镭神智能

Gloable leader in Lidar industry

Solution overview of 3D SALM autonomous forklifts system

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1. Application scene

Figure1 application scenes of autonomous forklift

According to the scenes shown in figure1, below function is required on autonomous forklifts system :

(1)Autonomous cargo handling. Including:

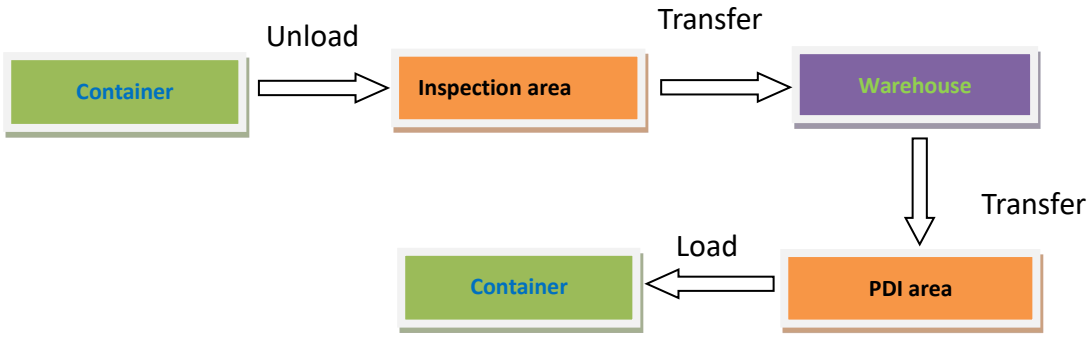

Figure2 cargo handling scenes

(2) Forklifts collaboration and deployment for multi-targets request.

At the same time, connect with user's MES interface to realize

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unmanned management of warehouse logistics.

2. Function of autonomous forklifts system

As for customers' request of unmanned warehouse management, Leishen owns mature autonomous forklifts system solution, including forklift body system and fleets management system.

2.1 Architecture of autonomous forklifts system

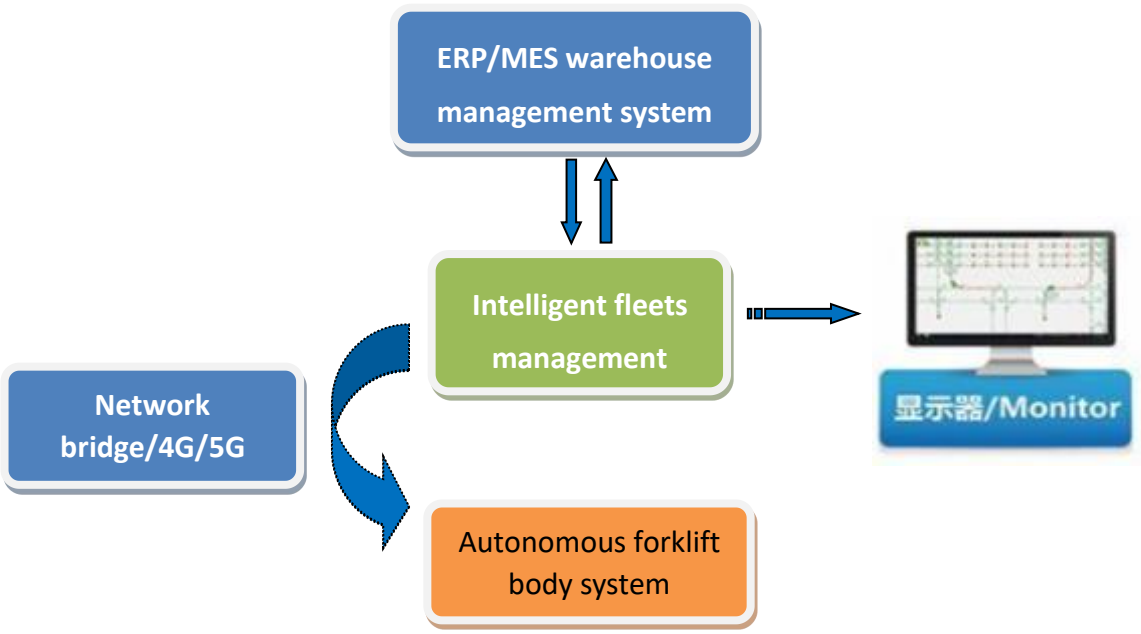

Figure3 architecture of autonomous forklifts system

As shown in figure3, autonomous forklifts system is composed of autonomous forklift body system and fleets management system.

Intelligent Fleets System is deployed on background server, acquiring targets from ERP/MES interface then distributing to stand-by

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forklifts. At the same time, the system tracks the working condition of forklifts and report to warehouse management system.

Autonomous Forklift Body System is an independent execution unit, acquiring operation instruction from Intelligent Fleets System through 4G/5G network. Autonomous Forklift Body System enables self-navigation according to its real-time location and destined location, and to realize autonomous cargo handling according cargo information. Meanwhile, autonomous Forklift Body System could report its working condition and progress to Intelligent Fleets System and warehouse management system through wireless communication.

