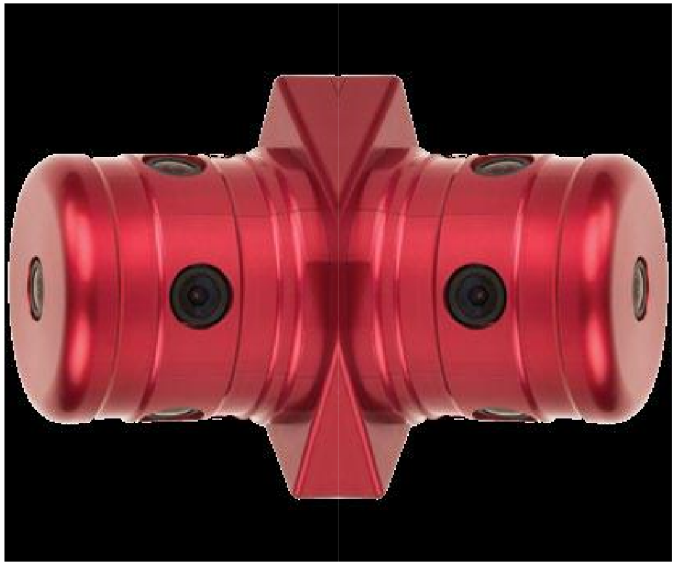
Remotely teleoperated vehicle

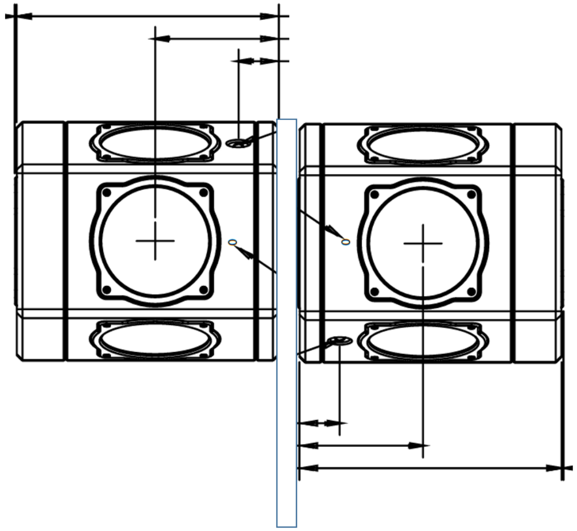
A single operator could operate several vehicles deployed around the world in safety

The user has a clear view and complete awareness of the operating environment
Artificial aids enhance the remote environments and the user knowledge

