THAT SINKING FEELING

SINKHOLE MITIGATION

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Team 7

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Fig 1: Sinkhole (Grupe, J (2022)

Recap

"To map land changes and compare histories of surface deformation and record the trend for cavity formation. Drone carried device to collect real time topical and below ground data using micro gravity sensor and infrared spectroscopy to predict soil properties. Able to access and hold historical data for time stamped comparison using Bluetooth or similar technology. Also able to take readings from surface placed Aggrometer's which are Bluetooth linked or make use of other technology"

Feedback

1. "This DI defines the data that is required to be aware of possible risk of sinkholes but does not define how this data may help mitigation nor solution."

2. "The misfocused target user group was the key underlying issue. Having an individual drone per house seems ungainly but also shows how much more of a challenge it would be to get un-specialised people to perform very specialised tasks and how difficult this would be"

Refocused Design Intention

To define the common cause of sinkhole occurrence in urbanised areas and from that develop an airborne solution that topographically scans the Earth in real time, gathering subsidence data into concise reports. This is so geophysical engineers can hone in on vulnerable karst sites where infrastructure is compromised in order to: ensure the safe evacuation of communities, identify where future construction should be avoided such as HS2 rail lines (Devlin, L, Kier, M 2024) and primarily excavate and fill these sunken voids before greater economical, societal and physiological damage occurs.

Introduction

In term 1, the relatively unpredictable and global occurrence of sinkholes were explored and consequently, the devastating and costly impact they have on society.

Sinkhole prevalence has significantly increased alongside urbanisation and business growth due to anthropogenic activities such as the installation of infrastructure in active karst landscapes.
They can cause extensive and costly damage to transportation and infrastructure networks (Guti'errez et al., 2009) which is said to be linked to leakages in buried pipelines (Xiao et al., 2020) and as sinkholes have no natural external surface drainage, they are most vulnerable to failing water distribution networks (NASA).

The detection and further assessment of a sinkhole remains a complex challenge as reports are only made in response to visible surface level changes. Sinkholes typically form over underground cavities that can only be detected via a geophysical surveyor or by taking up the land.

In Manchester, a lorry was nearly swallowed whole as the road gave way to a sinkhole. The cause was the prior collapse of a Victorian sewer whereby material washed into the exposed sewer expanding the cavity until it destabilised the top surface enough to break through. This happened underneath a reinforced concrete road so there was no surface evidence to identify a sinkhole was even present.

This highlights a need for increased land surveys, which should be conducted every 4-8 weeks, to understand the manmade systems forgotten about beneath the surface.

The impact on society is shown in cases such as Longridge, Lancashire. Residents have been severely inconvenienced from a local sinkhole as roads have been closed and public transport networks rerouted, however, businesses have been hit the hardest:

"I have lost over half of my business and I am really struggling and I can't afford to have staff in. Businesses deserve some compensation and support for this. I cannot move my business - this is my life." (Holt, J 2021)

"This is the worst it has been, none of us locally had any information about it which doesn't help or make you feel safe where you live. Everyone is just really fed up, a lot of people are struggling to get to the shops, and road users don't know where they are going because of the diversions." (Holt, J 2021)

"It has caused so much stress and anxiety for everyone locally and it has been tough to see the local businesses we all support not doing as well. It affects the whole of Longridge in one way or another." (Holt, J 2021)

Fig 2: The impact of sinkholes on society: Longridge, Lancashire

User Scenario

Sonya is an independent business owner in a small but urbanised town. Her business is her sole source of income and is run from the downstairs of her home. The town is semi-rural so although there are local amenities, there is still a need for public and personal transport to commute to work opportunities and access a greater variety of shops and social activities.

A sinkhole has formed due to a burst pipe outside of Sonya's property and as a result, the area is closed including the closure of a major commuter road. Despite the water provider receiving complaints of reduced water pressure, they chose not to investigate until it was too late. Bus routes have been rerouted, shops can't be accessed and neither can the commuter belt easily. Repairs were promised to take 1 week but 3 have now passed with no further updates of reaching a resolution from the council.

This has had a major effect on Sonya, she can't operate her business as customer's can't access her shop, she isn't making money and could face bankruptcy if the sinkhole isn't fixed soon. Furthermore, water supply has been shut off whilst the hole is filled and pipe repairs made creating further inconvenience.

This is causing her to have psychological and physiological stress which is having a long term negative impact on her mental and physical health. She holds the water board entirely accountable for this issue and intends on suing them for the detrimental impact this has had on her as a business owner and as a community member.

The responsibility falls unto the water board, what could they have done to mitigate this better? This report explores this further.

Literature Review

The UK's current water system is failing. Roughly 3 billion litres of water are lost daily through leaks in the pipe network and globally a further 90 billion litres are lost a day.

Water authorities must report leakage volumes to Ofwat, the regulatory body that assesses leaks with a 'top down' approach by looking at water balance and a 'bottom up' calculation that considers minimum night flows in discrete metered areas.
It has been found that Thames Water is amongst those most accountable for this issue as they are responsible for 217 billion litres of water lost over the course of 2021-2022, which is the equivalent of 426,875 Olympic swimming pools.

A study conducted by Angling Trust found that "on average, water firms replace 0.05% of the pipe network each year", by contrast, pipe networks are replaced at 0.5% a year across European countries (Angling Trust). These statistics indicate there is a misjudged perception by water authorities that such pipework systems will last for 2,000 years, 10 times longer than the European average (Angling Trust).

