LIONSBOT

2019
LIONSBOT SAFETY REPORT

OUR VISION

At Lionsbot International, we aspire to see a better and cleaner world powered by a full suite of safe cleaning robots.

www.lionsbot.com

Imagine a world made cleaner and better than ever. Imagine a cleaning industry that is not constrained by manpower limitations.

Imagine a workforce of cleaning robots, able to clean effectively and safely, with less human intervention. An autonomous workforce, able to adapt to any space and plan the best cleaning routes for greatest efficiency.To transform the cleaning industry, we marry advanced state-of-the-art technology, robotics and an in-depth understanding of the cleaning industry's needs.

INTRODUCING THE LEOBOT

The world's most nimble cleaning robot

The Leobot was developed to function safely on its own, with less human intervention. Our engineers have devised safety into the robots in every aspect of the design, development, production, testing and validation.

Leobots are the result of intensively focused research and development as well as countless hours of real-world tests and validation. Leobots never get tired, never get distracted and most importantly, never present unsafe situations.

With its advanced sensor systems and indigenously developed sensor fusion algorithms, the Leobot has the capability to cleverly sense the environment around it. It is designed to identify agents of interests in the cleaning path, or an obstacle that may appear all of a sudden into its path, and react accordingly.

From the beginning, there has been tight coordination between the software and hardware departments. We have developed possible failure mode effects and critical analysis for all the systems.

To ensure we deliver safe and reliable products, we address any concerns throughout the product development process. Tests were conducted in one of the most complex environments with a holistic testing strategy, combined with comprehensive and integrated approach to safety, thus enabling us to validate the safety of our robots. Safety lies at the core of all work processes and products developed at Lionsbot.

As our deployment experiences and improvements advance, we will drive closer towards our vision of making the world better and cleaner, powered by our full suite of safe cleaning robots.

HOW WE DESIGN SAFETY INTO OUR LEOBOTS

With safety as a priority, our robot development process starts with analysing the operations itself namely, the multitude of deployment contexts and their environmental attributes. We tear down every action needed for the robot to safely navigate and perform cleaning jobs.

We also examined how to scale these actions to a variety of contexts and dynamic settings. We then went through several iterations with prototyping and real-world testing to improve our autonomy frameworks and refine our core technologies, resulting in a class of safe autonomous cleaning robots.

We have designed and built a family of autonomous cleaning robots that are able to safely and efficiently perform a range of cleaning jobs in complex environments. These complex environments have varying densities of people, pets, permanent and temporary built structures, mobility devices and more.

We also tested our robot in some of the most complex situations to ensure it performs its job safely and efficiently in targeted markets around the world. These trials facilitated us to put our safety strategy through extensive tests and improved our precision in ensuring safety.

Our robots are learning on a day to day basis, and each robot deployed contributes to a shared knowledge base enabling our robots to learn from the collated experiences of the fleet.

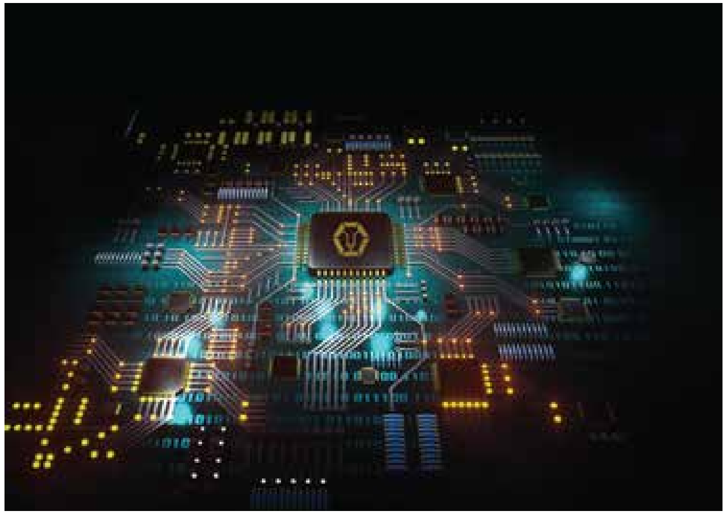
Individual robots learn to adapt their path planning strategies in response to human traffic. Maps can be shared between robots. Our learning framework allows the robots to redistribute jobs to optimise cleaning performance. In addition, our robots also learn from hundreds of “simulated use case” deployments that recreates outlier situations.

