ElectroCap Project Proposal

Forest Fires Detection

Hybrid System for Early Detection of Forest Fires

Team 2

For more information about the project's development, you can visit our web page:

https://web.tecnico.ulisboa.pt/~ist1109562/equipa2/

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Team

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Problem Definition

Currently, the core problem lies in the fact that forest fire detection is predominantly carried out by humans through visual inspection. This exclusive reliance on manual surveillance often proves inefficient, leading to several negative consequences for the effectiveness of firefighting, such as:

Delayed Detection

Depends on someone spotting smoke or flames.

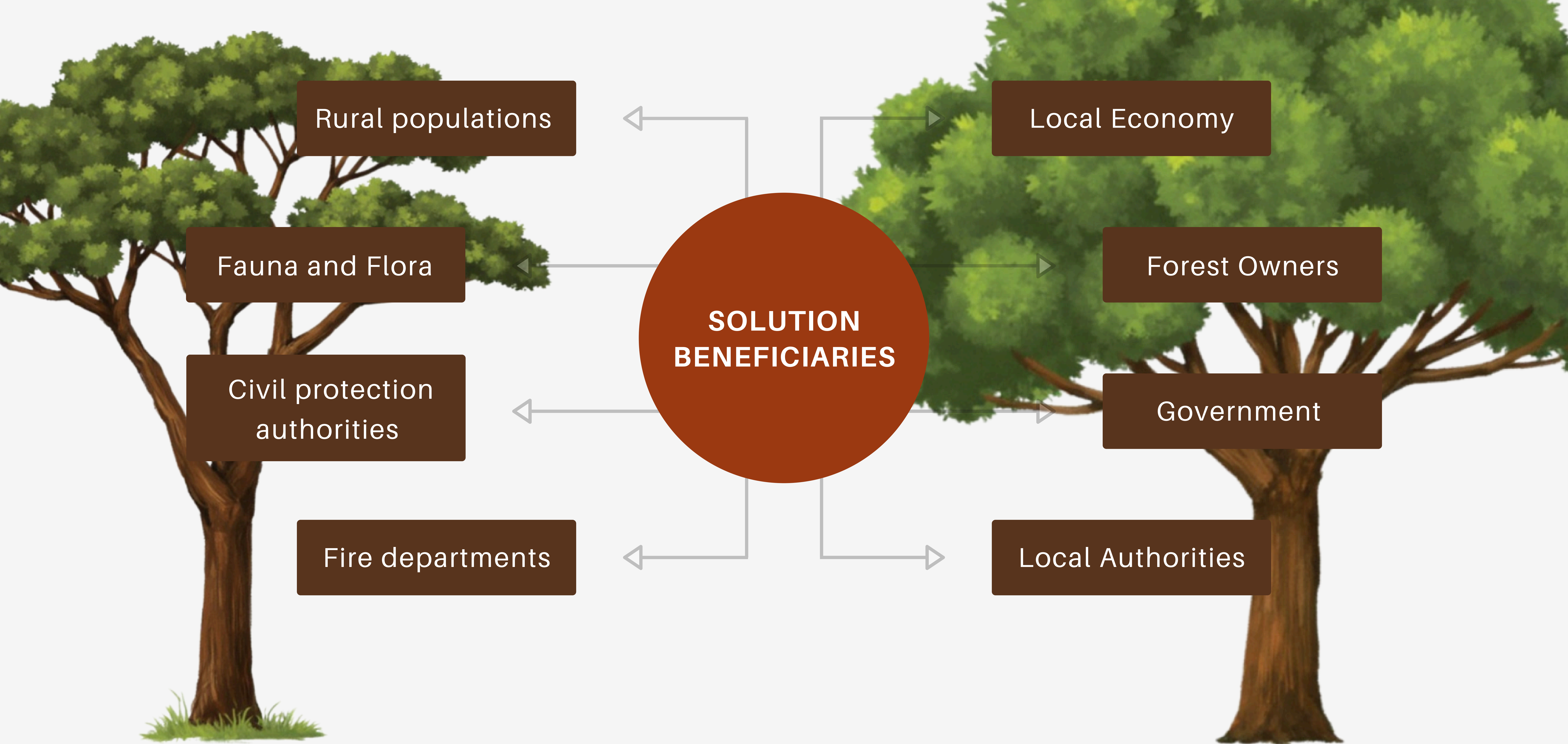
Physical and Geographical Limitations

It is limited by the line of sight, weather conditions, night period, and human fatigue.

Lack of Precision in Localization

It is difficult for a human observer to pinpoint the origin of the fire in dense forest areas, delaying the arrival of teams to the scene of the fire.

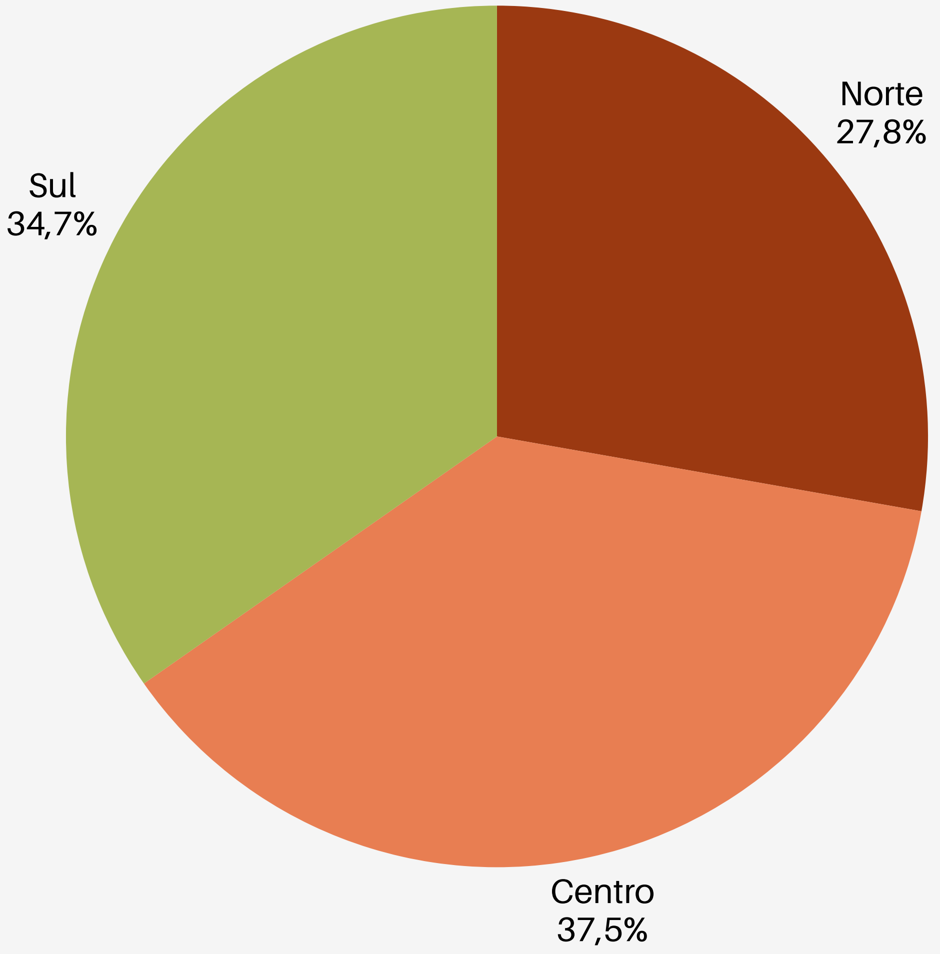
Solution beneficiaries:



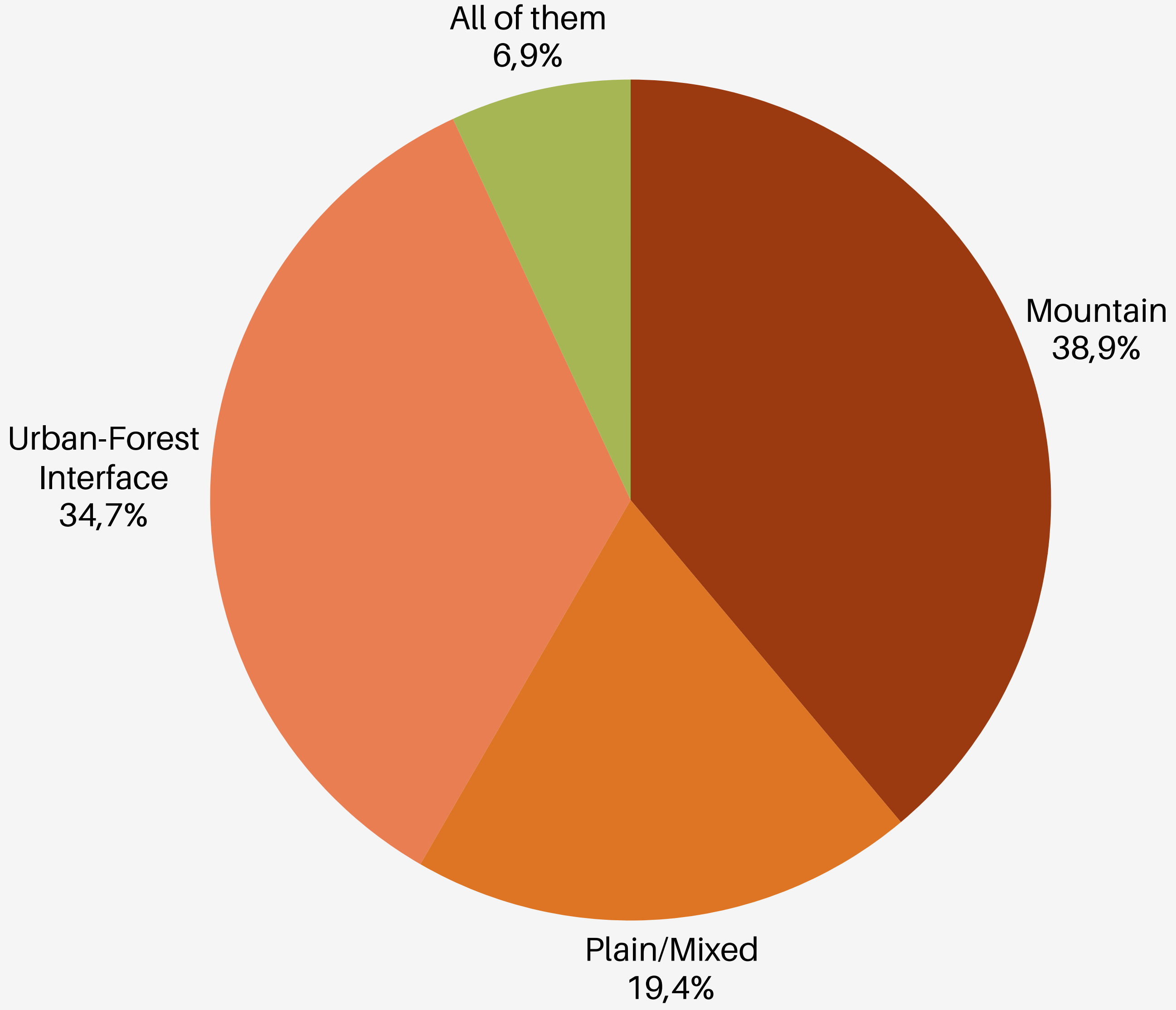
Validation & Study Sample

Our solution is grounded in real frontline data. To validate our system, we combined an in-depth qualitative case study at the Vendas Novas Fire Department with a nationwide survey of 72 civil protection entities. This mixed-methods approach ensures our technology is directly tailored to the geographical challenges and operational realities faced by firefighters across Portugal.