Current infrastructure predates back to the Victorian era when it was first installed some 200 years ago often in hard-to-reach and crowded areas deep underground, whilst reaching a span of over 300,000km. As a result, this has made leak detection and maintenance very challenging.

Today, one third of our traditional metal pipe network has now been replaced with PVC piping in the hope of reducing leaks statistics. However, these pipes are equally susceptible to leakage at the joints and only have a shelf life of 24-50 years (BTAC).

The Angling Trust has also lobbied for more investment to be made in improving infrastructure resilience after the Government produced the White Paper report 'Water for Life' in 2011, making clear that current infrastructure is no longer fit for purpose in meeting the demands of population growth or environmental changes. As of yet, there has been no notable improvement and there have been questions raised as to why this is when £10 billion of capital funding has been given to the water industry over the past 10 years.

This literature review may also be considered a 'Root Cause Analysis' which seeks to demonstrate how leaks are the common trigger of sinkholes in urbanised areas. The key issues to be noted here are:

1. There is a lack of tacit knowledge from professionals in understanding where and what sort of infrastructure lies beneath the surface and the topography of the land it sits in.
2. Due to the depth in which infrastructure is installed, there is a lack of feedback to enable the user to understand when pipes need replacing. The only indication is surface level deformation, in which case it may already be too late to resolve.
3. There is large element of human error in inadequately installing and managing these networks.
4. A layman cannot understand the complexities of the land or pipework system unless they are a geophysical engineer so there is a lack of affordance in regards to identifying the signs of pipe failure in time.

A better and more comprehensive system needs to be in place to make sense of what sits beneath the surface and how to identify subsidence as and when it forms due to aged and enlarged infrastructure.

Primary Research

Recently (as of 2024) a sinkhole has opened up in the seaside town of Bournemouth, caused by an old burst water pipe laid by South West Water. As a resident of Bournemouth, primary research was collected of the sinkhole and the impact this had on the community.

The biggest inconvience proved the town's public transport system being rerouted echoing the experience of Longridge, Lancashire. Having personally experienced the impact, it reiterated that failed water pipes are the biggest factor in triggering extreme surface subsidence and that the responsibility falls to the water boards to resolve this. This also confirms that a device is needed to simultaneously identify the network of where a leak is and consequently, the growing subsidence triggered by the leak as humans are unable to naturally understand when and why these changes are happening beneath the surface.

My design intention should satisfy the gaps not being addressed in the current managment of failed water systems and mitigation of sinkholes. Market research will be conducted to see how best this can be achieved with the current technologies available.

Fig 3: Sinkhole 1 (Powell, 2024)

Fig 4: Sinkhole 2 under management (Powell,2024)

Fig 5: Closures and repairs to pipework (Powell, 2024)

Fig 6: All buses rerouted (Powell, 2024)

Market Research

The following research investigates the current technologies used to identify sinkhole formation and infrastructure failure. Each of these technologies can be compared on; how effectively they work, how well they inform the user of data results, how simplistic and intuitive they are when processed using the mental user model, how well they can transmit data to remote systems under a users control, how accessible they are, how disruptive they can be to society and how viable these solutions are in the long-term.

*Market Research imagery can be found in the Appendix

FIDO

Artificial Intelligence connects to acoustic sensors throughout a water pipe network collecting and analysing data on the sound of leaks and flows. This technology helps to identify the location of a leak and how much water is being lost. The long term benefits to FIDO include; reduced street disruption from digging and roadworks, lower cost and resource use, improved efficiency, reduced water loss and improved water services. It is effective in communicating data across multiple softwares and smart devices for a user's clear interpretation of where to address repairs but not for sinkhole identification.

InSAR Satellite

NASA monitors changes on Earth with a squadron of unmanned satellites containing 'Interferometric Synthetic Aperture Radar' which measures subtle deformations in the Earth's structure, successfully detecting early sinkhole formation almost a month before collapse. It also shows sinkholes can form horizontally to the site of collapse, so the greater area should be analysed simultaneously. Long term, it is a cost-efficient tool for risk management and pivotal in monitoring man-made ground motion without unnecessarily uprooting infrastructure. According to NASA researchers, "with special radar satellite technology, we can monitor large areas for localized subsidence and provide highly valuable warning information that could protect people and their property." (Wdowinski, S). User engagement and understanding is hard to judge as InSAR is an independent and remotely operated software.

Field Installed Fiber Optics

Acoustically distributed fiber optics are installed alongside pipe work to detect vibrations in the ground, making it possible to detect leaks. Efficacy can be affected by: the distance between the optics and pipework, size of leak, water pressure, ground conditions and the fact that optics do not run in the same trenches as water pipes. They are suitable for long-range monitoring of large subsidence areas as they detect temperature and moisture changes and are sensitive to subsurface strain which helps to anticipate and prevent serious collapse. However, installation is disruptive, complicated and costly, data collection is limited to the specific zones they are installed in and ultimately, better results can only be achieved from improving the monitoring system which will incur additional costs.