Our safe autonomous cleaning robots are built to solve the challenges that cleaners face. We also looked at existing market solutions and worked on developing technology that was unique, and yet, solved industry specific issues. We integrate robotics and cleaning technologies to transform the industry.

Our iterative safety strategy does not stop with Leobot’s family of robots. We will learn from our first wave of deployments and continually improve for future developments.

- Built to navigate complex situations
- Continuously about the environment
- Adapting path planning strategies to respond to obstacles
- Solving challenges that cleaners face

AN OPERATING SYSTEM DEVELOPED FROM A FRAMEWORK OF SYSTEM TECHNOLOGIES



At the core of our robot's autonomous capabilities lies computers that perform the functions that are required, to help them interpret the environment around them. These computers enable our robots to make decisions on optimal cleaning strategies to safely and efficiently perform the tasks.

A structure of system technologies power our Leobot robots to perform safely and effectively.

Safety
Built into every critical component of our robots and decision-making algorithms.

Cleaning Behaviours
Utilises data to synthesise cleaning behaviours that result in a highly satisfactory cleaning performance.

Artificial Intelligence
Rapidly advances the robot's capabilities to detect and classify agents, objects of interests as well as their attributes.

Perception
A range of on-board sensors generates multi-dimensional information over time which provides our robots with a clear view of the operating environment.

Localisation
Capabilities that enable the robot to be aware of its location all the time.

Mapping
Synthesises of the high-definition maps of the environment to be cleaned. One map is shared among a Leobot class of robots.

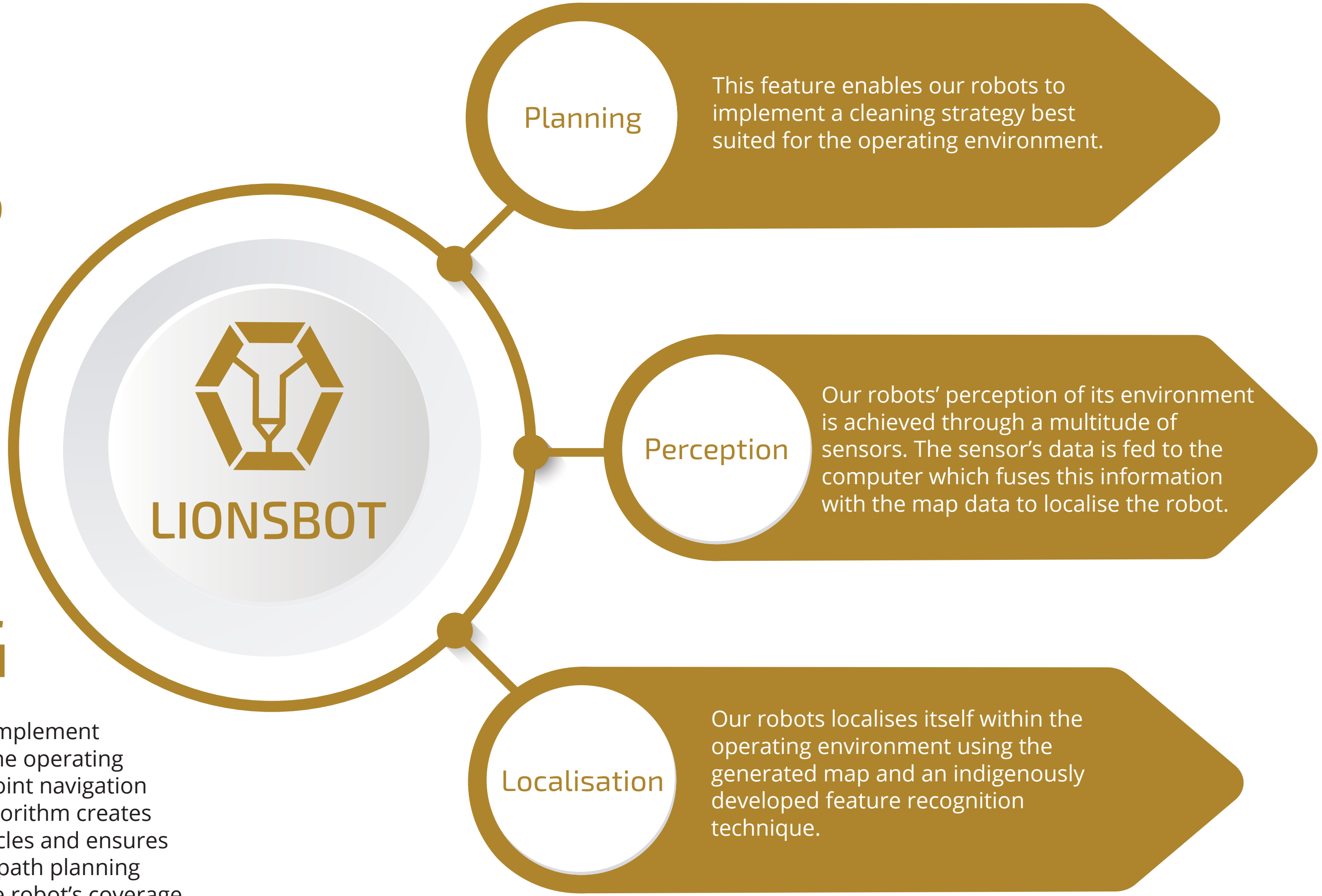
Planning
Realizes how to clean safely and effectively in its environment using information from sensors, decision-making algorithms and mapping.

