ENGN 8170 Group project
Corrosion and Gas Leaking Detection Robot
System Requirements Specification

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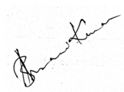
Bharani Kumar Karunyamurthi	Project Manager		23-08-2019

Executive Summary

The Oil and Gas industries of the world are facing challenges in detecting leaks and invest a lot in maintaining the pipelines. Any leaks / corrosion in a major pipeline can cause huge loss to the industry. The project focuses

- On building prototype robot meeting the basic requirements (leak detection) of the client.
- On the requirements of the client and focuses on functional build of the project.

This document discusses The document analyses requirements in detail where we focus possibilities of meeting the requirements of client (leak detection methods, motors for movement, communication, autonomy). The document also analyses customer's needs from an engineering perspective on developing the prototype within the given budget.

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1 Introduction

1.1 Context

The Gas leak/ corrosion detector robot has the scope of being implemented in the industry for the inspection. This document presents the context and scope that our team has been focusing and consistently developing on. The context of this project is to develop a reliable robotic solution with potential expansion capability.

1.2 Purpose

The primary goal of our team is to provide technical support and develop the fore said solution, The document gives in the technical analyses of the units (Communication, Locomotion, Sensors and Actuators, Power) in the project. These units are briefed in the functional analysis (3.33.3.3).

1.3 Scope

We discuss the stakeholders and customer needs and potential users of the product in the following sections along with the customer requirements. The scope presented here, gives the reader a brief introduction to our team's design methodologies, strategies to receive, analyze the available technologies and matching it correspondingly with the customer requirements.

2 Stakeholders Needs and Requirements

Stakeholders are primary members who determine the viability and boundaries in a project. Their needs were carefully gathered and prioritized in the following sections, in accordance to the goals of the project. Our primary stakeholder demands the need for a robust operation of robot to detect holes in pipes, which paves way to stop leakages. Assuring various operating conditions, abiding the regulations set, under proper maintenance, is what our company thrives to ensure. Careful consideration of the stakeholder's needs is necessary to set the detailed design requirements, thereby ensuring optimal performance operations.

2.1 Customer Requirements

Requirement I.D.	Customer Requirements
CR-1	The robot shall monitor real-time operating condition of the pipe.
CR-2	Inspection of the pipe's leakage shall be done by sensors
CR-3	The system shall communicate wireless to operators
CR-4	Locomotion of the robot shall be inside the pipe.
CR-5	The robot shall withstand stress/strain while moving
CR-6	The robot shall use Arduino or AVR micro controller for control of actuation and for interfacing.
CR-7	The robot shall be operated wireless for locomotion
CR-8	The system shall operate under appropriate pressure/temperature conditions inside the pipe.
CR-9	The material of the robot shall be determined in accordance to the test pipe conditions.

Table 1: Customer Requirements

2.2 Users

The users for 'leakage detection robot' were identified as follows

- Pipeline handling industries & factories: Detection of holes and stoppage of imminent disasters can aid in economical and technological amendments.
- Academics and researchers: Various sensory methodologies are studied in scope to leakage detection and our robot can be used interfacing researcher's ideas in action.

2.3 Interfaces

Internal System	External System	Interface
Communication	NRF24L09	Serial/ Wireless
Locomotion	Wheels	Motors and L293D
GUI	User	Arduino IDE/ Python script
Power	Li-ion/ alkaline batteries	System power input

Table 2: Interfaces

2.4 Constraints

2.4.1 Standards and Regulations

I.D.	Description	Source
AS/NZS 3000:2007	This Standard sets out requirements for the design, construction and verification of electrical installations, including the selection and installation of electrical equipment forming part of such electrical installations. These requirements are intended to protect persons, livestock, and property from electric shock, fire and physical injury hazards that may arise from an electrical installation that is used with reasonable care and with due regard to the intended purpose of the electrical installation [2].	Standards Australia
CASA AC 101-1(0) Section 5.7.1	The controller of a UAV is provided with sufficient visual cues to enable avoidance of other air traffic.	CASA

Table 3: Standards and Reguations

2.5 Assumptions

Assumptions I.D.	Assumptions	Relevant Customer Requirement
A1	The length of the pipe shall be about 1 metre and diameter shall be 10-15 cm for inspection.	CR-1
A2	The material of the pipe under test conditions is Polyvinyl chloride.	CR-9
A3	The pipe shall be in-fed with varying pressurized air from 1 atm.	CR-1, CR-8
A4	Locomotion of the pipe shall be done by using caterpillar/wheel/ wall-pressing type inside the pipe.	CR-4
A5	Locomotion of the robot under T-sections, Y-bends and 90(deg) channels are still under consideration	CR-4
A6	Pressure sensor module shall be operated in the pressure ranges of (300-1500 hPa) and temperature of (-40 to 80	CR-2
A7	Arduino is operated and is compatible with all electronics and has I2C interface (Wi-Fi or Bluetooth)	CR-6, CR-7, CR-3
A8	The robot shall use brush-less DC motor, servomotors and DC brushed gear motors, depending on the need for speed, torque and precision.	CR-4, CR-5
A9	Fabrication of the robot's is constrained to the type of gas that flows through the pipe and hence PVC is considered for prototype.	CR-9
A10	The temperature of the robot for testing is ambient temperature.	CR-8

Table 4: Assumptions

2.6 Environment

The operational condition of the robot's operation is listed as below

- The temperature of robot's testing condition is ambient temperature inside the pipe.
- The pressure inside the pipe is at 1atm and is varied for 2 other conditions.
- The Pipe used for testing is polyvinyl chloride (PVC).