1. What region is the Fire Station in?



2. What type of ground do they work on?



References:

Data compiled from feedback provided by Fire Departments across Portugal via email survey.

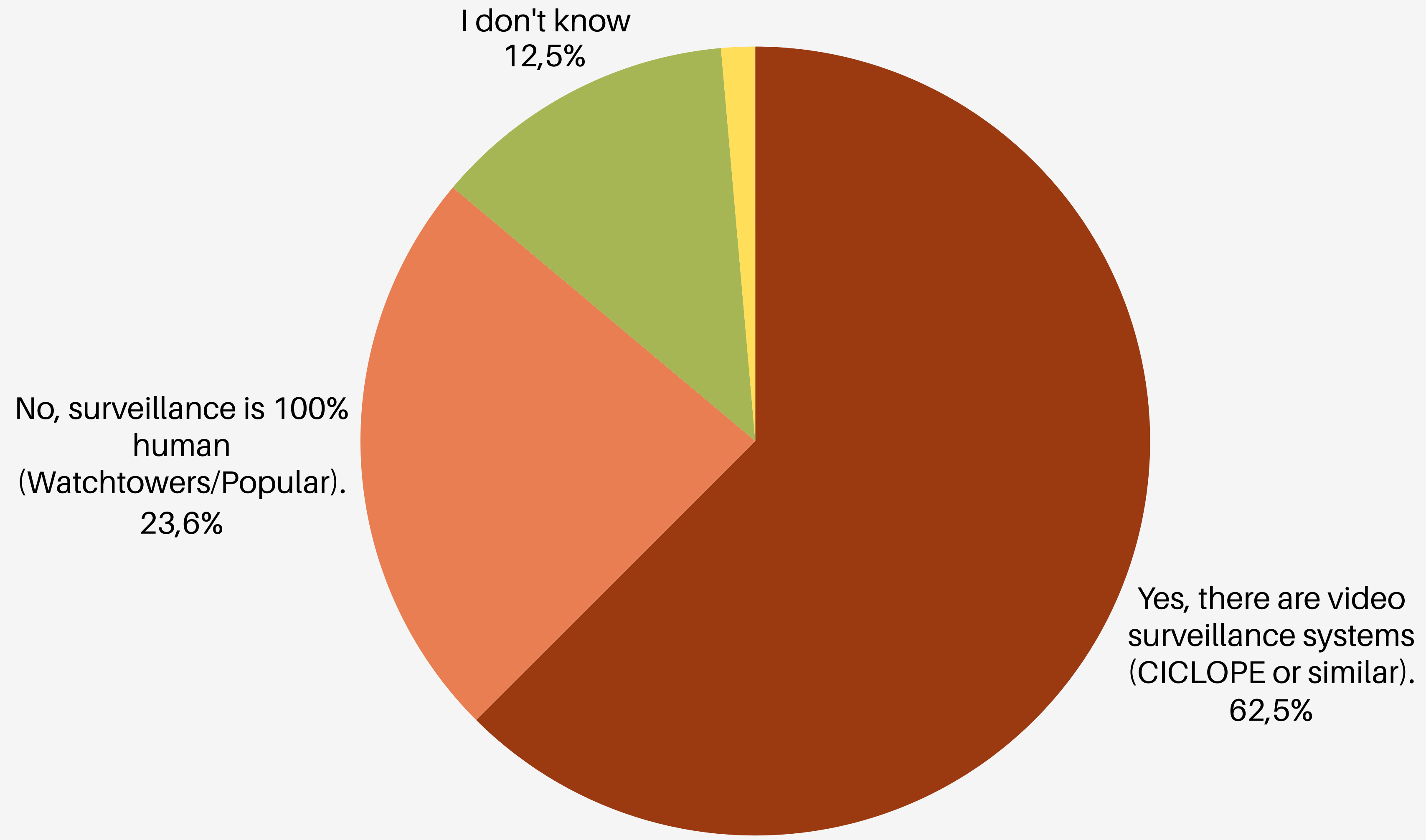
Forms sent to Fire Departments here You can see the statistics here

For more detailed information, you can consult the summary of the meeting with a Fire Department on our website.

Validation & Study Sample

Our survey data shows that while 23.6% of departments rely solely on human vigilance, 62.5% already use video surveillance systems (CICLOPE). Driven by these results, we secured a strategic partnership with them, which we will detail further ahead in the presentation, ensuring our system complements rather than competes with existing infrastructure.

3. **Has there ever been a technological system of sensors/cameras implemented in your area of operation?**



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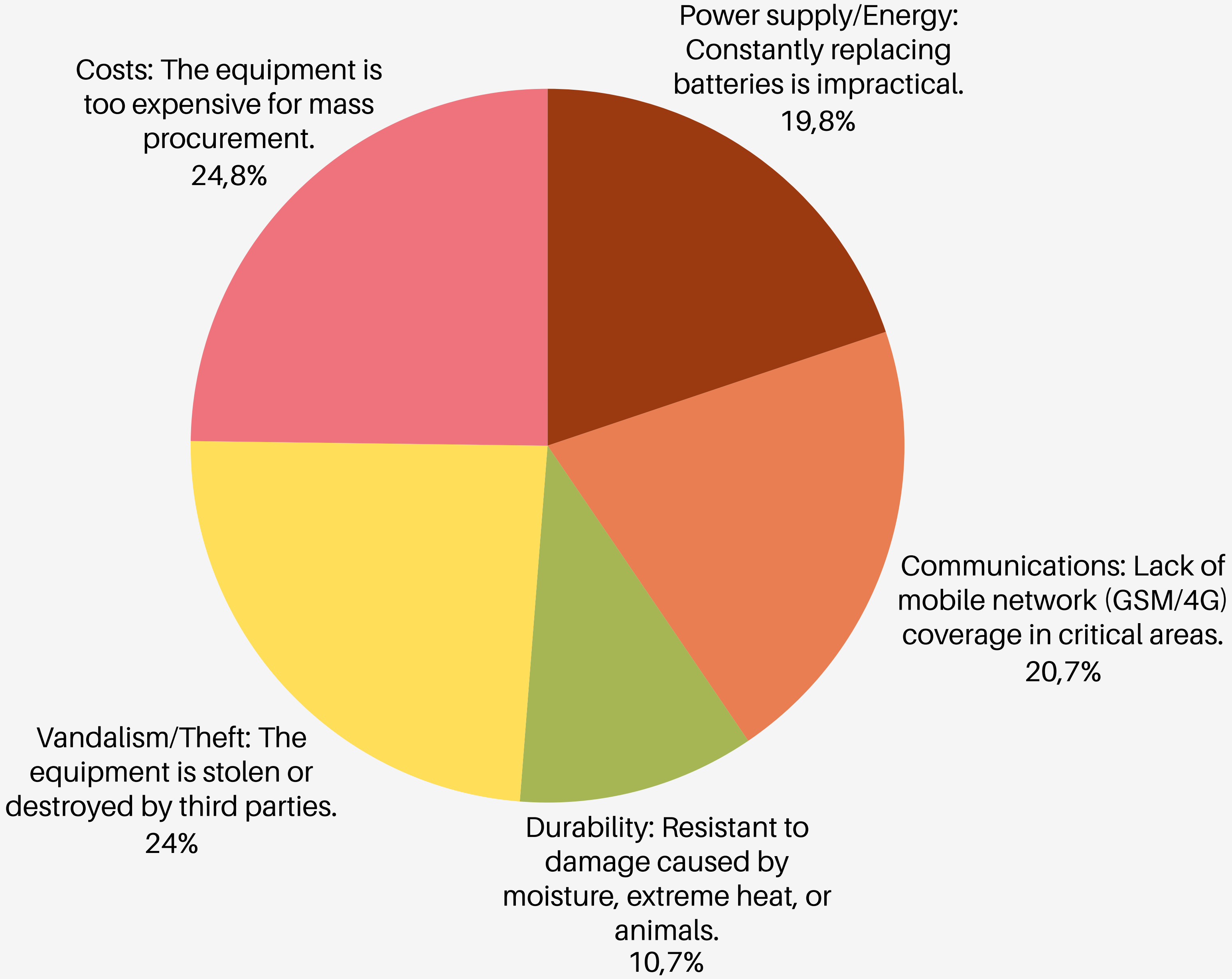
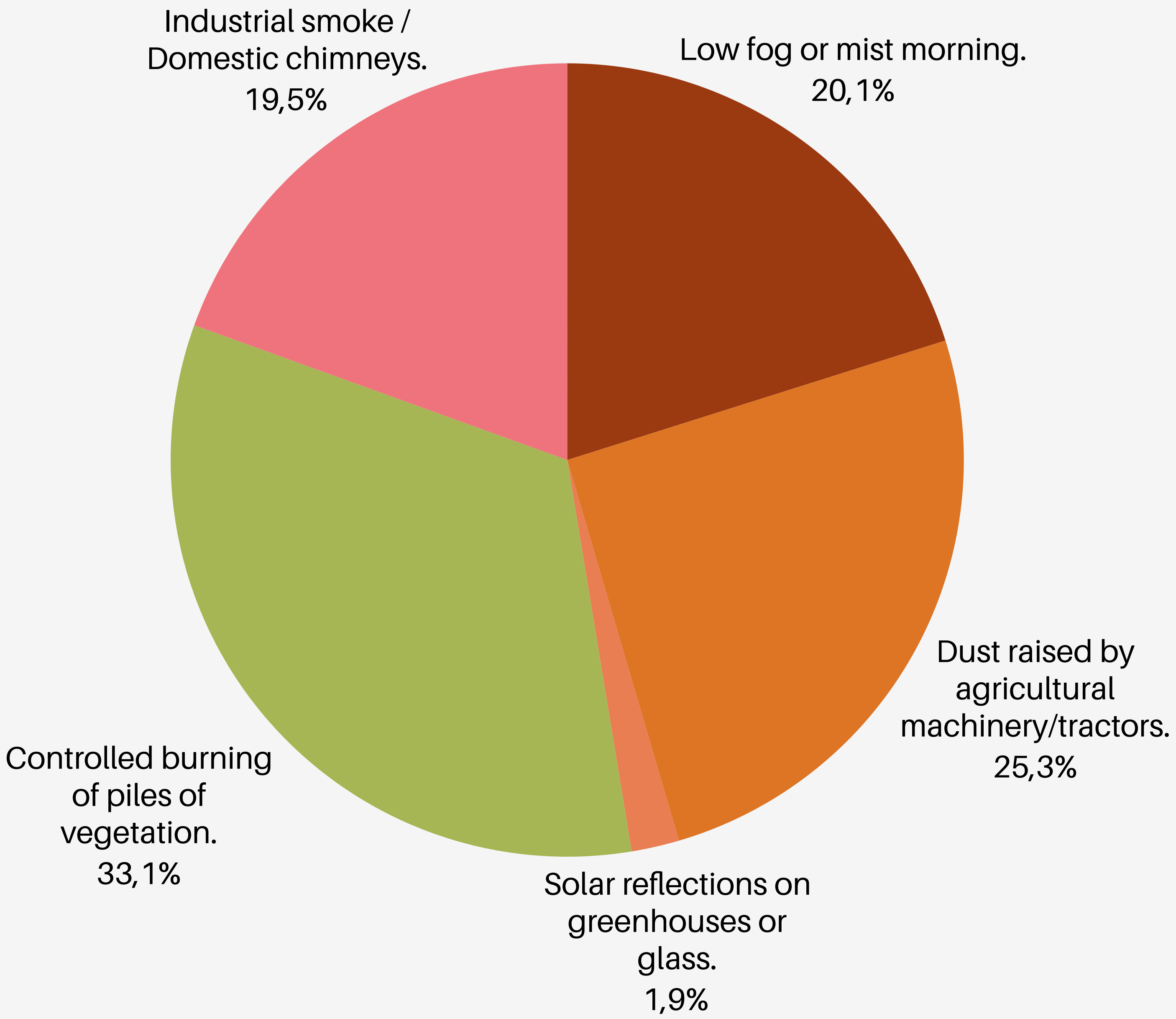
Validation & Study Sample