Controls
Points the path and decisions from Planning as commands that are sent to the robot actuators.

Cloud Infrastructure
Manages large amounts of data, vital health signatures, decision making and reports between individual robots and the Lionsbot command centre.

HOW THE LEOBOT OPERATES

The key elements in Leobots that play a crucial role in maintaining the level of safety are Perception, Localisation, and Planning.



PLANNING

This feature enables our robots to implement a cleaning strategy best suited for the operating environment. During the point-to-point navigation mode, our robot's path-planning algorithm creates an optimal path which avoids obstacles and ensures safety. During cleaning, an efficient path planning sequence is adopted to optimise the robot's coverage area. This enables our cleaning robots to safely clean with speed.

PERCEPTION

Our robots' perception of its environment is achieved through a multitude of sensors. The sensor's data is fed to the computer which fuses this information with the map data to localise the robot.

Perception identifies the objects, agents of interests and determines their location as well as attributes.

Leobot builds a map of its environment and identifies of important objects and agents. Using the map, Perception determines obstacle-free space within the operating environment.

Perception also identifies other environmental uncertainties such as uneven terrains, climatic conditions and unknown fixtures.

To perform Perception functions, the robot has LiDARs, a depth camera and an array of sonars. The diverse sensors provide combined data, allowing the robots to handle complex environments. Our LiDAR and depth camera scan an entire 1800 view in front of the robot.

Our primary sensor is LiDAR, which takes laser measurements for stationary and dynamic obstacles to provide a highly precise feedback. The sonar balances the LiDar as it uses sound waves to identify objects with abnormal light reflectivity such as glass objects.

The depth camera is used to detect and classify objects and agents of interests operating in the same environment. Depth estimation works by emitting InfraRed rays (IR) in roughly 30,000 dots arranged in a regular pattern.

They are invisible to people but not to the IR camera, which reads the patterns. The patterns show reflected surfaces at various depths, providing rich details about the obstacle.

We combine LiDAR and depth camera data to enable the robots to identify the obstacles accurately so as to avoid them and ensure safe cleaning processes.

LOCALISATION

Localisation utilises perception, control and mapping systems to enable the robots to define their environments.

Our robot localises itself within the operating environment using the generated map and an indigenously developed feature recognition technique.

During the map generation, the computer identifies the high feature points and names them as the localisation points. These points are shared through the cloud, enabling other fellow robots to understand the environment and perform their cleaning duties.

Once the robot is powered to start, the “scan match” features are used by the robot to first locate itself within the environment.