- The material of the robot is made in accordance to the prototyping conditions alone, However, it will vary when considering other mediums of operation.

2.7 Life Cycle

The robot's feasibility study is done considering on its entirety of operation. The robot's fabrication and choice of material is the key and must correlate in accordance to the fluid inside the pipe. Proper training for operation of the robot is necessary, with careful deployment for assembly of various parts of the robot. Maintenance of the robot is scoped and addressed even though not required by the client. Further, the lifetime for the robot is around 3 years.

2.8 Manufacturing and Construction

The Robot's chassis, linkages, collar and mounting's materials should be considered, by analyzing the fluid that is flowing inside the pipe, to avoid corrosion and limitation in operations. The mobility of the robot is also determined by the fabrication of the robot's chassis and the material in consideration. Various locomotive options (Wheels, Caterpillar, wall-pressing) requires change in overall design of the robot, hence choice of locomotion should be determined first.

2.8.1 Maintenance

The robot needs to be operated by carefully considering and maintaining the electronics, robot's body and wheels, which can be done by

- The electronics are to be mounted by fluid-proof material-coating, when operated inside the pipe. It is due to periodic check by the maintenance team.
- The material used for the robot's body should be checked with consideration to corrosion (sulphuring, chlorination, nitration) and ordered maintenance check in regular intervals.
- A calibration check is done on various communication and sensory modules, to ensure effective operation.

2.8.2 Training

Proper Training of personnel is done to ensure effective operation of the robot. Following training needs to be ensured to the technician in charge

- Technician needs to be trained to operate and monitor the working of sensors and I2C's (communication)
- Further, interface of motor with Arduino through coding, is necessary and hence interpretation and training in coding is required.
- The personnel employed should also be aware of the working environment risks and safety procedures.

2.8.3 Deployment

The 'leakage detection robot' can be deployed during emergency situations, under conditions where leakage indications are showcased. Otherwise, during maintenance phase where, flow in between two parts in the pipe is slowed (in detection to prone pressure/temperature drop) and investigated by introducing robot through the two parts.

2.8.4 Retirement

Depending on the year of usage, the chassis of the robot can be used in reinforcing/ rebuilding the new product. The electronics of the product can be reused if they aren't in fault for decommissioning of the product. The sensors and actuators(motors) can be reused. Retirement of the electronics (e-waste) of the robot needs to be effectively recycled. Electronics consists of copper, tin, aluminum, titanium, silver etc., yet only 10 to 40 % are recycled efficiently. The advised procedure for electronics recycling is given by,

- Collection and transportation: proper collection of e-waste goods and its segregation is essential to recycle it effectively and for transportation.
- Shredding, sorting and separation: Shredding of particles to 100mm, followed by a magnetic separation of the steel parts and others by water-separation process. Various visual-inspection methodology has been used in segregation of even further scrap constituents.
- Sale of recycled parts: the obtained segregated parts are then sent to recycling facilities.

3 Functional baseline

3.1 Systems Requirements

The System requirements was carefully developed such that the system requirement specification of the system precisely translates the customer requirements. The following Table 3 contains the list of system requirements and the justification of each system requirement which is a simple translation of the respective customer requirement. The justification part helps in easy interpretation of the system requirements for the external parties where the connection of the system requirements to the actual customer requirements can be easily observed.

3.1.1 Requirements analysis

In this following section, the system requirements which are derived from the customer requirements in order to fulfill all the customer requirements. The derived requirements have their own importance when compared with the other requirements. In order to know the priority of each requirement when compared to the other requirements we use pair-wise requirement analysis [10]. The pair-wise requirement analysis shown in the figure 1. So, the each requirement is compared with other requirements and obtained its priority/ranking whether it is important than the other requirement or not. If one of the requirements is not important when compared to others it is marked as '0' or if it more important than the others, then it is marked as '1'. Based on the relative importance, the score is calculated by adding all the values to the corresponding requirements and ranked according to it. One/more requirements with the highest and lowest score, gets the first rank(s) and last rank(s) respectively. When there is a tie in scores, same rank is given and the next rank to the current rank is skipped. The pair wise relationships and the rankings of them are graphically shown in the figure 2.

After the pairwise analysis, requirements are tabulated as per their ranking as shown in the figure 4. This ranking literally refers to the priority of the system requirements which are derived from the customer requirements.

