Digital Analytics and Robotics for Sustainable Forestry

CL4-2021-DIGITAL-EMERGING-01
Grant agreement no: 101070405

DELIVERABLE 2.1

Sensor Requirements for Multiple Robot Platforms

Due date: month 6 (Feb. 2023)
Deliverable type: R
Lead beneficiary: ETH Zurich

Dissemination Level: PUBLIC

Main author: Fan Yang, Fang Nan

1 Introduction

Overview This report outlines the requirements for sensors to perform specific tasks of autonomous agents, which will be deployed in the DigiForest project. The purpose of this document is to serve as a guide in searching for individual sensors that fulfill the requirements and to evaluate their performance. It includes information such as the required measurement range, accuracy, resolution, and response time. Available evaluations and comparisons can be derived from this report to assess the performance of the necessary sensors, and will also provide a baseline for future evaluations.

Contents This document is divided into the following components to address the sensor requirements for different hardware platforms:

- SAHA Robot - The Forest Harvester
- ANYmal legged Robot
- Flying RMF System

And evaluations and justifications for different types of sensors:

- IMUs and Joint Encoders
- LiDARs
- Depth/RGBD/TOF Sensors
- Integrated Peception Payloads

2 Overview of Automation Tasks

The DigiForest Project is a multi-disciplinary effort aimed at gathering comprehensive information about forest environments. This project involves collaboration among various robot agents that perform diverse tasks to collect information. The information collected by these agents is then shared and integrated to provide an overall perception of the forest. The sensors used by these agents are selected based on three task aspects: data collection, automation, and locomotion/control. These requirements are crucial in determining the suitability of a sensor for a specific task and ensuring its effective performance in the project. The project utilizes three kinds of autonomous agents: Flying RMF Drones, ANYmal-Legged Robots, and a SAHA Forest machine. Additionally, the project leverages the Hexagon BLK-ARC and BLK2Fly platforms to provide high-precision LiDAR mapping. These autonomous agents are tasked with performing perception, mapping, and various levels of automation to interact with the environment. Specifically, as mentioned above, the tasks are separated into three levels:

- Data collection - Each agent is required to perform online perception and collect data from various sensors that can be shared and utilized by the Forest Map Server.
- Automation - Flying RMF Drones and ANYmal-Legged Robots are required to explore and navigate autonomously through the forest environment, which can be challenging due to clutter and dynamics. The SAHA Forest Machine needs to be able to perform autonomous arm motion planning for tree harvesting and Point-to-Point autonomous navigation.

- Locomotion/Control - The ANYmal-Legged robot shall be able to locomote and traverse through the rough terrain in the forest environment. The SAHA machine shall be able to perform precise arm control for tree harvesting and operate on uneven terrain with active chassis control for whole-body balancing.

In conclusion, the DigiForest Project is a comprehensive effort to gather information about forest environments by leveraging multiple autonomous agents. The agents are required to perform various levels of automation tasks to interact with the environment.

3 SAHA Robot - Forest Harvester

3.1 Tasks

The project utilizes the SAHA robot as the forest machine for physical interaction with the environment. It is expected to perform tasks in three autonomous areas: 1) Autonomous Arm Control: In this aspect, the SAHA robot must perform precise arm motion tracking in task space for the purpose of cutting trees. It's important to note that the end-effector load on the robot's arm can vary greatly depending on the shape of the trees being cut. Therefore, the arm controller must be robust enough to handle these differences and perform safe manipulations. 2) Active Chassis Control: To successfully complete forest missions in complex or inclined terrain, the SAHA robot must utilize its active suspension system to ensure proper ground contact and balanced force distribution on all four wheels. This not only helps with the stability of the machine on these challenging terrains but also enhances the overall dynamic stability when the arm is in operation. 3) Autonomous Point-to-Point Mobility: With the capability to traverse various terrains, the SAHA robot must also have the ability to achieve high levels of autonomous point-to-point mobility. This requires the robot to have onboard perception and local navigation capabilities, enabling it to operate effectively in forest environments.