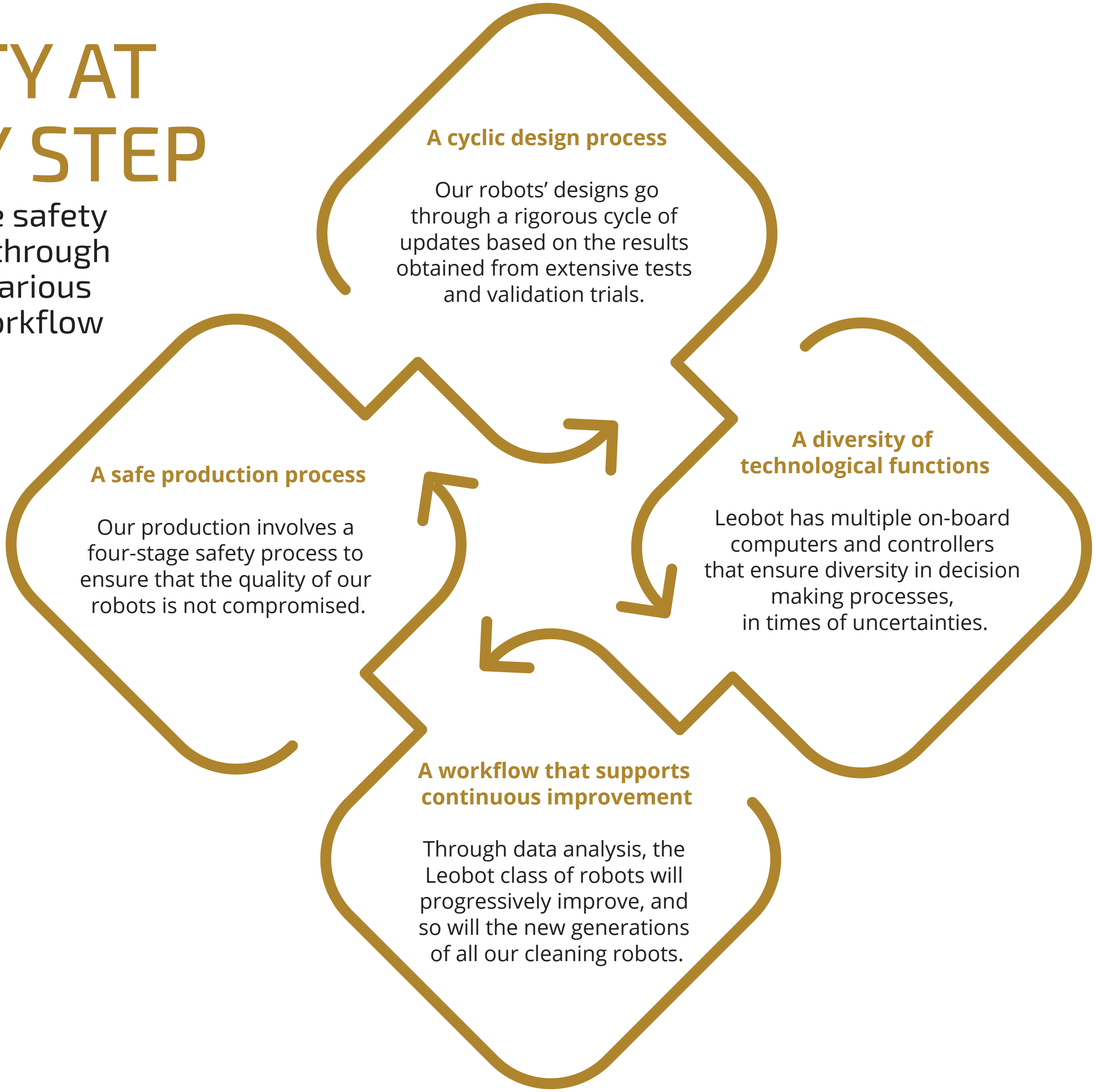
After which, it navigates to the high feature points previously defined by the map, to obtain more than a 90% localisation accuracy of the environment.

If the Leobot loses its ability to localise due to human traffic or a cluttered environment, the robot will initiate halt state immediately and request for passers-by to give way.

This ensures utmost safety as the robot is able to adapt to its surroundings. It will then try to localise itself again using the “scan match” features.

SAFETY AT EVERY STEP

We ensure the safety of our robots through establishing various design and workflow processes.



A CYCLIC DESIGN PROCESS

Our robots' designs go through a rigorous cycle of updates based on the results obtained from extensive tests and validation trials.

For example, Leobot is the 12th generation of its type. Our team designs and creates smart technological systems and tests them in real-world scenarios before updating the design process with the test results.

We integrate learning, particularly our robots' safety data, into next generations of cleaning robots and make them safer than ever.

We are extremely committed to this process of continuous improvement. This leads to new and smarter technological systems that make up our cleaning robot family.