Table 1. System Requirement Analysis

System Requirement ID	System Requirement	Justification	Customer Requirement Mapping
SR-01	The system shall be able to detect the gas leakage in the gas transmission pipelines.	The aim of the project is to detect the leakage in the gas pipelines using the robot.	CR-1
SR-02	The robot shall move backward and forward inside the pipe.	Forward and backward motion enable the access of the robot in different location of the pipelines.	CR-4
SR-03	The robot shall sense pressure inside the pipeline.	This allows the robot to detect the crack where the pressure will be comparatively low when compared to other positions.	CR-2
SR-04	The system shall be easily controlled using remote controller.	This allows the user to control the robot wirelessly through mobile or computer.	CR-7
SR-05	The system shall transmit the data such as pressure readings and the location of the robot inside the pipeline.	This enables the engineers to record the readings from IMU sensor for the pressure, accelerometer readings.	CR-3
SR-06	The system shall identify its location (distance) from the start of the pipeline.	This is to ensure the location of the leak or crack on the pipeline.	CR-3
SR-07	The system shall record the pressure, temperature, and accelerometer readings.	This enables the engineer to get the details of the readings of various sensors for the observation of abnormality inside the pipeline.	CR-2
SR-08	The system on full battery charge, shall operate for 2 hours continuously.	As it is used for long transmission pipelines, the robot should work continuously for 2 hours to complete a distance.	CR-6
SR-09	The system shall be able to traverse through the pipe of different sizes.	As the gas pipelines diameter varies, it should be capable of traversing through the diameter range of 200-400 mm.	CR-9
SR-10	The components of the systems shall not react with the gas and	Since most of the components are electronics, it should not cause any	CR-5

Table 1. System Requirement Analysis(contd.)

	cause harm to the pipeline and the environment.	chemical reaction which causes any damage or explosion of the pipeline.	
SR-11	The system materials shall have an operation life of 5 years.	Since the system is a crucial equipment for detecting leaks in gas pipelines, the system should work effectively for a span of 5 years before any major repair or replacement.	CR-5
SR-12	The system shall detect the hole of size greater than 10-20mm.	This is to localise the hole on the pipeline.	CR-2
SR-13	The system shall return to the start/end point once it traverses through the pipeline for distance/time.	Since there is limited power supply from the battery, the robot should return or stop to the start or the end point respectively before the battery dies.	CR-4
SR-14	The system may be completely autonomous.	The robot can move and operate autonomously in the pipeline without any external control.	CR-5
SR-15	The system shall be able to work under a line pressure of 1 to 5 bars of line pressure.	The robot should work at a pressure of 1 to 5 bars inside the pipeline in order to work effectively and to avoid any damage to the robot due to higher pressure.	CR-8
SR-16	The system shall be able to withstand a gas flow speed of approximately 15 lit/ sec	The robot should withstand the flow rate of the gas of 15lit/sec inside the pipeline to avoid the rise in speed of movement which may damage the motors and other components of the robot.	CR-5
SR-17	The system prototype shall have a pipe of 1m length and 50mm diameter.	The robot should move within the test pipeline of length 1m and 50mm diameter to effectively validate the test parameters.	CR-1
SR-18	The system will be able to move in complicated parts of the pipe like pipe bends.	The locomotion system of the robot should be flexible enough for the robot to be able to move through the pipe's complications such as turns and bends.	CR-4

Table 1. System Requirement Analysis(contd.)

SR-19	The system shall not be free floating in the pipe.	The robot design should be such that there are no free ends in the structure and the robot fits to the inner circumference of the pipe.	CR-5
SR-20	The system shall have a structure that will not be a hindrance to the flow of gas.	The robot should be small and compact as possible such that the structure does not hinder the flow of the gas in the pipe.	CR-5
SR-21	The system may be able to stabilize itself.	The robot can be able to stabilize itself in the pipe to avoid any turbulence and faulty readings.	CR-4
SR-22	The system shall have quick and easy installation.	The project should be easy to install for extended usage.	CR-6
SR-23	The system production cost should be within $300	The budget for the project provided is $300, which should not be exceeded.	CR-1

3.2 Design Requirements and Technical attributes

3.2.1 Design Requirements

The design requirements are derived from the customer requirements as shown in the figure . The design requirements have been clustered together under each of the customer requirements. Technical Performance Metric of each design requirement is also tables in the same figure with its direction of improvement.

3.2.2 Trade-off Analysis

Trade-off analysis is used to balance between two desirable but incompatible features and attributes [10]. We have analyzed the design requirements and theoretically decided the trade-off between the requirements. In our pipeline inspection robot, the objective of the project can be relatively compensated with the safety of the bot, pipeline and the environment.So, the safety comes at the first. The working of the system can be compensated with the budget of the project which is $300 i.e. in order to improve the accuracy, efficiency and output of the robot, financial aids should be improved through attracting investments from the partners of the company and other shareholders. If there is increase in accuracy, efficiency, safety and maintenance, then it will increase the budget. Therefore, change in any of the designs and safety will affect the cost of the project and performance of the system.

3.3 Functional Architecture

3.3.1 System Boundary Chart

We have analyzed the system and design requirements and produced the internal, external and future scope. These system boundaries can be used to form the sub-system in the upcoming stages and can be used to finalize the requirements while designing concept stage. The system boundaries are as shown in the figure 5.

