Sensing Pipelines
Using swarm technology for robots (Summary)

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Definitions & Abbreviations

Swarm = Robotics technololy using a lot of cheap, simple robots to accomplish complex tasks. Inspired by ant/bee colonies in nature.

PIG = Pipe inspection gauge
GPS= Global positioning system

Introduction

Pipe networks are used to carry liquids and gasses from point to point. These pipes need be mapped and inspected for possible failure indicators and blockades, so the operator of the network knows when to service or replace which pipes. This should be doneas accurate as possible using robots. For this, swarms of robots will be used. These swarms will be given instructions before their deployment into the pipe network - after that, they will be operating autonomously, with no communication to the surface. The robots will be able to communicate among themselves, providing information about the areas they have explored.

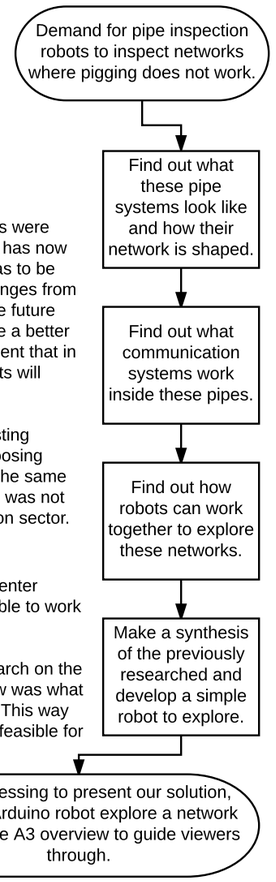
Research questions

- How a robot can move on different types of structure of the inner walls? The robot has to handle wet, slippery or rough walls without becoming stuck.
- How should the robot behave if communication fails while inside the network?
- How to keep shutdown of the system should be kept down to a minimum, so the pipe system can continue supplying its product?
- How do we enable the robots to store measurements from the sensors, as they can not send it directly to the main operator? The robot needs enough storage space for the measurements that can be done in one battery life time.
- How does the robot get power? Since wiring is not a possibility, robots need a power system that guarantees enough power for both inspection, communication, storage together with a system that guarantees the return of the robot to the starting/exit point.
- When the robots are inside the pipes, they must not interfere with the flow in the pipe. For example, it is not possible to drain a water pipe before inspecting it, because then dozens of houses will have no water supply.

Top-Level View / System Partition

Experts/ stakeholders
- E. Dertien
- RAM Group UTwente
- Pipeline companies

Computer
- Arduino robots
- Processing (Java)



o Top-level view

Our system is influenced by the world around it, while pipes were never in the ground for the largest part of earth's society, it has now become a tangle of different infrastructures. Our system has to be adjusted completely to the properties of the system, this ranges from diameter, materials and many other factors. Perhaps, in the future there will be no need for these robots, perhaps there will be a better alternative for pipe infrastructures. However, we find it evident that in the upcoming years a demand for inspection done by robots will remain, simply because it has a lot of advantages.

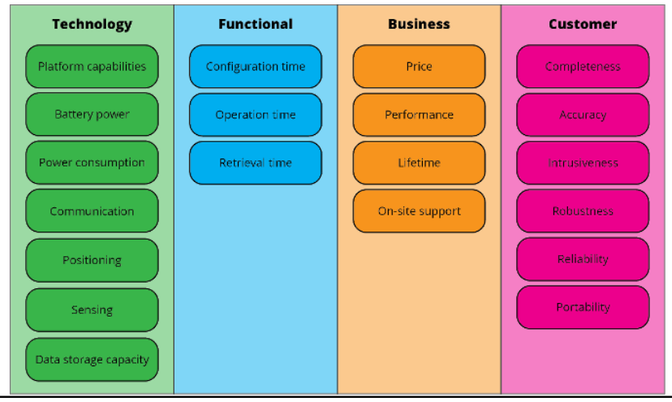
However, the scope of this project is focused on these existing infrastructures, so the world influences our systems by choosing different, perhaps new, materials and pipe constructions. The same way, a demand for this system was caused since 'PIGging' was not possible. This causes a need for innovation in the inspection sector.

o System Partition

We chose for a battery-powered robot, since we want it to enter undrained and running systems. This means it is not possible to work with cables.

To find out what sensors can be used, we did a small research on the types of pipes in the Netherlands. What we wanted to know was what diameters these pipes have, and what they were made of. This way we can scale the robot design and see whether or not it is feasible for our robot to mount the sensors used.