4. **What is the BIGGEST technical challenge in maintaining electronic equipment inside the forest?**



5. **What causes the most visual "false warnings" in the forest that could fool a camera?**



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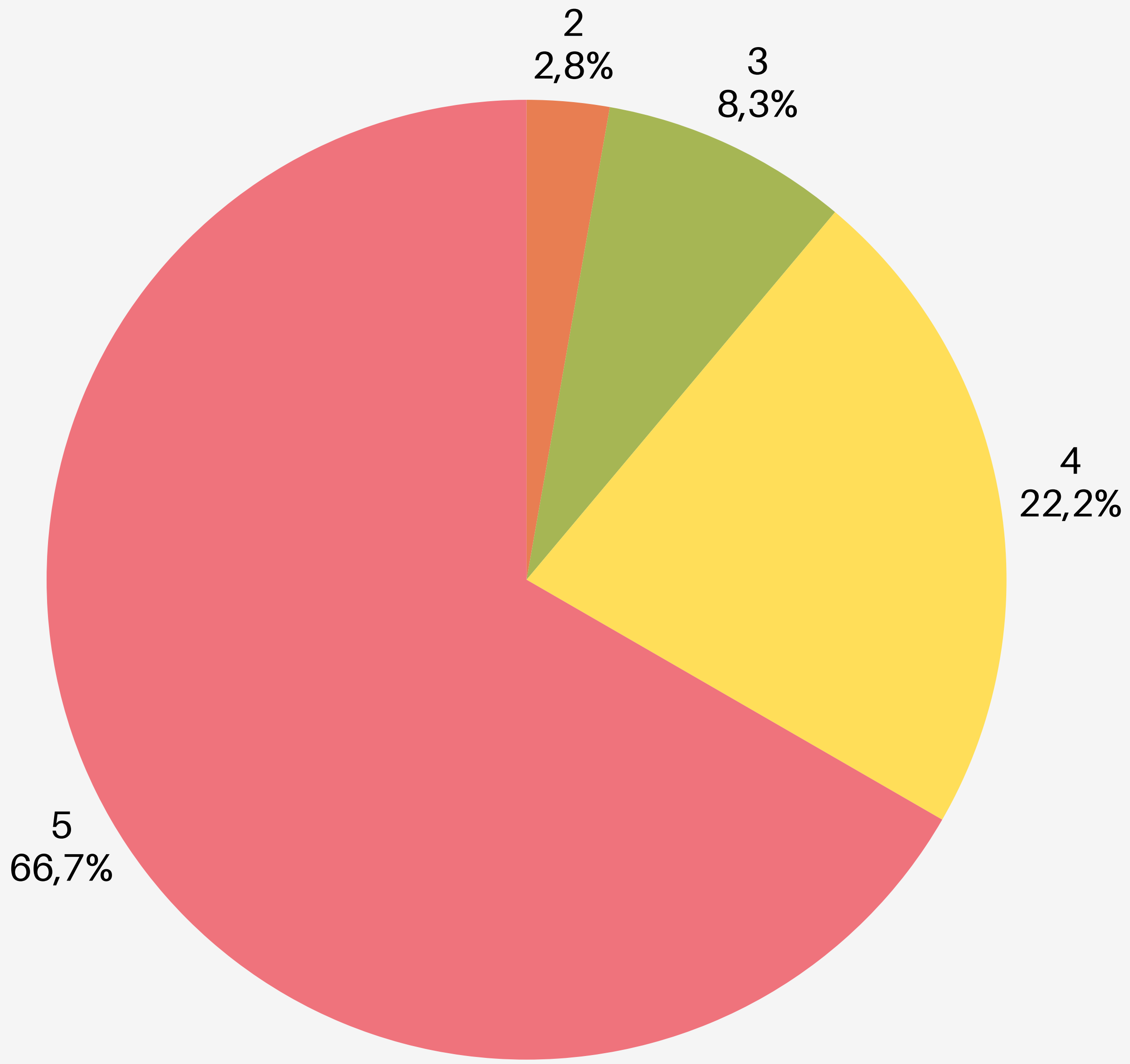
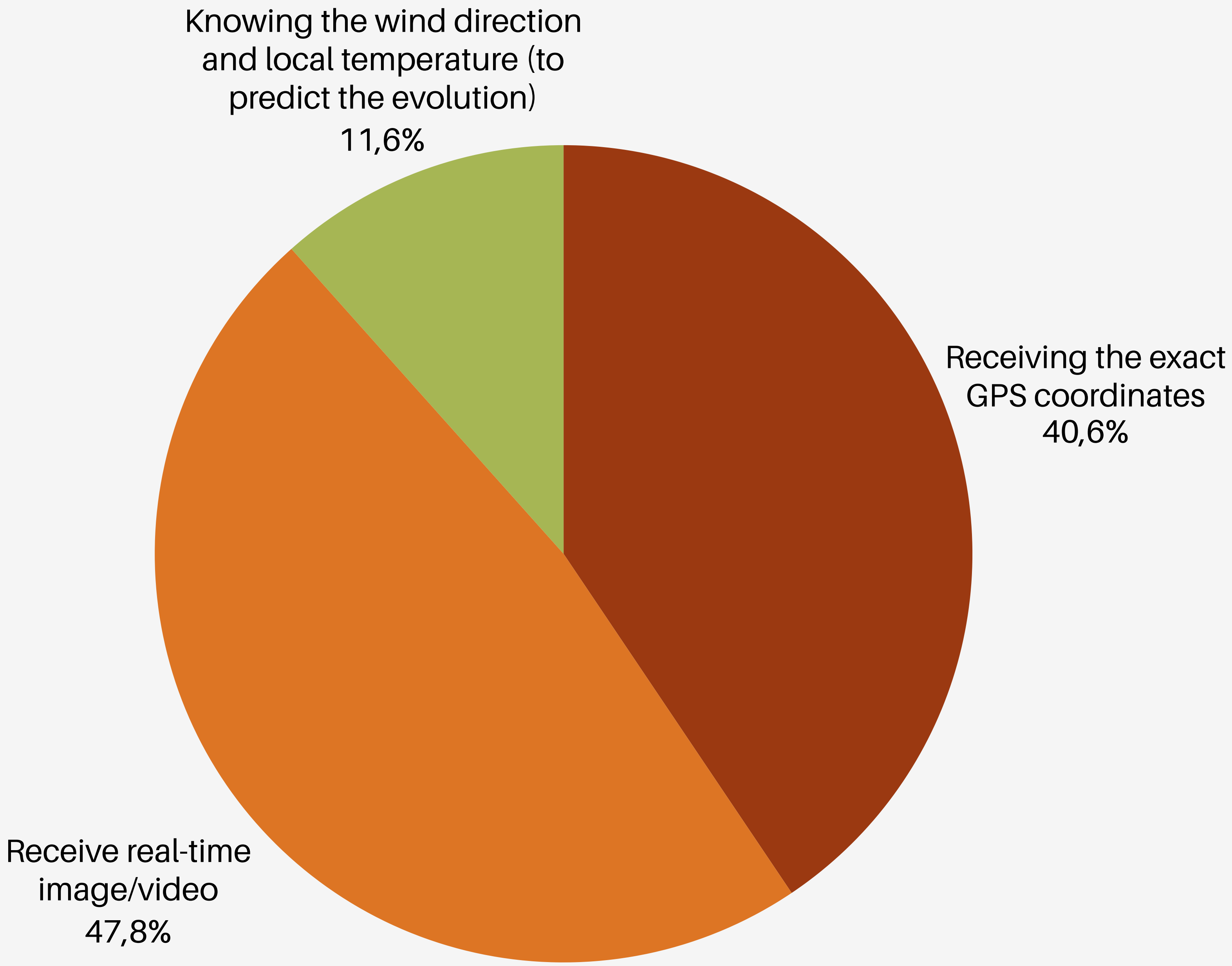
Validation & Study Sample