Possible solutions

Merging and customizing existing panoramic solutions

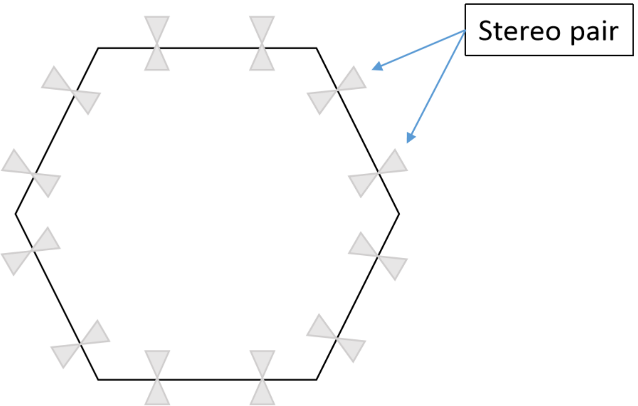


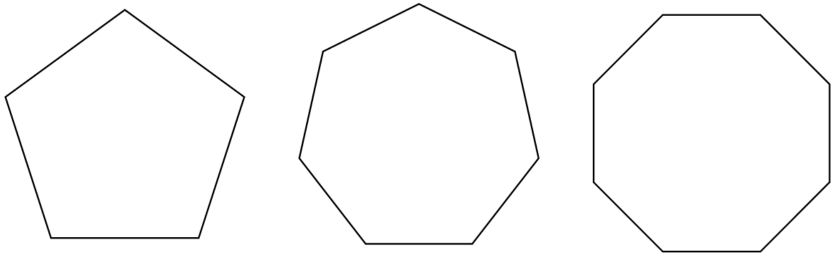


4.7 , 12 or 20 MP per eye

Possible solutions

Custom solution / multi-camera





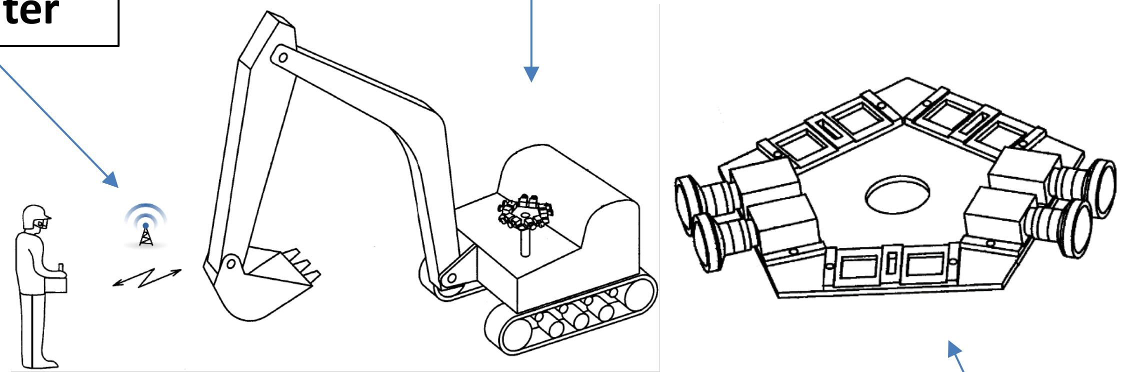
Multiple possible configuration

Architecture

Excavator:
- Arm
- Vision Head
- Streaming server

Wireless Router

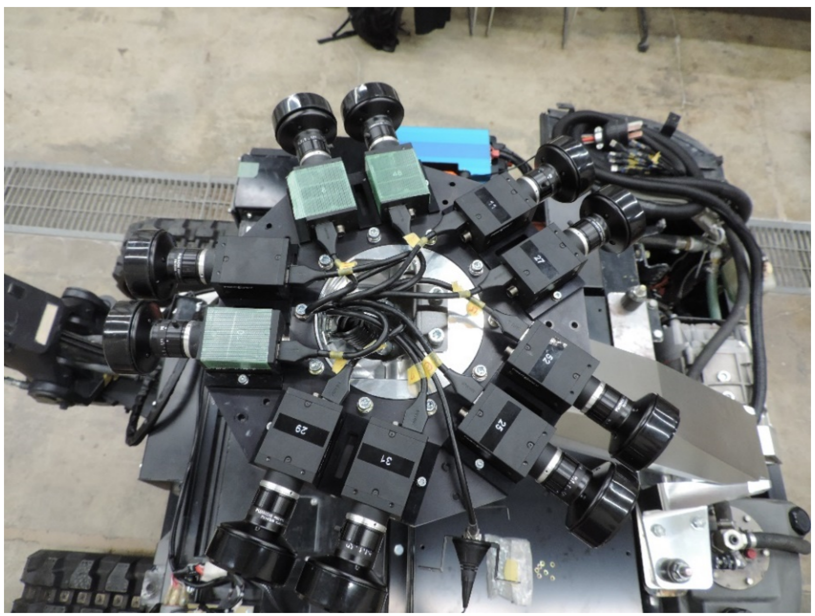
Operator:
- HMD
- Tele-controller
- Streaming client