This iterative design process is supported by our own profound integration processes, making our artificial intelligence an integral part of our cleaning robots. This combined approach enables us to produce robots with distinct technologies and robust functionalities.

A DIVERSITY OF TECHNOLOGICAL FUNCTIONS

Diversity is applied as a core principle to prevent uncertain lapses in our Leobot robots. Leobot has multiple on-board computers and controllers that covers all grounds in the decision making processes, in times of uncertainties.

1 **4G Connectivity**
Leobot is connected to the cloud network seamlessly with fast 4G Connection. It is also connected with an alternative local network path if the primary path fail

2 **Localization**
The Leobot's location is derived through an estimated of many different processes. If the localisation data from one process becomes unavailable, the robot can utilise localisation data collected by other resources, such as the depth camera, LiDAR or Inertial Measurement Unit (IMU).

3 **Large Battery**
We equipped Leobot with a high-electrical power source and an efficient power distribution to all important systems. Our robots are powered by Lithium iron phosphate battery technology.

4 **E-Stop**
Multiple emergency-stop methods are incorporated within the robot and to eliminate any possible collisions.

5 **Sonars**
Multiple Sonar sensors are integrated into the robot to detect objects that are overlooked by the LiDAR and depth camera.

6 **Safety Bumper**
Beyond the LiDAR, Sonar, and depth camera, the bumper acts as a physical barrier to prevent collisions.

7 **Object/Agent Classification**
The depth camera is fine-tuned to detect thin chains that the robot may encounter on its path. It helps the robot to avoid objects that may not be detected during the laser scans. LiDAR and Sonar data are fused with depth camera data to further classify these objects.

SAFETY IS SEAMLESSLY INFUSED IN PRODUCTION PROCESS

Our production involves a four-stage safety process to ensure that the quality of our robots is not compromised.

Even the best autonomous robots need to be built with high-quality standards, in order to gain customer trust and satisfaction. We also make sure the suppliers that manufacture components for our robots follow stringent international standards.

01 STAGE

We implement a quality check on all components that arrive from our suppliers. They are sent for an initial quality check to ensure that they meet our high-quality standards.

02 STAGE

We conduct checks on our fabricated parts to ensure that the quality and standards of fabrication are met before assembly.

03 STAGE

We have the sub-system test. At this stage, we test our sub-systems individually to ensure we meet pre-defined standards of functionality and performance.

04 STAGE

We conduct tests on the assembled robots. At this stage, we have a series of tests and a dedicated zone to validate the functionality of the robot. The robot which clears the final stage is good to go and clean the world.

A WORKFLOW THAT SUPPORTS CONTINUOUS IMPROVEMENT

We believe that our autonomous cleaning robots represent a giant leap forward for the cleaning industry. We are striving towards our vision of creating a better and cleaner world through assisting human cleaners.

The first step toward achieving that goal, is the worldwide deployment of our Leobot class of robots through rental schemes. This allows every customer to experience the overall efficiency and effectiveness of our own autonomous cleaning technology first-hand.

Our autonomous cleaning robots will clean only in user defined perimeter, and only on the locations for which a high-definition map data that was created earlier.

These robots will clean with the context of operational conditions and constraints.

We will make sure they are maintained and serviced in time, so that the robots' critical subsystems remain functional, supporting efficient and effective cleaning.