Ground Penetrating Radar (GPR)

Produces a continuous cross-sectional profile of the soil strata without interfering with the natural physiology of the land. Profile data shows reflections of the subsurface to a specific depth using ultra high frequency radio waves transmitted through a transducer. The transducer receives data in the form of reflected waves that process differences in the Earth's material. The transducer can be pulled along by hand, making it the only system so far that allows for direct user engagament as well as remote operation. GPR is able to locate utilities and pipelines of any material that has different dieletric or conductive properties than the surrounding soils. Since the introduction of PVC pipes, it is now harder to detect leaks but this isn't an issue with GPR. However, different materials in the soil can significantly decrease depth of penetration as high conductivity materials can attenuate or absorb GPR signals. Considering this, it may limit efficacy, for example, in sand GPR can reach a depth of 30m but in clay it only reaches 1m.

Seismic Waveform Tomography (SWT)

Seismic data, in the form of wavelengths, constructs a three-dimensional profile of the Earth's physical properties. These scans are presented to a user in a structural, thermal or compositional format which helps to distinguish between the Earth's core, mantle and tectonic plates. As it layers data into a 3D composition, new or worsening voids and cavities are identified, predicting the beginning of a sinkhole. SWT provides the user with a clear visual explanation of what is occuring deep below ground without disruption and can be interpreted a lot easier than sensor results.

LiDAR

Light Detection and Ranging sensors are airborne scanners that digitally penetrate and reconstruct underlain topography in high fidelity. Laser pulses sent to Earth measure the distance they are sent and time taken to return when reflected back off of an object. LiDAR is now used to detect and characterise newly formed sinkholes or previously undetected ones. Similarly to SWT, LiDAR also provides a clear and intuitive explanation of what cannot be visually understood at surface level and as a technology, it lends itself well to integration with drone software.

In summary, all the listed technologies have their respective strengths and methods of collecting data when addressing the DI. It would be efficient to combine the technology already available but find ways in which to improve functionality and user understanding. Most of these systems are not easy to judge with the Human Lens Model due to their remote operation, however if such technology was centralised into a drone device that could directly engage with a user, with the option of independent operation, then this would be the most beneficial approach. Further to that, NASA researchers have confirmed the benefit of airborne technology, such as drones, for the mitigation of sinkholes, stating "Radar data that is routinely collected from an airborne system or satellite can forsee a sinkhole before they become a danger to people and property" (NASA). Hence these factors will be further developed in my design considerations.

Design Considerations

A PDS has been drafted to define the core functionality the drone should achieve. This is reflected in the concept sketches and later, represented in the final product.

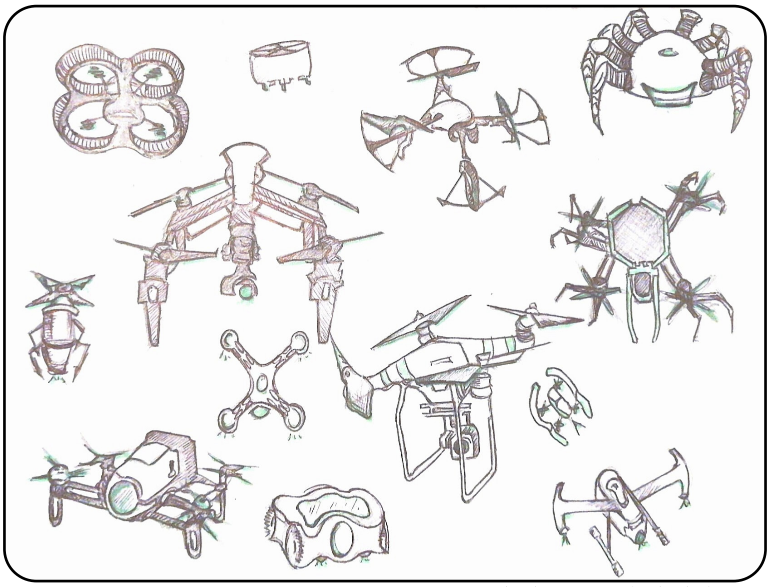


Fig 7: Initial concept sketches

1. Performance:
- Drone must be able to manage a flight time of at least 30 min per session.
- Drone must be able to land and be driven around a site for a more detailed scan.
- Drone must be able to connect to specialised radar satellites to communicate data and retain a log of topographical data.
- Drone must be able to make sense of the data, compare current with previous and then send a report to a secondary device controlled in real time by the user.
- Drone must contain GPR and SWT to see beyond the human capabilities and scan the topography for gravity degradation.
- Drone must have sensors to connect to existing leak and sinkhole mitigation technology, e.g. FIDO, Fiber Optics and Satellite.

2. Aesthetics + Finish:
- A logo representing the name of the product to feature on the front of the drone and lit by LEDs.
- Drone should have a neutral and unassuming aesthetic so as to help the LED’s stand out better for human perception.

3. Operation:
- There must be a series of visuals to educate the user on what command the drone is performing.
- Audio must also be used to indicate when the drone has synced with a pairing device for data transmission.
- There must be visual and audio feedback to indicate when the drone has finished its intended task and has completed data gathering and transmission.
- It must be able to be controlled and managed remotely through a mobile or tablet device.

4. Quality + Reliability:
- Drone must be charged but include an external battery to extend battery life enough to ensure drone safely redocks.
- Drone must save data on the device itself and send a copy to the devices it is synced to, to avoid data loss from human error.

5. Ergonomics:
- Controlling the drone should be with ease and with the use of a smart device.

6. Safety:
- Drone must do as intended: Mitigate the societal impact of a sinkhole by identifying formation in its early stages.