2.2 Autonomous Forklift Body System

Autonomous Forklift Body System is the execution unit, each autonomous forklift enables self-navigation, material handling and cargo recognition according to the targets assigned by Intelligent Fleets System. Autonomous Forklift Body System includes localization and navigation system, autonomous cargo handling module, sensors integration and movement control module, protection and alert module, power surveillance and self-recharge module, cargo recognition module.

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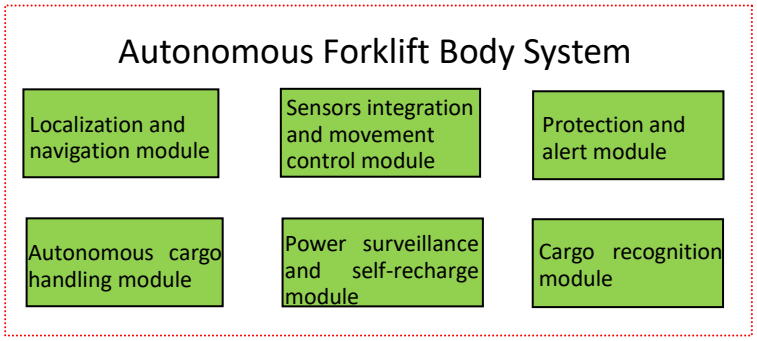

Figure4 Autonomous Forklift Body System function modules overview

2.2.1 Localization and navigation module

Localization and navigation module is the core of Autonomous Forklift Body System. Functions include mapping with 3D Lidar, SLAM localization, multi-sensors (Odometer, IMU, etc.) high-precision localization, path planning and trajectory control.

(1)Mapping: Map the warehouse scenes with 3D Lidar and SLAM algorithm

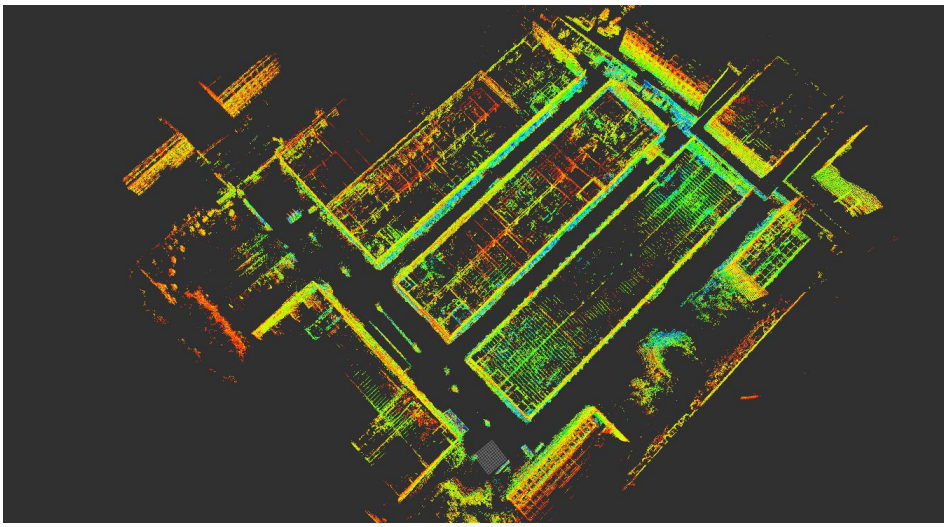

Figure5 warehouse mapping with 3D SLAM technology

Features of 3D mapping:

A. Mapping area could reach to 1 million square meters.(32G extension processor)
B. Grid resolution: 5cm
C. Mapping can be realized if the moving barrier occupies less than 10% of the map area
D. Map is editable, and virtual wall could be set.
E. Closes-loop function based on map-matching algorithm

(2) Multi-sensor high-precision localization: Match 3D Lidar points cloud data with map information, plus odometer and IMU data to realize high-precision localization of autonomous forklifts.