6. On a scale of 1 to 5, how useful would it be to receive an alert with GPS location?



7. What would be the most important feature in a system like this for your team?



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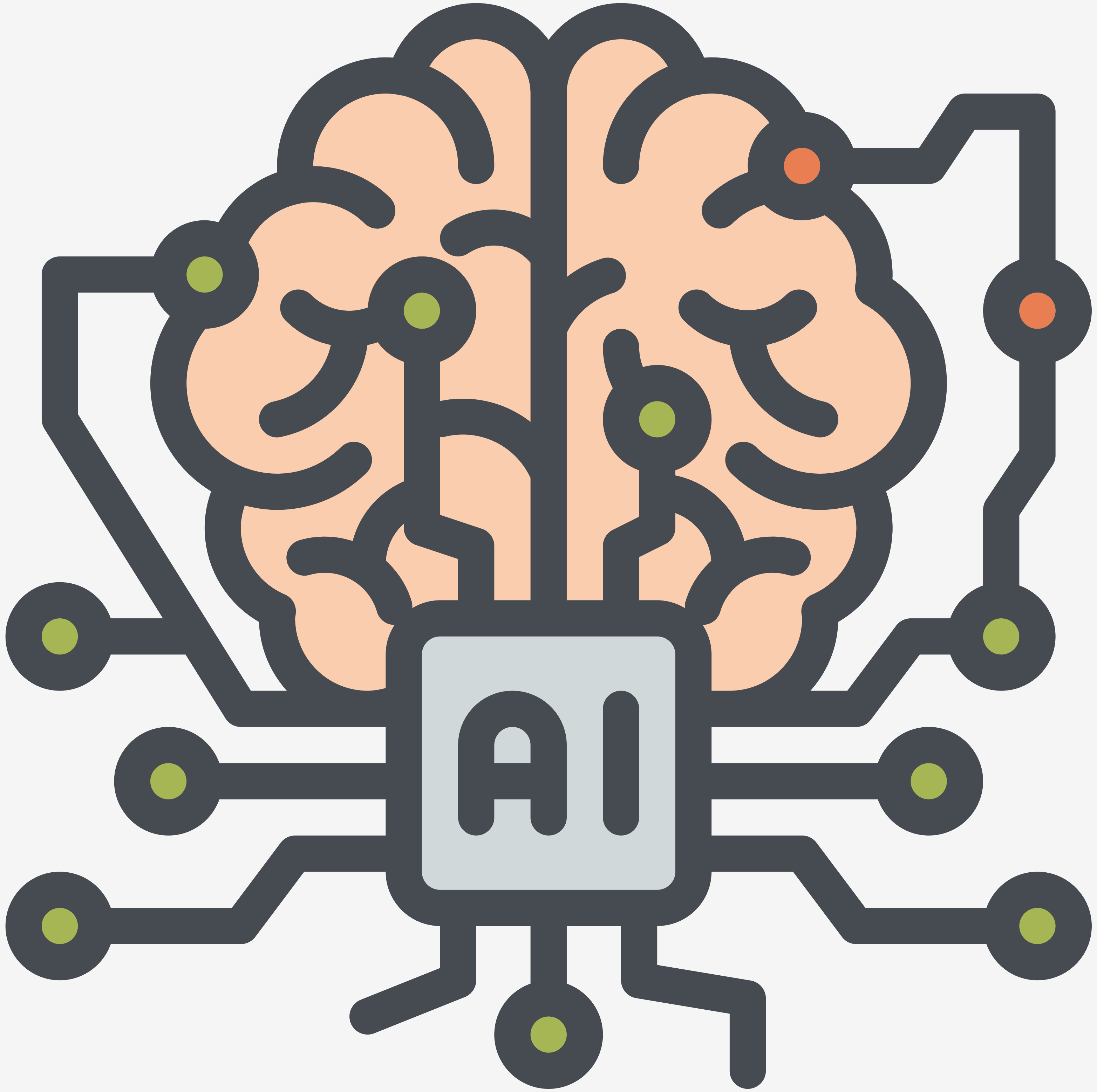
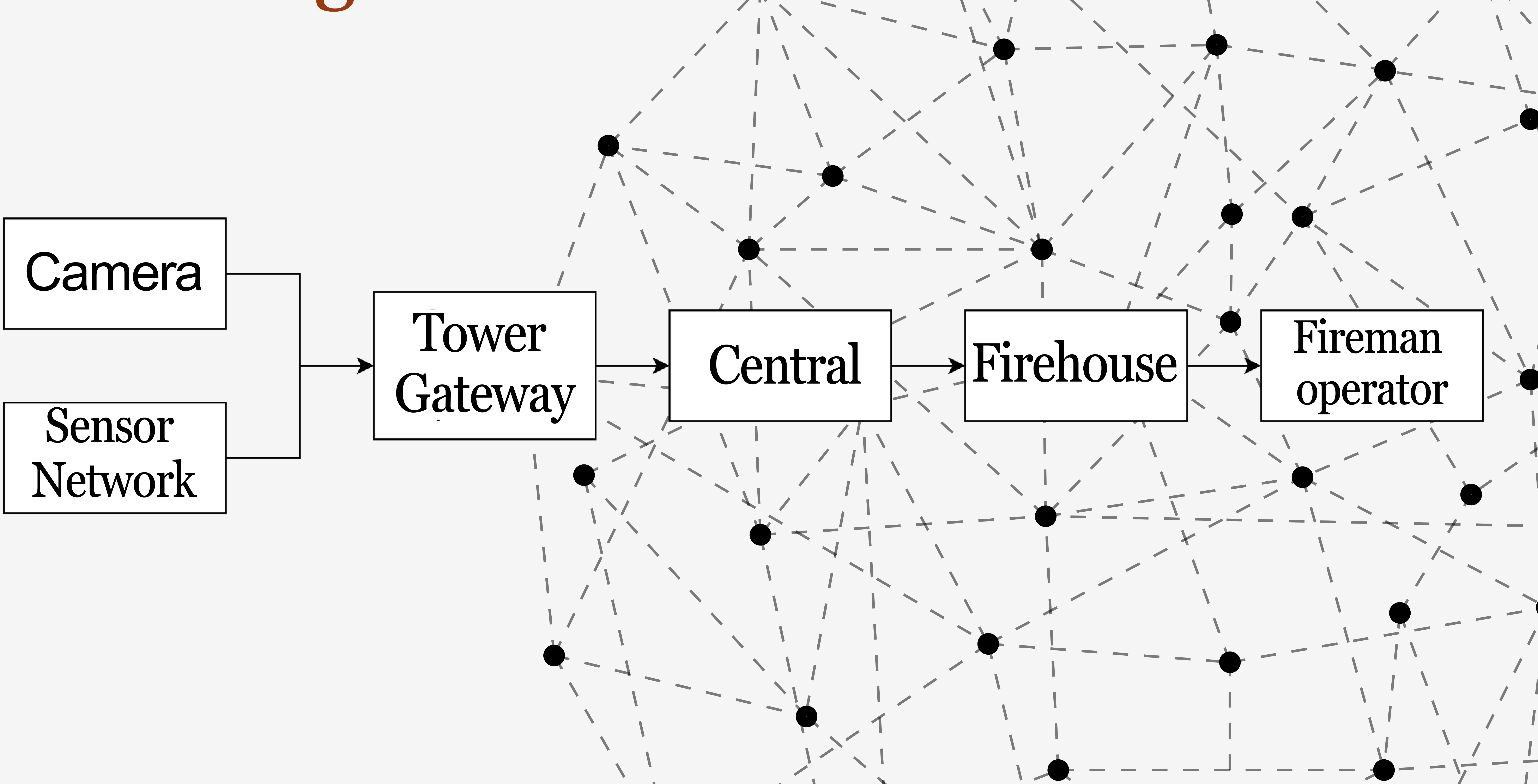
Technological solution -General view

Solutions: Automated detection through visual analysis of a predefined forest area powered by a machine learning model, complemented by a ground sensor network to ensure detection even during visual obstructions.

Core Concept: To capture wide views of forest areas by installing cameras on elevated poles (either by leveraging existing infrastructure like lookout towers or building new ones) and analyzing the footage in real-time. If visibility is compromised, the system seamlessly falls back on the ground sensors.



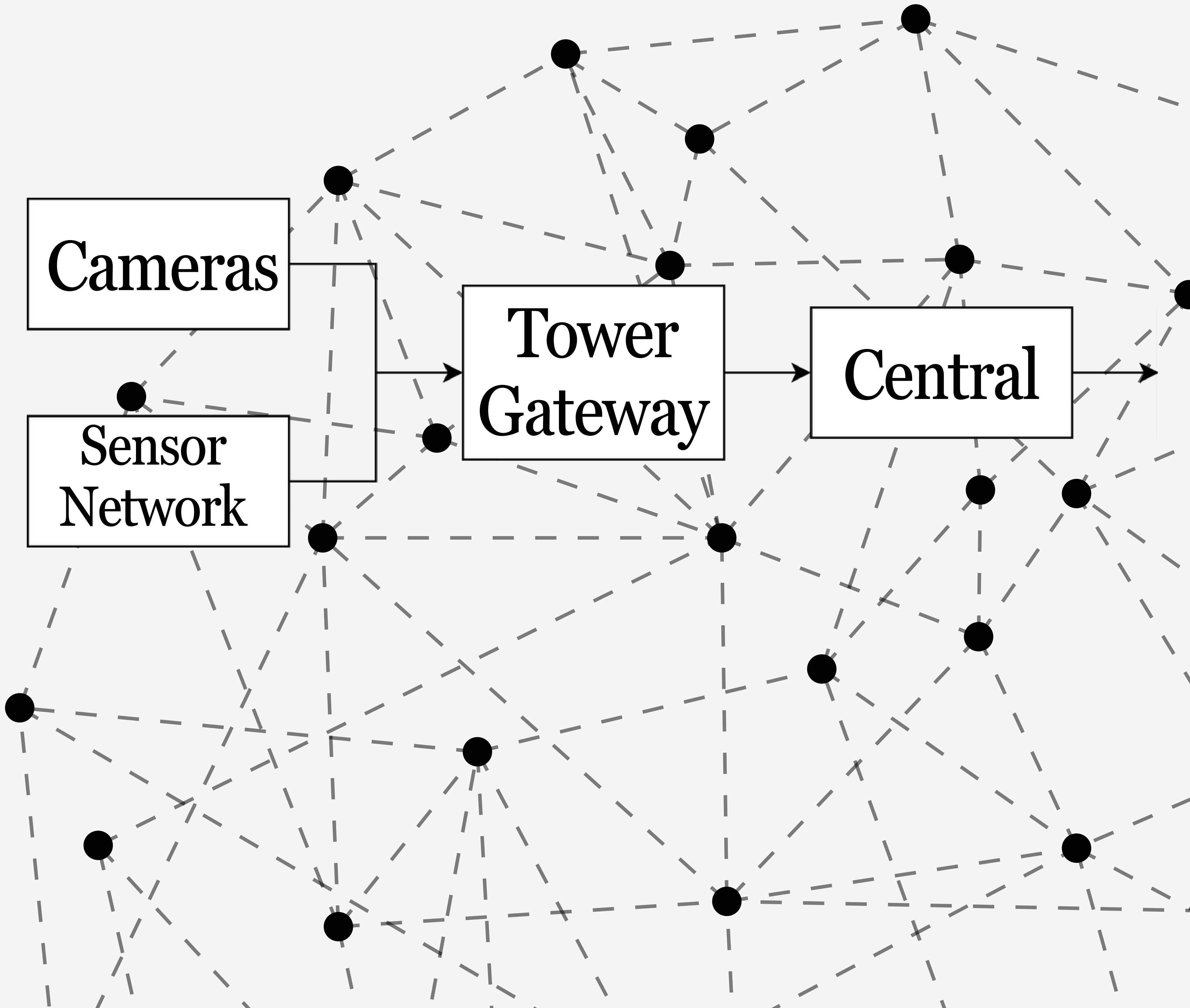
Technological solution -Problem architecture



Technological solution -Problem architecture

The cameras will be mounted on poles, which will also house a gateway to communicate with the processing center. They will frequently capture and transmit images of the area to the central hub for analysis.

In parallel, a mesh sensor network will be deployed, where each sensor analyzes the environmental conditions, such as temperature and the chemical composition of the air, within its coverage area. If an anomaly is detected, an alert containing the data is transmitted from sensor to sensor using multi-hop communication until it reaches the gateway, which then forwards it to the processing center.

