The Eighth International Conference on Advanced Cognitive Technologies and Applications COGNITIVE 2016,
March 20 - 24, 2016 - Rome, Italy

DATA
61

Mapping Underground Voids

by Multirotor Flying Vehicles

Charlotte Sennersten | PostDoc 3D System Researcher

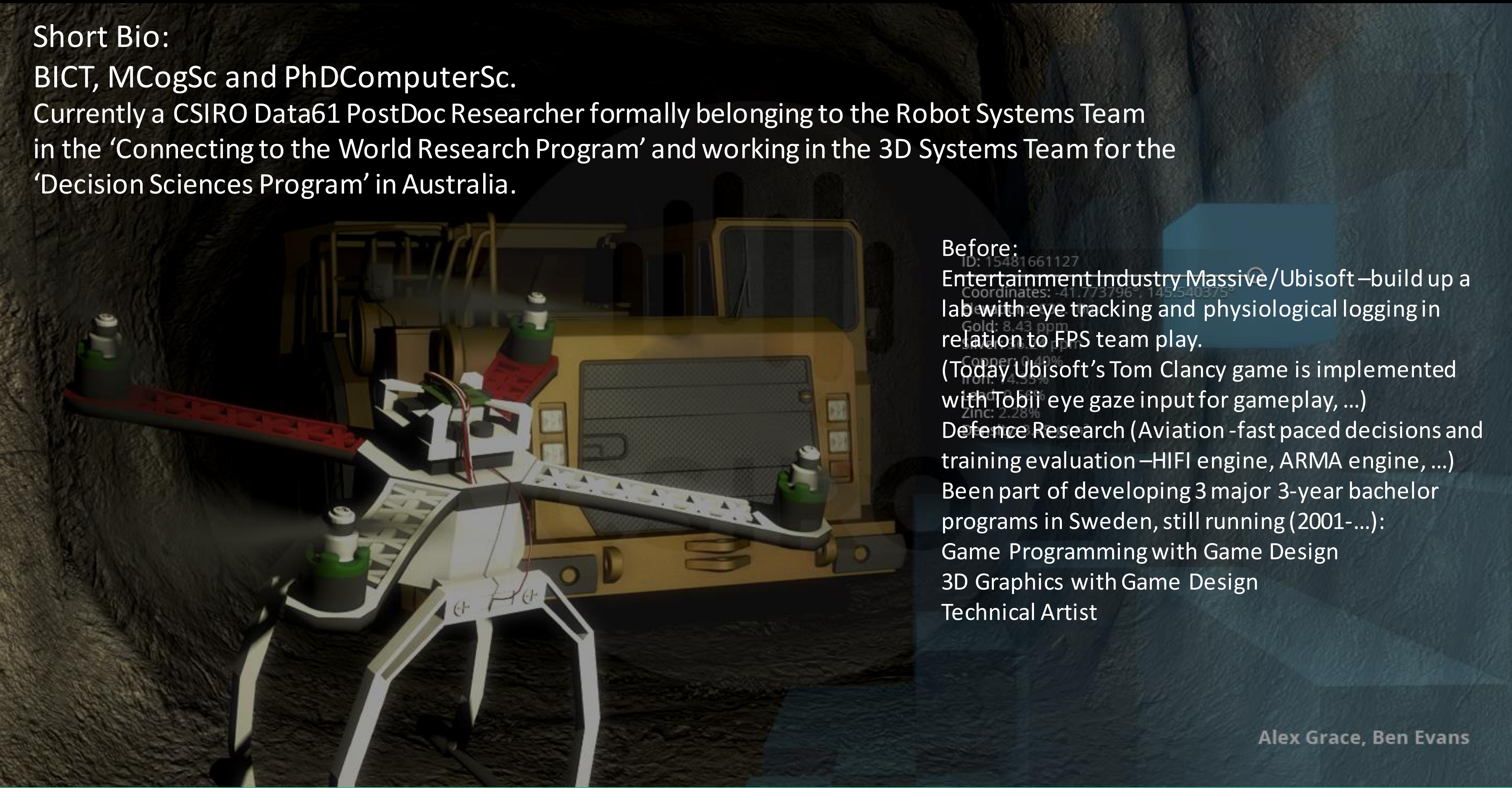
March 2016
www.data61.csiro.au

CSIRO

Short Bio:

BICT, MCogSc and PhDComputerSc.

Currently a CSIRO Data61 PostDoc Researcher formally belonging to the Robot Systems Team in the ‘Connecting to the World Research Program’ and working in the 3D Systems Team for the ‘Decision Sciences Program’ in Australia.



Alex Grace, Ben Evans

Before:

Entertainment Industry Massive/Ubisoft –build up a lab with eye tracking and physiological logging in relation to FPS team play.

(Today Ubisoft’s Tom Clancy game is implemented with Tobii eye gaze input for gameplay, …)

Defence Research (Aviation -fast paced decisions and training evaluation –HIFI engine, ARMA engine, …)

Been part of developing 3 major 3-year bachelor programs in Sweden, still running (2001-…):

Game Programming with Game Design

3D Graphics with Game Design

Technical Artist

Content for this hour 09:15-10:15;

1. Where in the world
    - 1.1 Research in CSIRO/Data61
    - 1.2 Research overview in Tasmania
    - 1.3 Our research, Data61

2. Context and why?
    - 2.1 Applications: Mine Virtualisation
        - 2.1.1 The 3D mapping pipeline
            - 2.1.1.1 Photogrammetry
            - 2.1.1.2 Structure for motion
            - 2.1.1.3 Lidar
        - 2.1.2 The 3D physics engine

3. Level of Autonomy
    - 3.1 ACT-R, the Robot Operative System (ROS) and Unity 3D
    - 3.2 How do we create local and global intelligence?

4. Systemisation of the world
    - 4.1 VoxelNet
    - 4.2 VoxelNet Off Earth applications

5. Future

RECENT PUBLICATIONS

C. Sennersten, A. Davie, and C. Lindley, (2016) “VoxelNet - An Agent Based System for Spatial Data Analytics”, The Eighth International Conference on Advanced Cognitive Technologies and Applications, Rome, Italy.

C. Sennersten et al., (2015) “Unmanned Aerial Robots for Remotely Operated and Autonomous Surveying for Inaccessible Underground Mine Voids”, The Third International Future Mining Conference, Sydney, Australia.

C. Lindley et al., (2015) “A Multilayer Three-Dimensional Index Tool for Recursive Block Models Supporting Terrestrial and Extra-terrestrial Mine Planning”, The Third International Future Mining Conference, Sydney, Australia.

M. Lochner, C. Sennersten, A. Morshed and C. Lindley, “Modelling Spatial Understanding: Using Knowledge Representation to Enable Spatial Awareness in a Robotics Platform”, IARIA Journal, vol. 7, no. c, 2014, pp. 26–31.

C. Sennersten, A. Morshed, M. Lochner and C. Lindley, “Towards a Cloud-Based Architecture for 3D Object Comprehension in Cognitive Robotics”, (2014), The Sixth International Conference on Advanced Cognitive Technologies and Applications, Venice, Italy, pp. 220–225.

Hardware and Software Team

Hardware	Software		
Multirotor Flying Vehicle	Pipeline for 3D Mapping	3D Mine Virtualisation	Remote Control
David Biggins	Md Sumon Shahriar	Alex Grace	Ben Evans
Maciej Matuszak	Andrew Davie	Charlotte Sennersten	

UAV Reasoning and workload

COGNITION & AI	Cognitive Psychology
Charlotte Sennersten	Martin Lochner

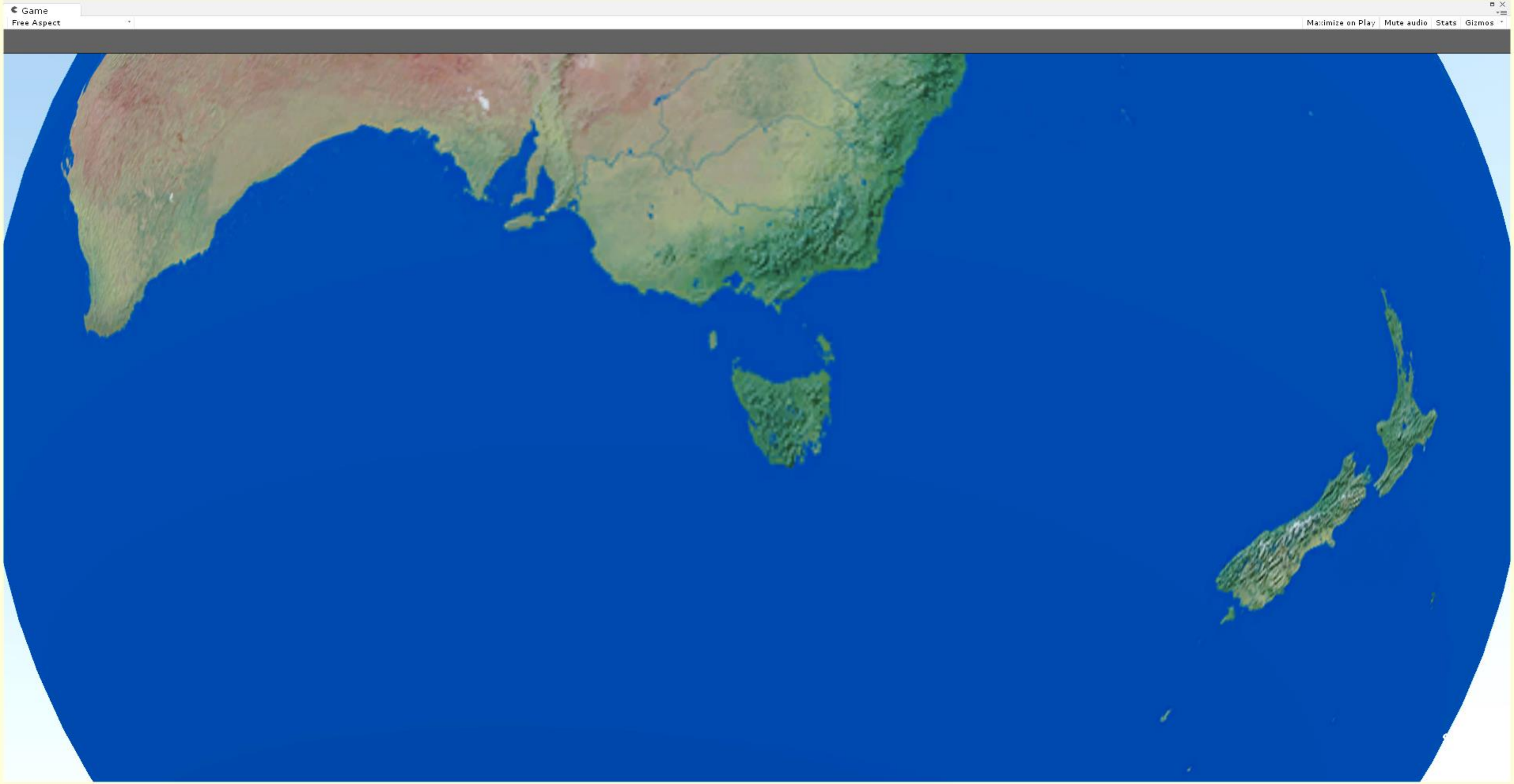
Data Mining and Machine Learning

Mill Plant Optimisation	XRF
Greg Smith	Greg Timms

Team and Project leader: Craig Lindley

1. Where in the world?


Game
Free Aspect
Maximize on Play
Mute audio
Stats
Gizmos
Status


Game
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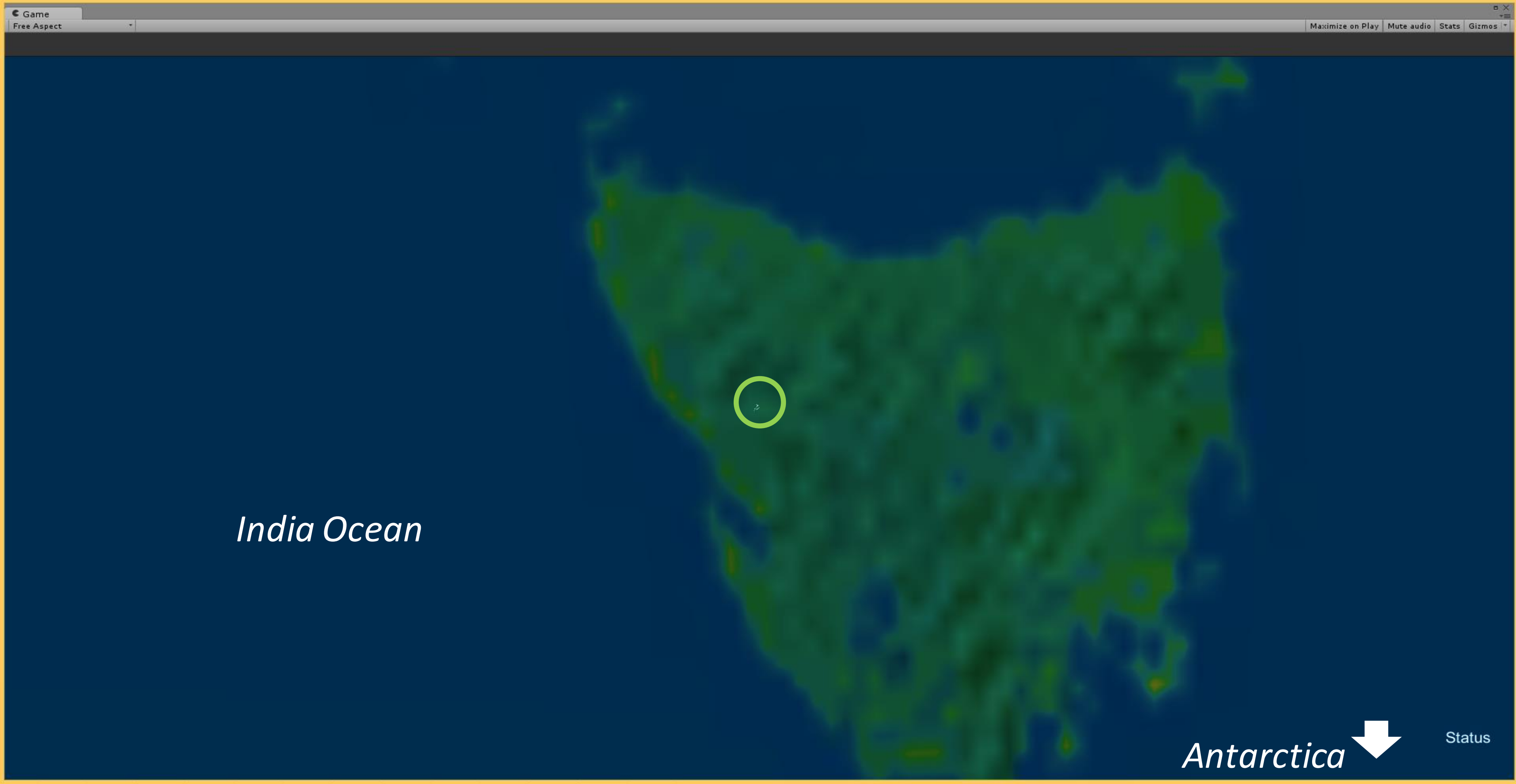
Game
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India Ocean
Antarctica
Status

1.1 Research in CSIRO/Data 61

CSIRO Business Units Nationally

Agriculture

Health and Bio Security

Data61

Energy

Food and Nutrition

Land and Water

Manufacturing

Mineral Resources

Oceans and Atmosphere

Astronomy and Space

1.2 Research overview in Tasmania

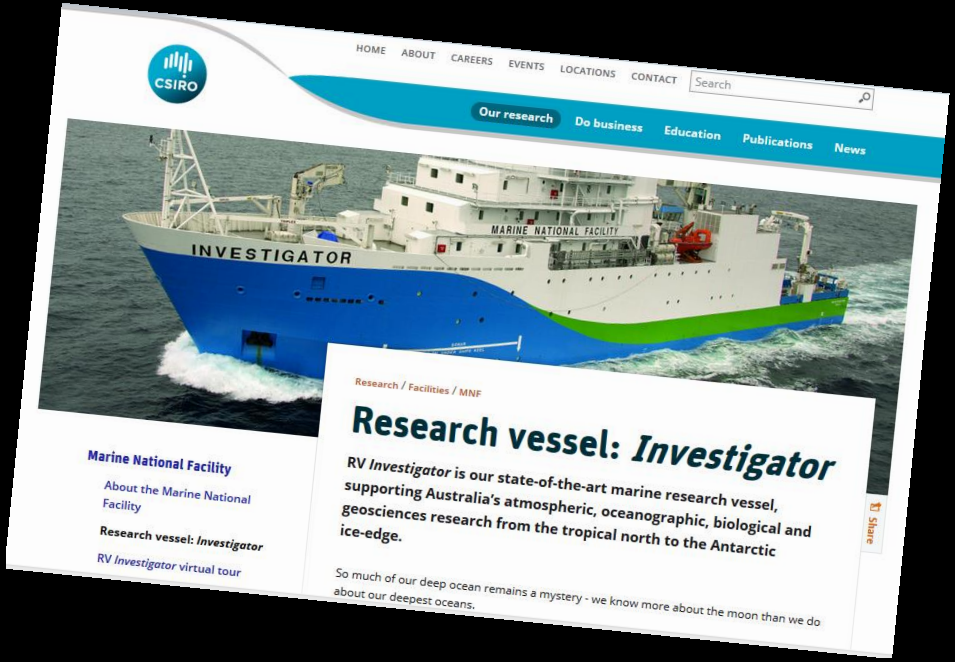
Business Units in Tasmania

Data61 (Former Digital Productivity and NICTA (National ICT Australia))

Mineral Resources

Oceans and Atmosphere

Land and Water



Research vessel: *Investigator*

RV *Investigator* is our state-of-the-art marine research vessel, supporting Australia's atmospheric, oceanographic, biological and geosciences research from the tropical north to the Antarctic ice-edge.