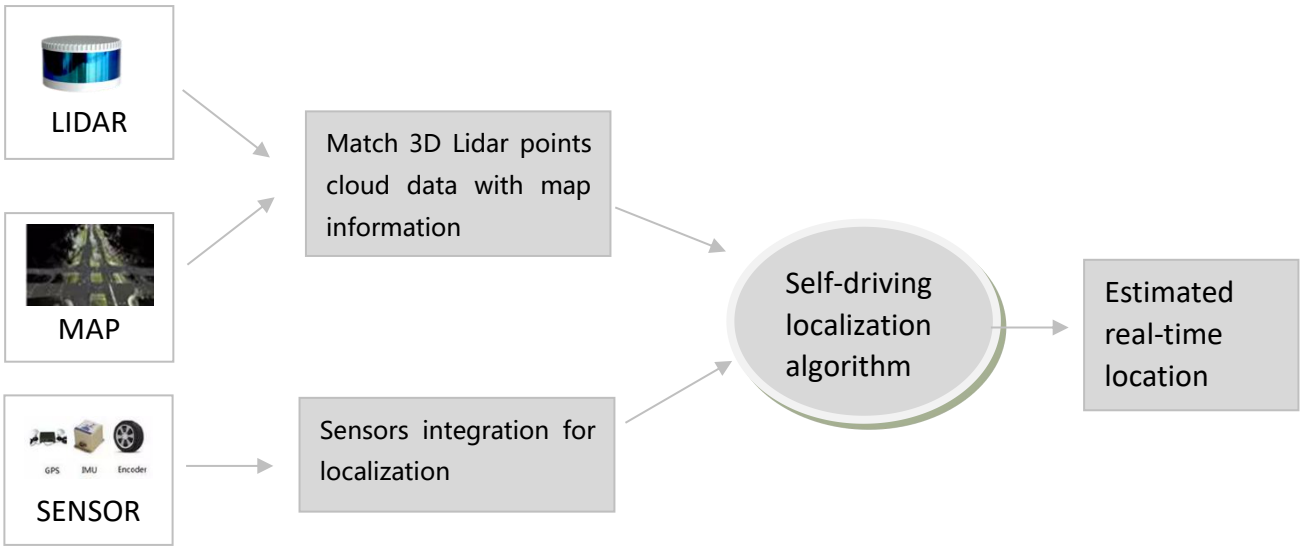

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Figure6 Principal of autonomous forklift localization

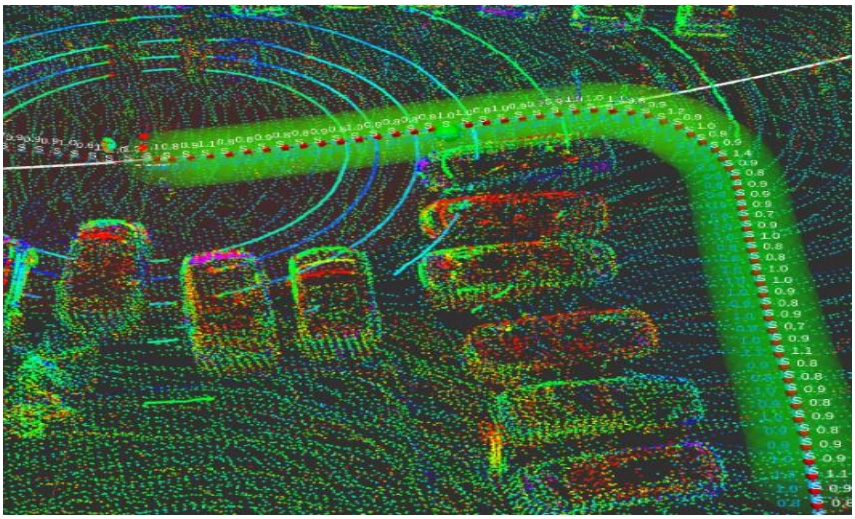

Figure7 Real-time matching of 3D Lidar points cloud and map

Features of multi-sensor high-precision localization:

A. Output localization frequency is 50Hz, meeting the localization requirement of speedy movement condition.

B. In indoor scenes, the average localization accuracy is ±2cm, and the repeated accuracy is ±1cm.

C. In outdoor scenes, the average localization accuracy is ±5cm, and the repeated accuracy is ±2cm.

D. There is no change on the accuracy in case the variation of the environment is no more than 30%.

Note: Localization accuracy may varies from different actuator and chassis.

(3)Path planning and trajectory control: Path planning is an critical

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function of autonomous forklifts. Hybrid algorithm could offer forklifts the optimal path according to the targets assigned by Intelligent Fleets System. Meanwhile, the system could schedule the motion and control the trajectory with the obstruction information.