Final Concepts

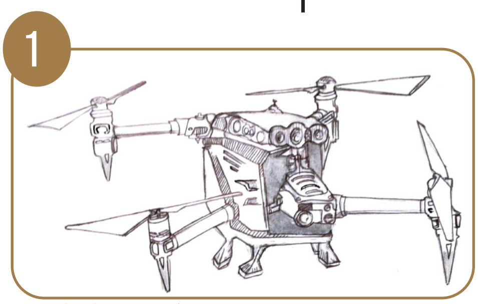


Fig 8: Concept 1

Large rig style drone with multi-dimensional cameras and one main camera supported in the gimbal frame of the drone. Complex scan software is installed in the body whilst key sensors are in the cameras. Drone can be landed and the spiked feet support it in the ground. These spikes could also feature smart technology that measures the moisture content of soil in leak detection, e.g. hygrometers or be used to communicate navigation and flight modes. Four blades to allow for greater propulsion.

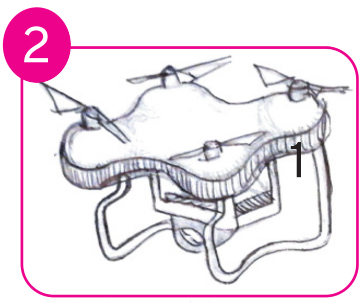


Fig 9: Concept 2

Butterfly body with suspended camera rig underneath. Camera can be rotated 360 degrees for improved scope of vision. It is weather resistant, able to operate in harsh weather and temperature conditions. Hover height can be calulated for optimum accuracy. The drone can be landed securely via the extruded undercarriage that also supports the core camera.

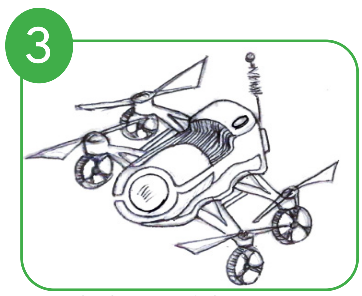


Fig 10: Concept 3

Streamlined with an antenna for improved data transmission. Four blades to support drone flight with integrated wheels so drone can be landed and driven. Has night vision so emergency scans can be made any time of day, especially when visibility is difficult. Has customisable configuration so that it is adaptable across multiple applications.

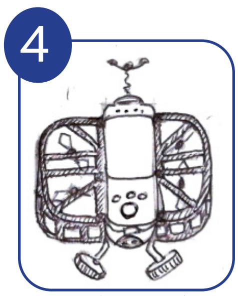


Fig 11: Concept 4

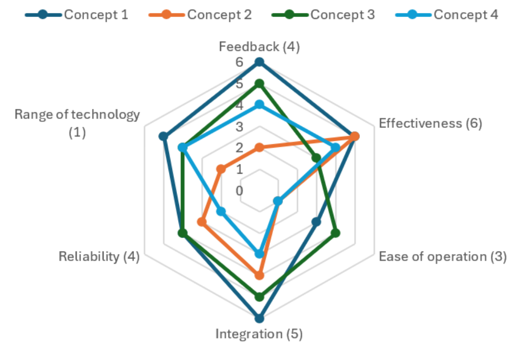
Lightweight and able to be fitted into a backpack. There are manual buttons to toggle features and settings on the drone although it will be mostly remote controlled. Enclosed blade design for safety.

Concept Evaluation

Table 1: Normative Model for Decision Making for the final four product concepts

Attributes	Concept 1	Concept 2	Concept 3	Concept 4
Feedback (4)	6	2	5	4
Effectiveness (6)	5	5	3	4
Ease of operation (3)	3	1	4	1
Integration (5)	6	4	5	3
Reliability (4)	4	3	4	2
Range of technology (1)	5	2	4	4
TOTAL	114	75	95	70
RANKING	1st	3rd	2nd	4th

Fig 12: Radar Graph of Normative Model Data Results



Feedback = How well the user understands how the drone is operating
Effectiveness = How well does the drone mitigate sinkhole development
Ease of operation = How ergonomical and intuitive is the drone's design
Integration = How efficiently is it able to sink with other technologies for data transmission.
Reliability = How well does the drone improve the results of data collection and reduce human error
Range of technology = How many tasks can the drone do, how sophisticated is the level of data able to be collected.

Key: Category criterion explanation

Of the concepts, 1 and 3 ranked the highest against 2 and 4 as overall, they offered; a greater range of integrated technology, had clear user feedback and were considered very reliable in terms of their intended functionality of addressing the problem scenario. Despite this, across the board all designs had their strengths and weaknesses with some of the lower ranking concepts scoring higher in effectiveness and ease of operation. Considering this, a merged concept, combining all the perceived strengths identified across all the concepts would rank as the strongest solution.

Having a larger drone lends itself well to housing more sophisticated technology, thus improving functionality. In order for some specialised technology to work best, a range of hovering heights should be able to be calculated or let the drone be grounded entirely. In the case of Ground Penetrating Radar it works best when closest to the surface whereas, when needing to communicate data between satellite technologies such as LiDAR or InSAR, a drone's signal would operate best at a higher altitude. Combining attributes of the second strongest concept, 3, the design should have wheels for grounding navigation which can be retracted when not in use. The 360 degree camera in concept 3 offers a better set up than any of the other concepts as it doesn't limit the scope of where the embedded sensors in the camera can scan.