3.2 Sensor Requirements

The specifications for the sensors used in the project are determined by the necessary and sufficient requirements for performing the tasks at hand. Based on the different autonomous aspects of the tasks, the sensor requirements are outlined as follows:

Machine Automation To automate the SAHA robot, measuring the position and velocity of all movable joints on the robot is essential. This provides the robot with proprioception, which enables it to determine the exact state of each link kinematically, once any link has been localized globally using exteroceptive sensors. While joint measurements are commonly performed with encoders, it is not always easy to fit joint encoders on an existing design of the machine. Therefore, IMUs are used on the arm of the SAHA robot for most joint measurements. We use the accelerometers in the IMUs to measure the tilt angle of each link, and the gyroscopes for angular rate measurements. A linear encoder is still used on the arm to measure the position of the telescopic joint, and a rotary one is used for measuring the arm slew joint. On the chassis of SAHA, we measure the turning angle with a rotary encoder and use the integrated position encoders in the ICMs to measure the suspension actuators. It was decided not to have the wheel odometry as the soil in a forest environment is expected to be slippery and uneven, making wheel measurements unreliable. The model selection of the proprioceptive sensors is mostly based on the following criteria:

- Accuracy: The accuracy of IMUs' tilt angle and angular rate measurement is crucial in determining the machine's state within the forest environment. A high level of accuracy and low noise level ensures the stability of the autonomous controller and allows higher control bandwidth. Due to the large scale of the robotic arm, joint position measurement accuracy below $\pm 0.5°$ for rotary joints and ± 0.5mm for linear joints are desired to get an accurate position estimation of the end-effector
- Frequency: The reporting frequency of the sensors is another critical factor that has a huge impact on the achievable control bandwidth. For stable low-level control a proprioceptive measurement frequency of at least 100 Hz is necessary.
- Range: The measurement ranges of selected IMUs and encoders must be adequate to cover all the operations that might be performed on the SAHA machine.
- Robustness: All sensors must be robust and capable of functioning reliably in harsh environments, such as the forest environment, where they are subjected to vibration, shock, and other environmental factors.
- Cost: The cost of IMUs is also an important consideration, as it must be economically feasible to integrate them into the forest machine.

Active Chassis Control The task of active chassis balancing control on the SAHA robot requires highly accurate chassis attitude feedback and high-bandwidth force feedback from each suspension cylinder. Therefore, unlike the requirement on arm IMUs, we require the IMU on the chassis of SAHA to have a higher accuracy of $\pm 0.1°$ for angular position measurements and less than $0.15°/\sqrt{h}$ random walk noise density for angular rate measurements. For the hydraulic cylinder feedback control, the integrated control module (ICM) developed previously by ETH and Moog [3] is among the best-performance hydraulic valves developed in recent years [1]. With an internal force control loop at 1000 Hz and integrated position and pressure sensors, its closed-loop system achieves 100 Hz force control bandwidth on a test bench [3] and more than 20 Hz when integrated on the suspension cylinders of a wheeled excavator [4]. Based on the adequate performance achieved in the previous work, the same module is selected for the SAHA robot.

Autonomous Point-to-Point Mobility To achieve autonomous point-to-point navigation, the SAHA robot must have two key capabilities:

- Perception of Surrounding Environment and Traversability: To achieve this functionality, the SAHA robot requires the use of onboard range sensors, such as LiDAR and Stereo Camera, which are used to gather information about the surrounding environment with an accuracy of more than ± 10cm within a local range of 20 meters. However, the information gathered by these range sensors alone is not enough to determine the different terrain properties that are crucial for determining the traversability of the environment. To overcome this limitation, the robot requires an additional RGB camera or an RGBD camera that provides synchronized color information of the environment. The RGBD camera must have an RGB image FOV of at least $100°$H $\times$ $60°$V. The main range sensor, LiDAR, must have a 10% reflection range of at least 25 meters, with a horizontal FOV of $360°$ and a vertical FOV of at least $90°$, to detect obstacles on the ground and above it, such as rocks and tree branches.

- Localization in Mapped or Partially-Mapped Areas: To achieve global Geo-consistency and localization in mapped or partially-mapped areas, the SAHA robot requires the use of a GNSS system that provides the global location of the robot with an accuracy of more than ±10cm. However, satellite signals can be frequently occluded in forest environments, which makes it necessary to adopt an additional ego-centric mechanism that provides continuous and consistent localization information. With the current state-of-the-art SLAM (Simultaneous localization and mapping) solution, it is desired that the range sensor has an accuracy of better than ±5cm within a range of 20 meters.