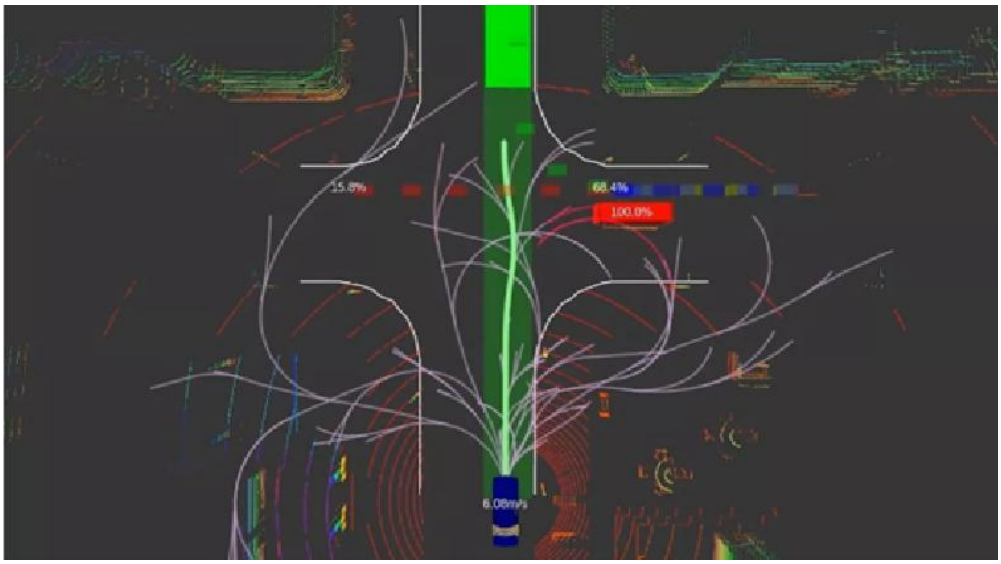

Figure8 Display of path planning and trajectory control

2.2.2 Sensors integration and movement control module:

Basement hardware and mechanism include forklift body with integrated sensors, motion model, motor controller and the execution(Linear and angular velocity information from path planning) components. STM32 is the main controller of the control board adaptive to a number of actuator vendors like Curtis, which realizes the single steering wheel motion model to drive and direct the forklifts.

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2.2.3 Autonomous cargo material handling module:

According to the pallet position information output by cargo recognition module, accurate self-localization function and lifter sensor data, this module could control forklift's movement precisely for material handling .

2.2.4 Cargo recognition module:

Adopt depth camera as the sensor of cargo recognition module, or the combination of 2D Lidar+camera. The module could identify the holes of the pallet through neural network deep learning then Lidar could output the accurate position information(x,y,z, θ) of pallet holes.

Figure9 Pallet AI identification and accurate localization

2.2.5 Protection and alert module

Safety protection is critical for autonomous forklift. Protection and alert module ensure its safe operation while working.

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(1) Set 3-stages safety area for forklifts with anti-collision Lidar

(2) Infrared sensors and buffer strips design for the protection on special parts.

(3) Fall-proof design

(4) Audible and visual alarm for abnormal condition

(5) Manual remote control is available.

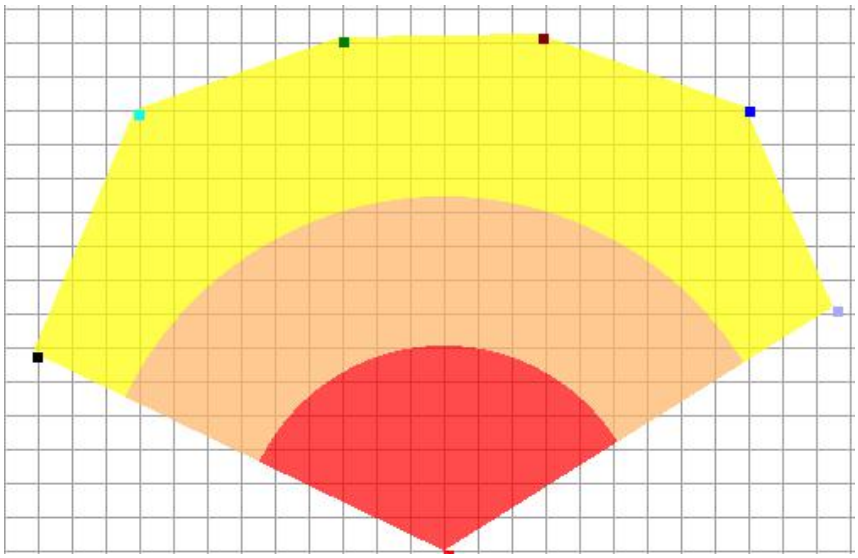

Figure10 Protection area setting with Leishen W anti-collision Lidar

2.2.6 Power surveillance and self-recharge module

Integrated AD on the basement control board monitor the power level of the autonomous forklifts in real time. Forklifts will report itself to Fleets Management System when its power lower than limited level. Under the instruction of Fleets Management System, the forklifts would autonomously move to specified area for recharging.

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2.2.7 Data flow of Autonomous Forklift Body System