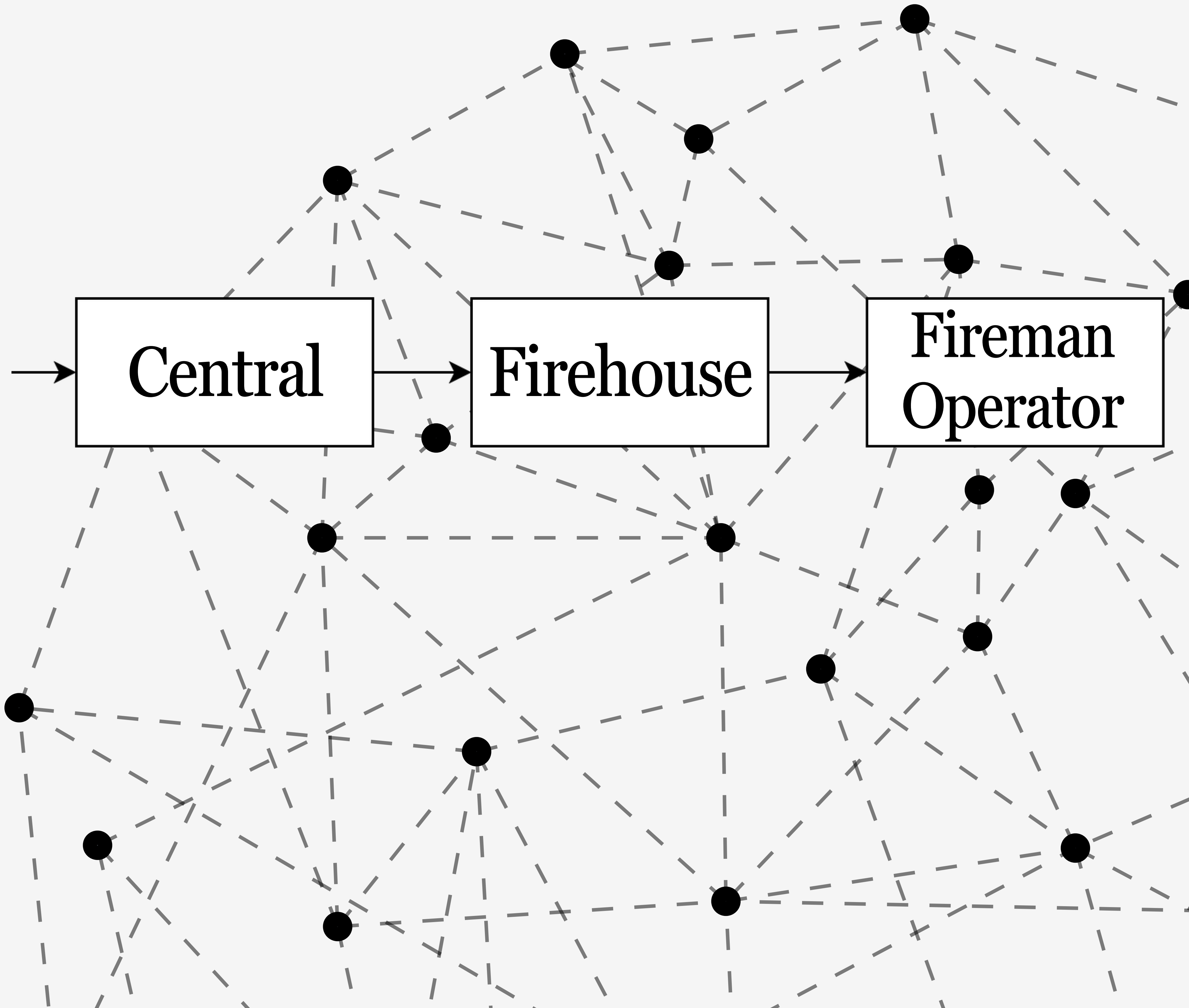


Technological solution -Problem architecture

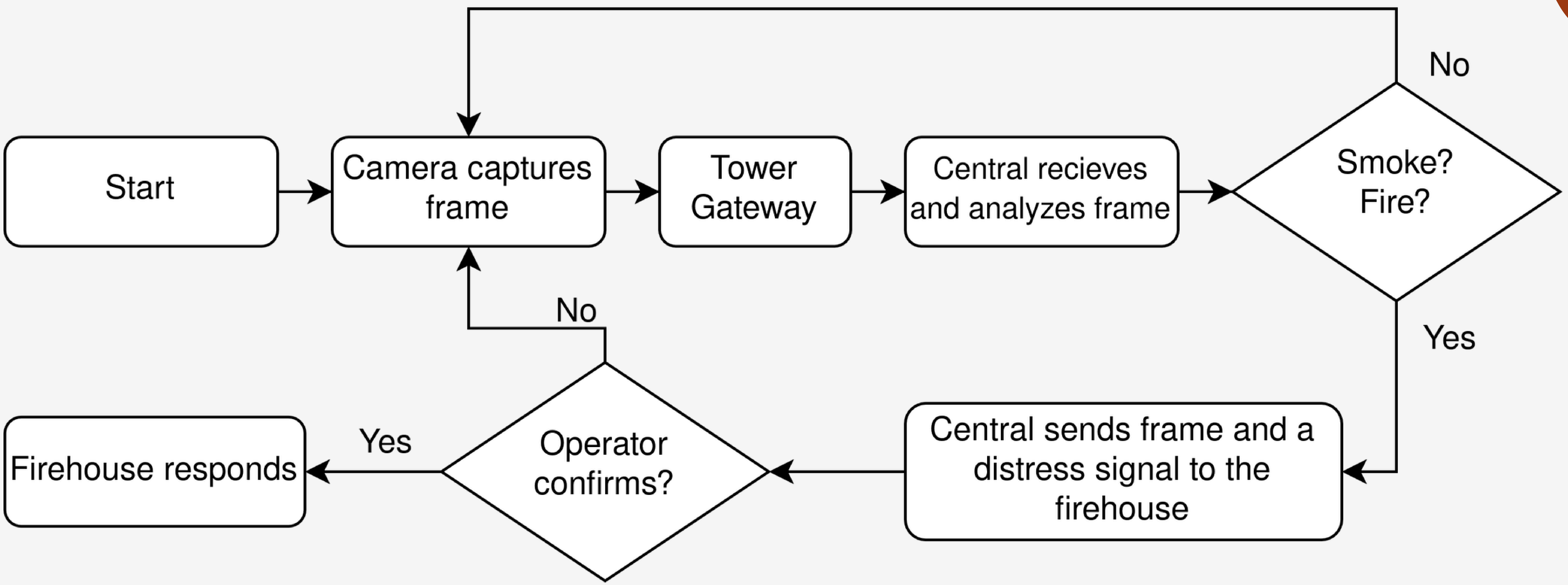
The processing center will be responsible not only for processing and analyzing all incoming data, but also for communicating directly with the fire departments.

The processing center can be deployed in a strategic regional location to handle data from multiple cameras and larger sensor networks. Alternatively, it can be mounted directly on the camera poles for localized processing, analyzing just its own camera feed and a smaller, immediate sensor network.

Naturally, in the first scenario, the central hub will possess significantly greater processing power. In the second scenario, being infrastructurally restricted to the poles, its processing capabilities will be more limited.



Technological solution -Camera Operation



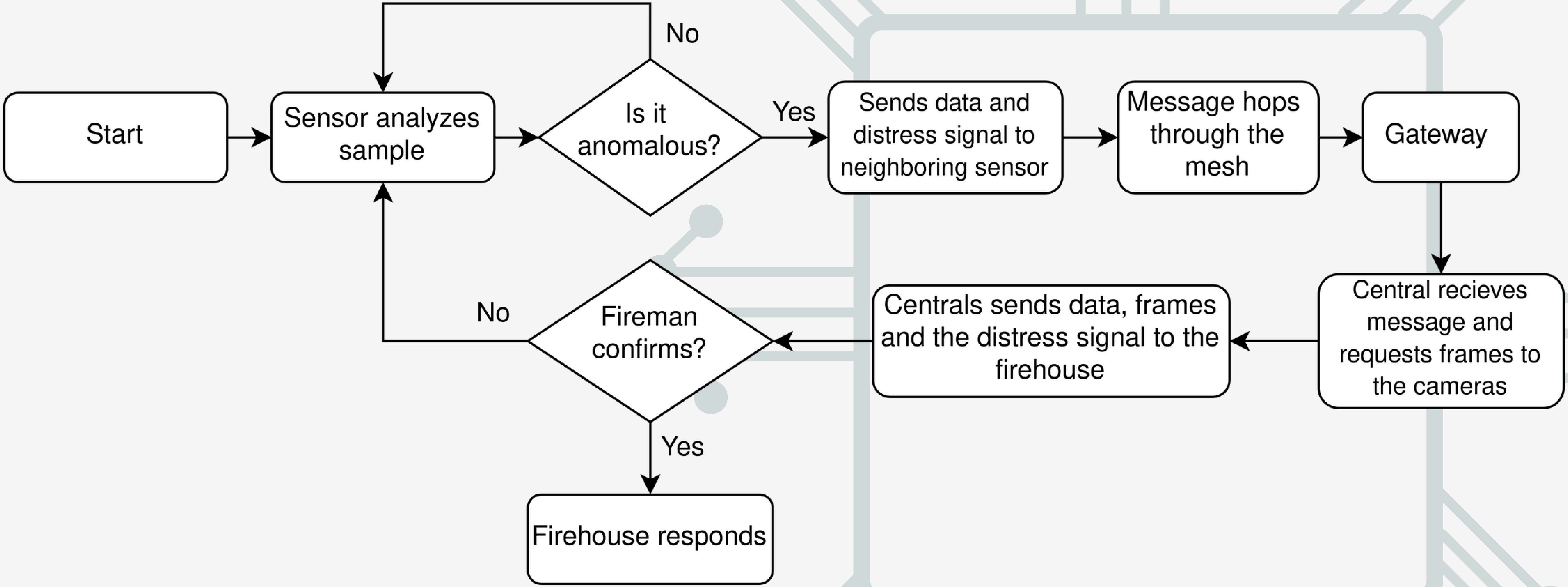
Technological solution -Camera Operation

The cameras will periodically capture images of their designated coverage area. This visual data will then be transmitted through the gateways installed on their towers directly to the central processing hub.

At the central hub, an image-analysis machine learning model will evaluate the incoming data to detect any signs of fire.

If a threat is detected, an automated alert, along with the images showing the anomaly, will be immediately sent to the fire department. The central hub will then await a confirmation signal from the operators to verify the alarm.

Technological solution -Sensor Operation



Technological solution -Sensor Operation

The sensors will periodically analyze air samples from within their respective coverage areas.

If an anomaly, such as smoke, is detected, an alert signal containing the relevant environmental data is transmitted from sensor to sensor via multi-hop communication until it reaches the gateway, and subsequently the central processing hub.

The central hub will then redirect the cameras in that region to point towards the triggered sensor and capture images. Once received, the hub will send this visual footage, the sensor data, and an alert signal to the fire station, waiting for final confirmation from the operators.