4 ANYmal Legged Robot

4.1 Tasks

In the DigiForest project, the task for the ANYmal robots is to provide information about the forest floor, which is not accessible by aerial vehicles such as drones. ANYmal is a legged robot that can traverse challenging terrains such as uneven or rough surfaces, steep slopes, and obstacles, making it well-suited for operations in dense forests. The objectives of the ANYmal robots in the DigiForest project are 1.) Data Collection: Collect data about the forest floor, such as the location and condition of trees, the quality of the soil, and any obstacles that may be present. 2.) Map Building: Use the data collected by the ANYmal robots to build maps of the forest floor, including information about the location of individual trees, their sizes and shapes, and their surrounding environments. 3.) Decision Support: Use the maps created by the ANYmal robots to support decision-making processes related to forest management, including determining the optimal locations for selective cutting, identifying areas that require maintenance, and assessing the impacts of different management practices on the forest environment. 4.) Navigation: The ANYmal robots will use their collected data and maps to navigate autonomously within the forest environment, avoiding obstacles and hazardous terrains, and reaching their designated targets efficiently and safely.

4.2 Sensor Requirements

As an autonomous robot that will be deployed in the forest environment as part of the DigiForest project, the ANYmal robot requires a set of sensors to perform its task effectively and safely. The following is a justification detailing the types of sensors that are required by the ANYmal robot and their importance for the robot to perform the required task.

- LiDAR: The ANYmal robot requires the use of a LiDAR sensor for real-time mapping of its environment. This sensor generates a 3D representation of the surroundings for tasks such as localization, path planning, obstacle avoidance, and precise navigation within the forest. The accuracy requirements for the LiDAR are similar to those of the SAHA robot, with a precision of better than ±10 cm. However, the LiDAR shall also have a greater detection range due to the additional mapping task, ideally exceeding 50 meters. This expanded range will allow the ANYmal robot to gather more comprehensive data, creating a more detailed and accurate map of the environment.
- RGB/RGB-D camera: In addition to a LiDAR sensor, the ANYmal robot also requires the use of an RGB or RGBD camera to gather additional information

about the environment for mapping and traversability analysis. The RGB-D camera provides both color and depth information, allowing the robot to recognize and identify objects within its surroundings. This information is particularly useful for tasks that require semantic knowledge of the environment, such as tree classification and terrain segmentation. By integrating both color and depth information, the ANYmal robot can build a more complete understanding of its surroundings, improving its ability to navigate and operate within the forest environment.

- GNSS-receiver: The ANYmal robot requires the addition of a GNSS sensor to provide it with accurate and precise positioning information. This GNSS sensor will provide the robot with information about its location within the forest, which is crucial for global navigation and localization tasks. The geo-consistency of localization is an important aspect of the task of ANYmal robots, as it enables the sharing the information and registering the maps between multiple robot agents in the global frame.

5 Flying RMF System

5.1 Tasks

The task of the RMF drones in the DigiForest project is to explore and report valuable forest data efficiently and autonomously. The drones are a critical component of the proposed next-generation forestry, as they will be responsible for fast data collection for map building without constrained by the traversability on the ground. They will operate above and below the canopy, in varying conditions, and collect data using sensors such as depth cameras, LiDARs, etc. The collected data will be used to build a detailed and accurate representation of the forest environment, which will be used for decision-making and planning purposes. The drones must be able to navigate safely and autonomously in dense forests, avoid different types of obstacles (e.g., tree branches) and leave for self-preservation. The drones may also be able to communicate and coordinate with other autonomous systems, such as taking off from ground vehicles (The SAHA forest machine), to ensure seamless data collection and mission operation.

5.2 Sensor Requirements

To achieve the objectives of the DigiForest project, the drones require a range of sensors that can accurately collect and interpret data in a forest environment. These sensors will enable drones to navigate, collect data, and make decisions. The specific sensors required by the drones will depend on the particular tasks they are designed to carry out. However, based on the objectives outlined in the project, sensors that may be required include:

- LiDAR: LiDAR sensors use laser beams to measure the distance between objects, generating a highly accurate 3D map of the environment. LiDAR sensors are ideal for autonomous navigation in dense forest environments, as they can detect obstacles and terrain features in real time. To ensure safe high-speed flight, the LiDAR sensors required for the Flying RMF (Remotely Piloted Aircraft) systems must have an extended range of detection, enabling them to identify obstacles from a distance. Additionally, it is crucial for LiDAR to have a large FOV of at least 60 degrees with a lightweight design to minimize the overall weight of the system.