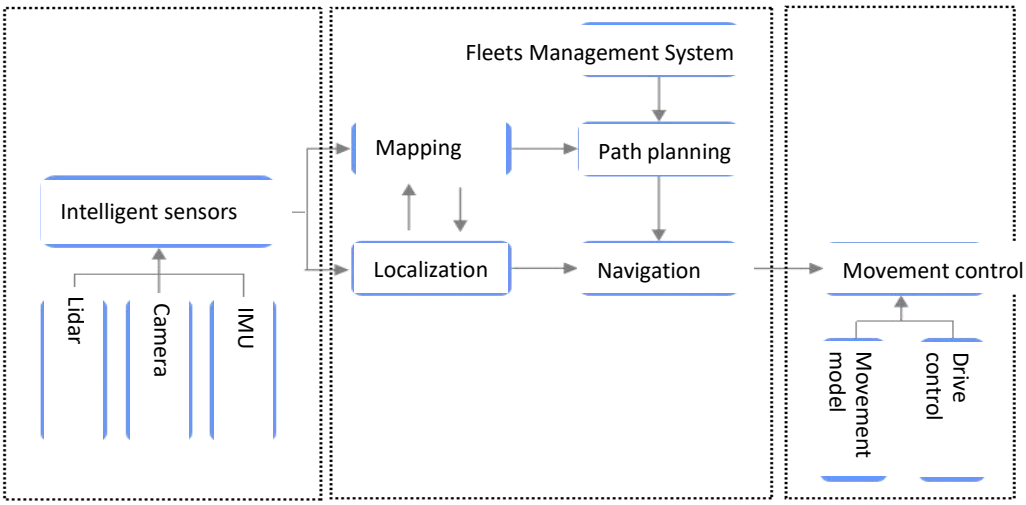

Figure11 Data flow architecture of Autonomous Forklift Body System

2.3 Fleets Management System

Fleets management system is the management center of the autonomous forklifts application. According to the targets assigned by ERP/MES system, working condition of autonomous forklifts and map of the warehouse, Fleets management system could formulate targets for each connected forklifts, as well as navigation routes. The targets and routes are the optimal ones under efficiency time priority principal.

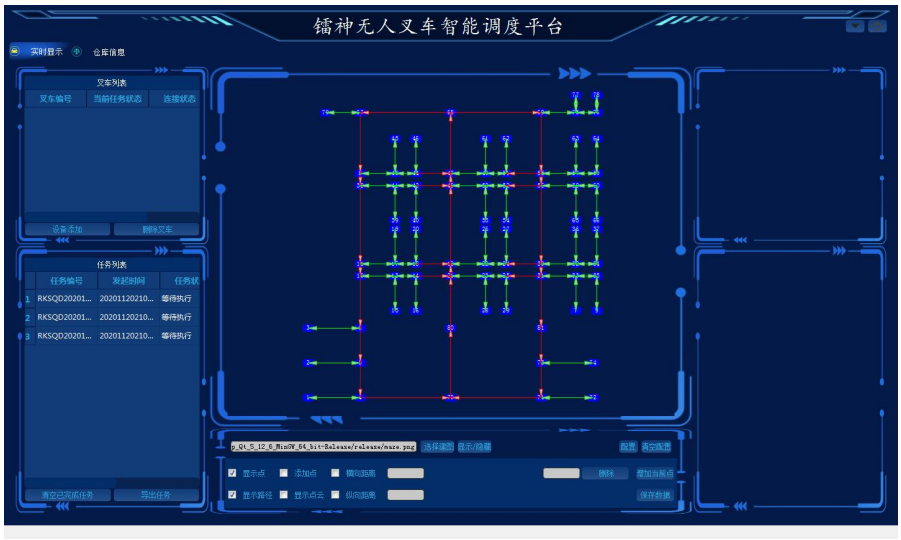

Figure12 Fleets management system v1.0 interface

As is shown in Figure13, Fleets management system is composed of 4 software modules:

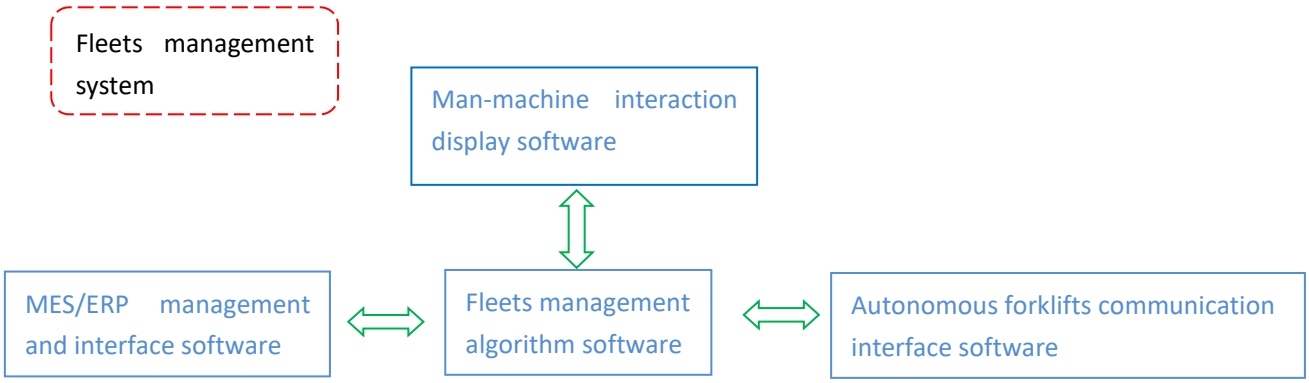

Figure13 4 software modules of fleets management system

2.3.1 MES/ERP management and interface software

ERP and warehouse management system is the top commander of the automation system. Interface communication protocol between ERP and Fleets management system is formulated based on factory's

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autonomous material handling request. Fleets management system receive the targets assigned by ERP/MES system through the interface at the same time, feedback information.