So much of our deep ocean remains a mystery - we know more about the moon than we do about our deepest oceans.

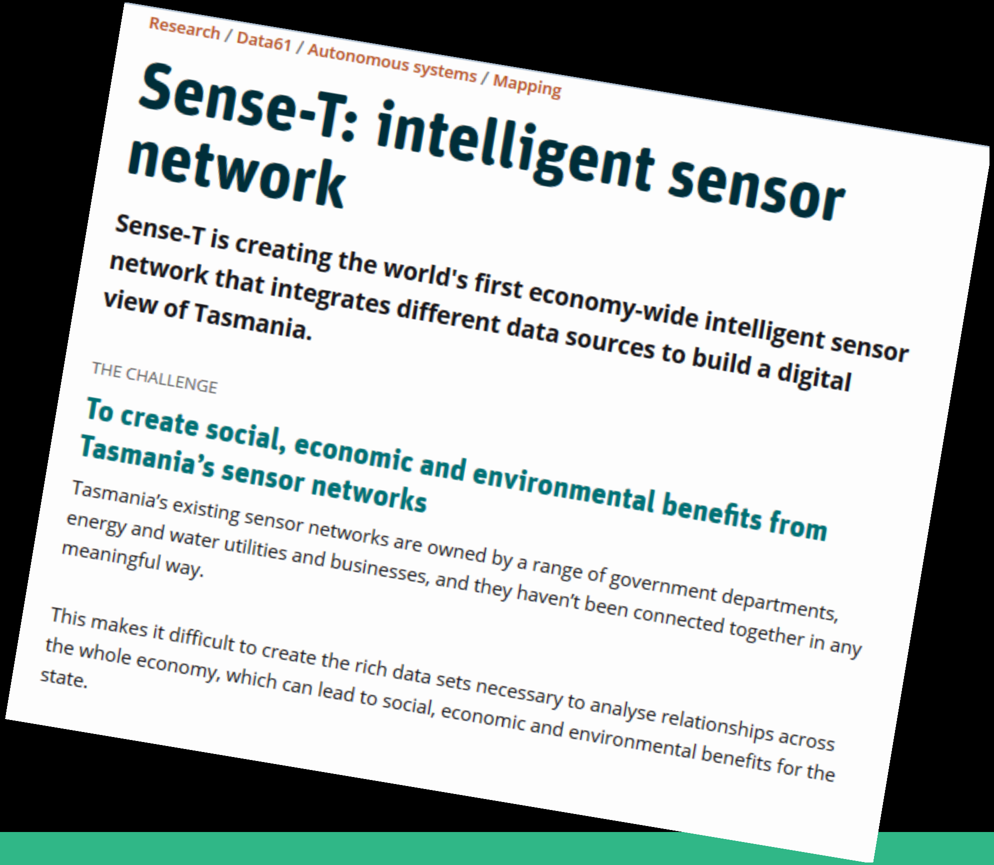
http://www.csiro.au/RV-Investigator-virtual-tour/rv_investigator.html?html5=prefer

Other Research in Tasmania

Access to detailed data

Innovation in sensor capabilities

Case studies
Smart tech keeping track of bats
Swarm sensing
Bio sensors in oysters



Research / Data61 / Autonomous systems / Mapping

Sense-T: intelligent sensor network

Sense-T is creating the world's first economy-wide intelligent sensor network that integrates different data sources to build a digital view of Tasmania.

THE CHALLENGE

To create social, economic and environmental benefits from Tasmania's sensor networks

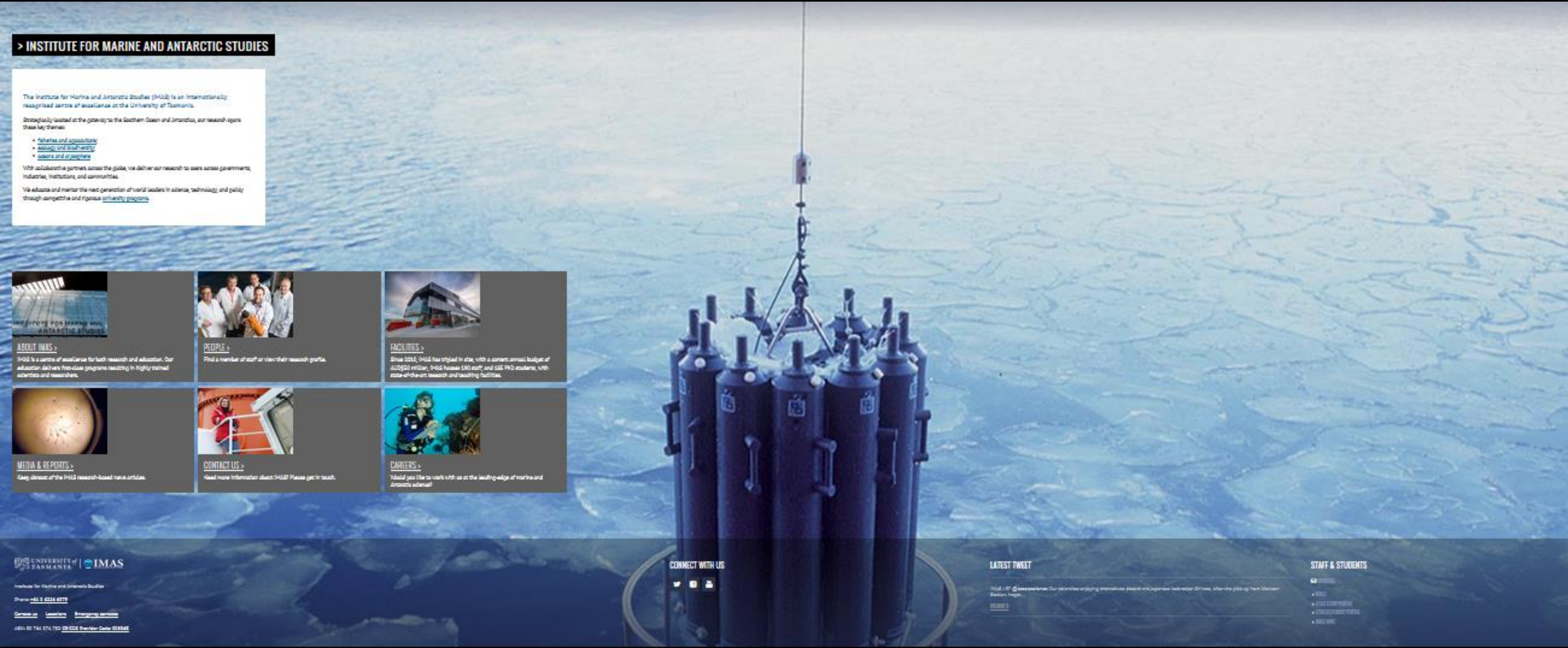
Tasmania's existing sensor networks are owned by a range of government departments, energy and water utilities and businesses, and they haven't been connected together in any meaningful way.

This makes it difficult to create the rich data sets necessary to analyse relationships across the whole economy, which can lead to social, economic and environmental benefits for the state.

Other Research in Tasmania

http://www.imas.utas.edu.au/

Other Research in Tasmania



> INSTITUTE FOR MARINE AND ANTARCTIC STUDIES

The Institute for Marine and Antarctic Studies (IMAS) is an internationally recognised centre of excellence at the University of Tasmania.

Strategically located at the gateway to the Southern Ocean and Antarctica, our research spans these key themes:

- fisheries and aquaculture;
- ecology and biodiversity;
- oceans and cryosphere

With collaborative partners across the globe, we deliver our research to users across governments, industries, institutions, and communities.

We educate and mentor the next generation of world leaders in science, technology, and policy through competitive and rigorous university programs.

ABOUT IMAS ›
IMAS is a centre of excellence for both research and education. Our education delivers first-class programs resulting in highly trained scientists and researchers.

PEOPLE ›
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FACILITIES ›
Since 2010, IMAS has tripled in size, with a current annual budget of AUD$50 million, IMAS houses 180 staff and 185 PhD students, with state-of-the-art research and teaching facilities.

MEDIA & REPORTS ›
Keep abreast of the IMAS research-based news articles.

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1.3 Our Research, Data61

Research

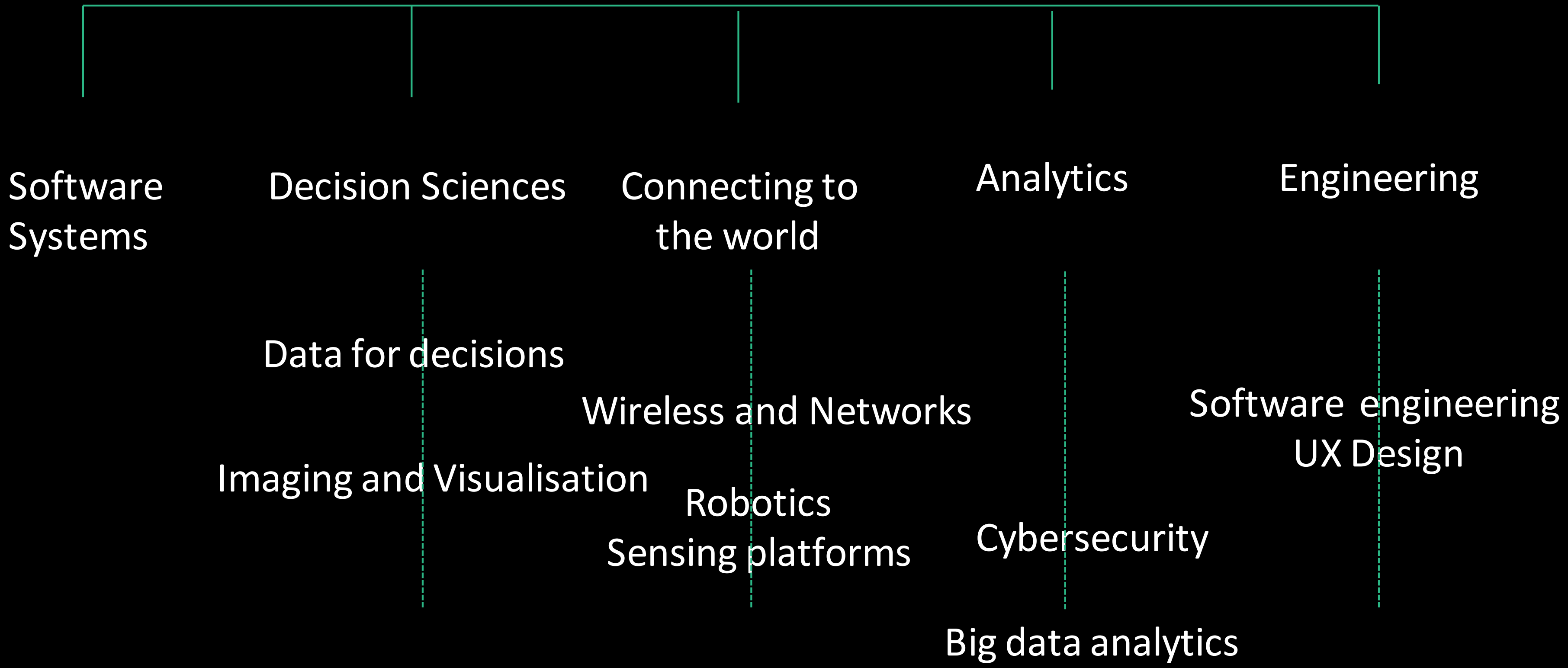
Data61

Data61 is the largest data innovation group in Australia. Bringing together our Digital Productivity team and National ICT Australia (NICTA), we are unrivalled in our intellectual capital and our network with the global technology marketplace.

FEATURED CASE STUDY

CSIRO and NICTA join forces to create digital research powerhouse >

DATA61 PROGRAMS



Software Systems

Decision Sciences

Data for decisions

Imaging and Visualisation

Connecting to the world

Wireless and Networks

Robotics

Sensing platforms

Analytics

Cybersecurity

Big data analytics

Engineering

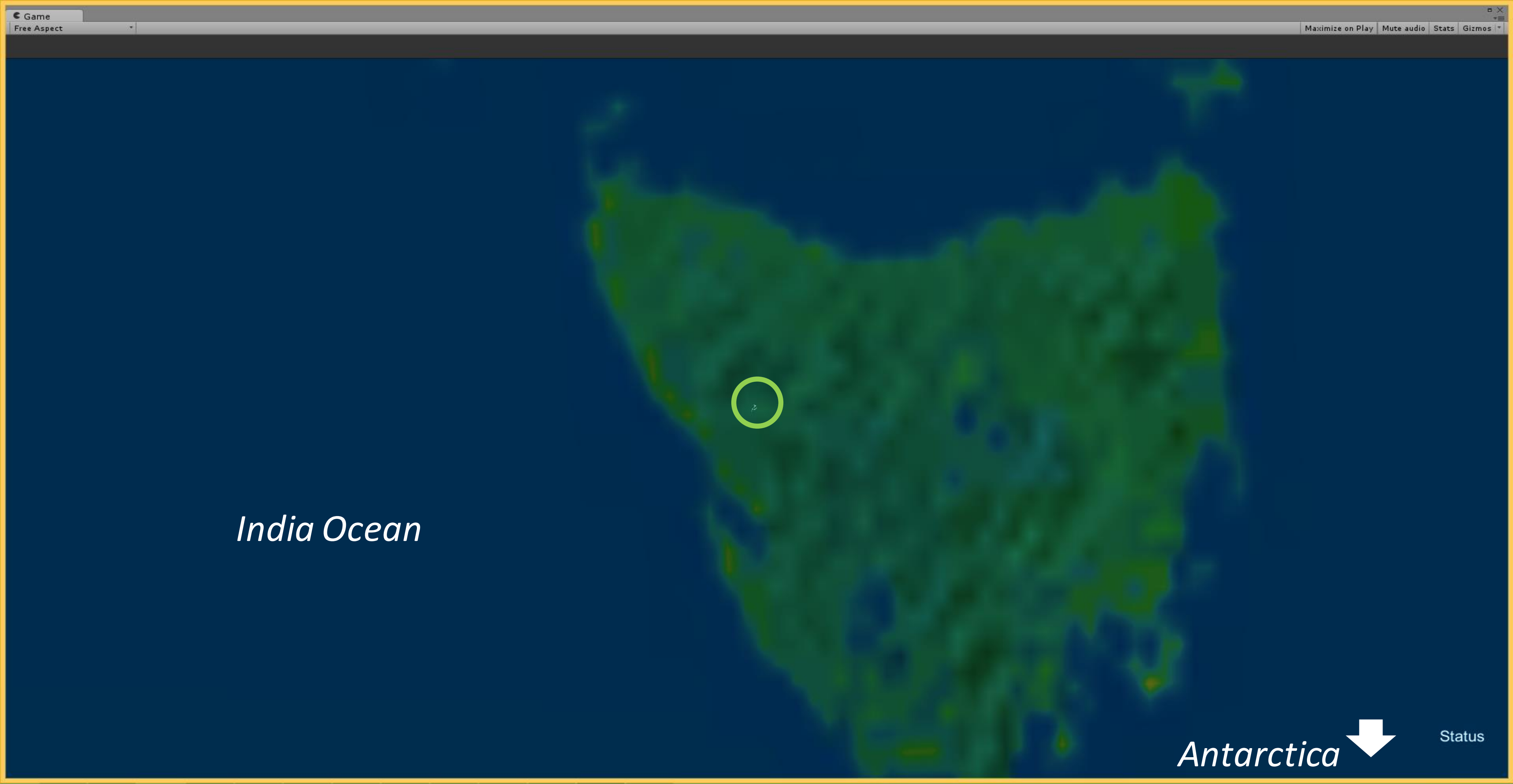
Software engineering

UX Design

Robotics
Sensing platforms

Field Robotics	We’re developing robotic system that can go anywhere, improving safety and efficiency for research and industrial applications
Guardian Technologies	A new breed of industrial robots and ICT systems
Internet of Things	
Sensing and Napping our Environment	
Telepresence Technologies	