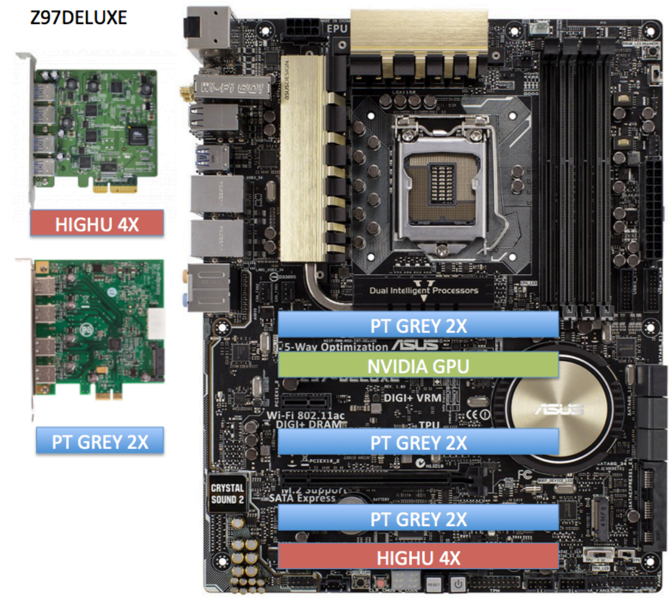


Vision head:
- 10 cameras
- Fish-eye lenses
- Mechanical base

Hardware

- PointGrey Grasshopper3 GS3-U3-41C6C-C a CMOS usb3 (5Gbps) 2048x2048px
- FE185C086HA-1 1" C mount fisheye lens
- Oculus HMD DK2 (94x100 DFOV) 860x1080px per eye
- Asus Z97 Deluxe Motherboard
- Wireless router 802.11 AC



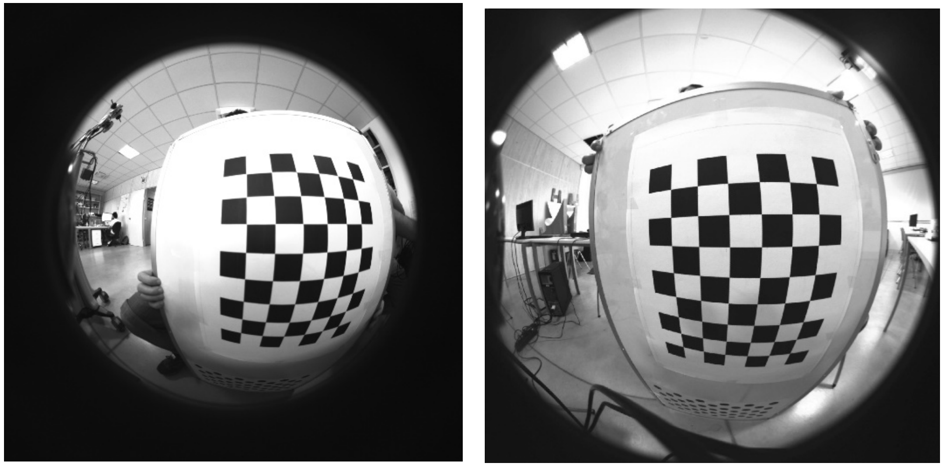


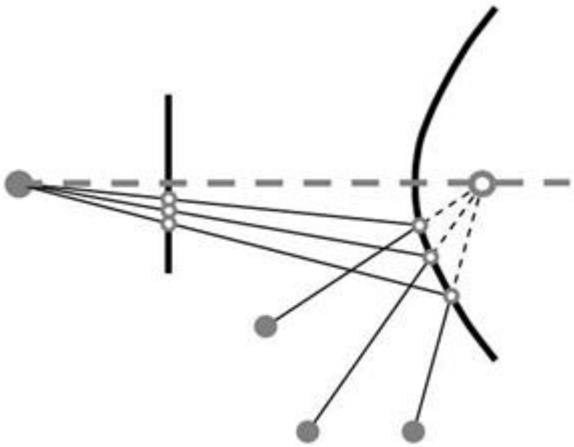
FE185C086HA-1		
Focal Length (mm)		2.7
Iris Range		F1.8 - F16
Operation	Focus	Fixed
	Iris	Manual
Angle Of View (H×V)	1"	185° × 185°(ø8.6mm)
	2/3"	185° × 140°35'
	1/2"	136°18' × 102°19'
Focusing Range (From Front Of The Lens) (m)		∞ - 0.2
Back Focal Distance (in air) (mm)		9.75
Exit Pupil Position (From Image Plane) (mm)		-49
Filter Thread (mm)		–
Mount		C
Mass (g)		160
Remarks		• With Metal Mount • With Locking Knob for Iris

UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Calibration

- Extraction of grid corners
- Linear Least Square minimization of 4th order polinomial
- Find image center
  - Minimization of reprojection errors for all grid points
- Non Linear refinement with Levemberg-Marquadt
  - Minimization of sum of squared reprojection errors



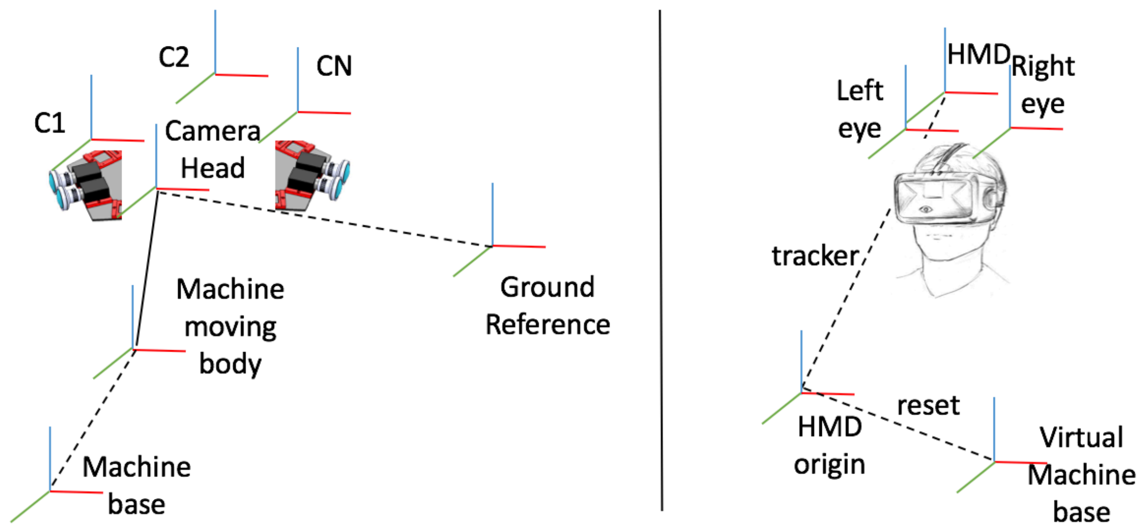


Cameras with Fish-eye lenses approximate well the single view point property

[Scaramuzza et al. 2006]

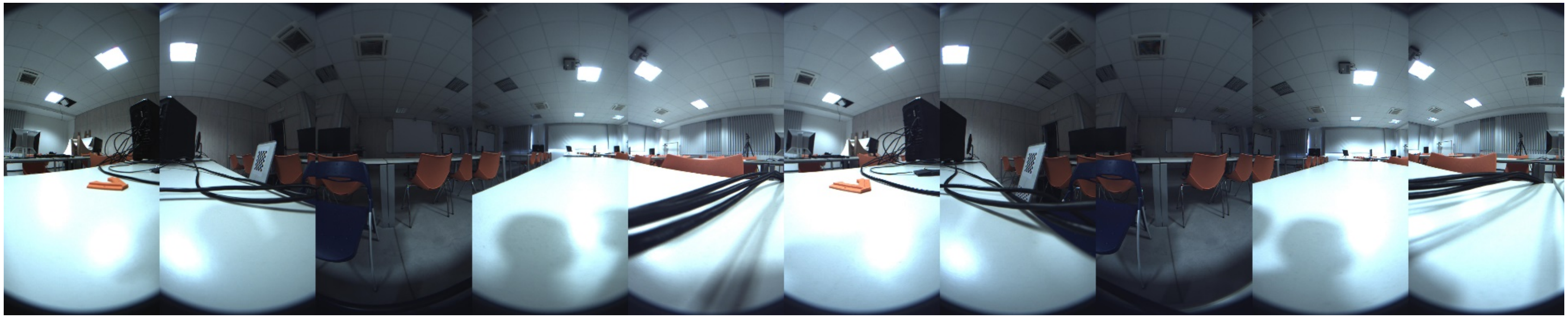
Frames

- Extrinsics between cameras
- Offset w.r.t. machine body
- Rotation of machine body w.r.t. machine base read from hall effect sensor
- Motion of HMD capture with embedded inertial unit
- Orientation information sent to the streaming server to select correct camera pair
- Alignement of user and machine frontal view