Visual indicators such as LEDs will be paramount to help the user's understand the function the drone is performing. In terms of operation, this would be more viable from a smart device as its affordance will be it is a format that is more intuitive to a user and can provide both visual and auditory feedback. A smart device will make it easier to combine and manage functionality such as data collection, analysis and transmission as well as the physical operation of the drone when setting scan routes.

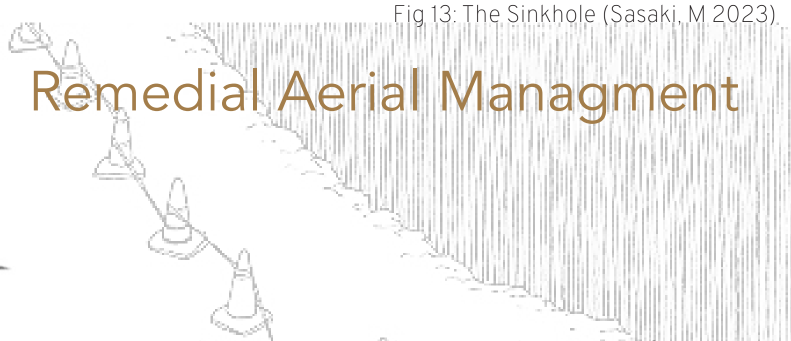
Final Design | R.A.M

Fig 14: Final Design

The capabilities and functionality of R.A.M will be evidenced in App Functionality on Page 10.

R.A.M, a sophisticated solution for identifing subsidence before it becomes a catastrophy

Fig 13: The Sinkhole (Sasaki, M 2023)



Remedial Aerial Managment

1. **Cameras:** The cameras are the user's direct line of vision, offering live streamed visuals to the user in HD quality. Humans are limited by their vision, not just at surface level but on the visible light spectrum we cannot detect infrared, a feature which helps in the scanning of voids in soil. The central camera can be rotated 360 degrees, supported by a gimbal frame and shock absorbers which provide cushioning to minimise vibration. Quick shots can be taken during live transmission in order to log specific areas of interest. To ensure high quality imaging is sustained there is horizon levelling and a mechanical lens shutter to eliminate rolling shutter distortion. A speaker is also incorporated to allow for distant communication between geophysical professionals.

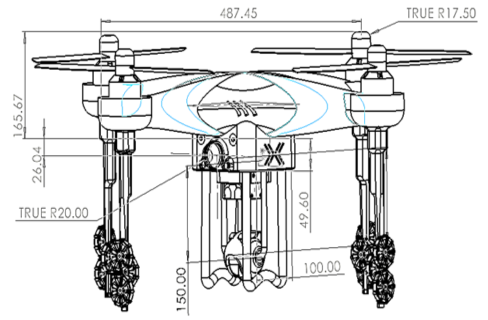


Fig 15: Front of R.A.M annotated

Fig 16: Front of R.A.M rendered

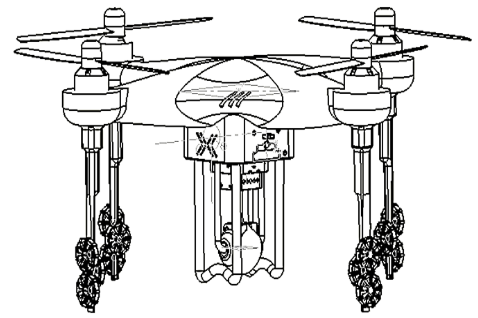


Fig 17: Back of R.A.M

2. **Feedback:** LEDs are in the main frame of the drone and signify different functions for the user's understanding either as flashes or colour changes. Front facing LEDs show if flight mode is passive (preprogrammed route) or active (freeflight by user), back LEDs show battery performance, and side LEDs indicate what scan is being performed.

3. **Roaming:** Drone can be driven on land in any direction. Its wheels are in a triangular formation, inspired by a tank, and are lowered as and when needed to help navigate rough and uneven terrain.

4. **Programming:** Customisable configuration for seamless adaptability across multiple technologies like InSAR and LiDAR satellites. Different shooting heights can be programmed for improved data collection.

5. **Mitigation technology:** Sensors in the cameras connect to the existing technologies researched like fibre optics and FIDO for data analysis. GPR, SWT and lasers are used to meticulously scan the land, rebuilding results in 3D to identify subsidence so that action can be taken before there are greater repercussions.

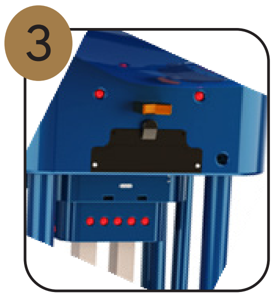
6. **Operation Modes:**
- Tracking and scanning identified pipework, terrain and extreme subsidence.
- Requesting satellite and sensor data for comparison against personally logged data to produce an analytics report.
- Data transmission is via WiFi/Bluetooth to a smart device or via encoded SD card and USB/USB-C ports, embedded knowledge familiar to a smart phone user.
- System updates maintain efficiency when syncing to a cloud storage system or transferring large files.
- At low battery, data is automatically saved and low power mode activated as drone redocks. Discriminable safety feature designed to respond faster than a human.
- Flight can be preprogrammed or free flight used.