- RGBD/Depth cameras: The utilization of depth cameras is crucial for providing fast-speed drones with high-frequency spatial information. While LiDAR sensors can accurately measure distances, their high fly speed and low-density frame rate may not be sufficient for ensuring safe navigation within a dense forest environment. To supplement this limitation, integrating RGB (Red Green Blue) cameras can offer a wealth of data for semantic interpretation, scene segmentation, and geometric modeling. This data, collected by RGBD (RGB + Depth) cameras, can be used to create detailed and colorized 3D models of the forest, including individual trees, terrain features, and other objects within the environment.
- Time-of-Flight (TOF) cameras: employ light-based rangefinding to measure the distance between objects within a shorter range accurately. This high-resolution sensor can detect thin structures, such as tree branches, making it ideal for ensuring the safe operation of drones. To meet the requirements for safe flight, the TOF sensor must have a high frame rate and accuracy that exceeds 1cm within a detection range of 5 meters. This high frame rate and accuracy combination will provide the drone with the necessary information to navigate safely in dense forest environments.

6 Justification/Evaluation

6.1 IMUs/Encoders

Based on the requirements in Section 3.2, the following sensors have been selected to be used on the SAHA robot:

- **ACEINNA MTLT335D**: ACEINNA MTLT335D is a 6-DOF IMU designed to be used as a tilt sensor for its high accuracy in pitch and roll angle measurements up to $\pm 0,05°$. It is also designed for application on autonomous heavy machinery and comes in a rugged package. Thus it has been selected as the main sensor for the arms measuring of the SAHA robot.
- **SBG Ellipse-A**: SBG Ellipse-A is a high-performance IMU with a feedback frequency of 200 Hz. Although it is slightly less accurate in pitch and roll measurements compared to ACEINNA MTLT335D, its gyroscope has less bias instability and has a higher measurement bandwidth at 133 Hz. It is also more expensive than the ACEINNA MTLT335D model. Therefore only one of it is placed at the chassis of SAHA to provide high-precision data to the SLAM system.
- **Sick BCG05**: Sick BCG05 is a wire draw encoder that provides high precision linear position measurements up to 0.01 mm resolution and ± 0.2 mm accuracy. It has been successfully used in the feedback control of hydraulic actuators in previous work [4] and it is selected to be used in measuring the telescopic joint on SAHA robot. Its measurement precision meets the requirements listed in Section 3.2.
- **Gefran GRN**: Gefran GRN is a hall effect rotary sensor that measures angular position at high resolution. The main drawback of this sensor is that it can only measure at a maximum speed of rotation of 120 rpm. However, it is still suitable for measuring the turning joint on the SAHA robot as we do not expect the turning to be fast.

This list of sensors is not complete, as the hardware is still being modified to install and evaluate the rest of the sensors. All the selected sensors are designed for automotive, agriculture, or construction machines and adequately protect against dust, water, shock, and vibration. They are also rated to work under extreme temperatures and humidity levels. These additional features would enable the SAHA robot to work robustly in a forest environment.

6.2 LiDARs

LiDARs are a crucial component of autonomous systems. As required above, they are responsible for generating a 3D point cloud of the environment, which is essential for accurate obstacle detection, mapping, and localization. Four LiDARs were considered for the evaluation, including Velodyne VLP-16, Ouster OS0-128, and HESAI QT64. The criteria for the evaluation included accuracy, range, field of view (FOV), resolution, durability, and cost. After evaluating various types and brands of LiDARs, the following three LiDARs have been found to be the most suitable for autonomous forest navigation:

- **Velodyne VLP-16**: This LiDAR is a 16-channel laser scanner that has a range[1] of 100 meters, a FOV of 360° horizontally and 30° vertically, an accuracy of ±3cm, a scan rate of 5-20 Hz, an angular resolution (horizontal/azimuth): 0.1° - 0.4°, and a cost of approximately 3.5 thousand dollars. This LiDAR is protected against dust and humidity with an IP67 rating.
- **Ouster OS0-128**: This LiDAR is a 128-channel laser scanner that has a range of 35 meters, a FOV of 360° horizontally and 90° vertically, an accuracy of ±5cm, a scan rate of 10-20 Hz, an angular resolution (horizontal/azimuth) of 0.2 - 0.4°, and a cost of approximately 12 thousand dollars. This LiDAR is protected against dust and humidity with an IP68 rating.
- **HESAI QT64**: This LiDAR is a 64-channel laser scanner that has a range of 20 meters, a FOV of 360° horizontally and 104.2° vertically, an accuracy of ±3cm, a scan rate of 10 Hz, an angular resolution (horizontal/azimuth) of 0.6°, and a cost of approximately 5 thousand dollars. This LiDAR is protected against dust and humidity with an IP6k7 & IP6k9k rating.