2. Context and Why?


Game
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India Ocean
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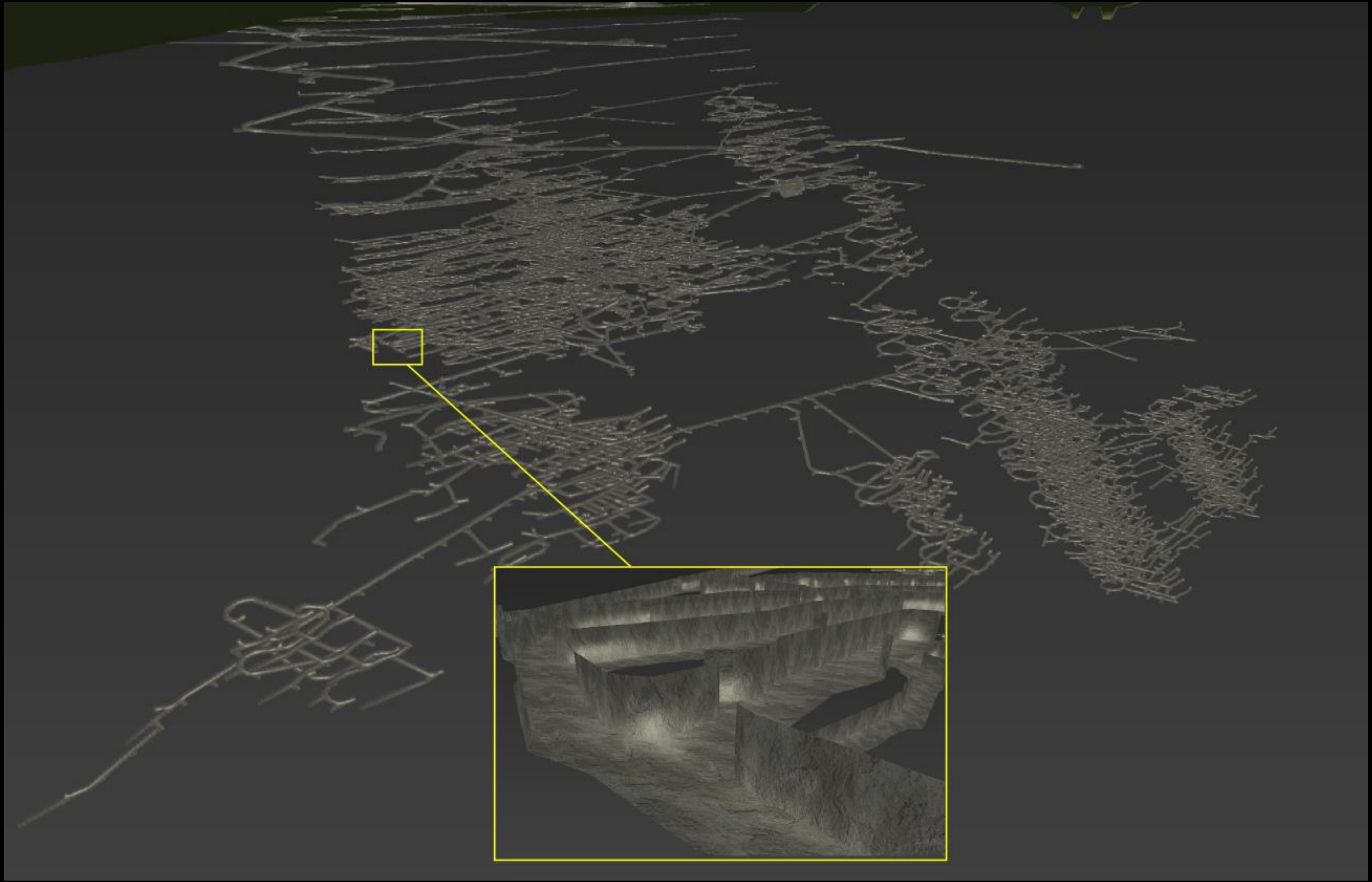
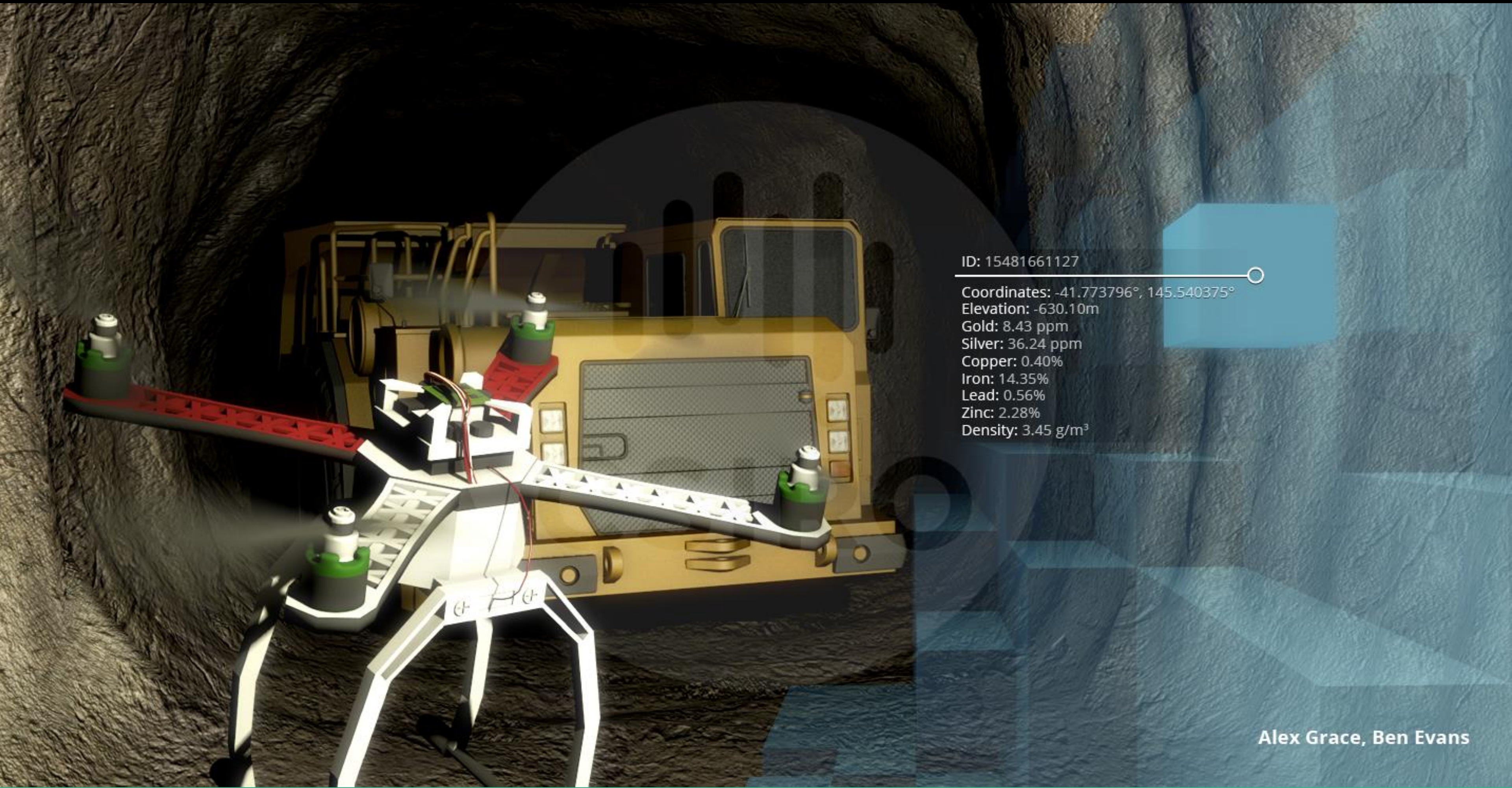
UAV Flight Underground

Mine Informatics Team,
Sandy Bay, Tasmania,
Australia, February 2015.

www.csiro.au





ID: 15481661127

Coordinates: -41.773796°, 145.540375°
Elevation: -630.10m
Gold: 8.43 ppm
Silver: 36.24 ppm
Copper: 0.40%
Iron: 14.35%
Lead: 0.56%
Zinc: 2.28%
Density: 3.45 g/m^3

Alex Grace, Ben Evans

2.1 Applications:
Mine Virtualisation

UAVs for Optimising Stope Design in Underground Mines

Project Overview

Problems to solve	Solution

• Underground mining procedures often extract excessive invaluable material from blasting and drilling
• This increases costs and wastes resources
• It’s difficult to know how much useful ore is in a given volume of rock
• The process of investigating this is costly and may carry risk
	• Use unmanned aerial vehicles (UAVs) for flying into unmapped areas
	• Use sensors on UAVs to
	    • Generate maps of greater accuracy
	    • Map dangerous or unknown areas
	    • Automatically classify mineralogy of rock surfaces
	• Outcomes include
	    • Decreased risk
	    • Higher quantity and greater accuracy of measurements

Virtualisation

The UAV must be able to fly beyond line of sight

- A first person camera feed gives us some information, but
    - Difficult to perceive depth
    - Little use for identifying mineralogy
    - Limited field of view
    - Lighting is poor
- Virtualisation addresses these issues by using other sensors on UAV and visualising this data in a virtual version of the mine
    - Better peripheral vision
    - Depth visualisation
    - Mineralogy visualisation
    - No lighting issues

2.1.1 The 3D Mapping Pipeline: Mine Virtualisation

UAVs for Optimising Stope Design in Underground Mines

REAL TIME FOR REMOTE CONTROL PURPOSE

CAPTUREING OPTICAL DATA → **BEING ABLE TO SEND DATA REAL TIME** →

→ CONVERSION OF FILE FORMATS → DATABASE

→ ACCESS FOR VARIOUS USERS

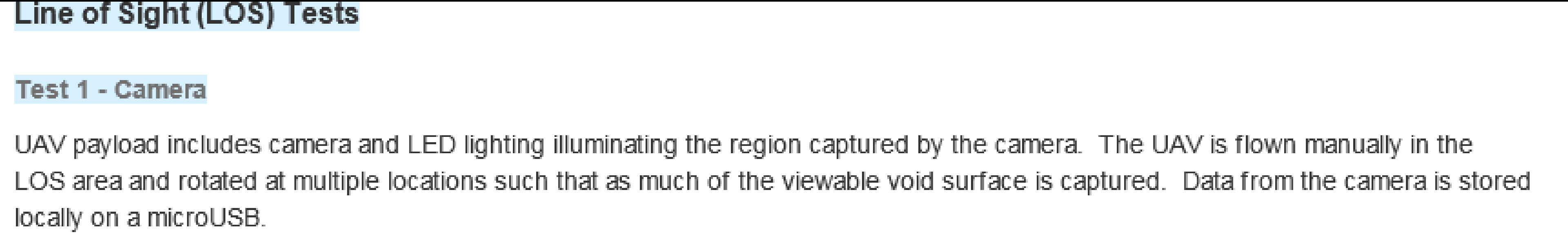
Line of Sight (LoS) Tests (for mapping devices)

	UAV with manual RC	Camera with storage	UAV legs attached	LED light source obtained	Camera mounted on UAV	LiDAR mounted on UAV	Battery mounted on UAV	RGB-D unit integrated with data logger	
Test1 Camera 1	X	X	X		X		X		
Test 2 LiDAR	X								
Test 3 RGB-D	X	X	X	X	X		X		

Non Line of Sight (NLoS) Tests (for mapping devices)

	UAV with manual RC	Camera with storage	UAV legs attached	LED light source obtained	Camera mounted on UAV	LiDAR mounted on UAV	Battery mounted on UAV	RGB-D unit integrated with data logger	
WiFi	X	X	X	X	X		X		

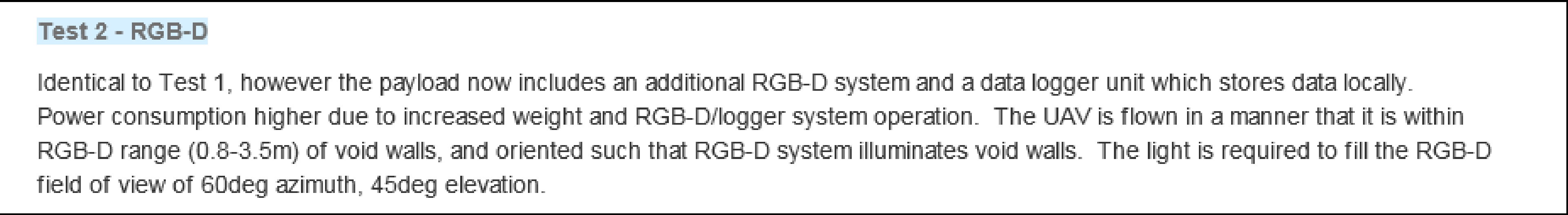
EXAMPLE OF TESTS FOR MAPPING DEVIICES



Line of Sight (LOS) Tests

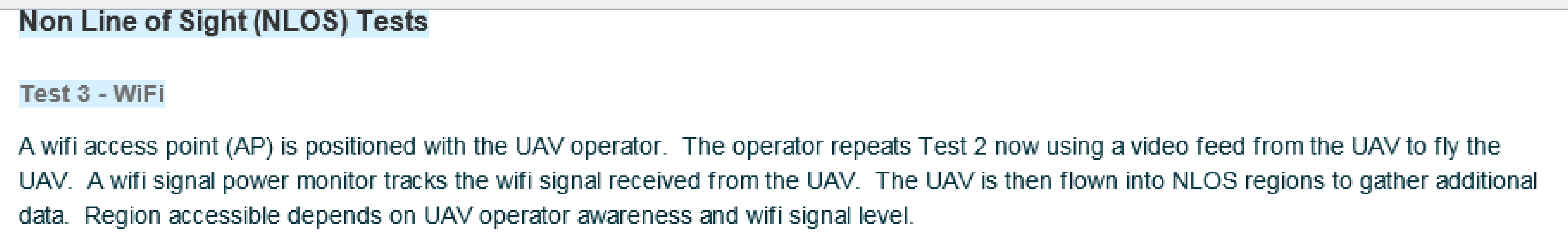
Test 1 - Camera

UAV payload includes camera and LED lighting illuminating the region captured by the camera. The UAV is flown manually in the LOS area and rotated at multiple locations such that as much of the viewable void surface is captured. Data from the camera is stored locally on a microUSB.



Test 2 - RGB-D

Identical to Test 1, however the payload now includes an additional RGB-D system and a data logger unit which stores data locally. Power consumption higher due to increased weight and RGB-D/logger system operation. The UAV is flown in a manner that it is within RGB-D range (0.8-3.5m) of void walls, and oriented such that RGB-D system illuminates void walls. The light is required to fill the RGB-D field of view of 60deg azimuth, 45deg elevation.



Non Line of Sight (NLOS) Tests

Test 3 - WiFi

A wifi access point (AP) is positioned with the UAV operator. The operator repeats Test 2 now using a video feed from the UAV to fly the UAV. A wifi signal power monitor tracks the wifi signal received from the UAV. The UAV is then flown into NLOS regions to gather additional data. Region accessible depends on UAV operator awareness and wifi signal level.

Line of Sight, Underground in Mine.

Round 1 (Boo) [WiFi]

START and Pilot Position 10m 20m 30m 40m (Maximum length)

Voidmapping:

Pointcloud import to ROS and export from ROS to mesh

Import to TerraSim/VBS and how to stitch added mesh to current pointcloud/mesh.

Citations from Lukas Kaul's Master's Thesis "A passively actuated 3D laser scanning system for mapping and autonomous navigation with a quadrotor UAV", 2014.