2.3.2 Fleets management algorithm software

Fleets management algorithm software is the core of the system. According to the targets assigned by warehouse management system, working condition of autonomous forklifts and map of the warehouse, the software could formulate optimal targets and navigation routes for each connected forklifts under efficiency time priority principal.

2.3.3 Autonomous forklifts communication interface software

This software enables the data exchange between Fleets management system and autonomous forklifts though 4G/5G Ethernet TCP. In specific, targets and routes instruction are sent to specified forklifts, and necessary real-time information of the forklifts will be feedback to the system simultaneously.

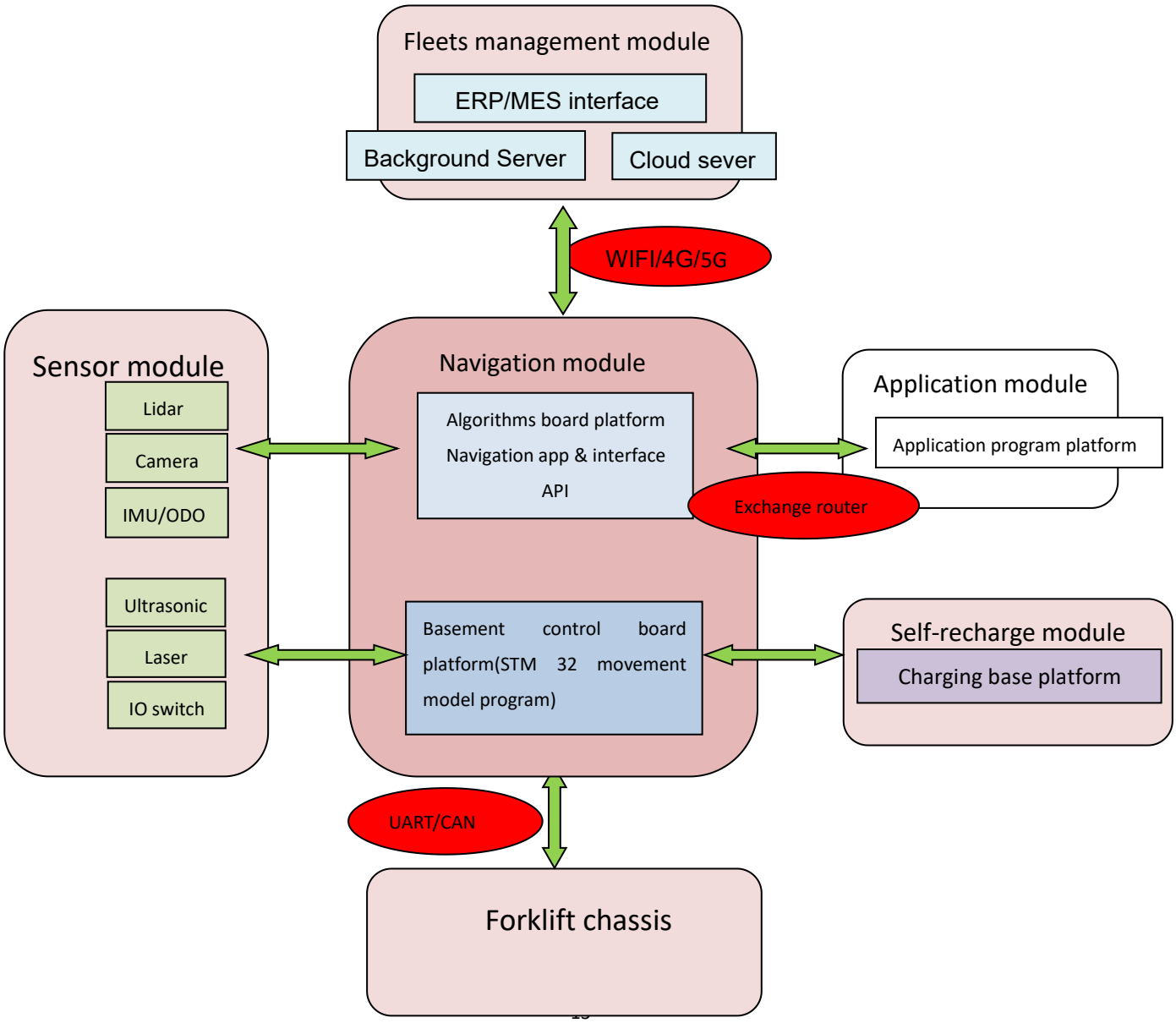
2.3.4 Man-machine interaction display software

Display the location, operation condition, targets condition of the forklifts, and the condition of the stack area. The software could monitor the alerting information and remotely control forklifts, furthermore, have the function of log recording, saving data , reporting and

information searching.