Based on the justifications and the requirements, the HESAI QT64 can provide a high level of accuracy and a large vertical Field of View (FOV), along with its reasonable cost compared to the other options. The QT64 offers a range of 25 meters with an accuracy of ±2cm. Its vertical FOV of 90° is especially important in a forest environment, where obstacles can be tall, and obstacles above the ground need to be detected. The QT64's scan rate of 10-12 Hz is sufficient for the needs of the SAHA forest machine.

OS1-128 offers similar accuracy and scanning range as the QT64, it has twice the number of scan channels. This could be advantageous in environments with particularly dense vegetation, as it would provide a higher density of measurements. The Ouster OS1-128 could be a viable alternative for environments with particularly dense vegetation, but for most forest environments, the HESAI QT64 offers the optimal combination of performance and cost.

The Velodyne VLP-16 was also evaluated, but its low scanning density limits its performance in dense forest environments. The Velodyne VLP-16 LiDAR sensor

[1] The range of the LiDAR refers to the maximum range of 10% Lambertian reflectivity

boasts a large detection range of 100 meters, providing robust and reliable depth information. With a 5-20 Hz scan rate, the VLP-16 can quickly and efficiently produce high-resolution scans. However, one of its limitations is its limited vertical field of view (FOV) of only 30°. This restriction makes it less suitable as the primary sensor for the SAHA machine in the DigiForest project but will be used for the other ground agent, ANYmal, or for as a complementary sensor to other LiDARs in the DigiForest project.

6.3 Depth/RGBD/TOF Sensors

Depth/RGBD/TOF cameras and LiDARs are used for range sensing in autonomous systems, however, they have different strengths and limitations. LiDARs use laser ranging to provide long-range, high-accuracy but sparse 3D point clouds, which are ideal for tasks requiring large-scale environmental measurements. On the other hand, depth/RGBD/TOF cameras are more cost-effective and provide real-time dense measurements in a relatively shorter range. In summary, there are three main advantages of utilizing Depth/RGBD/TOF Sensors as complementary sensors to LiDAR:

- Firstly, those cameras are typically less expensive than LiDARs, making them a more affordable option for large-scale deployment in the DigiForest project.
- Depth/RGBD/TOF cameras typically provide real-time data at a higher frame rate than LiDARs, which can be especially useful for navigation and perception tasks for high-speed movements.
- Finally, integration with RGB data: RGBD cameras provide both depth and color information, which can be used to improve the accuracy and robustness of scene segmentation and object recognition algorithms.

The report investigates three types of depth sensors: Zed2i, Realsense D400 series, and flexx2 TOF camera. The purpose is to provide a comparison of the features, performance, and applications of these cameras to aid in the decision-making process for the selection of the best depth sensors for a specific task or application of the autonomous agent:

- **Zed2i stereo camera**: The Zed2i is a high-performance depth camera that offers large-range depth sensing and AI-enhanced measurement. With a resolution of up to 4416 x 1242 for depth and color images, the Zed2i can capture depth information up to 20 meters away using Neural Stereo Depth Sensing, providing a high level of detail and precision. The camera provides two options for different focus lenses and FOVs: i) 110°(H) x 70°(V) with a 2.1mm focal length for wide FOV. ii) 72°(H) x 44°(V) with 4mm focal length for longer detection range. This camera is also protected against dust and humidity with an IP66 rating. The zed2i offers USB 3.0 connectivity and is compatible with Windows and Linux systems, providing a wide range of connectivity options. The starting price of the Zed2i is approximately $500, making it an affordable option for many applications.
- **Realsense D400 series**: The Realsense D400 series is a line of high-performance depth cameras that provide advanced depth sensing capabilities. These cameras are equipped with a high-resolution depth and color imaging system, capable of capturing depth information up to a distance of 6 meters. The depth and color

Figure 1: The Hexagon BLK-ARC Sensor Payload

cameras both have a wide field of view (FOV), with the depth camera having a FOV of 87° × 58° (H × V) and the color camera has a FOV of 90 × 65° (H × V). Additionally, the depth camera has a depth output resolution of up to 1280 × 720, with a frame rate of up to 90 fps, making it suitable for fast movement. The RGB camera can capture frames with a resolution of up to 1280 x 800, using a global shutter. The Realsense D400 series is compact and lightweight, making it an ideal solution for integrating various systems and applications. The starting price of the Realsense D400 series is approximately $400, making it a cost-effective solution for users who need high-quality depth sensing capabilities.