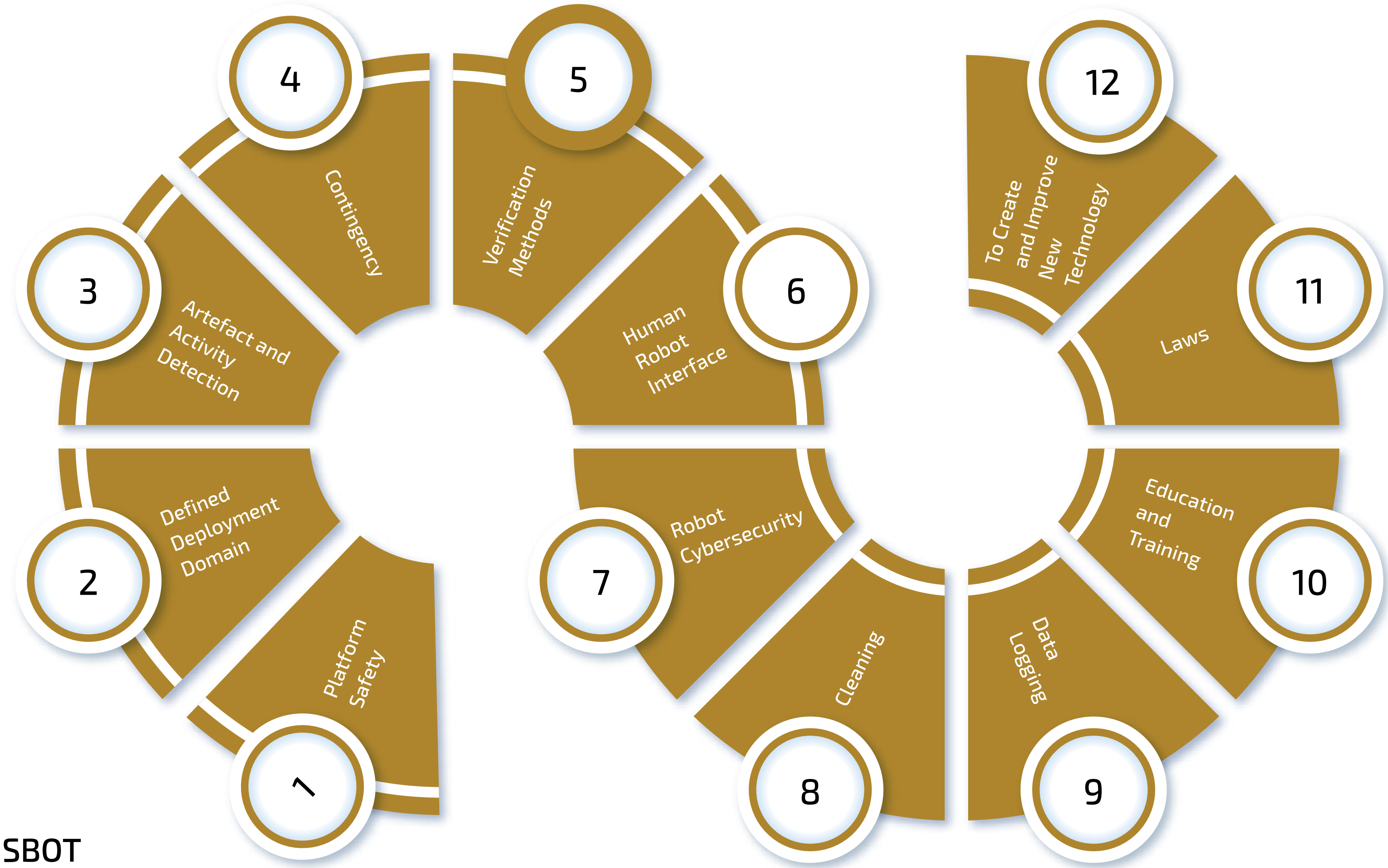
Powered by our cloud infrastructure, we will continuously collect data on our robots' performance and monitor them.

The collected information will enable us to identify areas of improvement in the cleaning patterns and processes of our robots.

The Leobot class of robots will progressively improve, and so will the new generations of all our cleaning robots.

ELEMENTS OF SAFETY

The development of our cleaning robots addresses 12 safety elements.



PLATFORM SAFETY

A systematic approach is applied for the design and verification methods to achieve the target of designing an autonomous cleaning robot that adhere strictly to safety principles.

Safety is engineered into the design and development of our robots through a variety of safety processes.

Designing an intelligent system through analysing safety performance

We design, develop and validate the techniques earlier outlined in this report for the development of our robot.

During our rigorous testing rounds, we seek to address two important questions..

- How does the robot maintain safety in operation even if a component malfunctions?
- If there is no malfunction, how does the robot ensure safe performance in the operational area?

We implemented a thorough risk analysis to address these questions. We studied these issues from variety of perspectives and used numerous tools to resolve them.

We applied assessments such as design failure mode analysis, failure mode effects and criticality analysis.

This approach enabled us to identify the risks of autonomous operations and develop a safety framework to address them.

Utilising the proper engineering tools

As we worked on addressing known risks, a numerous System Safety engineering tools were used to track the performance against these risks.

We evaluated the processes of all critical autonomous functions. We then performed a range of predictions for possible safety violations that could potentially occur without any system failures.

We developed our robots' decision-making algorithm to handle any unpredictable scenarios that they may face during operation.