7. **Core Functionality:** A 6-axis gyro improves stability during flight for easier control. Self-heating batteries internally support roughly 400 charge cycles, the equivalent of 40 mins flight time. A safe flight time is preprogrammed with the external battery providing extra charge to safely redock drone if insufficiently charged before take-off. There is built-in obstacle avoidance, excellent hovering accuracy and an automatic return to point of take-off.

Design Breakdown

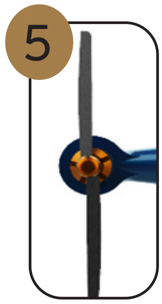
There are 3 front facing cameras to guide the drone during flight and one central camera used for radar scanning the land below. It has been given an ocular shape for the user to understand this is the drone's central vision where it identifies the vulnerabilites that are not visible by the human eye beneath the surface. It also helps the drone to have a 360 degree viewpoint during flight.

The wheels are to assist the drone once it has landed. If a more detailed scan is required the drone will land to increase scan penetration depth. It also allows the user greater control to reduce error.

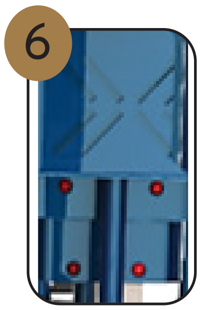


The back of the drone reflects common features known to the user from existing technologies: various ports for charging and data transfer, Bluetooth, WiFi dongel for immediate data transmission and an external battery so it is intuitive. The battery acts as a secondary safety system to allow the drone to have enough charge to redock safely on long flights, this is to avoid human error if not charged enough before pre-flight missions.

The central camera is supported by a gimble frame to allow a free range of uninhibited motion much like considering the muscluskeletal range of motion a human has by free will. It also acts as a frame work to support the sensor and radar technology that sits within the drone.



There are four blades to support the drone in flight and increase strength of propulsion. Access to regions that are otherwise unsafe to reach can be achieved.



There are a series of LEDs around the drone which signify different visual feedback to the user. Front facing LEDs indicate the drone is in flight mode, the sides show when and what scan is being performed and at the back where ports and charging can be found, the back LEDs show battery performace remaining.

Fig 18: Aerial view of R.A.M

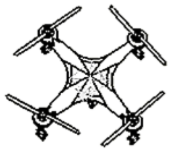
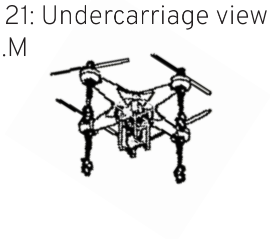


Fig 19: Side profile - back of R.A.M

Fig 20: Side profile - front of R.A.M

Fig 21: Undercarriage view of R.A.M



App Functionality

Fig 22: Wireframe 1

Fig 23: Wireframe 2

Fig 24: Wireframe 3

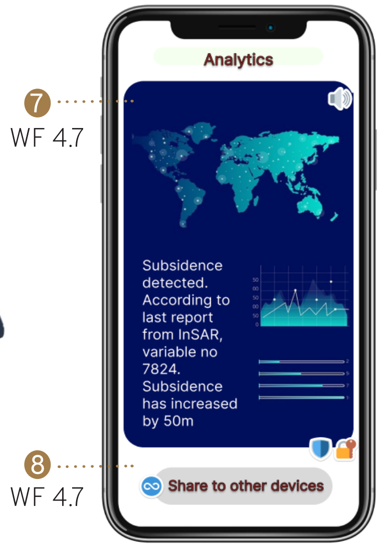


Fig 25: Wireframe 4

1. **Drone Navigation:** Manual monitoring, especially during grounded navigation, is directly livestreamed in HD with the option of taking screen captures. If an engineer or other institutional professional is on site, the drone operator may use the microphone icon to communicate directly. Responses can be amplified by the speaker icon (WF 1.2). Navigation acts as a joystick, the user holds on the circle for 8 seconds triggering R.A.M to rise and touch pad to be activated and locked to avoid activation of accidental commands and to keep the drone set at a calculated hover height. The circle is dragged towards the arrows which indicate the direction R.A.M is flown or driven (WF 1.1). When scanning is to be initiated, R.A.M can be set to hover or land. R.A.M has built in safety precautions. If battery becomes too low, the drone will automatically save data and return immediately to docking point, overriding any user commands.

2. **Drone Observation:** Considering Fitt's Law, R.A.M's navigation can also be preprogrammed from its docking station (WF 2.3) to singular or multiple areas of interest. R.A.M takes note of: water networks across an area, the type of terrain infrastructure is installed into, areas that are vulnerable to anthropogenic activity, naturally occurring largely unmonitored water sources prone to flood and drought and high-risk zones for immediate attention. This is highlighted to the user via a coloured key (WF 2.4) on the map. If the user clicks on a displayed icons, a description will pop up. Having a preprogrammed system reduces bandwidth and transport lag of data, lowering the chance of human error.

3. **Subsidence and leak detection:** There is a scrollable range of functions (WF 3.5) to select when beginning data collection. In the case of wireframe 3, Seismic Waveform Tomography is selected and below a live feed shows a 3D cross sectional profile being created of the sub-surface structure (WF 3.6). R.A.M has a discriminable, closed tracking loop system whereby its gain can be limited by the data it receives from external technologies. However, discrete and continuous controls are offered by the real time scan functions that allow for immediate intervention and understanding round the clock.