"…the range measurements ***can be projected into a common coordinate frame*** to generate a 3D pointcloud."

"The Zebedee mapping system is capable of producing highly accurate 3D maps of the environment. To do this, it manages the three steps of mapping: Data acquisition, data processing, and representation."

"A highly advanced SLAM algorithm that can register the measured points based on the detection of reobservations is used ***to project them into a common coordinate frame***."

- I am interested in what coordinate frame they use?
- How do you anchor a local position and its coordinate frame to a global one?

"Occupancy Grids

As sensor readings are never absolutely reliable, subject to noise and outliers, the problem of reconstructing the actual physical environment from sensor data becomes an estimation problem. Occupancy grid methods divide the environment into a spatially discretized grid, ***either 2D or 3D***. ***This grid is the map that the robot builds***. Each cell in the grid can be either empty, representing free space, or occupied, representing an obstacle."

- What update frequency does the cells have?

"Aerial Mapping

The term map also refers to the representation of geometrical features of real-world objects that can be used for further study of these objects.

Geometrical mapping: Usually acquired data with distance information between a number of points, one of which might or might not be fixed via RADAR, LIDAR, stereo cameras."

"Real-time perception and obstacle avoidance

The goal for the obstacle avoidance functionality is to be seamlessly integrated into the normal flight operation, assisting the pilot during operation rather than taking over control completely.

That means that the Eagle carrying the scanning sensors should be under full control of the human operator and fly as if flown completely manually when no obstacle is present. However, when the copter gets too close to obstacles, it should try to stay away from them automatically, while still reacting to radio commands. The desired effect is that of "virtual springs" that push the UAV away from the obstacle as soon as it comes too close." P.55

"The map assembler

The Zebedee SLAM is far too computationally expensive to run on the logging computer, especially in real time. This is why a separate local map building technique is introduced light enough to run in real time and precise enough to enable obstacle detection. " p.57

"…***the Cartesian coordinate system that does not rotate*** with respect to the world. However, it translates together with the UAV".

Below is a matrix in how I think our problem space.

Boo, it is remote control at A for B with manipulation with Operator Control & Vision System where I can contribute most. My last questions at QCAT was following: What degree of *Think* in Sense, Think, and Act is developed at current stage and the answer is collision detection. I want to understand more of the intelligence part or how to build for it, here the pointcloud/mesh/geodata/simulation /animation/GPS/decision/remote control…

Remote Control when to design FOR/FROM/REPLACE line of sight. Object tracking/steering.

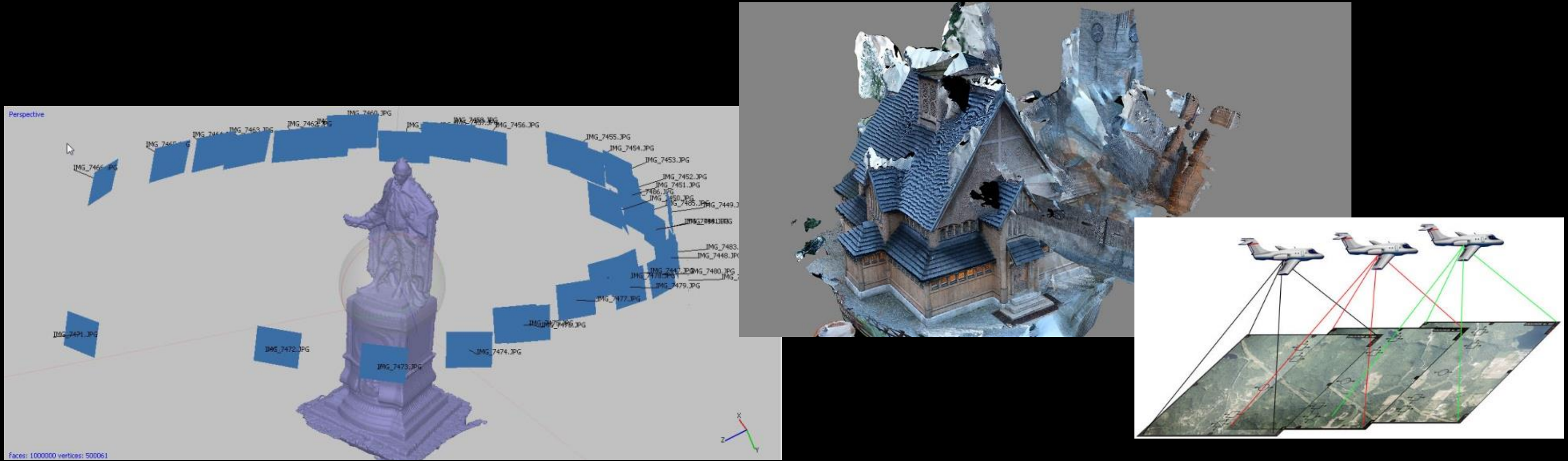
	Go from A to B	Aerial work at B	Remote control at A for B
Air			
Ground			
Water			

2.1.1. Photogrammetry:
Mine Virtualisation

UAVs for Optimising Stope Design in Underground Mines

Photogrammetry is the science of making measurements from photographs. The output of *photogrammetry* is typically a map, drawing, measurement, or a 3D model of some real-world object or scene. Many of the maps we use today are created with *photogrammetry* and photographs taken from aircraft.

http://www.photogrammetry.com/



2.1.1.2 Structure for Motion: Mine Virtualisation

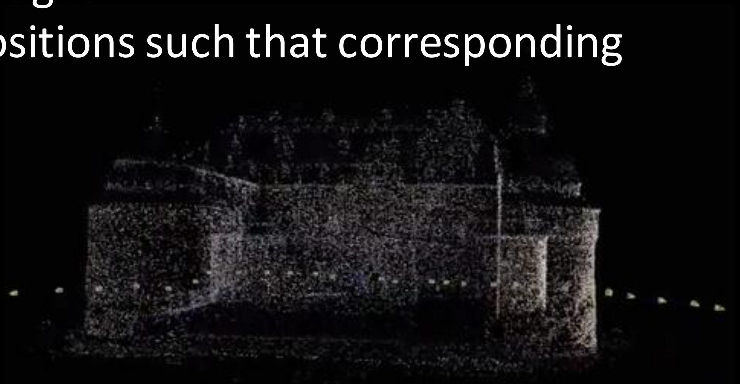
UAVs for Optimising Stope Design in Underground Mines

It is studied in the fields of computer vision and visual perception. In biological vision, SfM refers to the phenomenon by which humans (and other living creatures) can recover 3D *structure* from the projected 2D (retinal) *motion* field of a moving object or scene.

*https://en.wikipedia.org/wiki/**Structure**_from_**motion***

1. Take a lot of images of an object
2. Identify points in the images that possibly can be detected in other images.
3. Search for corresponding points in other images.
4. Compute camera positions and 3D point positions such that corresponding viewing ray cast intersect.

=670 images
= 50 000 3D points



https://www.youtube.com/watch?v=i7ierVkXYa8

2.1.1.3 LiDAR

Mine Virtualisation

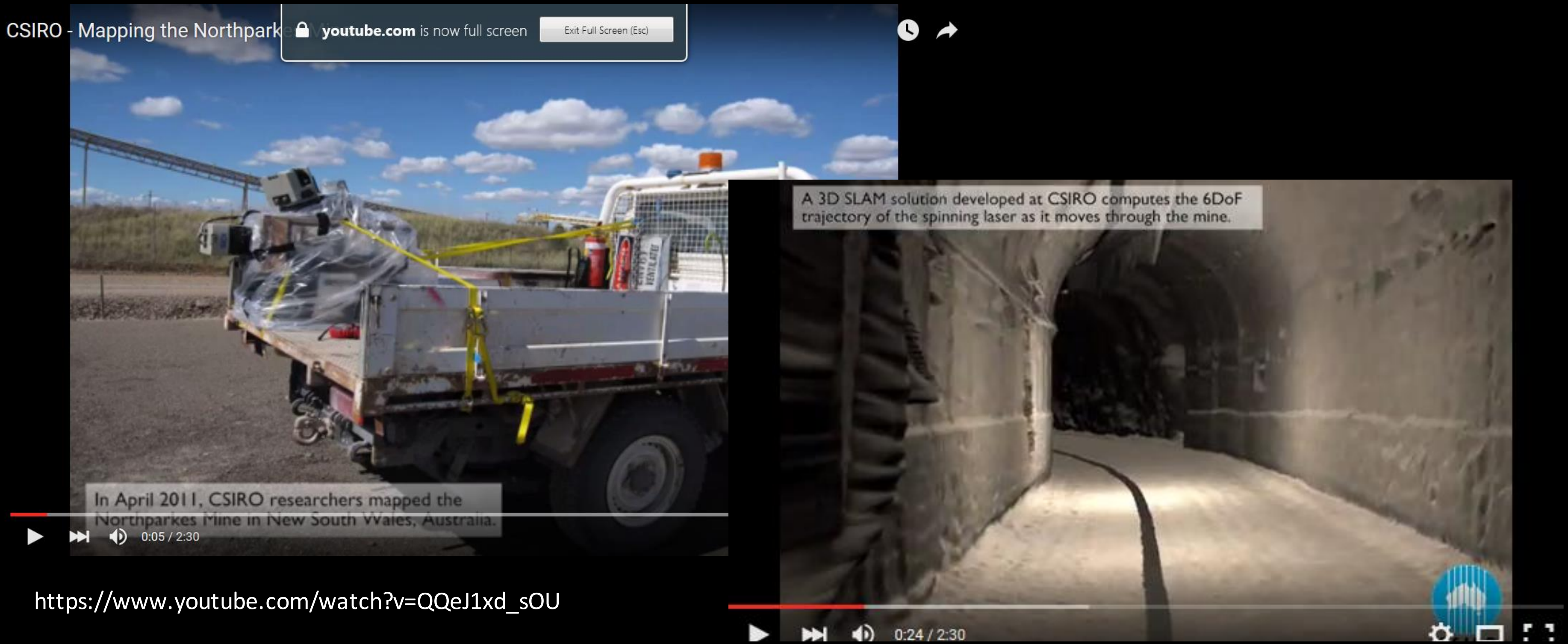
UAVs for Optimising Stope Design in Underground Mines

Hokuyo UST-10LX Scanning Laser Rangefinder
Product Code : RB-Hok-24

by Hokuyo

Be the first to review this product

- Small, accurate, high-speed scanning laser range finder
- Obstacle detection and localization of autonomous robots
- Detection distance (maximum): 30m
- Light source: Laser semiconductor (905nm)
- Scan speed: 25ms (Motor speed 2400rpm)



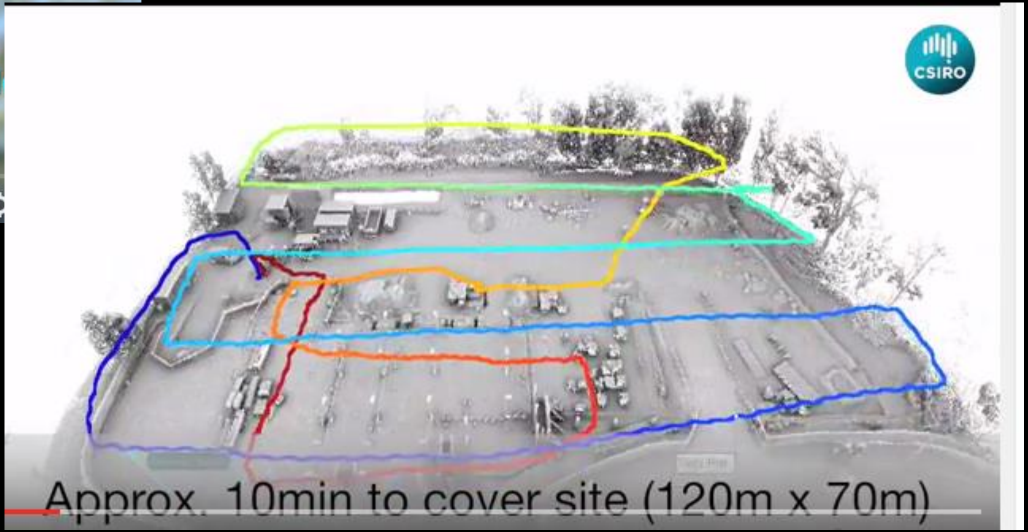
In April 2011, CSIRO researchers mapped the Northparkes Mine in New South Wales, Australia.

A 3D SLAM solution developed at CSIRO computes the 6DoF trajectory of the spinning laser as it moves through the mine.

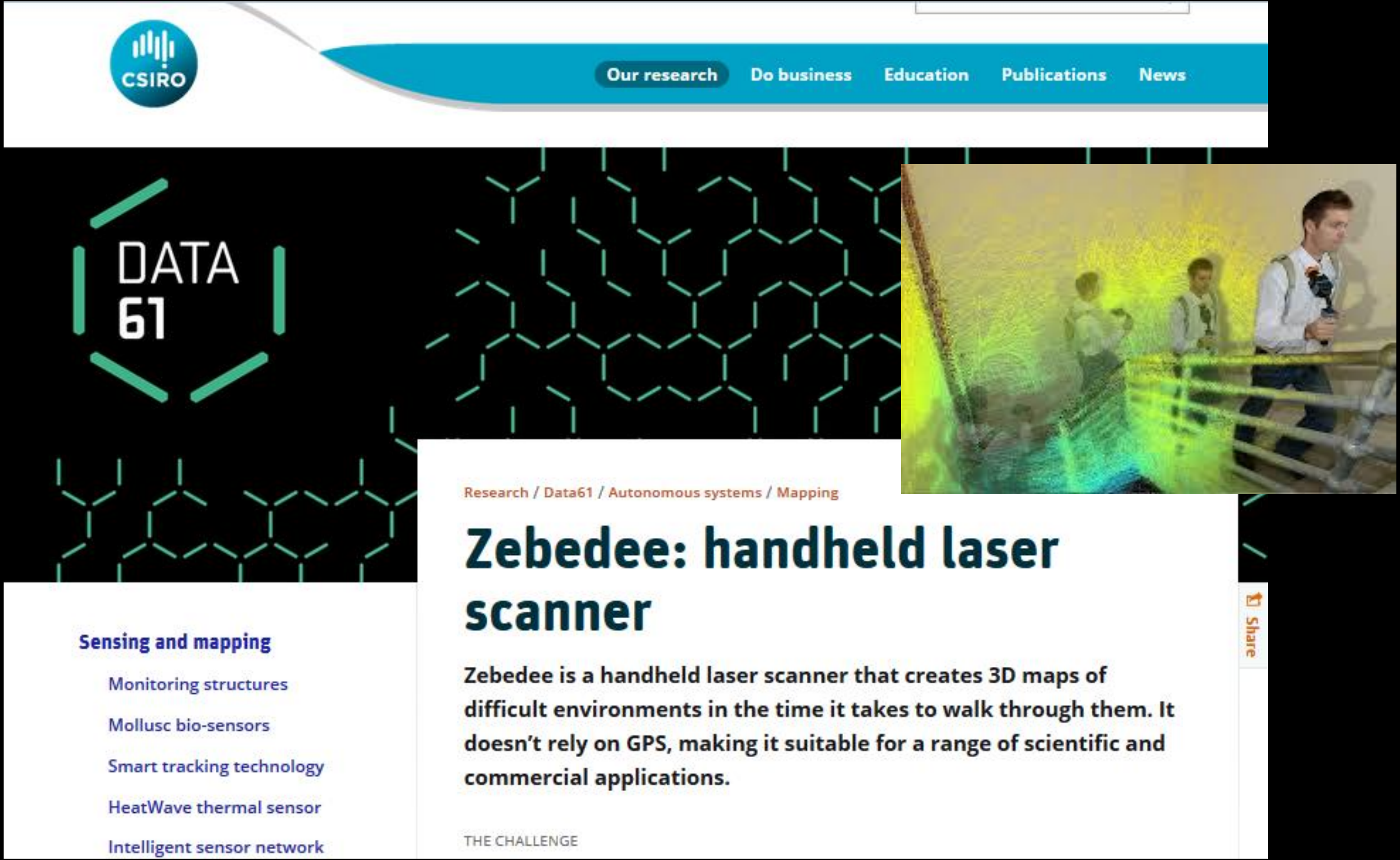
https://www.youtube.com/watch?v=QQeJ1xd_sOU

Published on Apr 29, 2012
In April 2011, CSIRO researchers mapped over 17km of the Northparkes copper/gold mine in New South Wales, Australia. The mine operators required a locally accurate 3D surface model in order to determine whether and how large equipment could be moved through the decline.

https://www.youtube.com/watch?v=CIB3EBuUJDo



Approx. 10min to cover site (120m x 70m)



Research / Data61 / Autonomous systems / Mapping

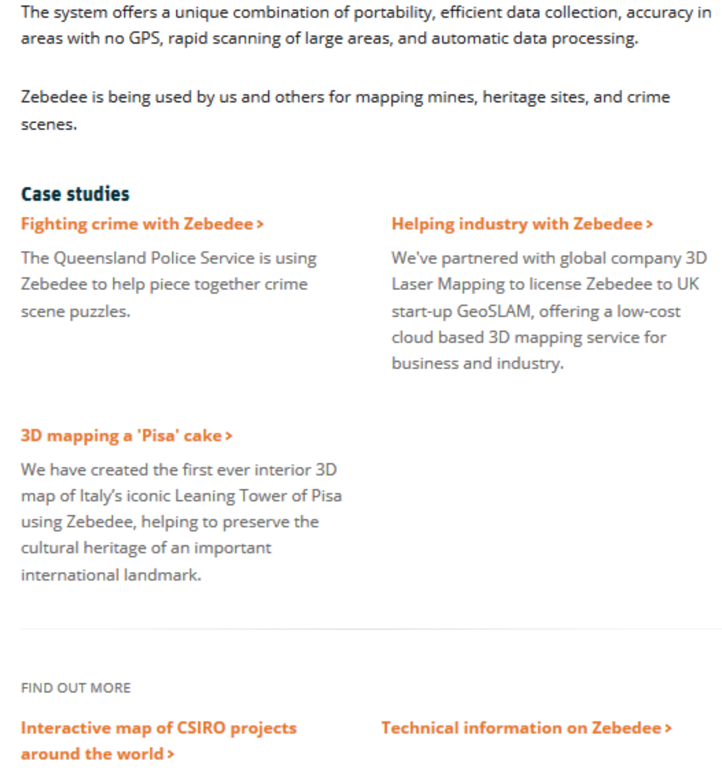
Zebedee: handheld laser scanner

Zebedee is a handheld laser scanner that creates 3D maps of difficult environments in the time it takes to walk through them. It doesn't rely on GPS, making it suitable for a range of scientific and commercial applications.