For example, we deployed our robots to the most crowded areas in Singapore. They demonstrated the ability to react to unforeseen scenarios and adapt to such scenarios. This training and simulation activities, address safety challenges related with navigating uncertain spaces.

Failure Mode Effects and Critical Analysis (FMECA) includes an inductive analysis of the design and process. The FMECA is a step-by-step approach which identifies all possible design vulnerability throughout the system.

These tools enable us to identify risks, implement and validate solutions to these issues. Our established engineering standards, along with military safety standard systems allow us to eliminate the root of risks.

If a risk is not completely eliminated, we then try to maintain a safe state to minimise the risk.

DEFINED DEPLOYMENT DOMAIN

Defined Deployment Domain refers to the place, speed and climate conditions, in which our robot is designed to function.

Our robots will be deployed only in locations that are fully mapped and terrains that meet our robots' capabilities. We define the appropriate environmental conditions based on our system safety process and results.

We perform numerous iterations of tests to validate our robots' cleaning performance, in the defined environment. Through the tests, we identify potential challenges in our operational domain. Through this process, our robots' autonomous system capabilities are continuously improved. We prepare our test conditions with all the possible challenges that our robots can experience in various operational domains.

Our operational domains include the environment's surface, weather and lighting conditions. The robots operate only in the designated mapped areas. Our robots' computers process the map as the boundary for the work area.

As a result, our robot plans cleaning tasks only in the defined area, and never out of the boundary.

As we continue to develop, we look forward to expanding our domain so that our robots can operate even in unfamiliar, unfriendly, and complex environmental conditions.

ARTEFACT AND ACTIVITY DETECTION

Artefact and Activity detection refers to the robot's detection and appropriate response to the conditions and situations that are relevant to the cleaning task.

With our safety systems and comprehensive verification processes, our robots are capable of detecting and reacting to a wide range of obstacles that it may encounter. This also applies to unpredictable conditions and scenarios.

When our robots are deployed in the pre-mapped environment, they exercise object detection capabilities. Our robots then consider the objects that they detect as they plan their path for cleaning.

The user can also use our map editing feature to declare zones for the robot. Examples could include the cleaning zone, danger zone, and zones with increased obstacles.

Our robots react differently in the various zones.
In the zone with increased obstacles, the robot actively checks its surroundings. The refresh rate between the sensors and the computers is heightened at this zone to ensure safe operation.

Because our robot is designed to be autonomous, it responds according to the pre-defined zone and performs the job in an efficient and effective way.

We succeeded in implementing learning capabilities to enable our robots identify and classify objects and agents of interests, as well as the responses that it should take in unpredictable conditions.

CONTINGENCY

Contingency is the transition to a safe-state, in the event of a situation that the autonomous system cannot handle. This ensures the safe operation of our robots.

Our robots' autonomous systems have the ability to remain in safe states when necessary. Leobot has a diagnostic algorithm that continuously monitors the autonomous systems and its overall health to achieve a safe and smooth operation.

We then introduced a stand-alone controller that is independent of our robots' main computer. The stand-alone controller is directly connected to the electromagnetic brake of the traction motors.

The diagnostic algorithm of our robots continuously sends signals to the stand-alone controller about the health data of our robots. If the stand-alone controller does not receive any signals from the main computer's health algorithm for more than two seconds, the robot will transition to the safe state and not move, until the issue is resolved through human intervention.

With our consistent System Safety approach, our contingency measures account for remaining risks that we identified through risk analysis.

We adopt to the guidelines of military industry to nullify risks in all applicable cases. We designed our systems to adapt to different conditions that would otherwise require contingency measures which may affect our robots' performance.

VERIFICATION METHODS

Verification ensures that the safety systems are executed appropriately to minimise risks during operation.

Our system safety approach has a verification method for all the structural, functional, and autonomous systems. We identify the potential safety risks during the design and development process.

This information enables us to recognise the design requirements that are needed for us to meet our safety standards. Throughout the development, we track these requirements and validate the end results, in order for the safety and reliability standards to be met.

Verification includes staged encounters to test our autonomous robot against numerous obstacle tests and performance. We also verify this through real-world performance testing, with which we collect test data statistically on a significant basis to show that our robots are safe.

Over the course of test data, we combine our robot verification with the FMECA to help us verify the system's integrity.