System Requirement ID	System Requirements	Robot shall detect the gas leakage in the gas transmission pipelines.	Move backward and forward in the pipe.	Sense pressure inside the pipe.	Easily controllable using remote controller.	Transmit the data such as pressure readings and the location of the robot	Identify its location (distance)	Record the pressure, temperature, and accelerometer readings.	Operate for 2 hours continuously and battery full charge.	Traverse through the pipe of different sizes.	Do not react with the gas and cause harm to the pipeline and the environment.	Operation life of 5 years.	Detect the hole of size greater than 10mm-20mm	Return to the start point once it traverses through the pipeline for distance/time.	May be completely autonomous.	Work under a line pressure of 1 to 5 bars of line pressure.	Withstand a gas flow speed of approximately 15 lit/ sec	Use a pipe of 1m length and 50mm diameter.	Move in complicated parts of the pipe like pipe bends.	The system shall not be free floating in the pipe.	It should be a structure that will not be a hindrance to the flow of gas.	Self stabilization	Quick and easy installation	Budget should not exceed $300	SCORE	%	Ranking
SR-1	Robot shall detect the gas leakage in the gas transmission pipelines.	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	20	7.49	3
SR-2	Move backward and forward in the pipe.	0	0	0	1	0	0	1	1	1	0	1	0	1	1	0	0	1	0	0	0	1	1	0	10	3.75	14
SR-3	Sense pressure inside the pipe.	0	1	0	1	1	0	1	1	1	0	1	0	1	1	0	0	1	0	1	0	1	1	0	13	4.87	12
SR-4	Easy control using remote controller	0	0	0	0	0	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0	1	1	0	8	3.00	16
SR-5	Transmit the data such as pressure readings and the location of the robot	0	0	0	1	0	0	1	1	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0	11	4.12	13
SR-6	Identify its location (distance)	0	1	1	1	1	0	1	1	1	0	1	0	1	1	0	0	1	1	1	0	1	1	0	15	5.62	10
SR-7	Record the pressure, temperature, and accelerometer readings.	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	5	1.87	18
SR-8	Operate for 2 hours continuously and battery full charge.	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	3	1.12	19
SR-9	Traverse through the pipe of different sizes.	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	1	1	0	1	0	7	2.62	17
SR-10	Do not react with the gas and cause harm to the pipeline and the environment.	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	22	8.24	1
SR-11	Operation life of 5 years.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0.37	20
SR-12	Detect the hole of size greater than 10mm-20mm	0	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	0	16	5.99	8
SR-13	Return to the start point once it traverses through the pipeline for distance/time.	0	0	0	1	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	1	1	1	0	10	3.75	14
SR-14	May be completely autonomous.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	21
SR-15	Work under a line pressure of 1 to 5 bars of line pressure.	0	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	19	7.12	4
SR-16	Withstand a gas flow speed of approximately 15 lit/ sec	0	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	18	6.74	6
SR-17	Use a pipe of 1m length and 50mm diameter.	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	0	10	0	0	0	0	0	0	16	5.99	8
SR-18	Move in complicated parts of the pipe like pipe bends.	0	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1	19	7.12	4
SR-19	The system shall not be free floating in the pipe.	0	0	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1	1	0	1	1	1	1	14	5.24	11
SR-20	It should be a structure that will not be a hindrance to the flow of gas.	0	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	0	18	6.74	6
SR-21	Self stabilization	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0.00	21
SR-22	Quick and easy installation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	21
SR-23	Budget should not exceed $300	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	22	8.24	1
																								Total	267	100	