THE CHALLENGE

Sensing and mapping

- Monitoring structures
- Mollusc bio-sensors
- Smart tracking technology
- HeatWave thermal sensor
- Intelligent sensor network



The system offers a unique combination of portability, efficient data collection, accuracy in areas with no GPS, rapid scanning of large areas, and automatic data processing.

Zebedee is being used by us and others for mapping mines, heritage sites, and crime scenes.

Case studies

Fighting crime with Zebedee >

The Queensland Police Service is using Zebedee to help piece together crime scene puzzles.

Helping industry with Zebedee >

We've partnered with global company 3D Laser Mapping to license Zebedee to UK start-up GeoSLAM, offering a low-cost cloud based 3D mapping service for business and industry.

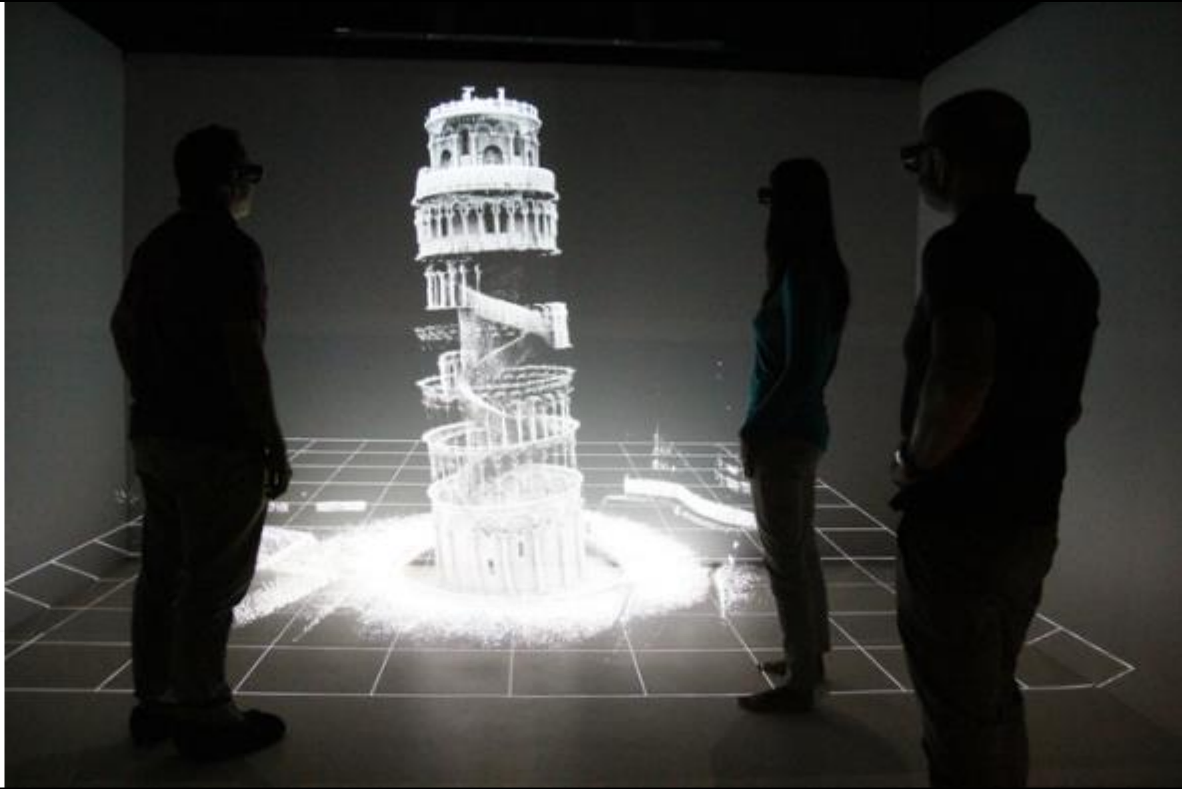
3D mapping a 'Pisa' cake >

We have created the first ever interior 3D map of Italy's iconic Leaning Tower of Pisa using Zebedee, helping to preserve the cultural heritage of an important international landmark.

FIND OUT MORE

Interactive map of CSIRO projects around the world >

Technical information on Zebedee >



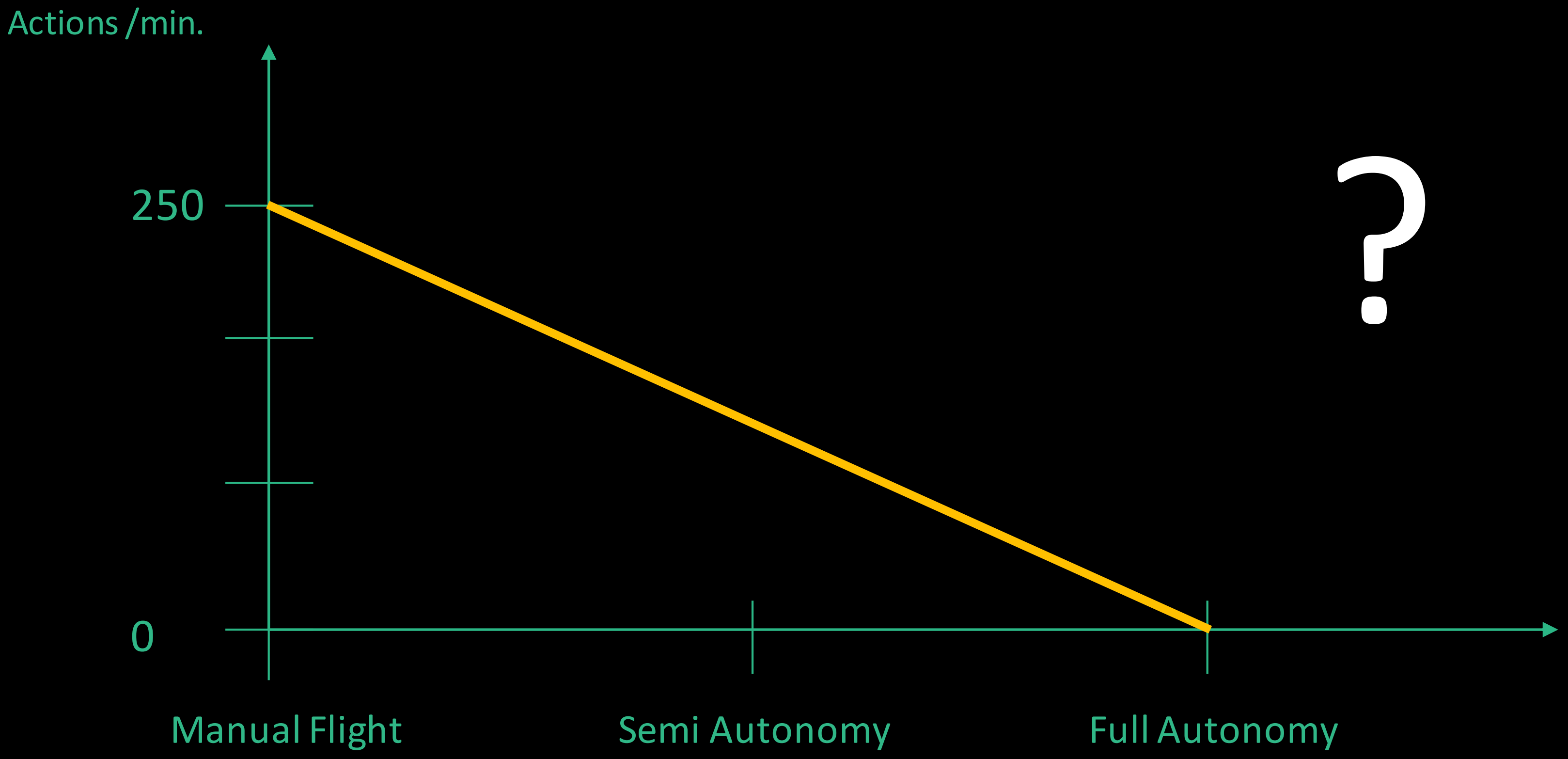
Within 20 minutes we were able to use Zebedee to complete an entire scan of the building's interior. This allowed us to create a uniquely comprehensive and accurate 3D map of the tower's structure and composition, including small details in the stairs and stonework.

When we have a LiDAR scan then we need to subdivide the whole data information into objects. Therefore a LiDAR scan needs to be run with “Classifiers” so we can extract the objects we are especially interested in.

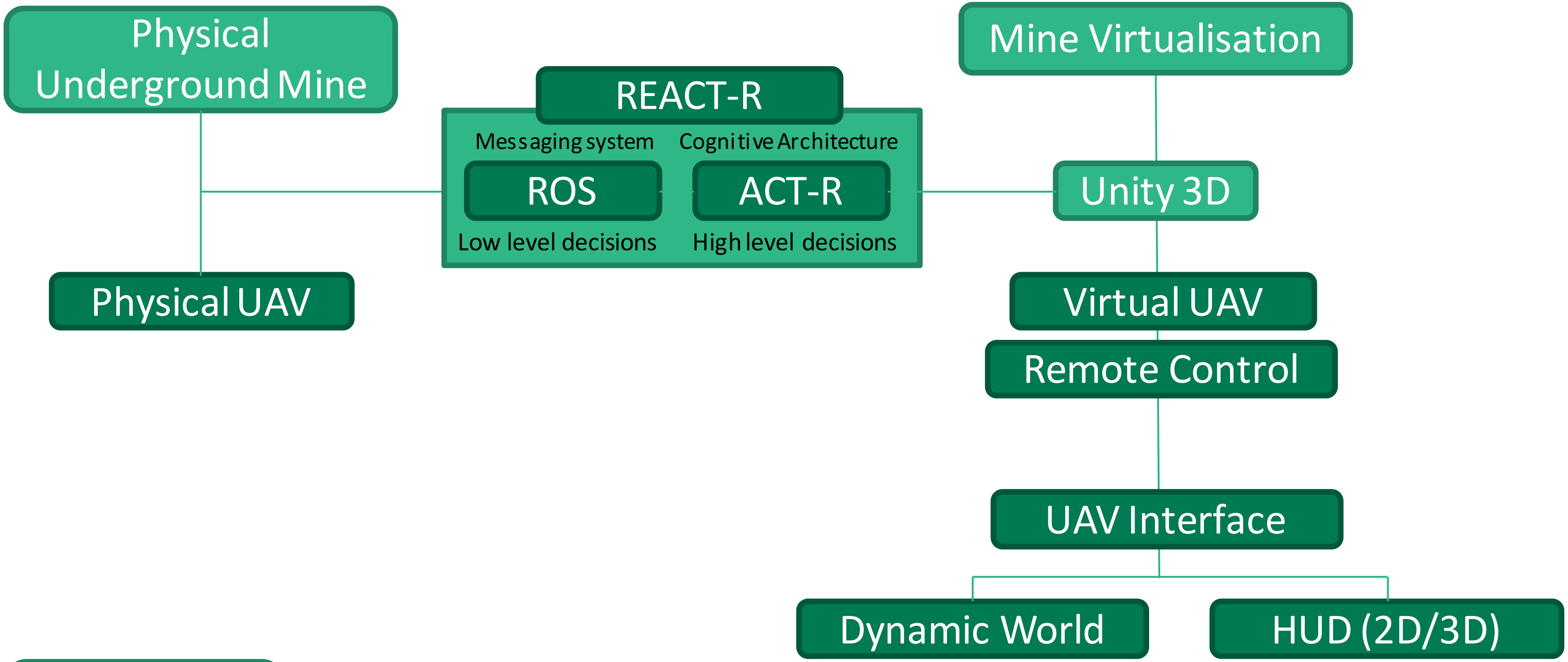
= OBJECTS

3. Level of Autonomy

LEVEL of AUTONOMY



3.1 ACT-R, the Robot Operative System (ROS) and Unity 3D



Physical Underground Mine

Physical UAV

REACT-R

Messaging system

ROS

Low level decisions

Cognitive Architecture

ACT-R

High level decisions

Mine Virtualisation

Unity 3D

Virtual UAV

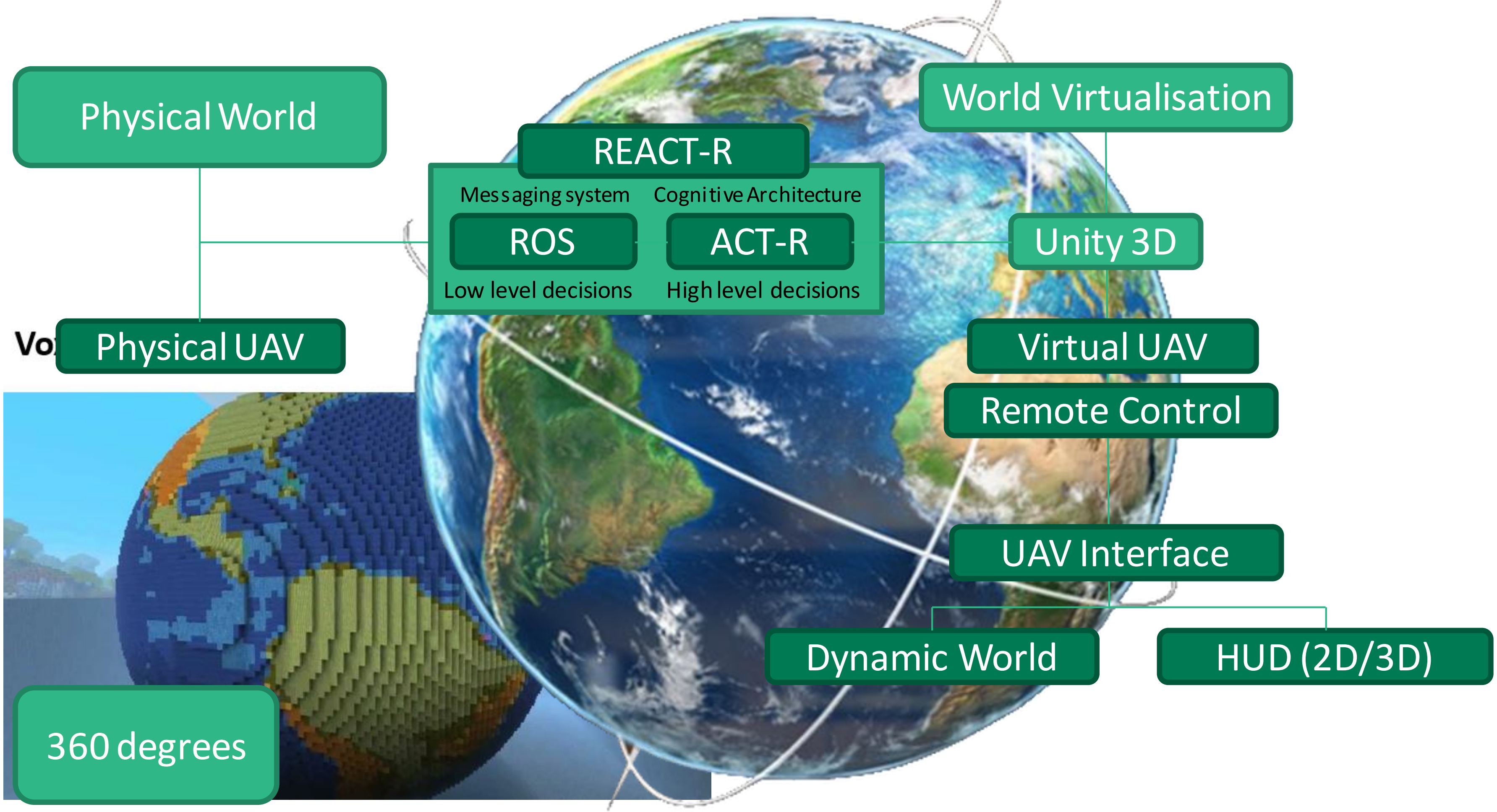
Remote Control

UAV Interface

Dynamic World

HUD (2D/3D)