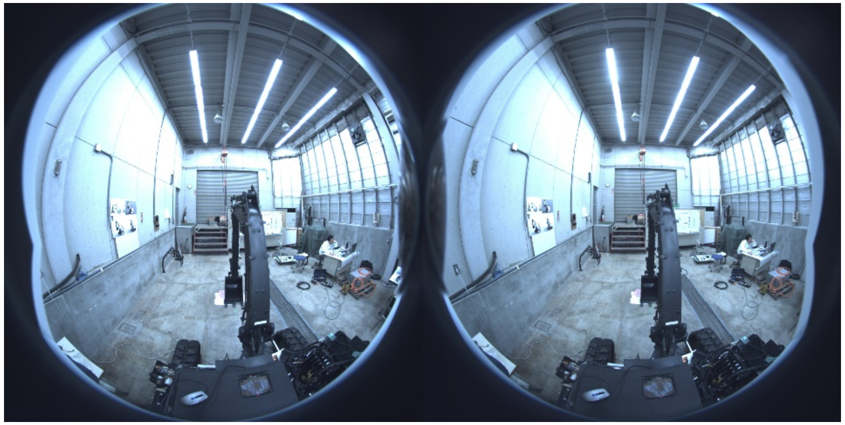


Streaming

Full frame 16000x1600px -> with half centered ROI 8000x1600px -> Gbit Ethernet



Wireless network -> reduced payload -> 3200x1600px (active stereo pair)



Acquisition and Compression

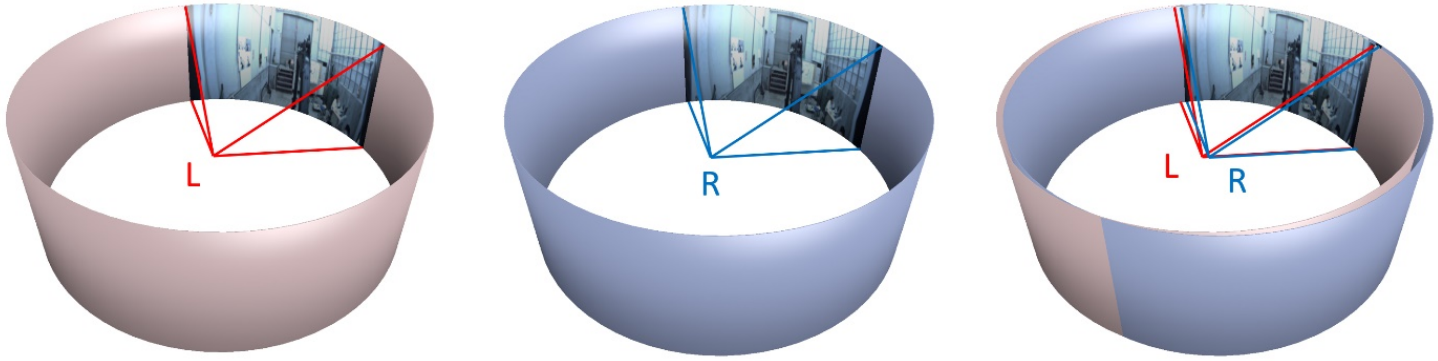
Theoretical bandwidth 20Hz rate	1600x1600	2048x2048
RAW8 (1 BPP)	51.2 MB/s	83.8 MB/s
YUV12 (3 BPP)	153.6 MB/s	251 MB/s

Pointgrey theoretical packetsize	1600x1600	2048x2048
RAW8 (1 BPP)	6400	10485
YUV12 (3 BPP)	19200	31457