System Concerns



Key Parameters & Concerns

- **Platform capabilities:** The robot platform has to be able to move through pipelines.
- **Battery power:** The robot should have enough battery to do a good and fluent inspection.
- **Power consumption**: The robot has to do all its tasks consuming the least energy possible, to be able to spend more time inspecting the pipeline.
- **Communication:** The robots should be able to communicate between other robots.
- **Positioning:** The robots should know where they are at all time inside the pipeline system.
- **Sensing:** The robots should know where are they going and find the issues in the pipeline. For this they need the appropriate sensors.
- **Data storage capacity:** The robots should have enough data space to store the information it's collecting from the pipelines.
- **Configuration time:** The time that the customer takes to configure all the robots before the inspection. It should be as easiest as possible and the time it depends on what is the user doing the configuration.
- **Operation time:** The time it takes to inspect the entire pipeline. This operation should be as fast as possible, because the user wants to have the pipes inspected as fast as possible.
- **Retrieval time:** The time that the robots take to go to the starting point. The robots should do this with the minimum time possible, so going through the shortest path.
- **Price:** Customers don't want to pay more than they can afford, so the robots should be balanced between quality and price.
- **Performance:** The customer requires the robots to do their inspection in a short period of time but with accurate information
- **Lifetime:** The robots should be able to be operative for a lot of inspections.
- **On-site support:** The providers need to be able to provide service to the robot on-site.
- **Completeness:** The customer wants to be sure that the robots have explored the entire pipeline system.
- **Accuracy:** The customer wants to be sure that the information that he is receiving is consistent with what is inside the pipelines.
- **Intrusiveness:** The robots can work properly in different environment conditions, like water, gas, waste, etc. without requiring the flow to be slowed or stopped
- **Robustness:** The customer would like that the robots will be able to adapt to different kind of situation, like different inclination.
- **Reliability:** The customer won't like to have one robot being stuck inside the pipeline because it is upside down or has broken down.
- **Portability:** The customer won't like to need help to transport the robots from one place to another.

States

A part of the robot can be in different states: Firstly, the robot can be fully active. Then it is mapping and/or inspecting the pipes. Secondly the robot could operate as communication beacon. Then is stays in the same place, but connect the robots to each other, so they can communicate with eacht other. Thirdly the robot can be switched off when in storage or being transported.

Design Strategies / Known Issues

- The robots get their power from a battery. A battery can run flat. A flat battery should not leave the robot somewhere in the pipeline. It will be very hard if not impossible to retrieve a robot from the pipeline in such a situation. Therefore the robot should not use systems that require disproportionate amounts of power. A robot should also keep track of the distance traveled and the power used so that it can calculate how much power is needed to return to the start point.

- Communication in pipelines has a lot of issues, metal pipes can interfere with the signal. Minerals, metals, etc. in the ground can also interfere with the signals. Because we are working with swarm technologies there will be a lot of robots. It will thus be possible to leave behind robots at specified intervals, or points such as junctions, to act as beacons in a communication network, doing nothing other than relaying signals it receives.

Roadmap

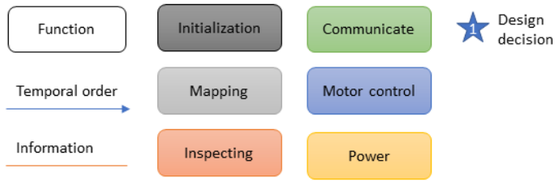
- **Present:** Pipe inspection is nowadays done using the 'pigging' method, in which a 'Pipe Inspection Gauge' is sent through a pipe. However, since these pigs are quite large, smaller pipes are inspected visually, which causes problems since they are often in the underground. Video inspection is often done for sewer systems when a leak is suspected.
- **Past:** In the past, pipe inspection was only done visually and very often only done when a system failed or was broken, for example inspecting water pipes only when a large difference between what goes into the system and what is taken out is noticed.
- **Future:** In the future, we expect the pipe industry to periodically inspect pipes to prevent failing and replace when a predetermined amount of wear is noticed. This inspection will be done by robots that will not interrupt the flow of these pipes, so the system does not need to be shut down. Perhaps, swarm technology will be used to cover greater areas of complex piping systems such as a sewer system in a district.