3. Autonomous forklifts system hardware architecture

Autonomous forklifts system hardware module is the operation platform for algorithms software modules. The system integrates the data of sensors like Lidar, cameras, ultrasonic radar and infrared radar to realize perception, mapping and localization with high performance processor; combines with background server to deploy Fleets Management System, basement control module and API to have customers had access to deploy autonomous forklifts in all kinds of scenes.



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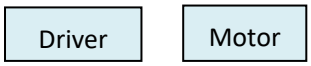

Figure14 Autonomous forklifts system hardware architecture

4. Autonomous forklifts system hardware configuration

Module	Category	Component	Function	Note
3D SLAM algorithm module	IPC platform	IPC processor	Sensor data collection, navigation hashrate calculation	IPC has been verified; IPC details to be confirmed by actual solution
	Basement control platform	Stm32 embedded main board	Control the movement of chassis, collect date of partial sensors	1. Leishen could offer customer self-designed basement control board 2. Customer could use their own board and Leishen could provide reference sound codes
Sensor list	Main Lidar	C16/C32	Environment perception；	C16 for indoor usage while C32 for outdoor
	Aided Lidar	W series Lidar	Obstacle avoidance, protection	Details to be confirmed by actual solution
		N series Lidar	Localize stack position	
		Single point Lidar	Fall detection	
	Visual sensors	Depth camera	Identify and localize stack	Details to be confirmed by actual solution
		RGB camera	Deep learning to detect containers, monitoring.	
	localization sensor	GPS	Outdoor localization	Details to be confirmed by actual solution

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	Ultrasonic sensor	Radar	Fork protection	Details to be confirmed by actual solution
	Switching value sensor	Anti-collision rubber	Protection	Alternative
		Other Switching value sensor	Switching value activated sensors	Alternative
Control system	Driver/Motor	Movement control kits	Chassis movement control	Recommend electric forklifts' general actuation, motor and reduction box
		Other calibrated actuators	Chassis movement control	To be evaluated according to customer request.Calibration fee will occur for uncalibrated actuators
Recharge system	Charging pile plate	Charging pile plate	Autonomous self-recharging	Provide 8A/30A recharging solution based on customer request

5. Solution advantages

Traditional navigation principle include magnetic taps, bar code taps, reflector board and 2D slam. Our system adopts 3D Lidar and 3D Slam algorithms, which is the latest navigation solution. Advantages include:

(1) Flexible deployment and convenience

Lidar could map the environment and localize itself with real-time perception, thus no assistant facility is required to deploy in the environment. Only need more mapping and calibration operation for expanding the working scenes.

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(2) Environment adaptation

3D slam mapping and sensors fusion matching localization enable the forklifts' high precision localization and navigation under complicated environment, indoor or outdoor. AI technology and laser detection could help localize stack and targets, which promises the autonomous forklifts' material handling function in warehouse.

(3) Performance stability

The system could keep high localization and navigation accuracy under complicated environment with 3D slam algorithms.

(4) High operation efficiency

MES/ERP system combined with Fleets management system make the autonomous operation more efficient.

6. Deployment process of autonomous forklifts system

6.1 Preparation

Choose appropriate forklifts to refit its automation control signal according to customer's warehouse layout, racks and pallets, as well as collect the pallet information for AI deep learning.

6.2 Unit test and calibration

Test and calibrate function modules of each modified autonomous forklift, including mapping and navigation, pallets identification and

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localization, autonomous cargo handling, obstacle avoidance and 4G/5G internet interface communication. Ensure the autonomous forklifts could stably complete work cycles: From cargo stack to cargo racks, then return to cargo stack from cargo racks.