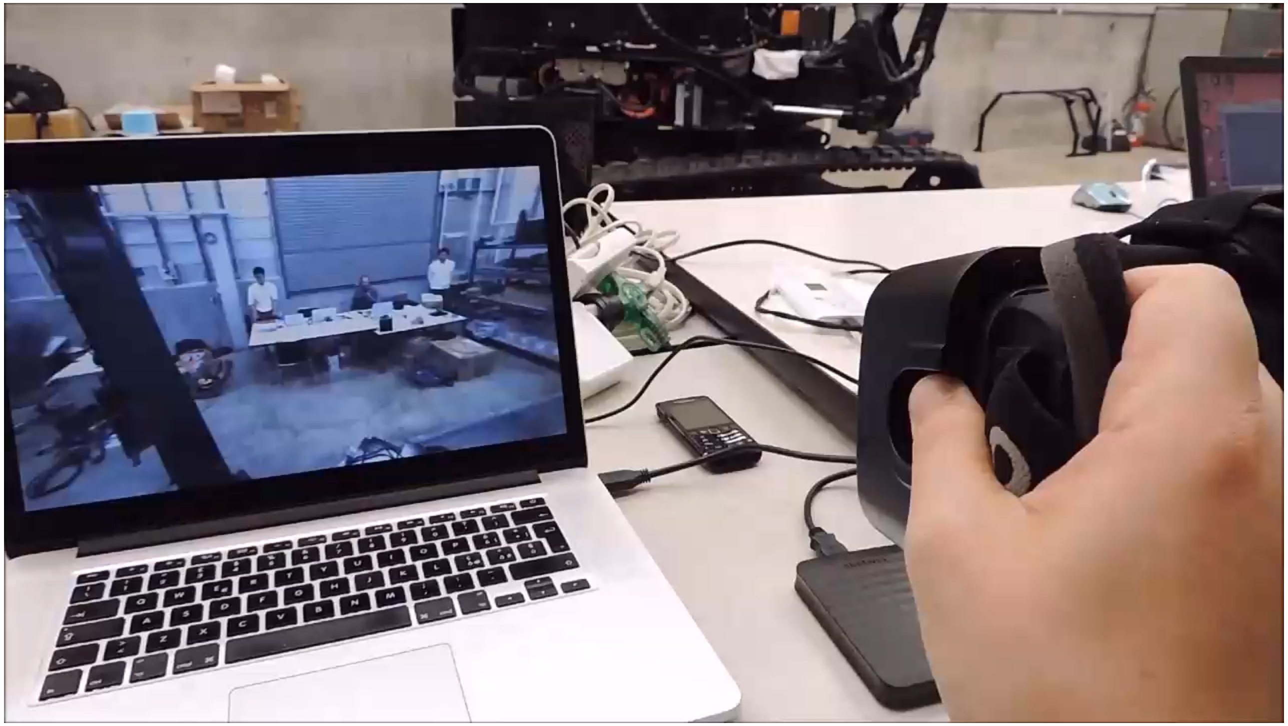
- Acquisition in RAW Bayer format (1 BPP) for reducing PCI Express requirements
    - Packet overhead due to camera
- Conversion in YUV12 on the CPU for feeding the compressor
- Compression using VP8 (WebM) -> 5-10 Mbps bitrate depending on configuration
    - CPU based compression could be replaced by Intel hardware compression
    - More recent h265 could be improved for further reducing bandwidth

Visualization

- Two virtual cameras corresponding to user eyes
- Virtual cylinder surface for rendering covering 90% field of view
- Eye-separation offset between cameras for stereo perception
- YUV decoding pixel shader to minimize decoding
- HMD distortion compensation to adapt to lens distortion