Figure 1: Pair wise requirement analysis

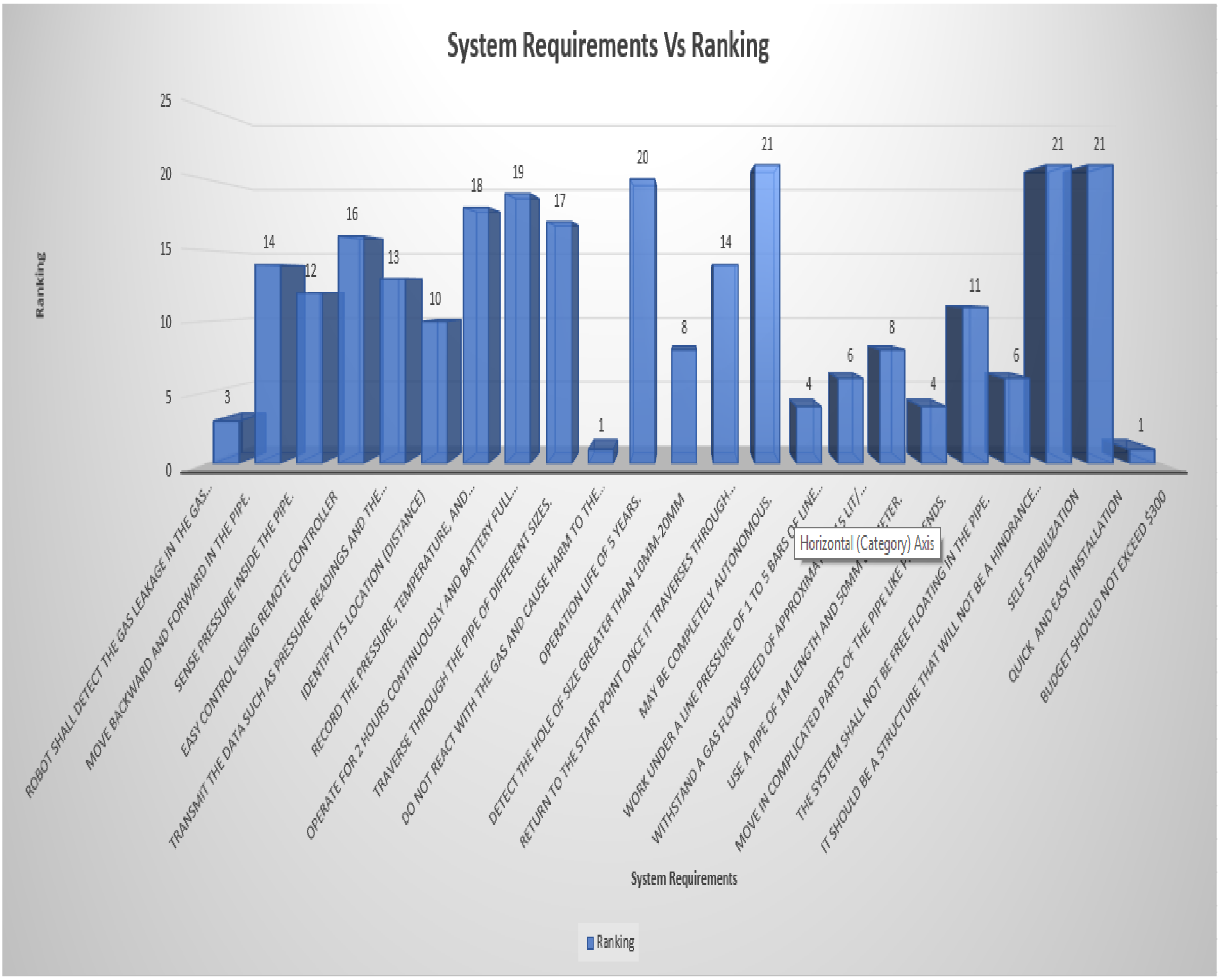

Figure 2: Pair wise requirement ranking Graph

System Requirement ID	System Requirements	Ranking
SR-10	Do not react with the gas and cause harm to the pipeline and the environment.	1
SR-23	Budget should not exceed $300	1
SR-1	Robot shall detect the gas leakage in the gas transmission pipelines.	3
SR-15	Work under a line pressure of 1 to 5 bars of line pressure.	4
SR-18	Move in complicated parts of the pipe like pipe bends.	4
SR-16	Withstand a gas flow speed of approximately 15 lit/ sec	6
SR-20	It should be a structure that will not be a hindrance to the flow of gas.	6
SR-12	Detect the hole of size greater than 10mm-20mm	8
SR-17	Use a pipe of 1m length and 50mm diameter.	8
SR-6	Identify its location (distance)	10
SR-19	The system shall not be free floating in the pipe.	11
SR-3	Sense pressure inside the pipe.	12
SR-5	Transmit the data such as pressure readings and the location of the robot	13
SR-2	Move backward and forward in the pipe.	14
SR-13	Return to the start point once it traverses through the pipeline for distance/time.	14
SR-4	Easy control using remote controller	16
SR-9	Traverse through the pipe of different sizes.	17
SR-7	Record the pressure, temperature, and accelerometer readings.	18
SR-8	Operate for 2 hours continuously and battery full charge.	19
SR-11	Operation life of 5 years.	20
SR-14	May be completely autonomous.	21
SR-21	Self stabilization	21
SR-22	Quick and easy installation	21

Figure 3: System Requirement ranking

Customer Requirement ID	Design Requirement ID	Design Requirement	Eng Characteristic	Aim	TPM
CR-1	DR-01	The system shall be able to detect the gas leakage in the gas transmission pipelines.	Pressure, LIDAR	-	Pa, nm
	DR-02	The system prototype shall have a pipe of 1m length and 50mm diameter.	Distance, Diameter	+	M, mm
	DR-03	The system production cost should be within $300	Budget	Y	$
CR-2	DR-04	The robot shall sense pressure inside the pipeline.	Pressure	+	Pa
	DR-05	The system shall record the pressure, temperature, and accelerometer readings.	Pressure, degree celcius,	-	Pa, celcius, m/s^2
	DR-06	The system shall detect the hole of size greater than 10-20mm.	Diameter	Y	mm
CR-3	DR-07	The system shall transmit the data such as pressure readings and the location of the robot inside the pipeline.	Software	-	Binary
	DR-08	The system shall identify its location (distance) from the start of the pipeline.	Hardware	+	cm
CR-4	DR-09	The robot shall move backward and forward inside the pipe.	Move forward and backward	Y	binary
	DR-10	The system will be able to move in complicated parts of the pipe like pipe bends.	Motion	+	
	DR-11	The system shall return to the start/end point once it traverses through the pipeline for distance/time.	Software	Y	binary
	DR-12	The system may be able to stabilize itself.	Control Systems	+	months
CR-5	DR-13	The components of the systems shall not react with the gas and cause harm to the pipeline and the environment.	Longevity	Y	years
	DR-14	The system materials shall have an operation life of 5 years.	Longevity	Y	years
	DR-15	The system shall be able to withstand a gas flow speed of approximately 15 litres per second	Flow rate	+	lt/sec
	DR-16	The system shall not be free floating in the pipe.	Spring compression	-	N/m
	DR-17	The system shall have a structure that will not be a hindrance to the flow of gas.	Dimensions (length, height, width)	-	mm
	DR-18	The system may be completely autonomous.	Software/hardware	-	
CR-6	DR-19	The system shall have quick and easy installation.		+	
	DR-20	The system on full battery charge, shall operate for 2 hours continuously.	Electrical charge	Y	Ah
CR-7	DR-21	The system shall be easily controlled using remote controller.	Software	+	Binary
CR-8	DR-22	The system shall be able to work under a line pressure of 1 to 5 bars of line pressure.	Pressure	Y	Pa
CR-9	DR-23	The system shall be able to traverse through the pipe of different sizes.	Diameter	Y	mm