360 degrees



Physical World

Vo

Physical UAV

REACT-R

Messaging system

ROS

Low level decisions

Cognitive Architecture

ACT-R

High level decisions

World Virtualisation

Unity 3D

Virtual UAV

Remote Control

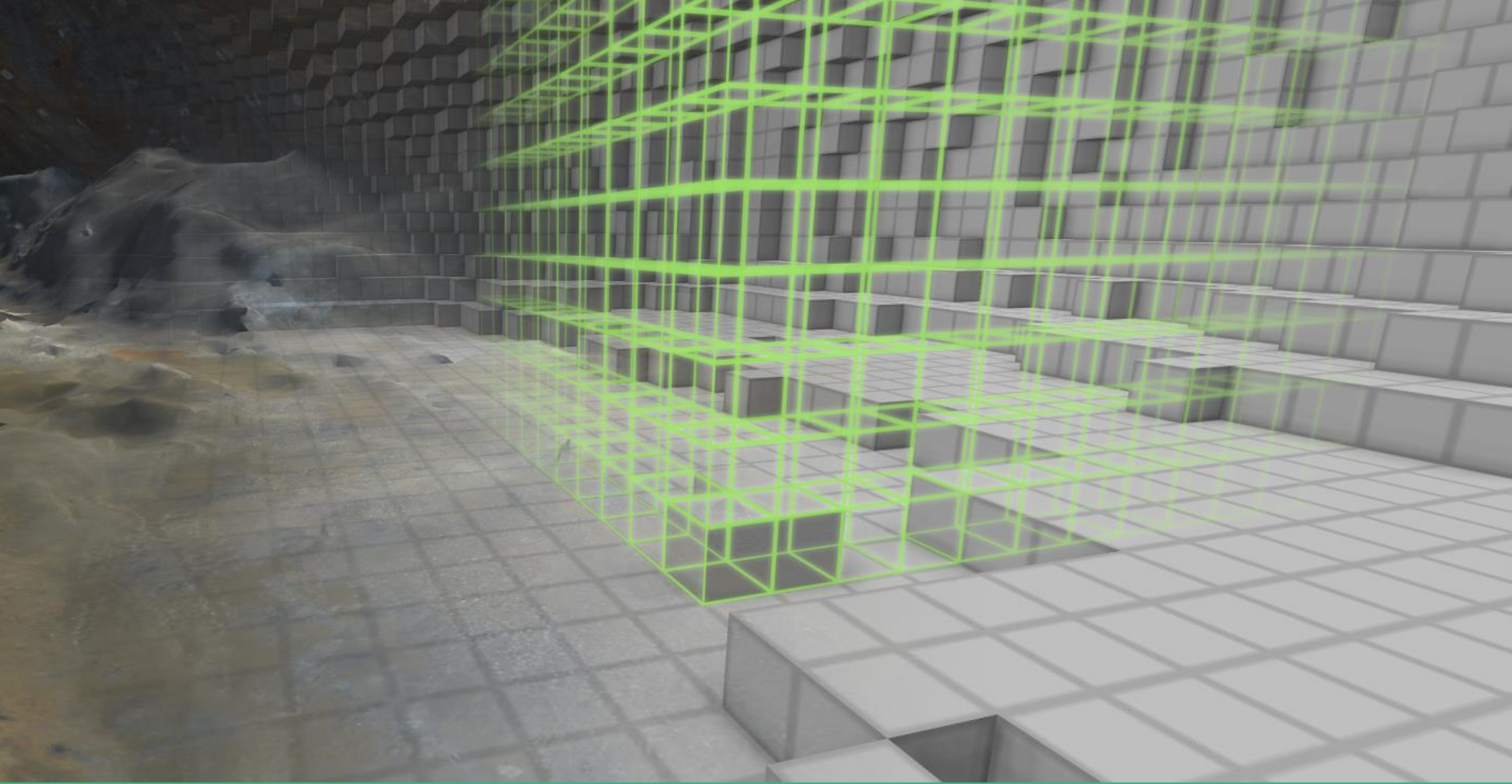
UAV Interface

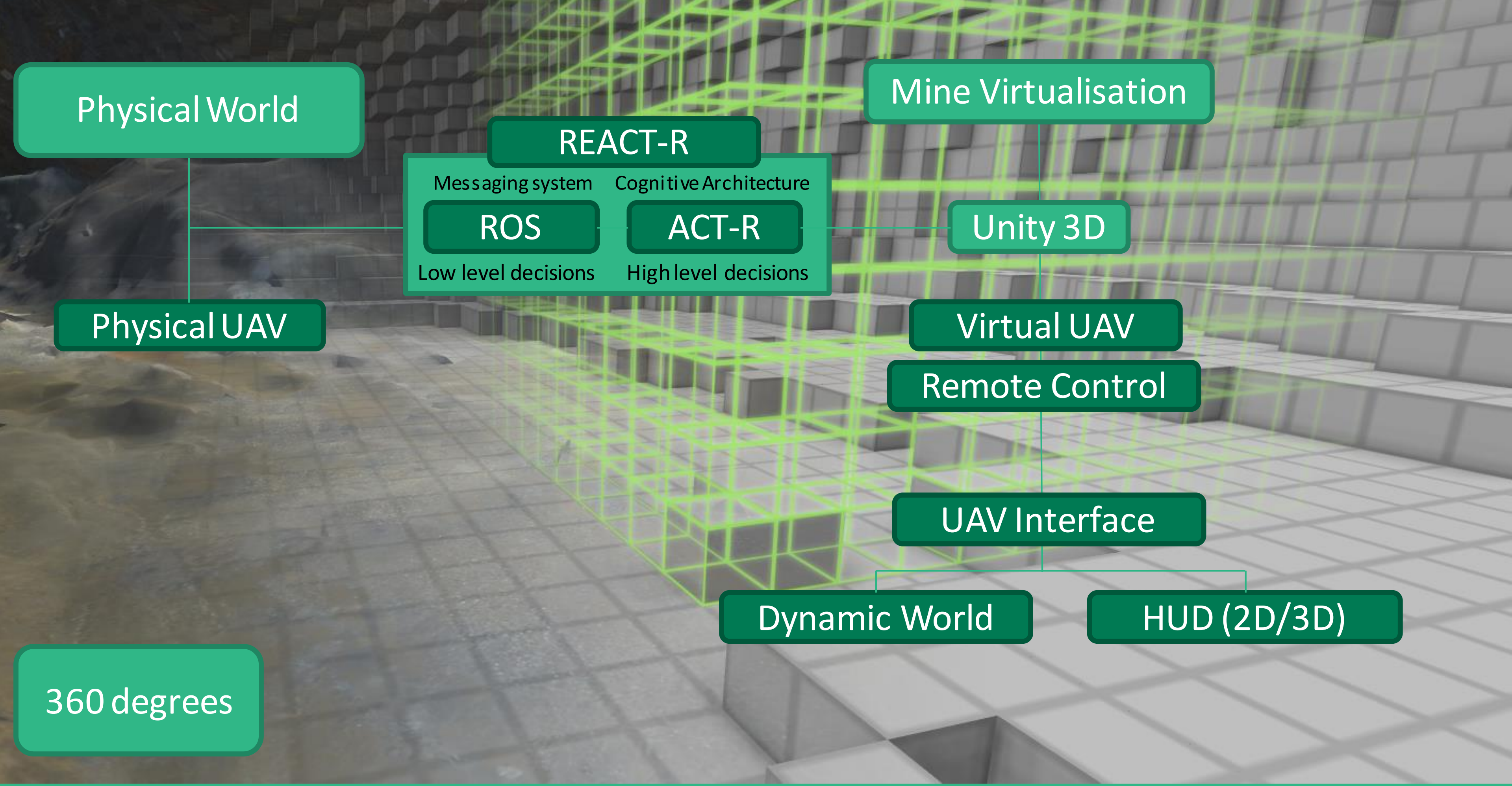
Dynamic World

HUD (2D/3D)

360 degrees

3.2 How do we create local and global intelligence?





Physical World

REACT-R

Messaging system

ROS

Low level decisions

Cognitive Architecture

ACT-R

High level decisions

Physical UAV

Mine Virtualisation

Unity 3D

Virtual UAV

Remote Control

UAV Interface

Dynamic World

HUD (2D/3D)

360 degrees

4. Systemisation of the world

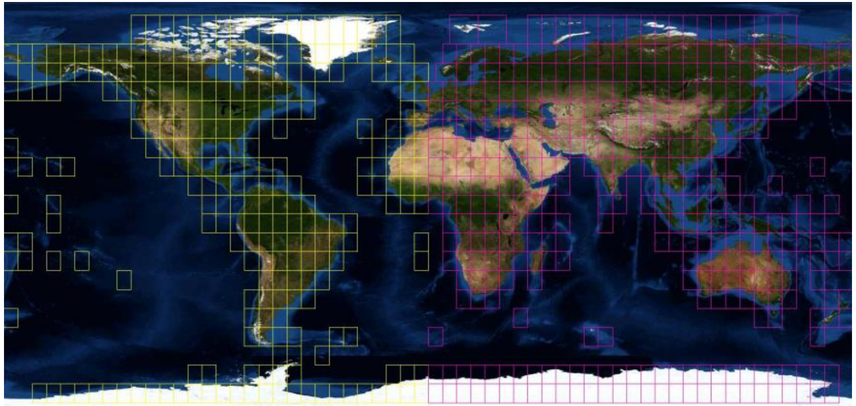
Geolocation

The virtual mine is geolocated

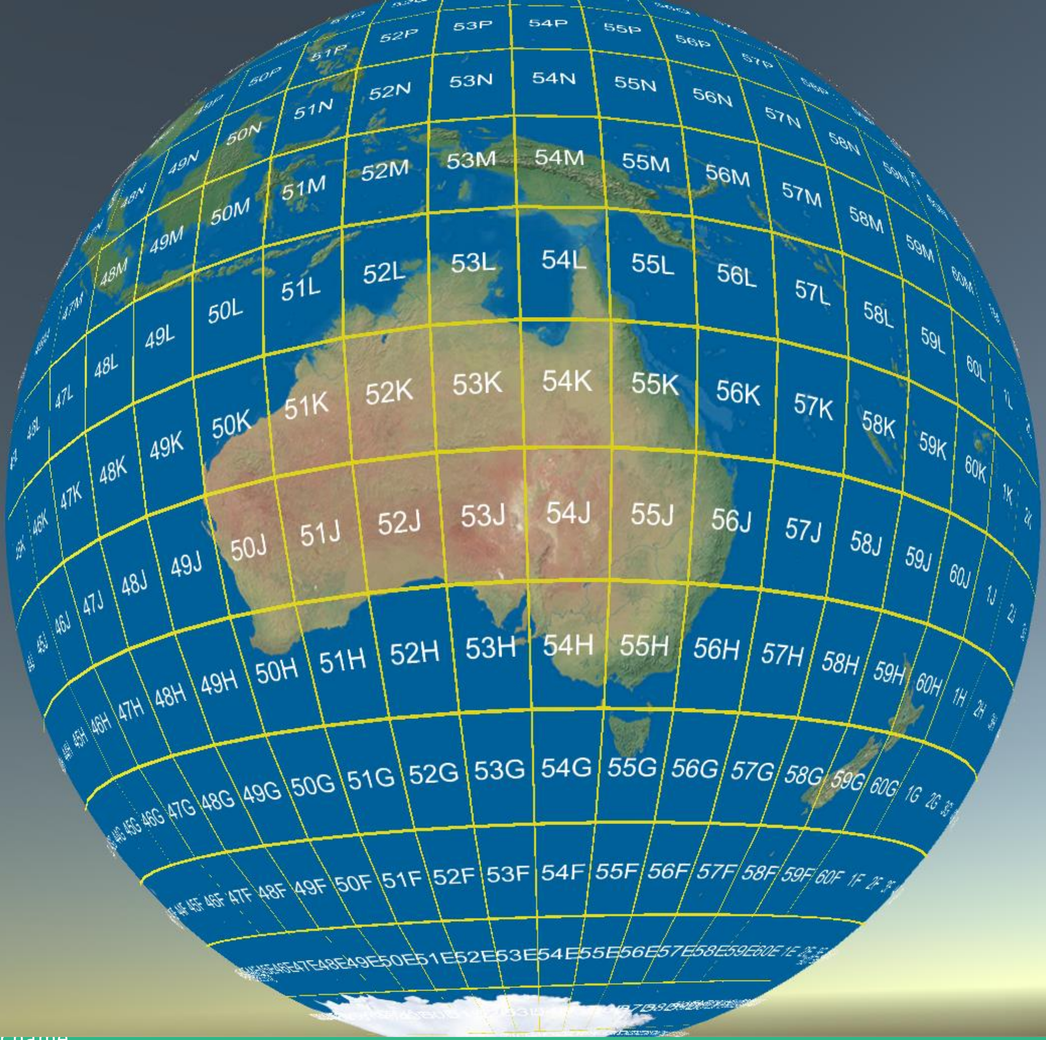
- Uses GPS and altitude coordinates

Internally the system uses the military grid reference system

- Earth is split up into zones, which contain chunks, which contain voxels
- Voxels can be of any arbitrary uniform dimensions
- Can be used in a global context and can handle any geographical structure on or near the Earth's surface



Grid Zone Designators that intersect land (http://mgrs-data.org/, 2015)