Visualization

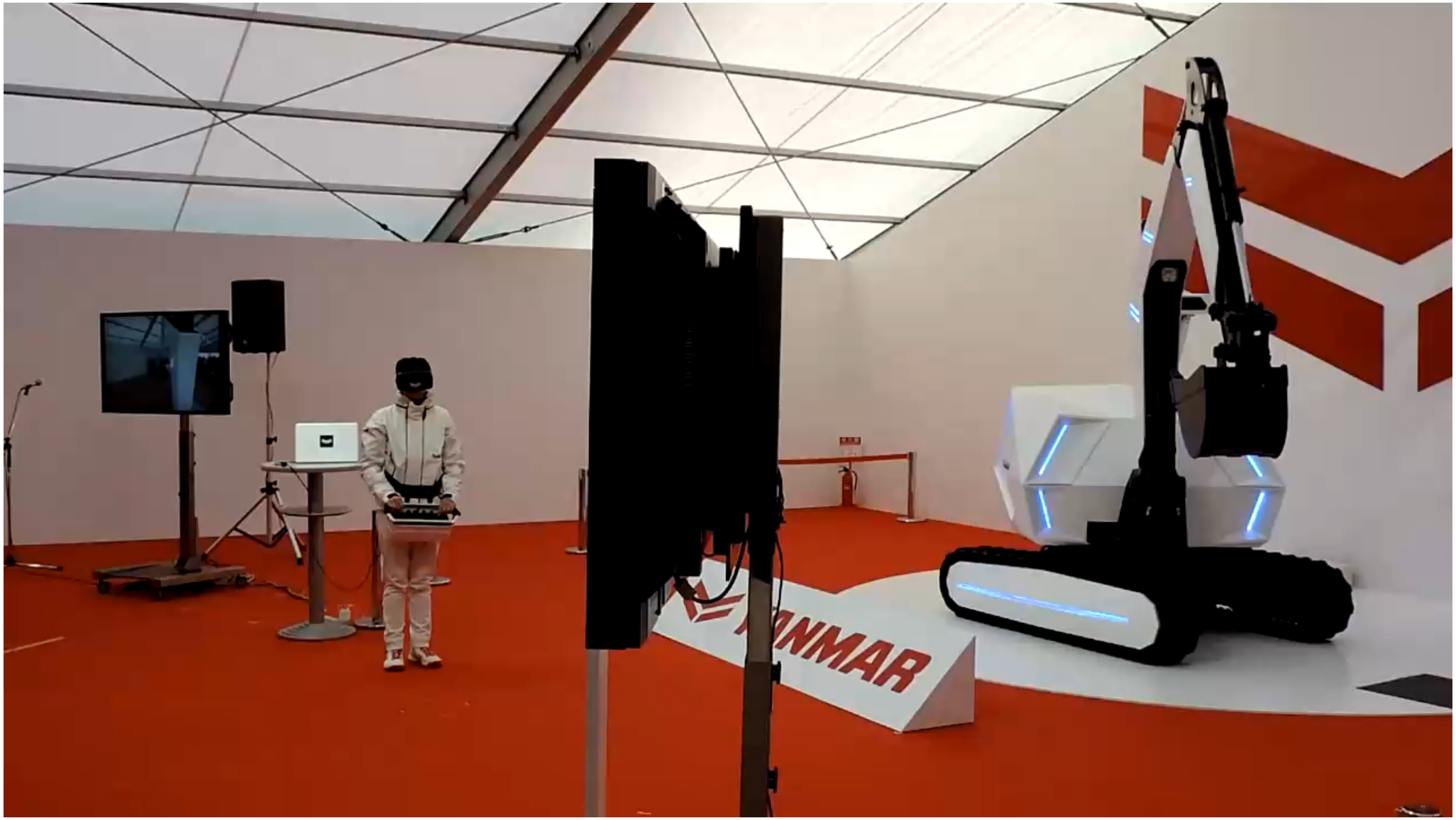


Augmented Reality

The use of HMD combined to the rendering of the stereo stream on a 3D virtual scene allows to augment the video stream with elements that can improve the operator awareness and the whole working operation.

In the preliminary demo we allow the user to enable an AR aid that displayed underground pipes taken from a reference CAD of the corresponding construction site overlapping them on the scene in transparency. Combined with the stereo vision, this aid allows to perceive the depth of the pipes and avoid, during excavation, possible breakage of the infrastructure. The projection of the augmented elements on the scene is made consistent with the point of view of the operator and the rotation of the machine body over the base.

System in action



Conclusions and Beyond

Development of a teleoperation system for the remote operation of working machine comprising realtime panoramic stereo streaming to an HMD worn on the operator head.
Integration of the vision head on a concept machine.

Improvements on operator interface for working machine teleoperation:

- Teleoperation at the Tip (End-Effector) of the working arm
- Haptic feedback
- Intention prediction and teleoperation aids
- Suggestion on safe path to reach the intended goal

Integration of feature tracking and localization algorithms for AR

THANK YOU!