4. **Analytics:** Data gathered directly from R.A.M and existing technologies are processed and simplified into an analytics report for the user. Reports are encrypted and have multiple security systems on them (WF 4.7) to allow for safe transferal of sensitive data whether that is by WiFi/Bluetooth (WF 4.8) or via data cables. Across all wireframes, a teletext option for data or functions to be read to the user is provided which is to avoid resource competition amongst the other human factor senses and allow seamless 'blind operation'.

It is said that "Human errors have increased by 50% in the past year" (Glover, A) when interacting with smart technologies and that "£98.6 billion is lost annually due to human error" according to the IT Governance Institute. In the case of sinkhole mitigation, error can be rule and knowledge based, humans are unable to recognise subsidence or impending void collapse due to limited understanding of the underlain infrastructure and slips can occur during the failure to recognise and manage other systems, e.g. water pipes, that lead to blunt or active errors like extreme leaks and subsidence.

R.A.M aims to mitigate human error as much as possible through a centralised data system. Firstly, it detects changes that are not visible to the human eye, specifying the exact cause and the future impact they could have. Secondly, considering the principles of Hick's Law, R.A. M's core functionality is operated via a smart device providing the user a very functional but simplified navigation system to avoid redundancy and indecision with controls. The system provides additional accessibility in an audible and icon format throughout to be as intuitive and familiar as possible to other smart technologies. This is so embedded user knowledge can be consistently transferred between applications when being interpreted in the gulf of evaluation and later execution.

Heuristic Evaluation

1. Visibility of System Status: Physical feedback is provided via LED's on R.A.M's exterior and digital feedback is presented on route navigation, teletext, iconography prompts and concise analytical reports. Potentially transmission feedback could be disrupted from radio signals and poor weather conditions.
2. Match Between the System & Real World: R.A.M is primarily for the use of geophysical engineers however, to report to the water board and related bodies (Ofwat, etc), it must accommodate a layman's understanding, a glossary of terms could be beneficial to reduce future human error of misinterpreted data.
3. User Control and Freedom: R.A.M has a safety system that acts independently to resolve errors that occur unbeknownst to the operator so as not to cause a lapse in the judgement. This override feature was intended to minimise error however, this could be improved with user training, warnings, and system reports.
4. Consistency and Standards: The digital interface uses easily recognisable iconography and maintains consistency with hierarchy, typography, and a colour scheme.
5. Error Prevention: The physical and digital interface of R.A.M was designed to minimise human error as much as possible with the addition of its underlying safety system.
6. Recognition Rather than Recall: The user doesn't have to rely on memory as R.A.M collects and stores data it gathers into concise reports.
7. Flexibility and Efficiency of Use: R.A.M is designed for interpretation by all users however, if key terminology cannot be fully understood then for future improvement, a step through demo could explain operation.
8. Aesthetic and Minimalist Design: Sleek drone body with clear visual indicators whilst the digital interface has a balance of resource competition attributes whilst limiting the overuse of text.
9. Help Users Recover from Errors: R.A.M already provides messages for the user's attention, in extension to this system errors could also be cited. R.A.M was designed to be partially self-automated however, a lack of user engagement could also lead to error.
10. Help and Documentation: A more comprehensive instruction manual will be necessary for drone set up and maintenance as well as an external support service that can be reached in case of system failure.

Normative Evaluation

This Normative evaluation will be based against the considerations stated in the market research to determine how successfully R.A.M has achieved the DI and PDS, especially against competitor technology.

Overall, R.A.M remains the top performing solution with a score of 44. Feedback was ranked lower due to the external LED's being the only way functionality is communicated on the drone itself compared to the intuitive functionality of its smart device. In regards to its interface, it's possibly too simplistic for a professional's use which could be limiting the detail of data collected and interpreted through the Human Lens Model.

	R.A.M	FIDO	GPR	SWT	Fiber Optics	InSAR	LiDAR
Feedback	6	5	5	5	6	6	6
Effectiveness	8	6	7	7	6	7	7
Operation	6	3	6	5	3	6	6
Integration	7	4	4	4	3	5	5
Reliability	8	5	8	7	7	7	6
Technology	9	6	9	9	7	8	8
TOTAL	44	29	39	37	32	39	38

Table 2: Normative Model for Decision Making of R.A.M

R.A.M successfully identifies the cause and progression of leaks and subsidence at whatever stage. However, potential data disruption could occur from the drone's overriding safety system when protecting the battery. This can affect the accuracy of data collected. The reliance of a smart device to operate the drone could cause issues; access to other controls may be restricted, system may lag and if the system has fault or updates it may prevent the use of the drone altogether. A separate controller would resolve this.

R.A.M has merged the use of two technologies from the market research into its main system and integrates the rest by connecting via Wifi or Bluetooth . In theory the suggestion is these combined features create a superior product but without testing, these technologies may operate best at an individual level.

In terms of R.A.M, reliability and technology go hand in hand. The more technology available, the greater the efficiency and effectiveness of results and in the case of system failure with one software another can take up the slack. In combination, R.A.M provides the best picture of Earth's sub-surface network compared to current technologies and human insights. It minimises cost and disruption to society and will remain a valuable tool in years to come when population growth and anthropogenic activity adds pressure to the environment.