Figure 4: Design Requirements of the system

Internal System Functions	External System Functions	Functions outside of scope
Locomotion	Type of Pipe	External environment conditions
Communication (transceiver)	User	
Software	Data Analysis	
Camera	Power Supply	
Control	Length/Diameter of pipe	
Temperature/pressure detection	Video display/recording	
Data output		
Absolute Position Recording		

Figure 5: System Boundaries

3.3.2 Requirements Breakdown Structure

The requirements can be broken down based on the components and mapped with the design requirements. This is important in a requirement analysis which is to map each of the sub-system of the sub-system of the robot with customer and design requirements. This breakdown structure is shown in the figure 6.

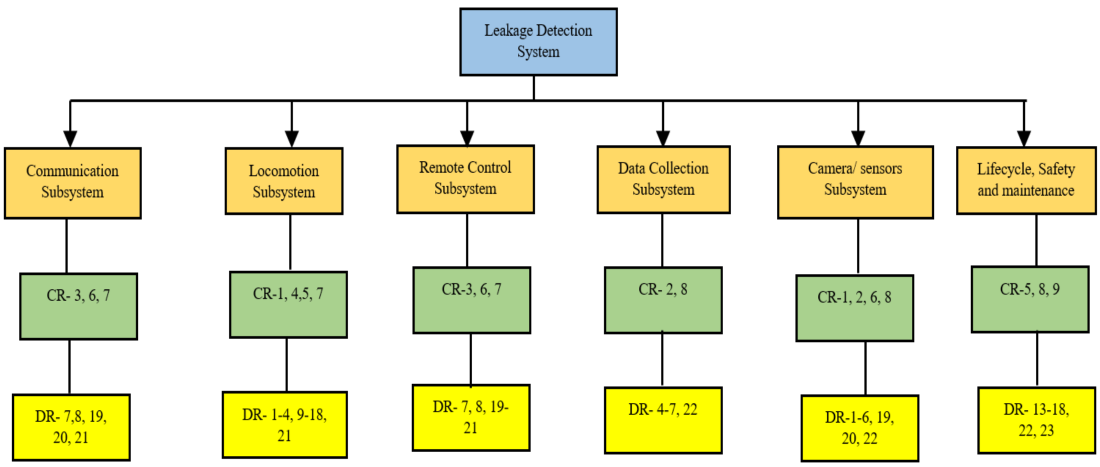

Figure 6: Requirements Breakdown Structure

3.3.3 Functional Block Diagram

The functional block diagram as shown in the figure 7 summarizes the overall functioning of the systems and subsystems. The interaction of external system with internal systems or vice-versa. The external inputs are operator, Wi-Fi signal from the outside of the system. The operator controls the the motion of the robot, the sensor detects the leakage of the pipe and we also get the information like location of the robot and the location of the leak, pressure at the location, temperature using IMU, pressure and temperature sensors or IR thermal camera. These data from the robot which is inside the pipe transmits the data to the operator wireless which is done using wireless sensor and the Wi-Fi signal which is provided from the external of the system.

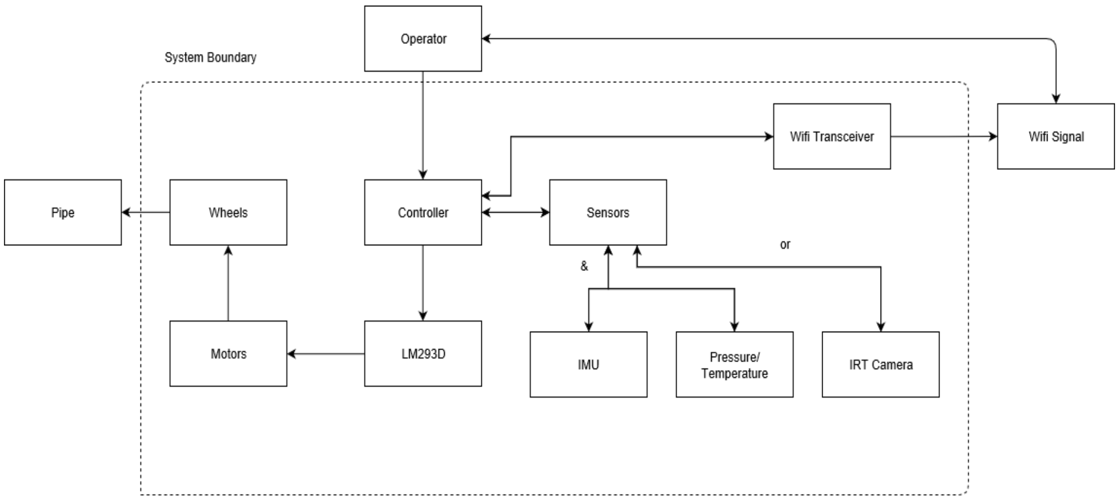

Figure 7: Functional Block Diagram

3.3.4 Function Flow Chart

This section deals with the work-flow of the robot in order to traverse inside the pipe and find the leakage and crack in the pipeline and transmits the location of the leak to the controller. The flow-chart of functioning of the system is shown in the figure 8.

