

Pilot site & testing

The application of these technologies in the tunnel use case

(La Ribera de Folgosos, León, Spain)



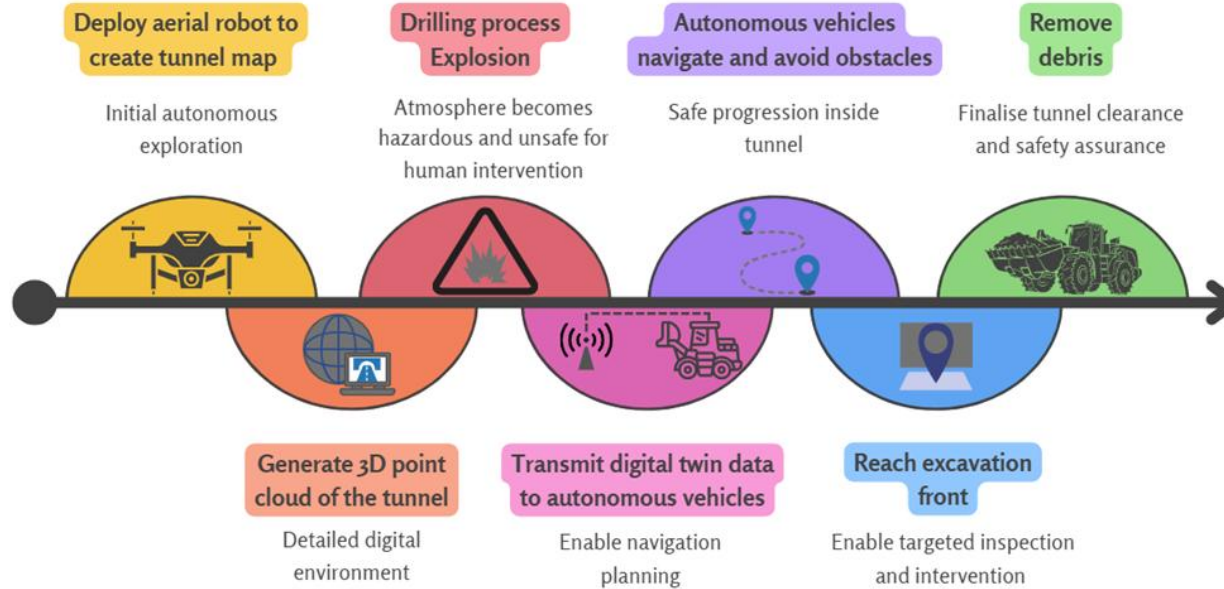
Unmanned aerial vehicle



Digital twin

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TUNNEL CONSTRUCTION



- Explosion in tunnel: air unsafe, workers cannot enter for 1 hour
- Solution: Autonomous robots (drone, wheel loader, dumper)
- Benefits: Cost reduction, improved safety
- Operation: No GPS, updates Digital Twin in real-time

The Testing Environment: Santa Bárbara Foundation (SBF), Spain

- **Location:** 500-meter experimental tunnel in León, Spain.
- **Why SBF?** A perfect “ tunnel lab” providing a real-scale, controlled, and safe environment.
- **Key Features**
 - Confined space with realistic tunnel geometry.
 - GNSS-denied environment (no GPS).
 - Allowed for safe simulation of post-blast conditions.



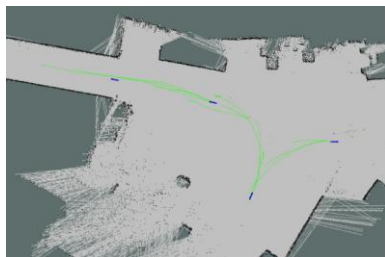
Autonomous Wheel Loader Deployment

- 3D Mapping using Wheel Loader's onboard sensors and 2D map adaptation for autonomous navigation
- Waypoint selection and autonomous navigation validation (localization + trajectory planning + execution)



Autonomous Debris Removal

- Loading operation on excavation front
- Unloading operation on a dumper



Tunnel Exiting maneuver



Autonomous Aerial Robots

Pre-Detonation Phase: Tunnel Exploration

- **Fully autonomous navigation of the tunnel and a real-time 3D Mapping.**
 - The exploration phase from outside the tunnel to the excavation front took approximately 310 seconds, with a maximum speed of 1.5 m/s and 0.75 m/s² acceleration.
 - The return-to-home action was completed in just 170 seconds, with a maximum speed of 2.5 m/s and 1.25 m/s² acceleration.

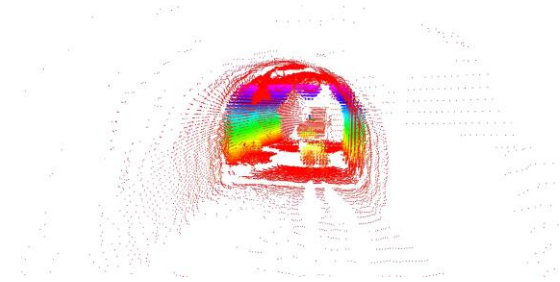
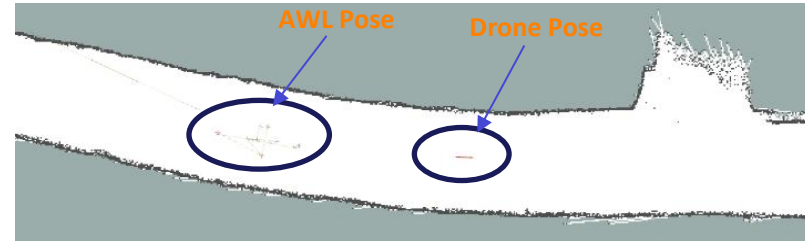
Post-Detonation Phase: Navigation

- **Fully Autonomous Exploration of the tunnel with degraded visibility conditions.**
 - Although the exploration capability is shown in these conditions, you also have the option of navigating by referencing the positioning to a previous map.



UAV & AWL Cooperation

- Drone acts as a scout for the AWL
- Communication between vehicles were carried out through MQTT.
- Both vehicles are located relative to the same 3D map.
- Drone poses can be used as navigation waypoints for AWL



Aerial Robot and Autonomous Wheel Loader cooperation inside of the tunnel (Left: Real video recorded on-site; Right: Drone's sensor view)

Conclusions

Technical Validation: A Unified Digital Ecosystem

- **Realistic Validation:** Proved feasibility in a harsh, GNSS-denied environment (500m tunnel, low visibility).
- **Autonomous Operations:**
 - **UAV:** Accurate real-time 3D mapping & thermal imaging in degraded visibility.
 - **AWL:** Autonomous navigation and mucking based on UAV data (Dynamic Mission Execution).



Conclusions

Impact and The Way Forward

- **Core Goals Achieved:**
 - **Reduced Downtime:** Validated pathway to minimize the "idle hour."
 - **Enhanced Safety:** Kept personnel outside the hazardous zone.
- **Efficiency:** Enabled earlier initiation of mucking activities.

BEEYONDERS has placed a solid foundation. While further development is needed for full commercial deployment, the feasibility and benefits are now proven.