6.3 In-site Deployment

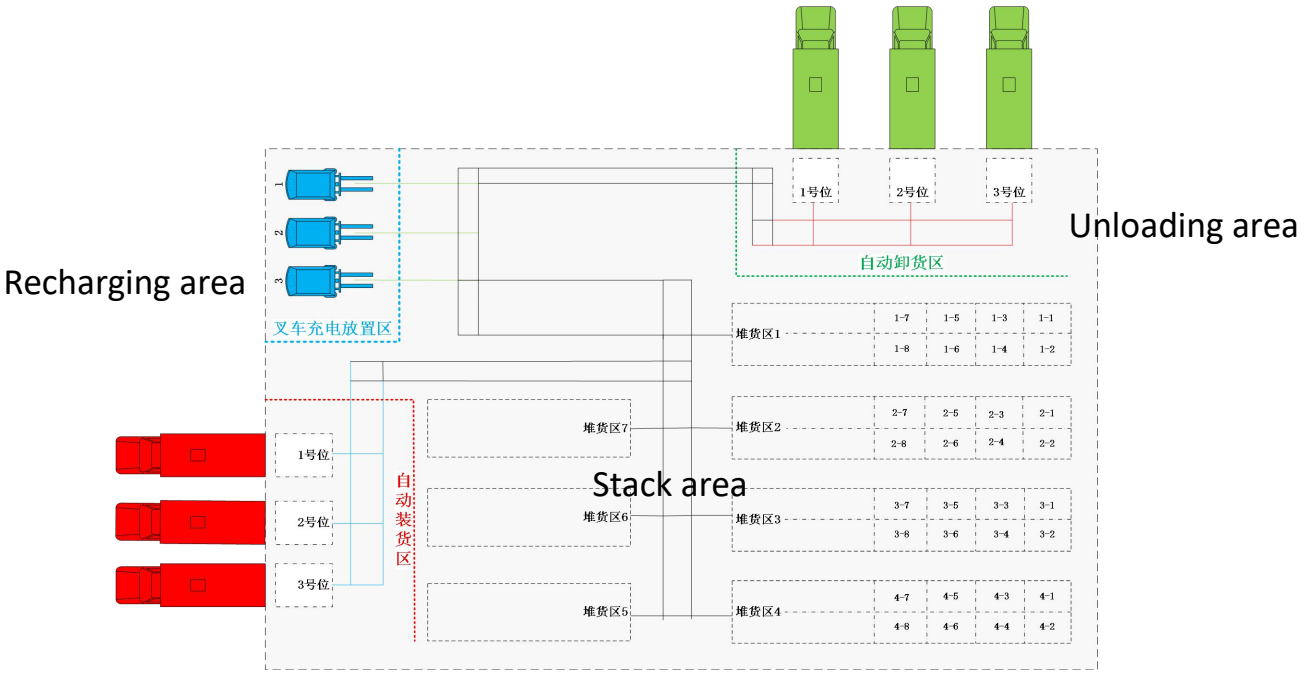
(1) Divide working areas for forklifts based on customer's warehouse layout.

(2) Select a calibrated forklift to map the warehouse by following a planned route.

(3) Match the 3D points cloud map with the actual working area, storage the information in Fleets Management System for position information management.

(4) Share the map to each connected autonomous forklift.

(5) Below is a deployment sketch map(3 autonomous forklifts, 3 loading station and 3 unloading station)



Loading area

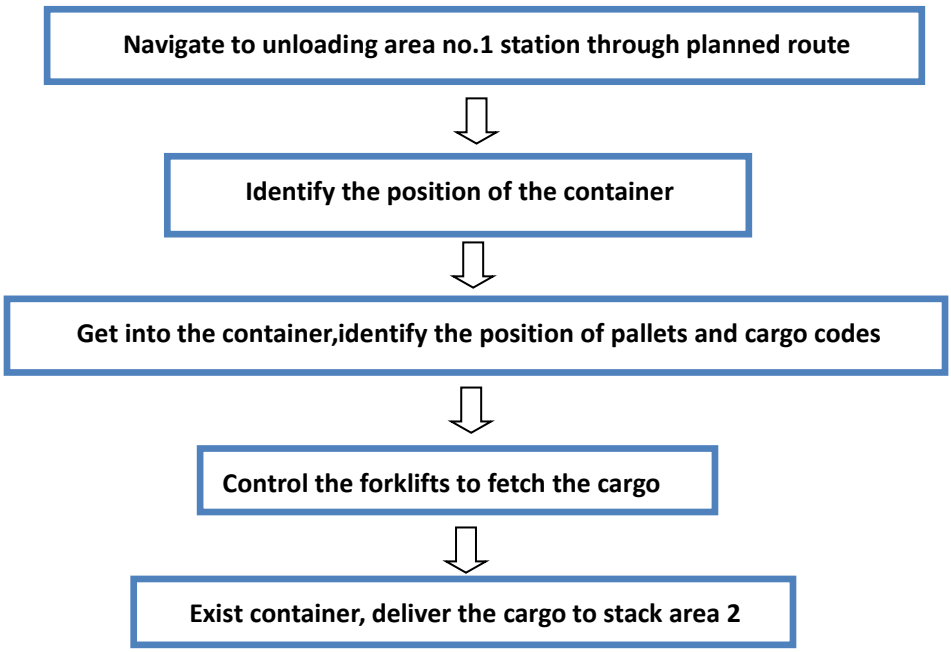
Figure15 Autonomous forklifts deployment sketch map

Cargo handling process:

A. ERP/MES management system: Release targets list

B. Fleets Management System: manipulate forklifts to execute targets(e.g.:Date, unloading, no.1 station, no.1 forklift, route, stack area no.2, gear box, 0001 batch, q'ty: 20, code:0x11-0x21)

C. Forklift execution process：



D. Repeat the process till finish the target, feedback target condition information

E. When target finished, forklifts would go back to recharging area or execute the next target.

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7. Calibration plan

Calibration stage	Mission	Time required	Person involved	Assistance
Stage 1	1. Forklift selection 2. collect pallet information for model training	3 weeks	Project leader, software engineer	Data collection
Stage 2	Forklift modification	4 weeks	Software engineer, control engineer	Pallet test
Stage 3	In-site deployment	2 weeks	Software engineer, control engineer	Warehouse
Stage 4	Optimization	2 weeks	Project leader, Software engineer, control engineer	Test ground