Future User Evaluation Plan

The core principles of Human Factors relate to user engagement and their understanding of a system. The concept of R.A.M, both digital and physical, delivers this focus and has created engagement that was otherwise limited with the current systems on the market.
Initially, usability inspection would take place with a professional however, it would be beneficial to conduct usability testing to formally evaluate R.A. M's functionality and operation against how well the intended user has understood. Usability inquiries can be made after testing of which, user satisfaction may be measured using the Likert Scale. Where issues or user errors are noted, these could be addressed by providing packed kits that offer the user instructions on R.A.M's operation and set up and with a customer support service for advice. Any user dissatisfaction can be gathered as insights for later improving the product.

Conclusion

Ultimately, R.A.M is a solution that provides clear and intuitive data to help humans understand the changes happening beneath the surface, when it otherwise wasn't possible due to the limits of our physiological and psychological human factors. It serves to mitigate future severe economic destruction to alleviate the emotional, psychological and physical impact this has on society.

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Appendix

Appendix Figures

Fig 26: Aligned Fault System

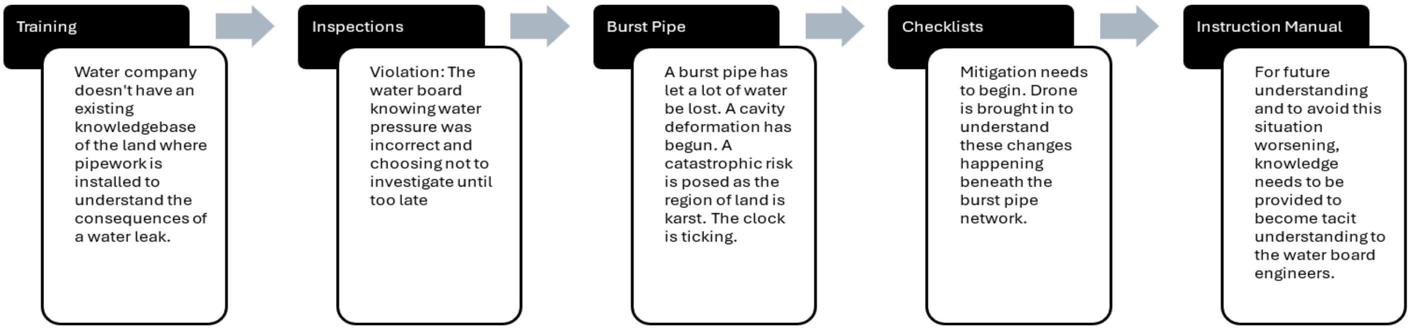

Fig 27: FIDO (FIDO)

Fig 28: InSAR Satellite (sixense)

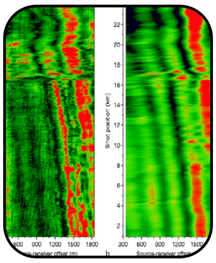

Fig 29: SWT (Wang, Y)

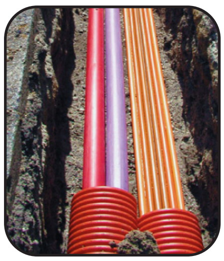

Fig 30: Fiber Optics (Telenco)

Fig 31: GPR (Geo-Model)

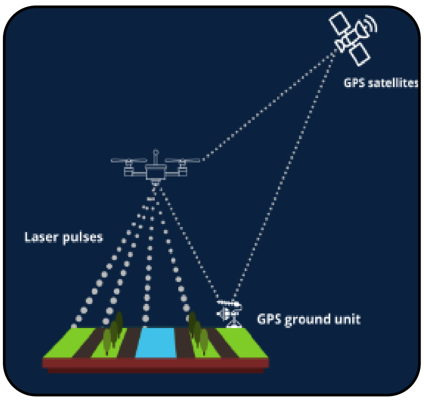

Fig 32: LiDAR Satellite (scout Aerial Australia)

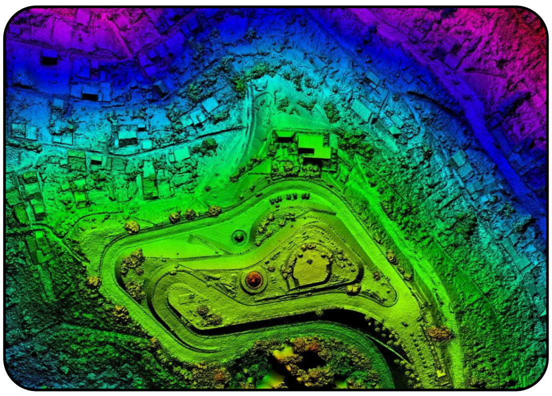

Fig 33: LiDAR Scanning (FIXAR)

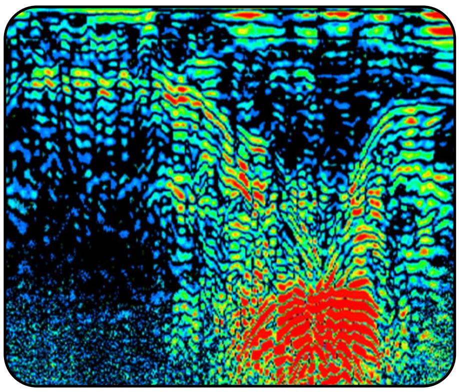

Fig 34: GPR Scan (KBGBR)