References

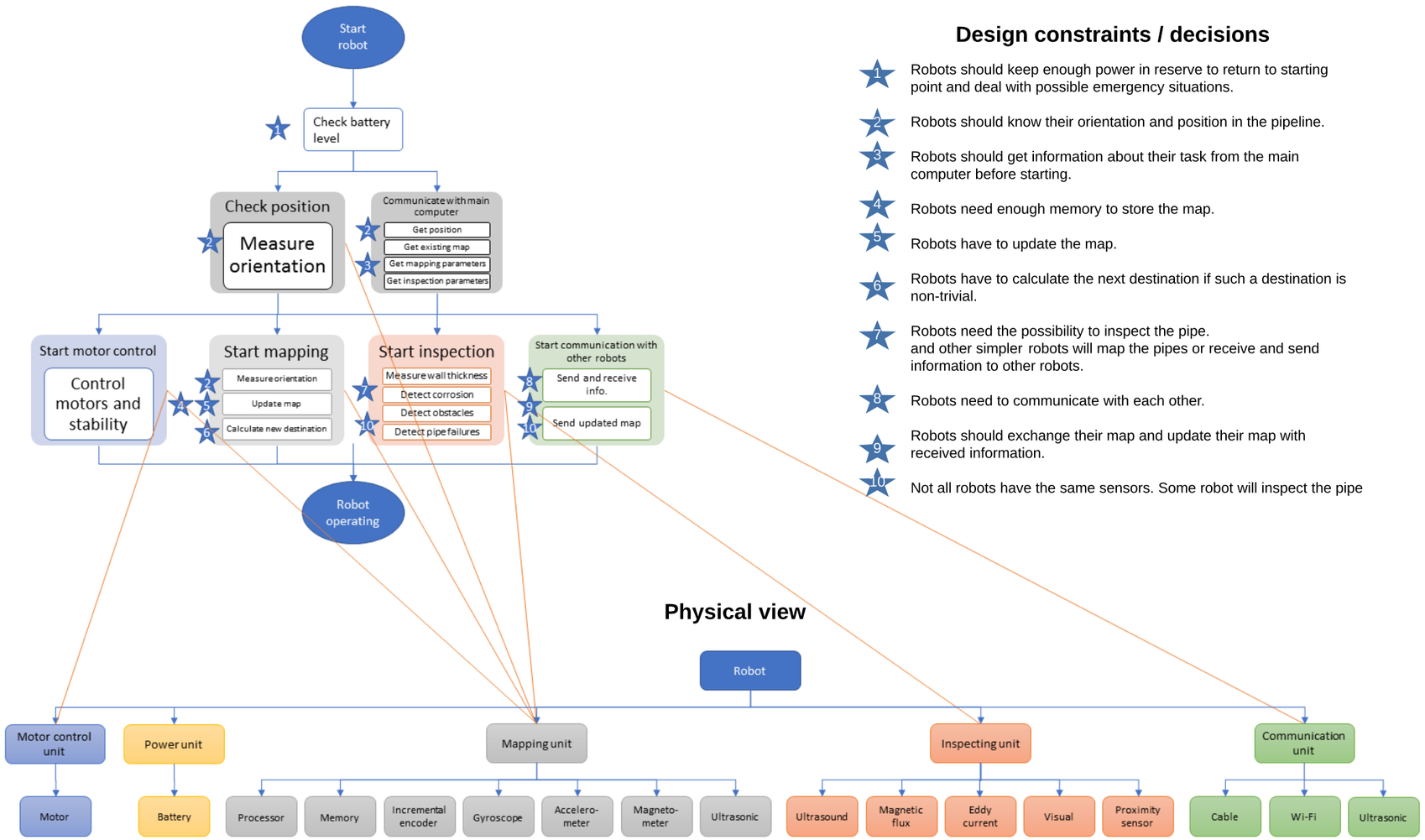
-Experts: Edwin Dertien (e.dertien@utwente.nl), Robin de Graaf (r.s.degraaf@utwente.nl)
-Other documents: - Swarm technology (Research Advance in Swarm Robotics, 2013)
- Node Localization in Robotic Sensor Networks for Pipeline Inspection(IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS)
- Research of Pipeline Robot Tracking & Localization Technology Based on ELF-EP Communication (Haiming Qi, Xiaohua Zhang, Hongjun Chen, and Jinrui Ye)
- A New Localization Method for Mobile Robot by Data Fusion of Vision Sensor Data and Motion Sensor Data (Tae-jae Lee, Wook Bahn, Byung-moon Jang, Ho-Jeong Song, and Dong-il "Dan" Cho)
-Relation with other models: N.A.
-Model hierarchy: This model was derived from the A3 architecture shown by P. Daniel Borches