- **Flexx2 TOF camera**: The Flexx2 is a high-performance, lightweight and efficient Time-of-Flight (TOF) camera that provides precise depth measurement within a limited range of less than 4 meters. With a depth accuracy of less than 1% of the distance and a Field of View (FOV) of 56° x 44° (H x V), this camera offers high resolution and accurate depth sensing capabilities. The Flexx2 is designed to be compact and lightweight, weighing only 13g, making it an ideal choice for drones. With a frame rate of up to 60 frames per second and low power consumption of fewer than 1 watt, the Flexx2 offers both efficiency and energy savings. This camera supports USB Type-C connectivity and can be easily integrated into different systems and applications with its compatibility with software platforms such as OpenCV, Matlab, and ROS, along with its C/C++ based SDK.

7 Integrated Sensor Payloads

7.1 Hexagon BLK-ARC

The Hexagon BLK-ARC is a highly integrated laser scanning module designed for robotic applications, as shown in Fig. 1. The module can be integrated with robotic carriers to provide autonomous mobile mapping capabilities. The Hexagon BLK-ARC has different sensing modalities, including a laser scanner, three RGB cameras, and an IMU. The laser scanner has a 360° field of view in the horizontal plane and a 270°

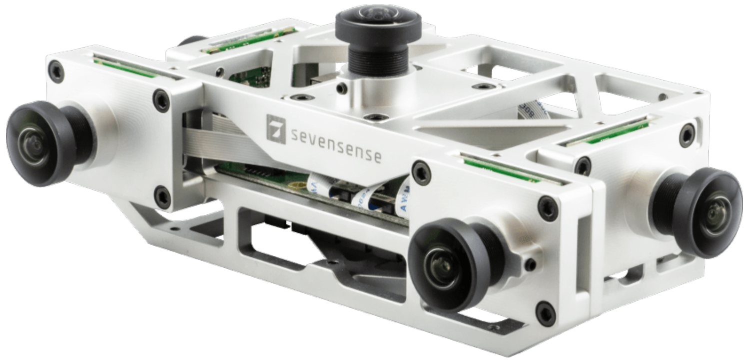

Figure 2: The Alphasense Sensor Payload with 5 high-resolution RGB cameras and one synchronized IMU

field of view in the vertical plane, with a range of up to 25 meters. The panoramic vision system includes three RGB cameras with a resolution of 4.8 MP and a global shutter. The IMU provides additional data that is combined with the information from the laser scanner and the cameras to deliver detailed and colored mapping results. The Hexagon BLK-ARC uses the GrandSLAM [2] technology, which was developed by Leica Geosystems. The technology combines information from LiDAR, vision, and IMU to build the map online. The Hexagon BLK-ARC can operate in temperatures ranging from 0 to 40°C and is protected against dust and humidity with an IP54 rating. The BLK-ARC is planned to provide real-time data streams for two ground-based systems: the SAHA forest machine and the ANYmal Legged Robot. The data from the BLK-ARC can be integrated into the perception and mapping pipelines of these systems with the goal of reducing the number of additional LiDARs and cameras needed onboard. Additionally, the standardized output from the BLK-ARCs makes sharing data between different robots easy, enabling seamless collaboration in multi-robot missions.