Examples of our approaches implementation procedure:

- System, sub-system and component level tests for performance
- Safety-based verification of system, sub-system, and components
- Fault insertion testing of safety control inputs, outputs, computation and communication
- Verification of safe-state transitions within the fault tolerant time interval
- Durability and efficient cleaning tests.

HUMAN ROBOT INTERFACE

The Human Robot Interface (HRI) refers to the communication between the robot and the people.

We have developed a highly user-friendly Human Machine Interface that can be seamlessly used by human operators from a diverse demography.

Principles of universal design are at the heart of our user interface design, targeting key stakeholders such as developers, maintenance staff, distributors, robot operators, and the general public. Our interfaces are also developed to be elderly-friendly, considering the segment of veteran cleaning supervisors and robot handlers.

- Principle 1: Equitable Use
- Principle 2: Flexibility in Use
- Principle 3: Simple and Intuitive Use
- Principle 4: Perceptible Information
- Principle 5: Tolerance for Error
- Principle 6: Low Physical Effort
- Principle 7: Size and Space for convenient use

The general public can interact with the robot via a mobile application. Individuals can control the robot through the application. The robot can display expressions via the personality features.

The personality features include expression via sounds, LEDs on the robot's body and eye-panels. If our robot faces an issue that requires the user's attention, it notifies them via the mobile application as well as its personality features.

For example, if there are people standing in front of the robot during its course of cleaning, the robot will announce, "please, make way for me to clean" while the LED colours on its body changes.

The general public can also choose from different types of voices and languages from the mobile application that they wish for the robot to perform. The robot is able to play songs during its cleaning operation if it is asked to entertain during its task.

ROBOT CYBERSECURITY

Since the start of our software development, we have incorporated security into every aspect of our robots. We have designed our cybersecurity, based on a 'defence-in-depth' approach involving variety of regulations, such as robot registration, data encryption across all communication layers, secure programming, and diagnostics.

Without proper authentication, the robot's mainframe cannot be accessed. It is impenetrable.

CLEANING

We designed our robots to perform an effective yet, safe cleaning. We do not use any hazardous chemicals or unsafe cleaning processes. We use the safe yet powerful cleaning solution, 'Z - Water', alongside normal water to ensure an effective cleaning process.

Our scrubs are industry-graded and our robots do not leave any streaks of water after cleaning. We designed the cleaning module of our robot in a practical way which combines scrubbing and vacuuming.

We have also made our robot's cleaning module to be as simple as plug-and-play for easy maintenance purposes. With the guidance of the user manual, the robot handler can perform the maintenance with ease.

However, we would still recommend performing the maintenance only with trained individuals to ensure safety.

EDUCATION AND TRAINING

During development, we figured what a user needs to know to operate our robots. Our robots were designed to be a helping hand for human cleaners. The mobile application and the user manual provide useful information and safety cautions.

Since we deploy our robots primarily with the objective of improving job productivity, it will be necessary for the human cleaner to learn how to best operate the robots.

With this in mind, we have developed our mobile application and user manual to be as simple and intuitive as possible. We have set up the Lionsbot Training Academy and developed tailor-made courses and training sessions for distributors, cleaning supervisors, robot handlers, and maintenance staff.

We have predicted possible lapses and developed troubleshooting tips that trained users need. Apart from this, the trained users are able to call our service team if the problem persists.

LAWS

We designed our cleaning robot to comply with International Safety and Legal Standards in its operational design domain.

DATA LOGGING

We record the data from each robot that is out on deployment. Our data logging systems log vital information from every robot. These data sets are synced to our cloud network. Data is logged, stored securely and protected against loss.

The logged data includes data from sensors, robot actions, systems and sub-systems health, cleaning efficiency and other information that is required to constantly improve our safety level and robots' performance.

The system is designed to log data even during the safe-state. If a fail-state arises, the data logging system collects pre-defined data from the robot.

This data helps us evaluate our design and cleaning efficiency during robot development and deployment, supporting constant improvement for forthcoming generations of our autonomous cleaning robots.

TO CREATE AND IMPROVE NEW TECHNOLOGY

This is just the beginning. We are in the process of adding several new classes of robots into our product family. We are actively expanding our capabilities with new technologies and refining the existing technologies. We are striving to make our robots more affordable while maintaining the premium quality of our service.

Our robots have the potential to transform the cleaning industry, making the world cleaner and better than ever.

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