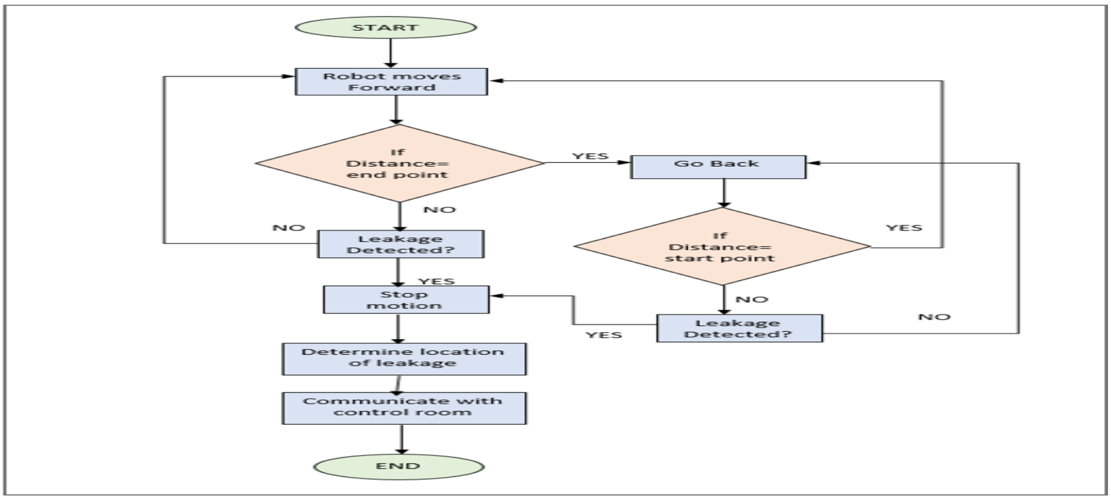

Figure 8: Function Flow Chart

3.3.5 Functional Flow Block Diagram

Functional flow block diagram is a way of representation of the sub-function and function of the system . This section deals with the functions of the system in the form of functional flow block diagram. This functional flow block diagram is as shown in the figure 9 and figure 10.