Technological solution -Required Hardware

Station Ecosystem

- Gateway / router
- Computer

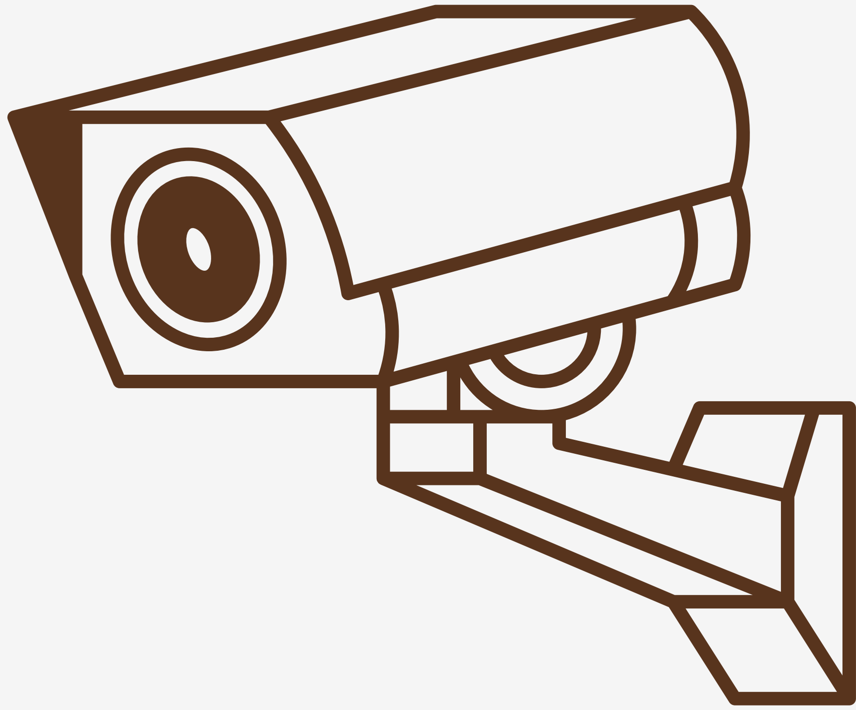
Tower Ecosystem

- Gateway / router
- Rasberry Pi
- Optical camera
- LoRaWan Hat

Sensor Ecosystem

- ESP32
- LoRaWan Module
- Power supply (Battery/Solar)
- GPS module
- Temperature Sensor
- Volatile Organic Compounds Sensor

Technological solution - Capture hardware (camera)



Camera Type: Optical Camera

Justification: Chosen based on the project's budgetary restrictions.

Comparative Analysis:

- **Optical Solution:** Highly effective for daytime flame and smoke detection; however, it faces visibility limitations for smoke during nighttime.
- **Thermal Solution:** While theoretically the ideal choice, long-range thermal detection is technically complex and exceeds our budget, making it unfeasible for this project.

Technological Solution - Image/video quality

Maximum capacity: Can reach 4K (Bitrate: 15-30 Mbps) using 5 GHz.

Real application (operational): With a 5GHz Non Stand-Alone network, the expected image quality is 1080p (5-8 Mbps).

Stability:

- Significant interference due to rain or coulds is not expected, especially since the system will primarily be used during summer.
- The network interface to the Tower operates at 5Ghz, ensuring functionality even if the core network transitions to standalone mode.

Network Management: There is the possibility to use network slicing in high-demand areas to garantee the required resources.

Data acquisition of an high-quality camera: In a commercial implementation of the project, a higher-quality camera would be necessary. However, due to budget constraints, this prototype will remain at the proof-of-concept stage, and no higher-resolution camera will be acquired for this purpose.

Technological Solution

- Location/Camera Installation

Local: The main idea is to install the system on existing surveillance towers used by forest guards, reusing the already available and well distributed infrastructures.

Alternative Location: If there is no nearby tower in a specific area, new towers will need to be installed, using a minimalist design to avoid disrupting the landscape and to reduce costs.

Height: The installation height should be as high as possible on existing structures. However, it will always depend on the terrain and the surrounding trees.

Competitors and similar previous works – Main competitors on the market

Company	Company	Company	Company	Company
Pano AI	They provide an end-to-end solution that uses ultra high definition 360° cameras installed on connected towers via 5G/LTE networks.	Proprietary deep learning software is used to detect fires and determine their exact location.	Extremely high implementation cost (subscription-based model) and strong dependency on heavy infrastructure.	Low-cost solution using affordable hardware like Raspberry Pi / ESP32 which enable coverage of high-density areas with a lower budget.
IQ FireWatch	A global leader in ground fire detection using specialized multispectral sensors installed on surveillance towers.	These systems analyze optical and infrared wavelengths near the risk area to distinguish smoke from fog and dust with high precision.	Heavy industrial system. Requiring expensive towers and a too high investment, not being feasible on small florest areas or regions without stable eletcricity.	Our system is lighter and more flexible, and can be installed on trees or simple towers. The integration of ground sensors (ESP32) provides microclimatic data that tower based cameras alone cannot capture.

Previous published papers

– Research and Implementation

Research	Reference	Contributions	Limitation	Our new developments
YOLO Early Detection Thesis	(PDF)…	It demontrates the high efiecny of the machine learning model YOLO to detect early stage smoke/fire, being a far better approuch over the tradicional image processing methods.	This study focus on static images and limited datasets without the real time integration with ground sensors and cameras on real world scenarios.	We use edge computing (Raspberry Pi) to process real-time video, rather than relying only on static image analysis.
Repo: YOLOv8 Fire & Smoke	GitHu…	Modern implementation of YOLOv8, which provides a better performance, detection speed over previous versions of this model.	The traditional systems rely mainly on RGB (optical spectrum), which is more prone to false positives (e.g., dust, warm colors).	Our approach adapts the model to incorporate infrared data, improving night detection and temperature-based discrimination.

Competitor analyses and previous works – Recent Research (2023/2024)

- Frontiers in Env. Science (2024): Art. 10.3389/fenvs.2024.1486212. Analyses new environmental metrics for detetion.
- Paper IJCRT (2023): IJCRT2306821. Integration of new alert systems

Where do we win (Sensor Fusion)?

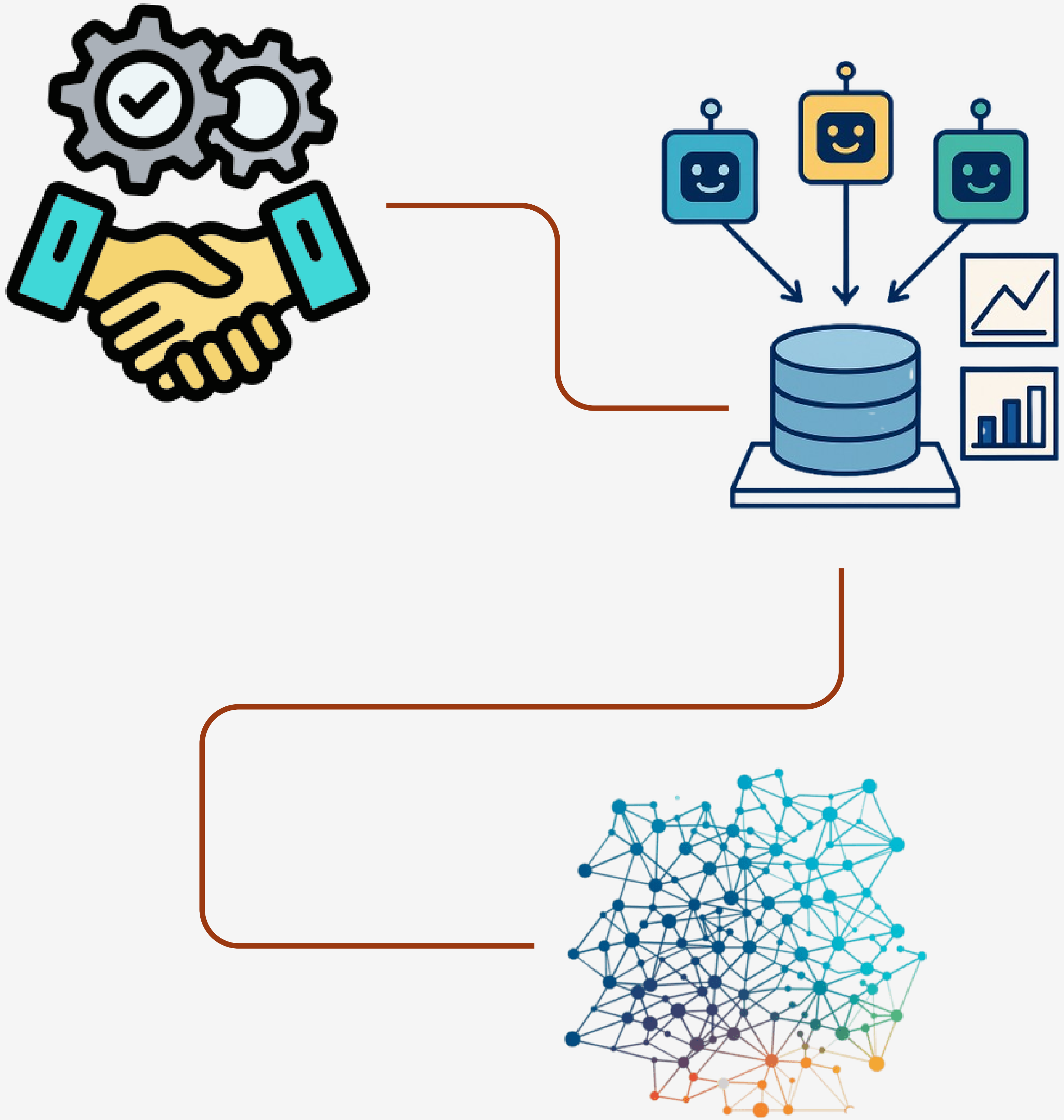
Both studies required an expensive and sturdy system. However our project can overcame those obstacles putting together the "vision" (YOLO) with the sense of smell (sensors) and with human validation,this triple architecture make the protect sturdy and affordable once the technology used is cheap.

Technical Challenges

- Creation of the Mesh Network and reliable message transmission through multi-hoop communication.
- Triangulation/Geolocation of the ground sensors.
- Power supply of the ground sensors.
- How to properly train a Machine Learning model to analyse real time images as they are captured?

Institutional Collaboration: INESC-INOV

- **Formal Partnership:** Key milestone achieved by establishing a strategic collaboration with INESC-INOV.
- **CICLOPE Framework:** Secured institutional access to specialized image datasets via the CICLOPE Project.
- **Model Optimization:** Direct integration of high-fidelity data into the training and refinement of our YOLO detection model.
- **Performance Edge:** Leveraging professional datasets guarantees superior system accuracy and detection capabilities.