Sensing Pipelines
Using swarm technology for robots (Overview)

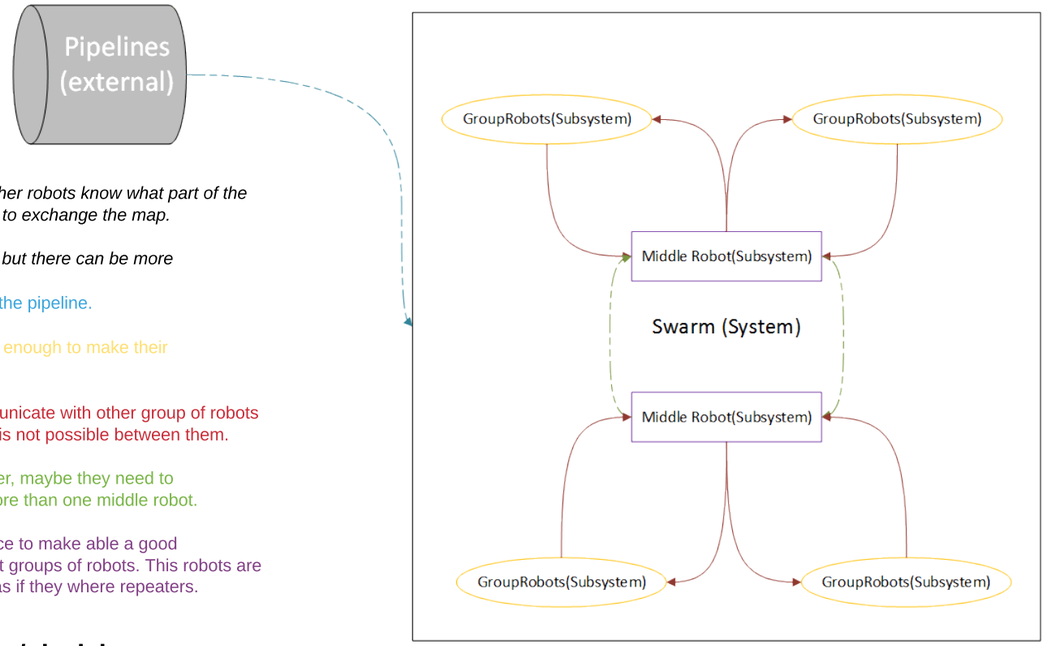
Legend



Functional flow



Scope View



- *We need communication to make other robots know what part of the pipe system is already explored and to exchange the map.*
- *We only represent 4 group of robots but there can be more*
- Information obtained from exploring the pipeline.
- In the group of robots they are close enough to make their communication being able.
- We need the middle robots to communicate with other group of robots that are that far that communication is not possible between them.
- If two group of robots are even farther, maybe they need to communicate each other through more than one middle robot.
- Middle robots are staying at one place to make able a good communication between the different groups of robots. This robots are not exploring, just making the work as if they where repeaters.

Design constraints / decisions

1. Robots should keep enough power in reserve to return to starting point and deal with possible emergency situations.
2. Robots should know their orientation and position in the pipeline.
3. Robots should get information about their task from the main computer before starting.
4. Robots need enough memory to store the map.
5. Robots have to update the map.
6. Robots have to calculate the next destination if such a destination is non-trivial.
7. Robots need the possibility to inspect the pipe.
   and other simpler robots will map the pipes or receive and send information to other robots.
8. Robots need to communicate with each other.
9. Robots should exchange their map and update their map with received information.
10. Not all robots have the same sensors. Some robot will inspect the pipe

Physical view

Quantification view

Robot procedures	Time in Gas pipelines(ms)	Time in Water pipelines(ms)	Time in Waste pipelines(ms)
Detect a bifurcation in the path			
Divide swarm to explore the different paths			
Process data obtained from the pipeline			
When an issue is found, reaction time of going to the user to give the information			
Calculate the position in the pipeline system			
Go through a corner			
Robot know if it is the first one in the group or not			
Process the camera data to become useful information			
Detects an inclination in the pipeline			
Preparation for a 90º path			
Generate explored pipeline system map			
Join others robots explored map to its own explored map			
Send map to other robot(s)			