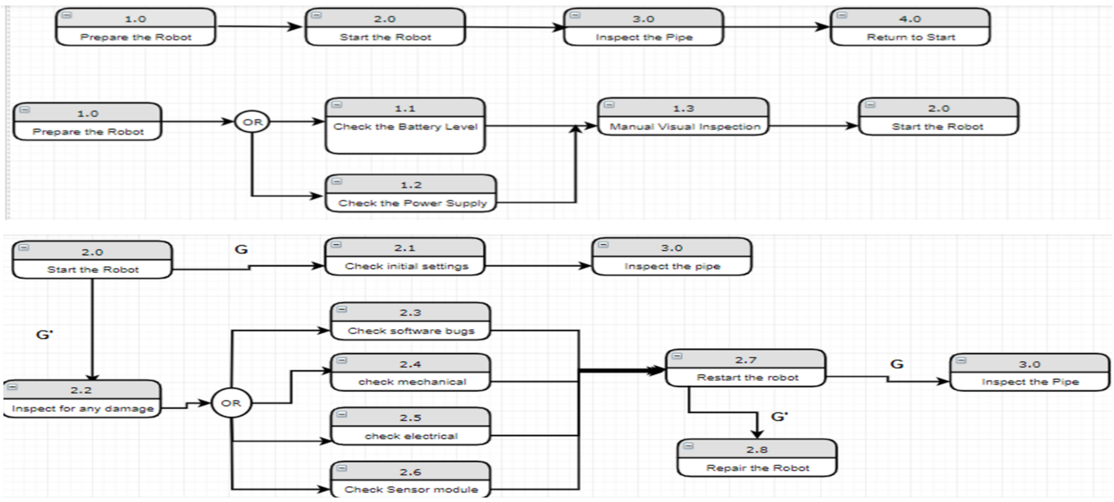

Figure 9: Functional Flow Block Diagram

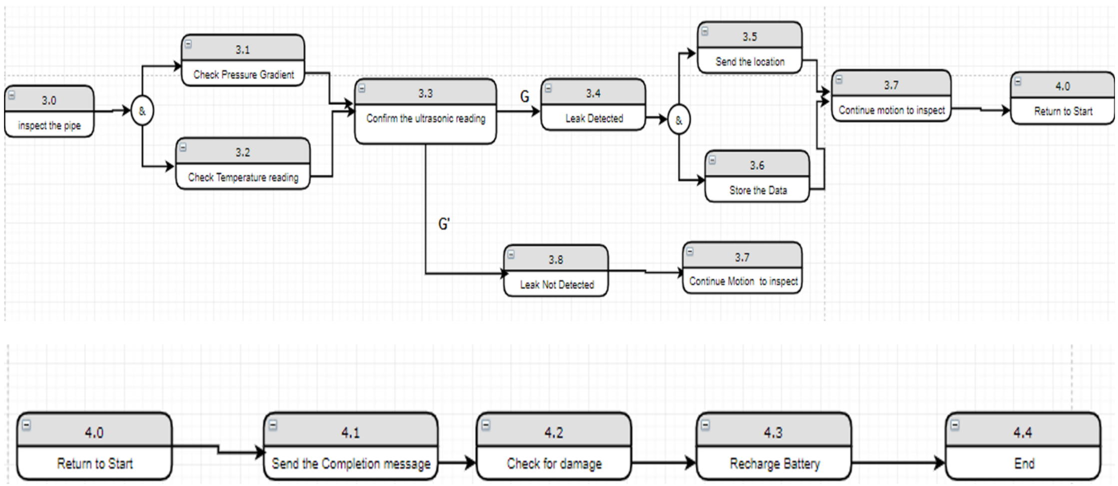

Figure 10: Functional Flow Block Diagram

4 Requirements Verification

Requirement verification is a process of ensuring whether the customer expectations are satisfied with our design requirements. The requirement verification is shown in the figure 11, 12 and 13. Currently, we have started designing the robot. So, the verification given in the image below are suspected to change while we are designing the robot.

Figure 11: Requirement Verification

Customer Requirement ID	Design Requirement ID	Design Requirement	Engineering Characteristics	Aim	TPM	Acceptable range	Verification
CR-1	DR-01	The system shall be able to detect the gas leakage in the gas transmission pipelines.	Pressure, LIDAR	-	Pa, nm		Test different sensors to develop the best leakage detection system as per the requirements.
	DR-02	The system prototype shall have a pipe of 1m length and 50mm diameter.	Distance, Diameter	+	M, mm	distance>1 diameter>20	Verify the measurement of the pipe while designing and after designing.
	DR-03	The system production cost should be within $300	Budget	T	$	<300	Examine the budget provided for the development of the prototype given by the authority.
CR-2	DR-04	The robot shall sense pressure inside the pipeline.	Pressure	+	Pa	<1	Test the pressure sensor inside the pipeline with different pressure levels.
	DR-05	The system shall record the pressure, temperature, and accelerometer readings.	Pressure, degree Celsius,	-	Pa, Celsius, m/s^2	-	Test the readings from the PMod Nav in workspace environment.
	DR-06	The system shall detect the hole of size greater than 10-20mm.	Diameter	+	mm	>10 <20	Test the robot by using a cracked pipe which is of diameter 10mm – 20 mm.
CR-3	DR-07	The system shall transmit the data such as pressure readings and the location of the robot inside the pipeline.	Software	-	Binary		Test the working of the wireless module by using test environment for sending and receiving the test data.
	DR-08	The system shall identify its location (distance) from the start of the pipeline.	Hardware	+	cm	-	Test the accelerometer which is in IMU sensor during movement of the sensor.
CR-4	DR-09	The robot shall move backward and forward inside the pipe.	Move forward and backward	Y	binary	Y	Test the simulation of motors and wheels of the robot on a surface.

Figure 12: Requirement Verification Contd.

	DR-10	The system will be able to move in complicated parts of the pipe like pipe bends.	Motion	+	degree	<120	Test the movement of the robot by keeping it at pipe-bend like structure.
	DR-11	The system shall return to the start/end point once it traverses through the pipeline for distance/time.	Software	Y	binary	<3m of pipe	Test and implement the code that will drive the robot.
	DR-12	The system may be able to stabilize itself.	Control Systems	o	-	-	Test the movement of robot on different surfaces with/ without obstacles.
CR-5	DR-13	The components of the systems shall not react with the gas and cause harm to the pipeline and the environment.	Maximum withstand-able pressure	o	-	-	Analyse the properties of the gas in the system and look out for any reactions that might take place.
	DR-14	The system materials shall have an operation life of 5 years.	Longevity	-	years	>5	Research about the endurance capacity of different components.
	DR-15	The system shall be able to withstand a gas flow speed of approximately 15 litres per second	Flow rate	x	litre/sec	~12-17 litre/sec	Test the robot inside the pipeline with different pressure levels.
	DR-16	The system shall not be free floating in the pipe.	Spring compression	o	N/m	-	Test the robot inside the pipeline with different pressure levels.
	DR-17	The system shall have a structure that will not be a hindrance to the flow of gas.	Dimensions (length, height, width)	-	mm	< diameter of pipe	Test the pressure of the gas before introducing the robot and after introduction of the robot.
	DR-18	The system may be completely autonomous.	Software/hardware	-	-	-	Implement the system without any remote control and check.
CR-6	DR-19	The system shall have quick and easy installation.		+	days	1-3	Compare with the other existing pipeline inspection robot for the installation time while testing.

Figure 13: Requirement Verification Contd.

	DR-20	The system on full battery charge, shall operate for 2 hours continuously.	Electrical charge	-	Ah	0-2 hours	Test the system by running the robot for 2 hours with dedicated monitoring.
CR-7	DR-21	The system shall be easily controlled using remote controller.	Software	Y	Binary	-	Test the running of motors and reception of data using wireless module.
CR-8	DR-22	The system shall be able to work under a line pressure of 1 to 5 bars of line pressure.	Pressure	+	Pa	100000-500000 Pa	Test the robot inside the pipeline with different pressure levels.
CR-9	DR-23	The system shall be able to traverse through the pipe of different sizes.	Diameter	+	mm	Diameter>200	Test the simulation of motors and wheels of the robot on a surface.

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