51P
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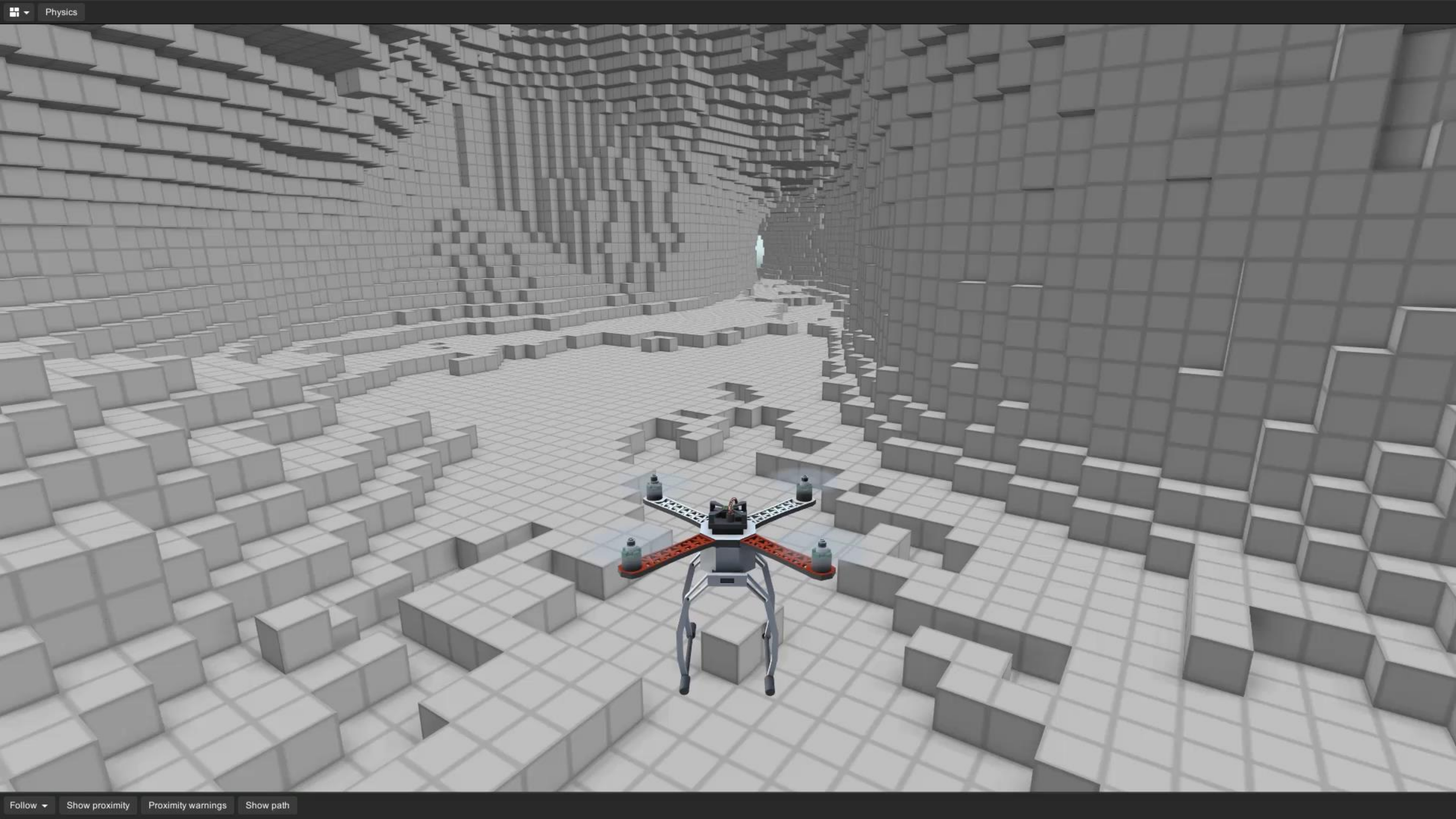
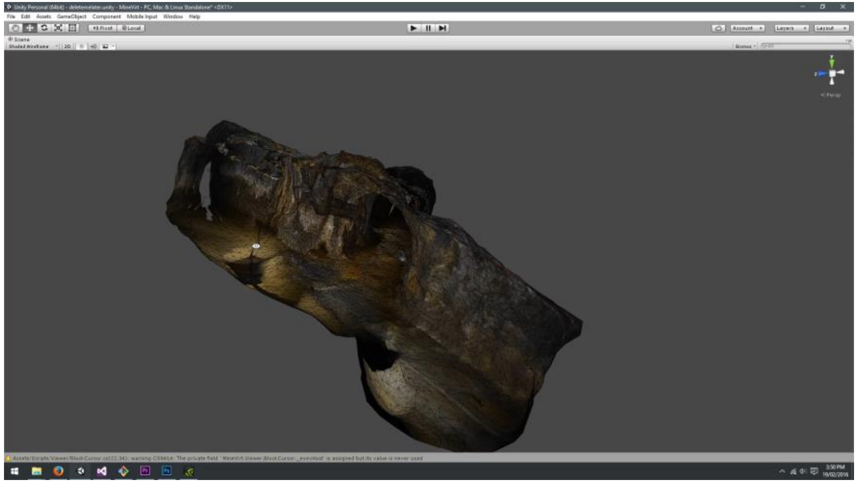
60E

4.1 VoxelNet


Physics
Follow
Show proximity
Proximity warnings
Show path

Voxels from Point Cloud

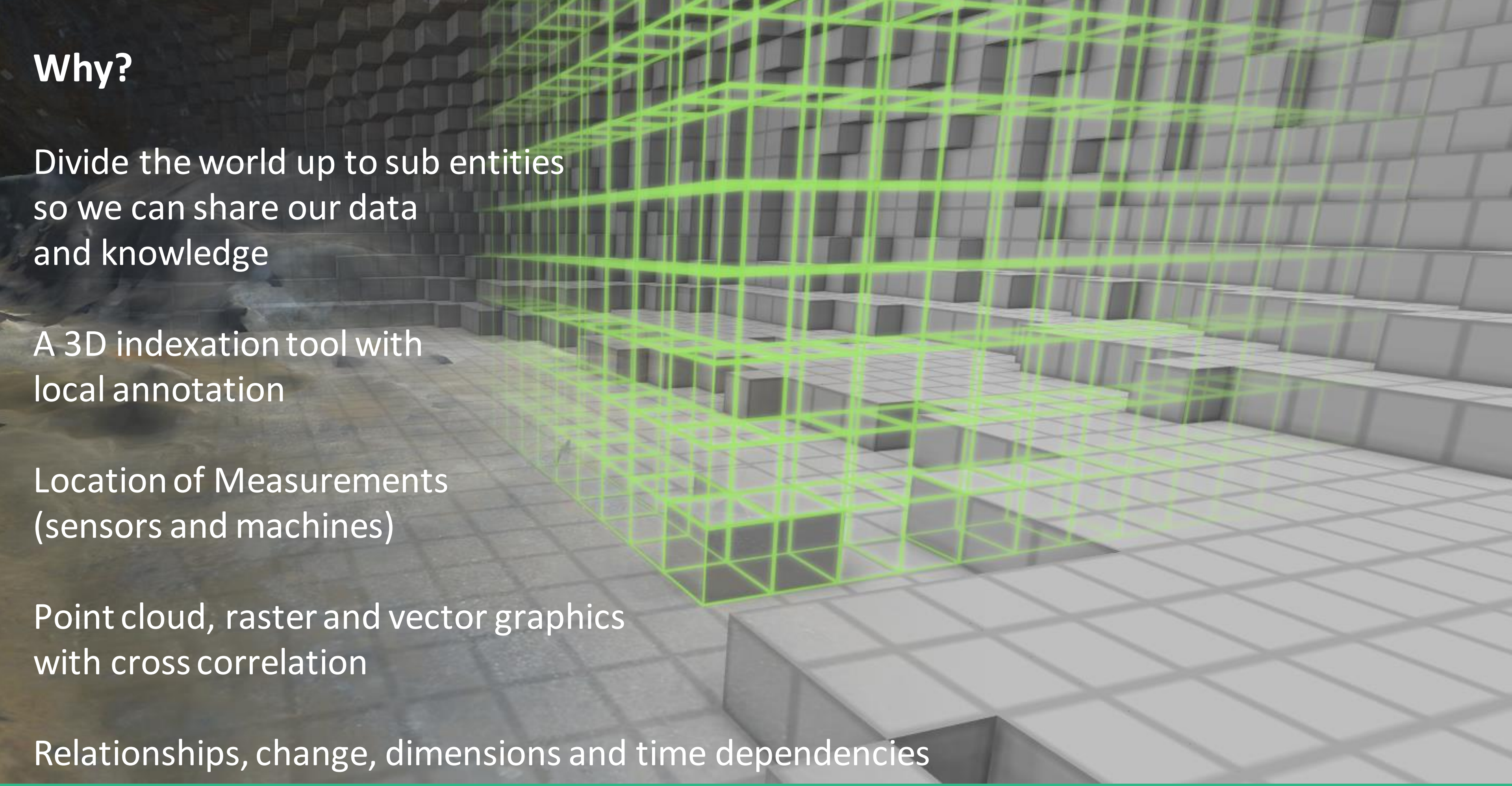
Point cloud data from the UAV can be used to construct a high resolution model of the mine surface, which can then be voxelised.



Mesh from point cloud

Mesh to voxel conversion

Why?



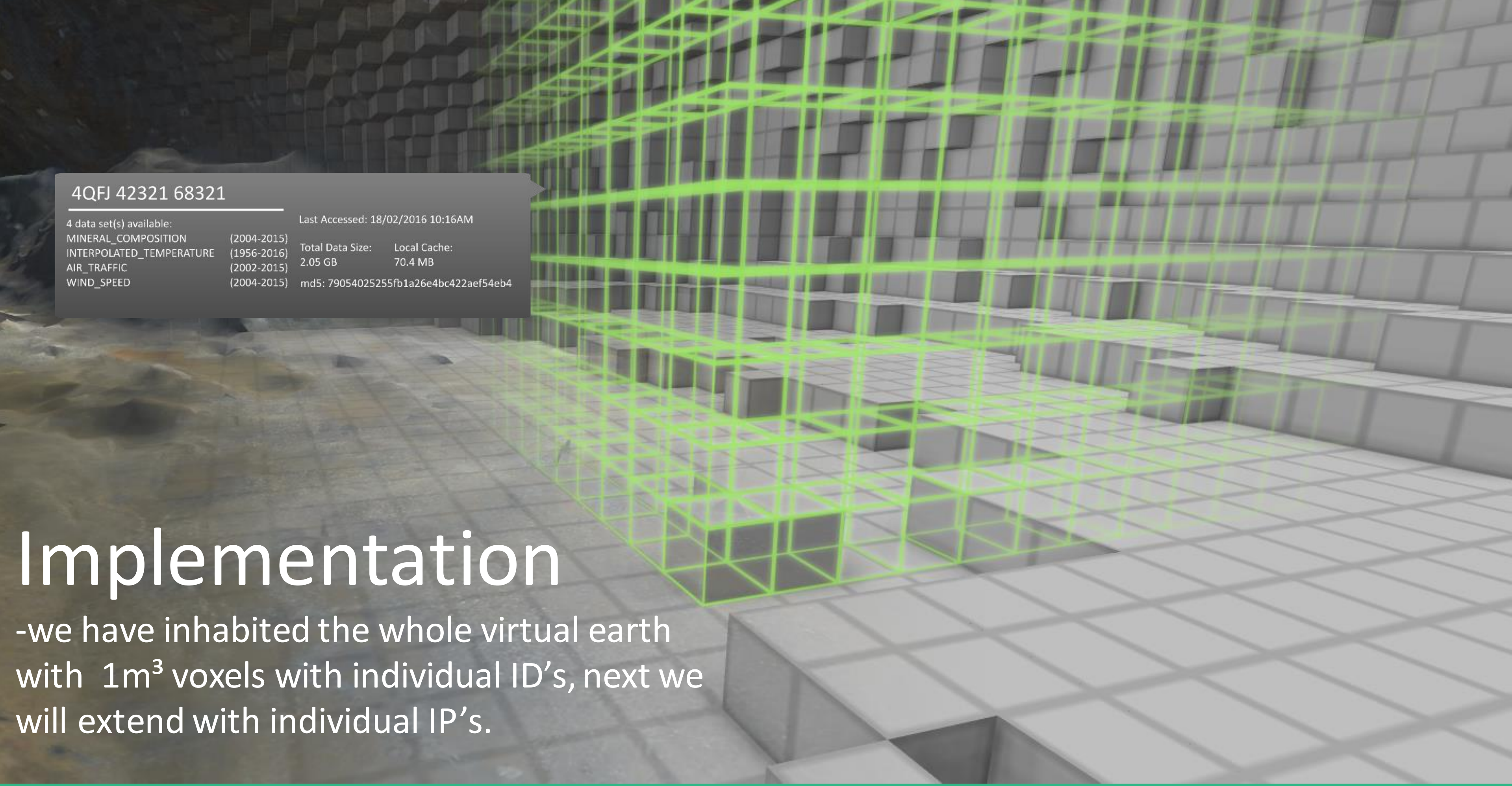
Divide the world up to sub entities so we can share our data and knowledge

A 3D indexation tool with local annotation

Location of Measurements (sensors and machines)

Point cloud, raster and vector graphics with cross correlation

Relationships, change, dimensions and time dependencies



4QFJ 42321 68321

4 data set(s) available:

MINERAL_COMPOSITION	(2004-2015)
INTERPOLATED_TEMPERATURE	(1956-2016)
AIR_TRAFFIC	(2002-2015)
WIND_SPEED	(2004-2015)

Last Accessed: 18/02/2016 10:16AM

Total Data Size: 2.05 GB

Local Cache: 70.4 MB

md5: 79054025255fb1a26e4bc422aef54eb4

Implementation

-we have inhabited the whole virtual earth with 1m^3 voxels with individual ID’s, next we will extend with individual IP’s.


(-41.768777 S, 145.548039 E, -205.69 H) @ 35°
55G (103092.17, -205.69, 695532.74) @ 36°
Map
Show path
Status
Follow
Show proximity
Proximity warnings
Show path
First person
Show proximity
Show path

4.2 VoxelNet Off Earth Applications

VoxelNet in an asteroid/comet mining context

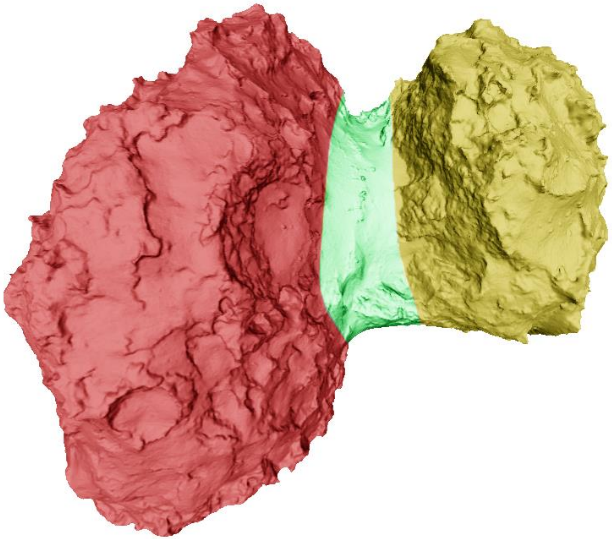
Detailed studies of asteroid mining are presented by NASA (2005) and Lewis (2015). If a spherical body of diameter 1km is mostly made of iron, even at a low terrestrial commodity price of $60/t, this represents a value for a single body of around $240 billion (Lindley et al., 2015).

A thorough pre-planning phase is required due to the expectation of asteroid/comet mining to be *highly automated* (Mueller, et al. 2015).

Block Model Operations

TERRESTRIAL MINING BLOCK MODEL OPERATIONS	OFF EARTH MINING BLOCK MODEL OPERATIONS
GIS interpolation algorithms such as kriging	GIS interpolation algorithms such as kriging
Visualisation tools such as filtering for ores	Visualisation tools such as filtering for ores
Optimum ore removal sequence	Optimum ore removal sequence
	Surface Temperature Calculations
	Rotation/Orbit variation after removal of mass
	Gravitation at various surface points

67P/Churyumov–Gerasimenko


(ESA, 2014a)

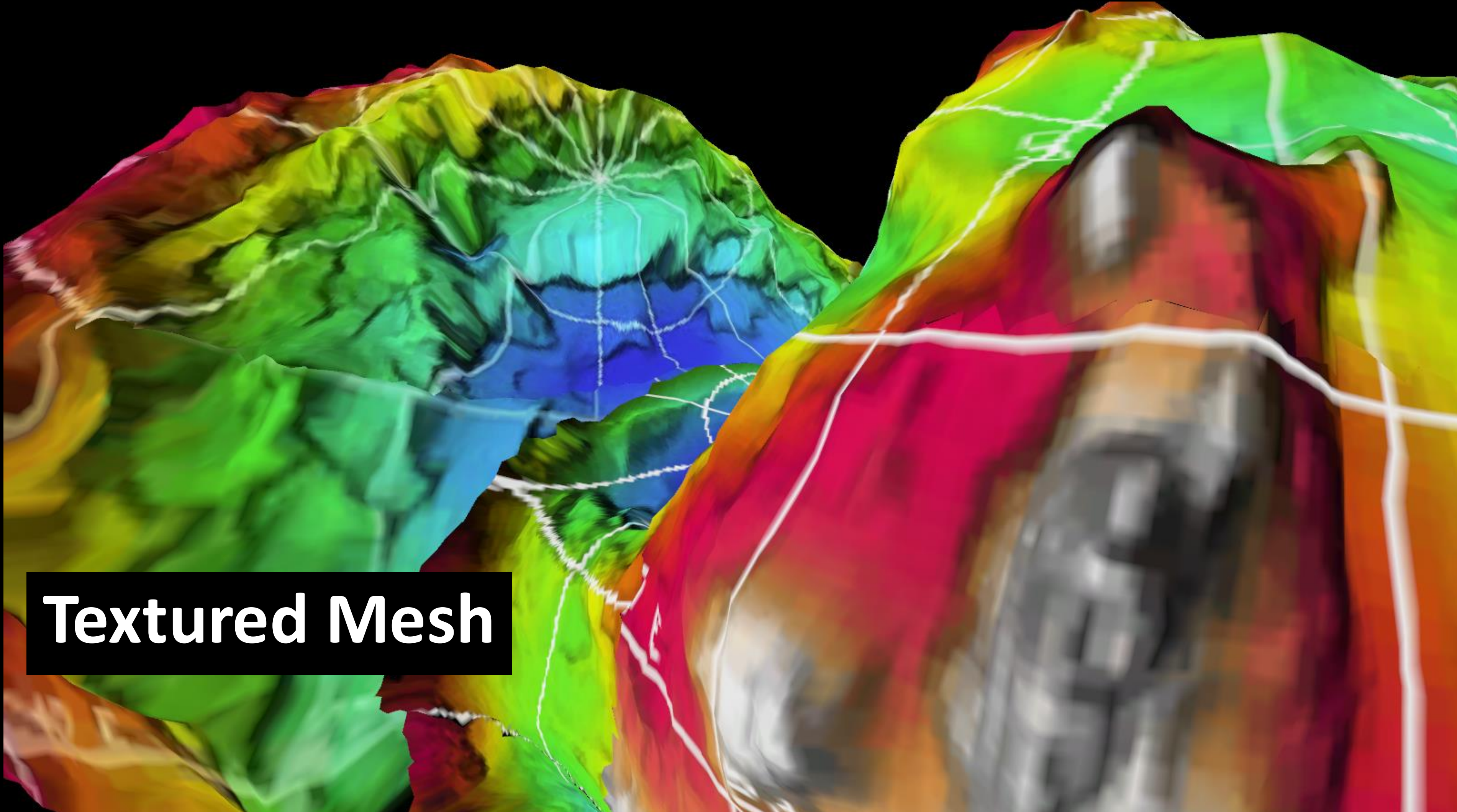
- Rosetta’s lander Philae touched down 12th of November 2014, becoming the first spacecraft to make a soft landing on a comet. (ESA, 2015a)
- Cylindrical/Spherical Mapping techniques can result in ambiguities (Preusker et al., 2015).
- Military Grid system/UTM is not applicable in this context.
- Approx 4km in diameter. (ESA, 2015b)
- Use Cartesian indexing as mining would likely occur throughout the *entire volume* rather than the *crust*.