7.2 Alphasense

Alphasense is a visual-inertial sensor payload that offers spatial awareness with its 360° view. This sensor is specifically designed to provide high-quality state estimation, simultaneous localization and mapping (SLAM), local perception, semantic understanding, and depth sensing. Team CERBERUS [5] employed and tested the Alphasense system during the DARPA SubT challenge to enhance the perception and localization capabilities of their legged robot, ANYmal. It is comprised of 5 high-sensitivity cameras (2 front stereos, 1 left, 1 right, and 1 upwards-looking camera) and a synchronized IMU (Bosch BMI085), as shown in Figure 2. The RGB cameras in Alphasense have a resolution of 1.6 megapixels and can capture high-quality images. The synchronization between the onboard IMU and cameras is highly precise, with a delay of less than 100 microseconds. All of the sensors are pre-integrated on an aluminum frame, providing a compact and robust system for visual-inertial sensing. Alphasense will provide the ANYmal-legged robot with RGB perception information for terrain analysis and mapping. The synchronized IMU and camera can also assist the lidar-based localization system, providing robust localization under different environmental conditions. In this way, Alphasense is critical in enabling the ANYmal robot to navigate and understand its surroundings effectively.

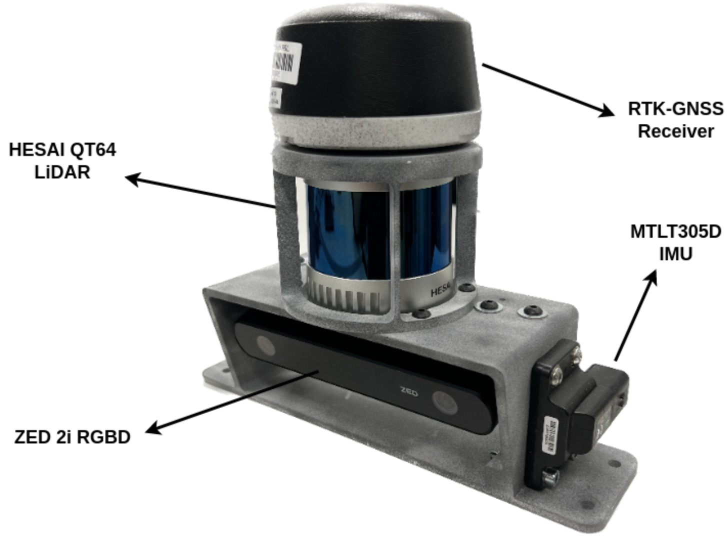

Figure 3: The SAHA Perception Payload. It includes one Hesai QT64 LiDAR, on Zed 2i RGBD camera, one IMU, and one GNSS receiver.

7.3 SAHA Perception Payload

The SAHA perception payload is a specially designed sensor package for the SAHA forest machine. It serves as the main sensor system for perception, localization, and navigation tasks. The package includes a variety of sensors, including a HESAI QT64 LiDAR, a Zed2i RGBD camera, an IMU (ACEINNA MTLT305D), and an RTK-GNSS receiver, as depicted in Figure 3. With the combination of these sensors, the SAHA robot can achieve a panoramic field of view through the laser scan of the LiDAR and a forward view of the ground terrain using the RGB point cloud from the Zed2i sensor. Additionally, the RTK-GPS receiver on top and the online LiDAR-based localization provides the robot with a consistent global position.

8 Summary

The purpose of this report is to provide guidelines for selecting sensors that meet the specific requirements of autonomous agents for the DigiForst project. The report includes a justification for different types of sensors, such as LiDARs, RGB/D cameras, and TOF sensors, and discusses the need to consider overall redundancy to reduce system weight and cost. Pre-integrated sensors for various autonomous agents are also described. The report provides evaluations and comparisons of sensor performance, which can be used to determine the best sensors for specific tasks and provide a baseline for future evaluations. The report lists the sensor requirements for the SAHA robot, ANYmal legged robot, and the fly RMF system. Overall, this report is a valuable resource for selecting sensors to perform specific tasks for different autonomous agents in the DigiForst project.

References

[1] Victor Barasuol et al. "Highly-integrated hydraulic smart actuators and smart manifolds for high-bandwidth force control". In: *Frontiers in Robotics and AI* 5 (2018), p. 51.

[2] Leica BLK. *BLK2GO Technology*. URL: https://shop.leica-geosystems.com/leica-blk/blk2go/technology.

[3] Marco Hutter et al. "Force control for active chassis balancing". In: *IEEE/ASME Transactions On Mechatronics* 22.2 (2016), pp. 613–622.

[4] Dominic Jud et al. "Heap-the autonomous walking excavator". In: *Automation in Construction* 129 (2021), p. 103783.

[5] Marco Tranzatto et al. "Cerberus: Autonomous legged and aerial robotic exploration in the tunnel and urban circuits of the darpa subterranean challenge". In: *arXiv preprint arXiv:2201.07067* (2022).