Testing and validation metrics

Main metrics:

- Range;
- Precision;
- False alarms per camera per day;
- Time-to-detect;
- Latency e FPs;
- Energy Efficiency

Test and Validation:

- Separate the data by source (camera/local);
- Split the dataset into training/validation/testing sets;
- Create stress tests (night,rain,fog condition);
- Validate precison and false-alarms;
- Test FPS, latency and energy consumption

Model Selection and Traning:

- YOLO

Adjustments to reduce errors:

- Reduce false positives by tunning thresholds and apply time windows filtering

Division of labor

✓ on going work ✓ accomplished work

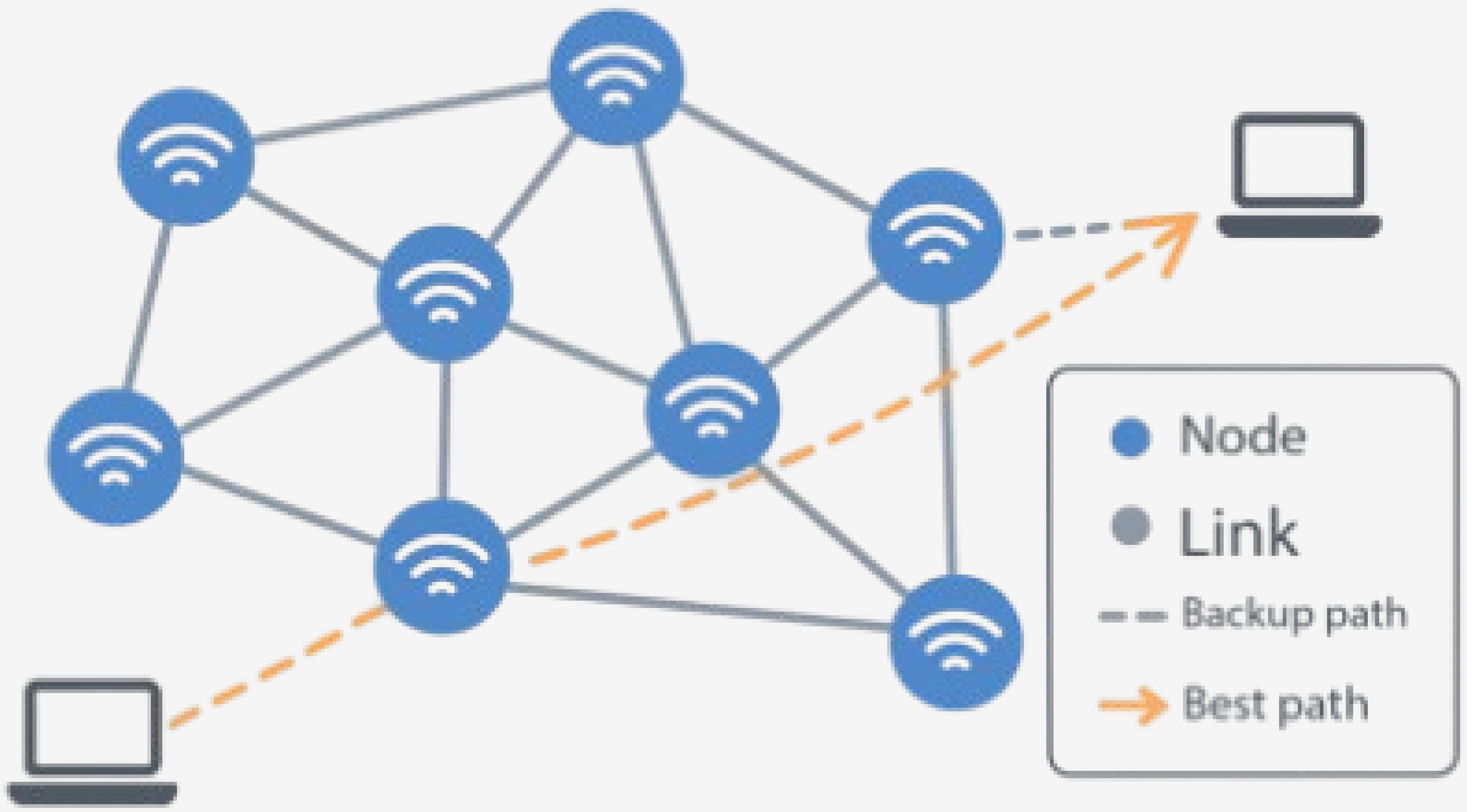
Bárbara Trigueirão	Gonçalo Caetano	Salvador Carvalho	Carolina Rodrigues	Marco Mendonça	Diogo Vicente
Lead Sensors Developer	Lead Computer Vision Developer	Lead Telecom Developer (on going)	Lead Fronted Developer (on going)	Lead Hardware Developer (on going)	Lead Data Analyst (on going)
PitchDeck (accomplished)	PitchDeck (accomplished)	PitchDeck (accomplished)	PitchDeck (accomplished)	PitchDeck (accomplished)	PitchDeck (accomplished)
Firefighters interviews (accomplished)	Circuits Designer (accomplished)	Hardware Selection (accomplished)	Web Developer (on going)	Data processing from sensors	Firefighters interviews (accomplished)
Sensor's Programmer	Software development for Multihooping	Data processing from sensors	Data Processing for YOLO	Software development for Multihooping	Create a response form for firefighters + analyses (accomplished)
Web Developer (on going)	Sensor's Programmer	Web Developer (accomplished)	Graphical Designer (on going)	Computer Vision Developer	General communications Developer

Mid-Program Status

- **Inter-ESP Communication:** Successfully established communication between ESP devices using LoRa WAN technology.
- **GPS Testing:** Through an open-source interface, successfully tested the GPS module of the ESP devices.
- **Partnership Development:** Initiated a partnership with the “Ciclope Project”, which will support us in the development and integration of the camera system.
- **Tower System:** Defined key components including the router, camera architecture, and communication with the Raspberry Pi. Additionally, we outlined a potential future feature that would allow automated camera positioning.

Technical Execution and Prototype Logistics

- **PoC Validation:** Successfully demonstrated stable node-to-node Mesh Communication using an open-source platform.
- **Robust Network:** Confirmed reliable decentralized connectivity and data exchange in a test environment.
- **Logistics Planning:** Initiated the logistical workflow and physical architecture design for prototype assembly.
- **Field Deployment:** Current focus is mapping deployment strategies for upcoming field testing.



Validation & Impact Assessment

- **Data Collection Complete**: Successfully finalized extensive data gathering regarding the core project challenge.
- **Impact Evaluation**: Conducted a thorough analysis of the solution's impact and potential effectiveness within the target environment.
- **Viability Validated**: Early findings confirm the high value and viability of our proposed approach.

Achieved Results

Communication System

- Established communication between ESP devices using LoRaWAN
- Sensors can be located via GPS through an open-source interface
- Communication range spans several kilometers
- Multi-hopping identified as a viable solution to reach the central tower

Partnerships & System Planning

- Initiated partnership discussions with the Ciclope project
- Support expected for camera system development and integration
- Defined optimal installation locations
- Data processing strategy focused on cloud-based solutions
- Database acess to train properly the model

Achieved Results

Electronic Circuit Design

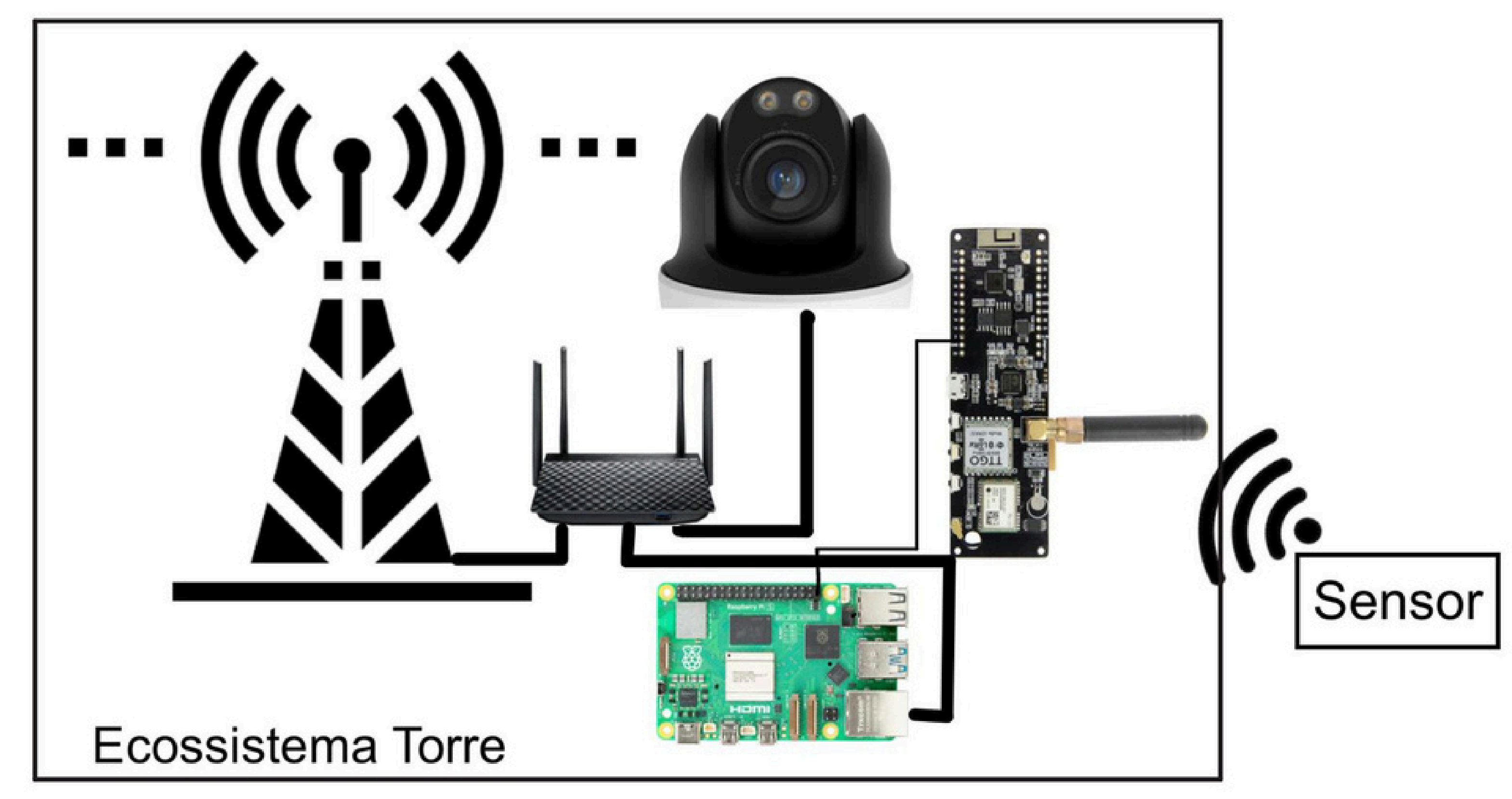
- Designed circuits for each ecosystem
- Included sensors and connections to ESP32 ,Heltec and LILY boards
- Energy source integration still pending
- Detailed designs to be presented in upcoming presentation