Voxelisation of 3D Shape Model

1. Create a voxelised shell from each individual triangle.

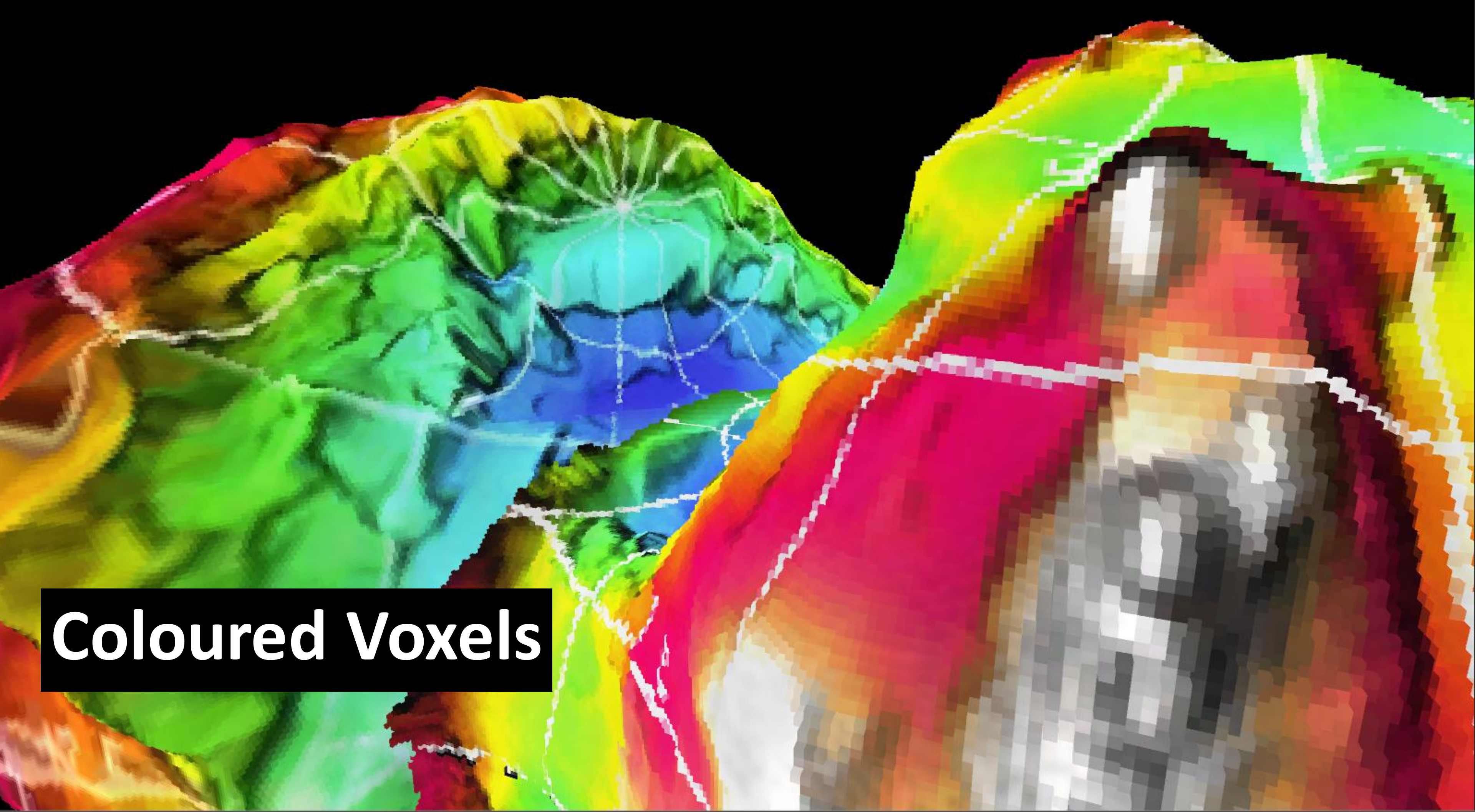
1. Sample texture UV on surface using barycentric coordinates.

1. Use scanline algorithm with face normals to fill mesh.



Textured Mesh

Coloured Voxels



References

- National Aeronautics and Space Administration (NASA) (2005), Space Resources and Space Settlements, special publication 428, 304p (University Press of the Pacific: Honolulu)
- European Space Agency (ESA) (2014a), Photo of Comet 67p by Rosetta's OSIRIS narrow-angle camera on 3rd of August 2014.
- European Space Agency (ESA) (2014b), Shape Model of Comet 67p/C-G, Web Article (http://sci.esa.int/rosetta/54728-shape-model-of-comet-67p/).
- European Space Agency (ESA) (2015a), Rosetta Fact Shet, Web Article (http://sci.esa.int/rosetta/47366-fact-sheet/)
- European Space Agency (ESA) (2015b), Rosetta's Target: Comet 67p/Churyumov-Gerasimenko, Web Article (http://sci.esa.int/rosetta/14615-comet-67p/)
- Lewis, J S (2015), Asteroid Mining 101: Wealth for a New Space Economy 168 p (Deep Space Industries Inc: Moffett Field)
- Lindley, et al. (2015), A Multilayer 3D Index Tool for Recursive Block Models Supporting Terrestrial and Extraterrestrial Mine Planning, Proceedings of the Third International Future Mining Conference, p 295.
- Mueller, et al. (2015), Swamp Works – A New Approach to Develop Space Mining and Resource Extraction Technologies at NASA's Kennedy Space Center, Proceedings of the Third International Future Mining Conference, p 297.
- Preusker, et al. (2015), Shape model, reference system definition and cartographic mapping standards for comet 67P/Churyumov-Gerasimenko, Astronomy and Astrophysics 583:A33, 11p.

5. Future

The Prototype

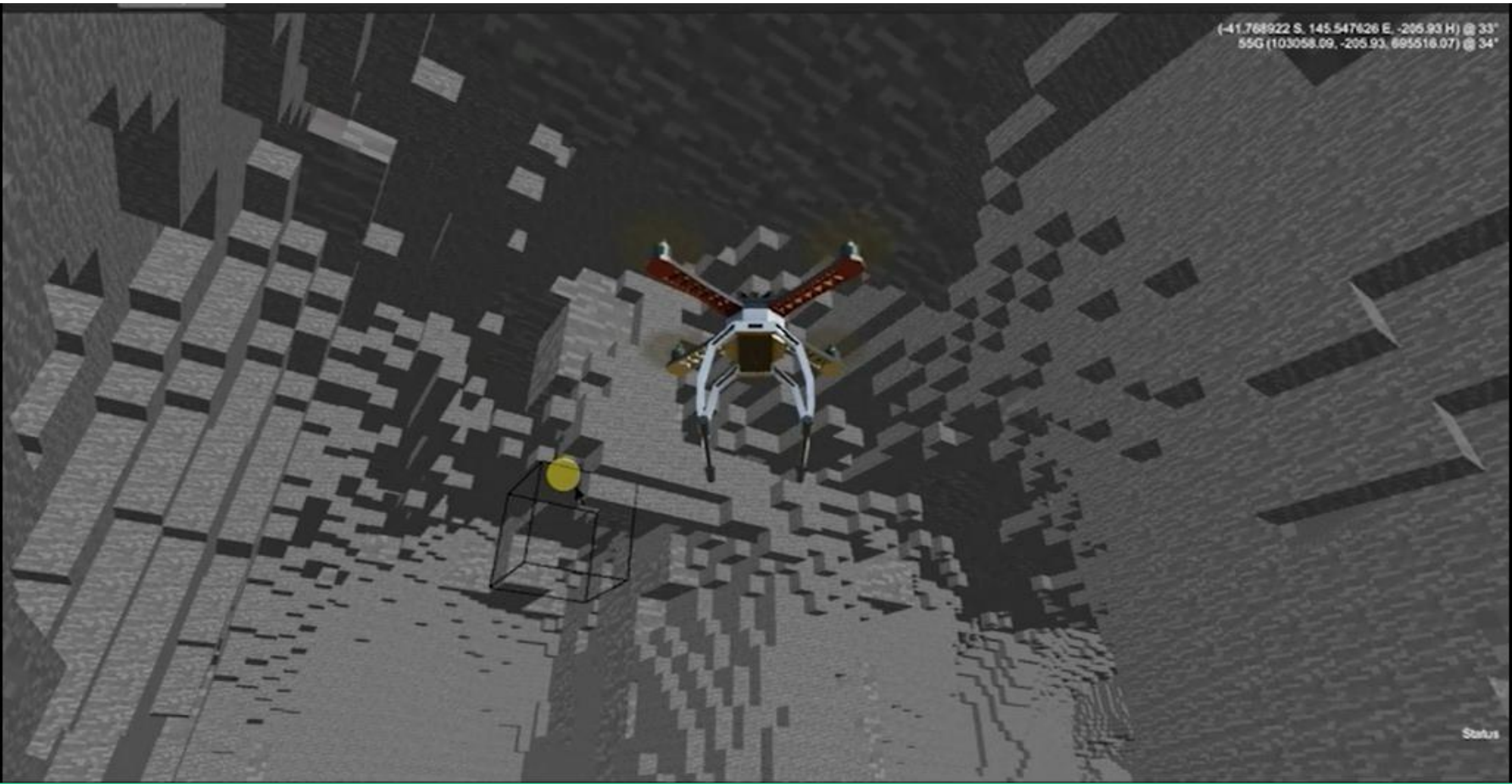
A voxel-based rendition of a mine's geometry was generated from existing data

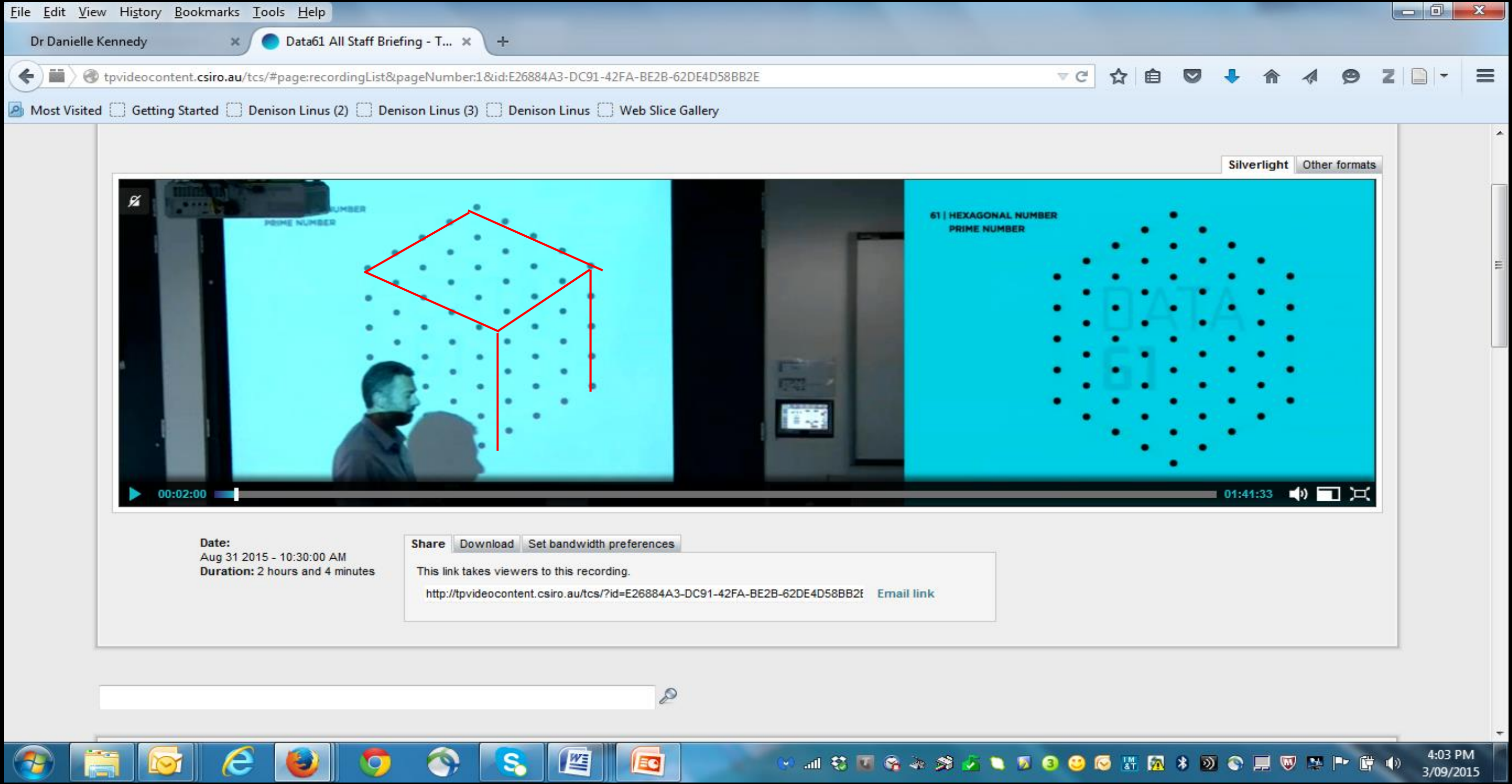
- Voxels are identified as rock or air
- UAV flight is simulated in a real time physics engine
- Depth perception is enhanced by using
  - a proximity shader, and
  - ruler guides
- Adjustable camera angles
- Map view provides overview of mine

Where do we go from here?

- Leave the simulated UAV and track a real one
- Visualise more voxel data
- Create a real time feedback loop of UAV data
- Use this data for path finding (for autonomous flight)


(-41.768766 S, 145.548011 E, -205.57 H) @ 40
55G (103089.78, -205.57, 695533.91) @ 41
Statu


(-41.768922 S, 145.547626 E, -205.93 H) @ 33°
55G (103058.09, -205.93, 695516.07) @ 34°
Status



tpvideocontent.csiro.au/tcs/#page:recordingList&pageNumber:1&id:E26884A3-DC91-42FA-BE2B-62DE4D58BB2E

Date:
Aug 31 2015 - 10:30:00 AM
Duration: 2 hours and 4 minutes

This link takes viewers to this recording.

http://tpvideocontent.csiro.au/tcs/?id=E26884A3-DC91-42FA-BE2B-62DE4D58BB2E

DATA
61

Thanks from us!

If you want to collaborate or if you have any questions please contact me/us!

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CSIRO