Tower Ecosystem

- Defined key components: router, camera architecture, Raspberry Pi communication
- Planned system integration for data transmission
- Future feature: automated camera positioning based on sensor signals

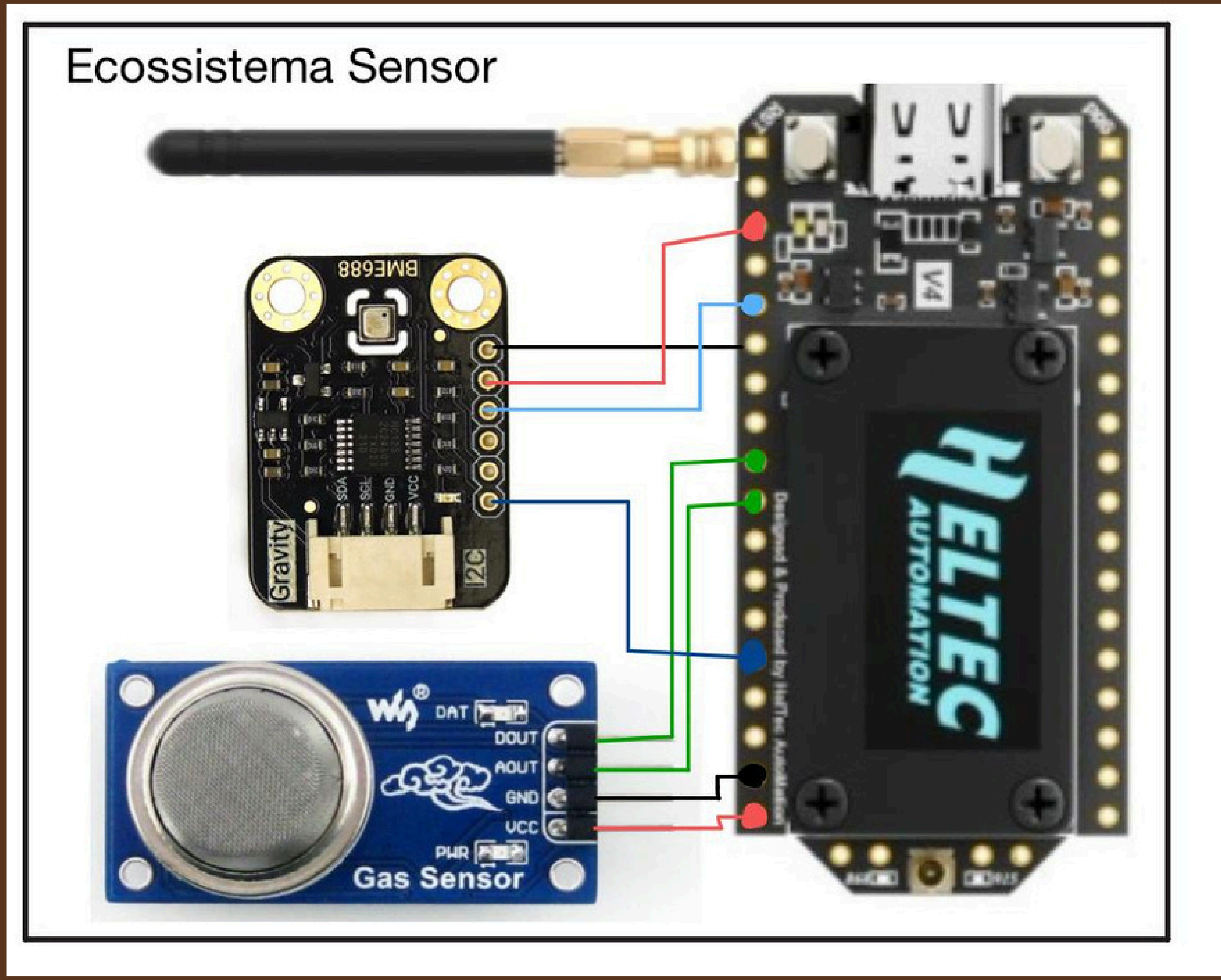
Architecture Diagram

Tower's Ecosystem



They are separate ecosystems but can communicate via multi-hop sensor networks. When smoke is detected, the signal reaches the tower, which redirects the camera to the affected area and sends the information to the central system using a stronger antenna.

Sensor's Ecosystem



Challenges faced by the team

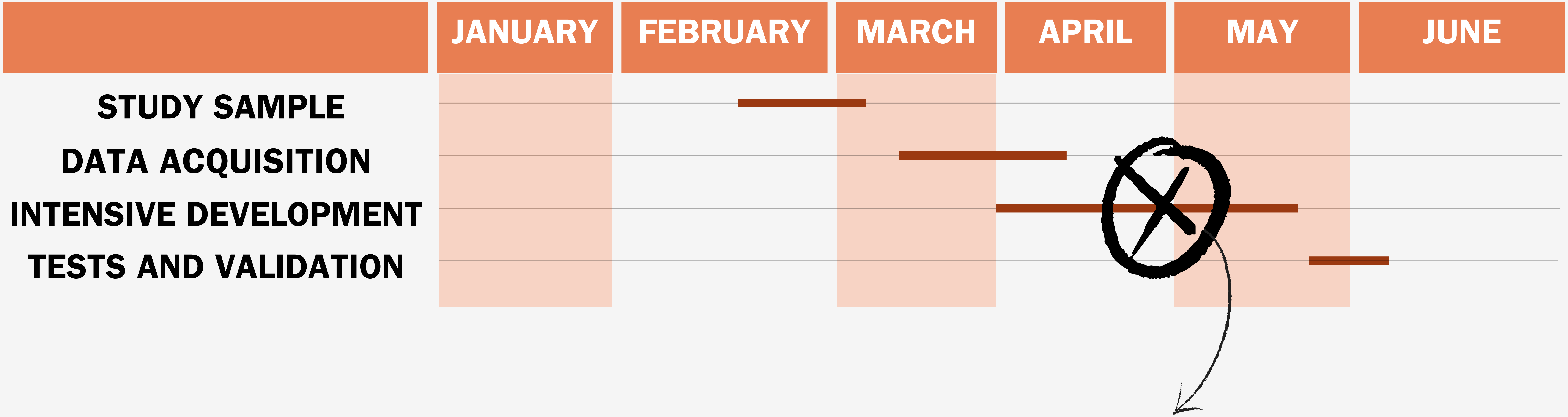
Problems:

1. Budget approval for the requested materials is still pending, and they have not been delivered, preventing the start of assembly.
2. The YOLO model cannot be trained properly due to the limited number of images captured by our cameras.
3. There isn't an online platform with the necessary boards to design and test circuits.

Solution:

1. Rescheduling of the calendar for tasks that do not require the ordered materials.
2. Partnership with INESC-INOV (ciclope) will allow us to have access to a larger database, allowing us to train the model properly.
3. Design the circuit manually and simulate it with equivalent boards.

Deviations from original schedule

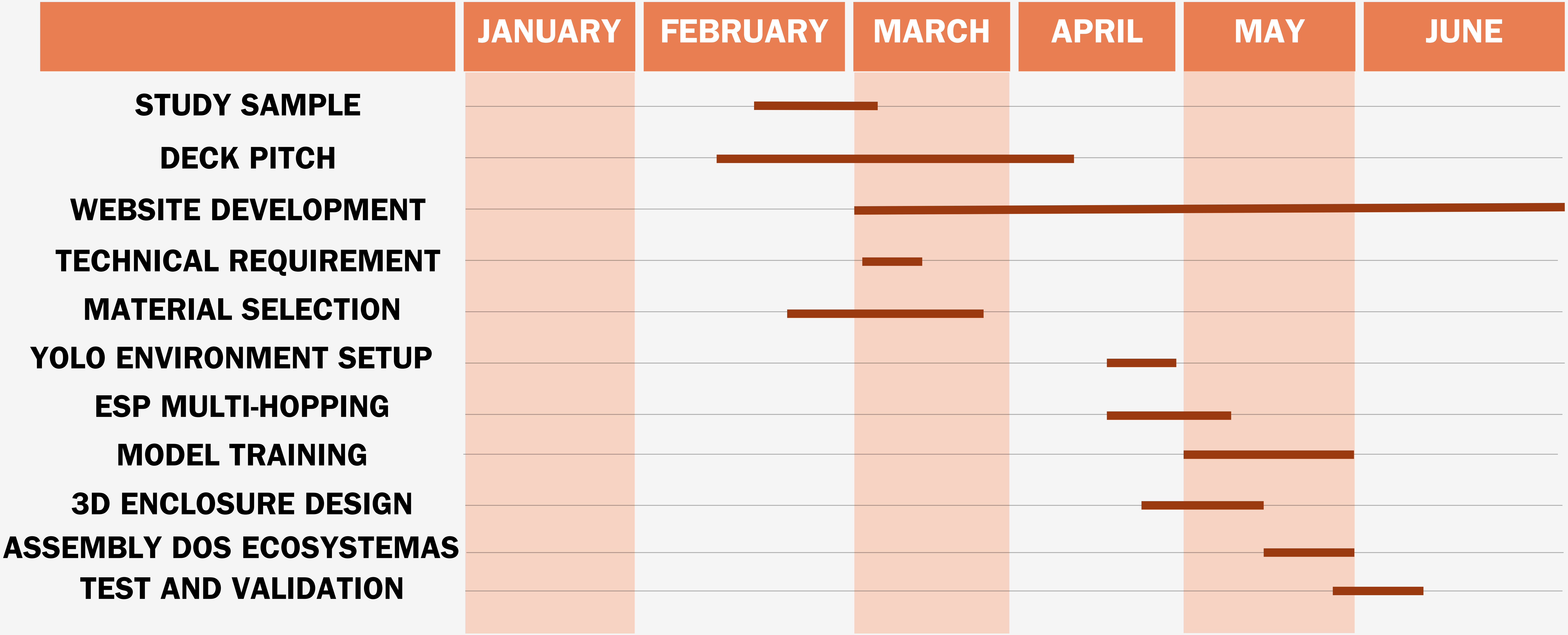


The intensive development phase is currently behind the initial schedule. This delay is due to the pending delivery of essential materials and the finalized setup of our partnership with CICLOPE. We are waiting for these components to align before we can fully proceed.

Contribution of each team member

Bárbara Trigueirão	Gonçalo Caetano	Salvador Carvalho	Carolina Rodrigues	Marco Mendonça	Diogo Vicente
Lead Sensors Developer	Lead Computer Vision Developer	Lead Telecom Developer	Lead Fronted Developer	Lead Hardware Developer	Lead Data Analyst
PitchDeck	PitchDeck	PitchDeck	PitchDeck	PitchDeck	PitchDeck
Website development	Hardware Selection	Website development	Website development	Hardware Selection	Interviews with Fire Stations
Interviews with Fire Stations	Circuits Design (Tower and sensor ecosystem)	Hardware Selection	Graphical Designer	Circuits Design (Tower and sensor ecosystem)	Surveying fire stations and analysis of results

Corrected Schedule



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Thanks!

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https://web.tecnico.ulisboa.pt/~ist1109562/equipa2/

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