Fruit Mapping Mobile Robot on Simulated Agricultural Area in Gazebo Simulator Using Simultaneous Localization And Mapping (SLAM)

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***Abstract*—Precision Agriculture using mobile robot aimed to increase efficiency and quality of crops treatment and monitoring, since robot can produce better result in term of data quality and accuracy than manual treatment by human labor. Limited by technology development and complexity of agricultural environment, precision agriculture nowadays is still not fully-autonomous, but partially autonomous to handle more simpler - but need high accuracy - tasks. Some of them is mapping and monitoring task. This research proposed a method for generating map in simulated agricultural area using Simultaneous Localization And Mapping (SLAM), by generating grid-based/volumetric map using fine-tuned SLAM-Gmapping algorithm and combine it with properties/informations obtained from each detected crops/plants using fruit detection with visual sensor and tree location detection using 2D laser scanner sensor. Experiment conducted in simulation environment Gazebo and Robot Operation System (ROS) for scenario of simulated fruit mapping in apple farm, and give a good result with a good accuracy.**

I. Introduction

Mobile robot development nowadays implemented in many daily aspects, one of them is mobile robot for agriculture purposes. Development of agricultural robots nowadays are rapidly increasing because the needs of food consumption that always increased over time did not followed by the availability of human resource for agricultural industries. Compared to traditional agriculture industry, agricultures management using automation and robotics approach have some advantages, which are effective and accurate plants treatment that leads to increasing amount of harvested products, and can covers a wide area with minimum amount of human resources.

Many researchers had done the researches for agricultural robots task for several subtasks: 1) transplanting and plant seeding, 2) plant protection and weed control, 3) harvesting, and 4) supporting tasks e.g. navigation and path planning [1]. Transplanting and plant seeding focused on early step of agricultural development, planting the seeds into soil automatically. Plant harvesting is about how the robot interact with the plants to harvest fruits. Plant protection and weed control help the farmers on daily work such as plant watering, giving pesticides, and exterminating pests and weeds automatically. Supporting task focused on the robots autonomous movement and data acquisition as the foundation to another tasks.

One of the problem in agricultural robot is, its development and implementation is difficult and expensive. For the simple task e.g. mapping and navigation, stable and accurate equipment is needed. Implementation and production of ground mobile robot with medium size that capable to explore outdoor environment need an intensive research and trial-and-error and hard to maintain. Although using a stable, factory-made ground robots is possible, the unit cost of the robot is expensive. Ground mobile robot also must be equipped with an accurate sensor e.g. RGB-D camera, LIDAR, GPS, etc [2], which is very expensive. Moreover, experiment must be done in real agricultural fields or an artificial area which simulated the specific condition of real field. For early development and educational purposes, real-world and real-robot implementation and experiment of agricultural robot is expensive and have a high difficulty. To encounter that, one of the solution is using simulation environment.

Some of established researches in agricultural robot already done their research in computer-simulated environment. MoboSoft develop SAFAR, a simulator specifically built to simulate autonomous navigation of robot based on real-world maps from Google Earth [3]. Not only in specific simulator, some of the researchers built and test their robots and algorithms in an established multi-purpose robotics simulator e.g FroboMind[3] and Webots [4].

Implementing automation in agricultural field surely can lowered daily cost and rise efficiency. However, fully-automated agricultural system is very costly. To build the robot with its algorithm to do all tasks in agricultural fields (from planting, monitoring, and harvesting) need an advanced technology and complex algorithms. To overcome the cost problem, it is better to collaborate manual labor by farmers with automation in some aspects that suitable to be done by robots. As the development of agricultural robots are spread on a wide-range of tasks as mentioned earlier, it is hard to determine which task is the most important than the others [1]. However, considering computer can give better result in iterative and routine task in a long time, robot might be most suitable for monitoring task, which sometimes take a place in very wide area and conducted repeatedly in a day.

This research will focus on development of monitoring task, which take case in monitoring and mapping of ripe fruit. Main task of the robot is to navigate autonomously in the fields and conduct Simultaneous Localization and Mapping (SLAM) to build field map for the first run, and conduct fruit monitoring using visual sensor in the next run. Map generated by the robot will provide location of the trees and marking which tree that have a ripe fruits.

Experiment of this research will be conducted in computer-simulated environment over Gazebo simulator and Robot Operation System (ROS), since it is open source and fully-customizable. This research will use simulated red apple trees as the plants for the field, which is generated by customizing existing 3D model available in 3D Warehouse of SketchUp [5]. For robot, this research will use Husky Robot from Clearpath Robotics equipped with 2D LIDAR sensor LMS1xx and camera as visual sensor.

II. Related Works

Research in agriculture robotics has been conducted in various aspects, some of them are in the field of navigation and control, object tracking, and field monitoring. Duggal conducted monitoring of pomegranate growth stages using Unmanned Aerial Vehicle (UAV) [6]. In another task, Zaidner propose a novel sensor fusion method for navigating vineyard sprayer robots [7]. Nguyen et. al. implement an apple detection algorithm using RGB-D camera [8].

Research about mapping in agricultural area specifically using ground mobile robot has been conducted worldwide with a variation of plant type, sensors, and robot used. Gimenez et. al. conducted research about mapping of semi-structured fruit grove using LiDAR sensor and GPS [9]. In similar case, Shalal et. al. use sensor data fusion between laser scanner and camera to make a map of tree and non-tree objects, and localize around the field using Extended Kalman Filter (EKF) [10]. Another approach proposed by Reina, which combine four sensors (stereo vision, LIDAR, radar, and thermography) at once for increasing ambient awareness of automatic agricultural vehicle. This combination give a multiple perspective for mapping and obstacle avoidance [11].

III. Simultaneous Localization And Mapping (SLAM)

Simultaneous Locallization And Mapping (SLAM), or also known as Concurrent Mapping and Localizaiton, is an term known as an approach to solve a ”chicken-and-egg problem” of robot localization and mapping. This problem appear because to make a good map of robot’s environment it need a precise self-position estimation, however good localization only can be achieved when a well-defined map is available [12]. In SLAM problem, for each time slice t robot only know its measurement from sensors ($z_{1:t}$) and controls given ($u_{1:t}$) and need to find the probability of all pose/robot state ($x_{1:t}$) and the map of the environment (m). This term known as Full SLAM, as can be expressed as equation 1. It also available SLAM that only finding current state only (x_t) and ignore all previous states, known as Online SLAM which can be seen at equation 2.

$$p(x_{1:t}, m|z_{1:t}, u_{1:t}) \tag{1}$$

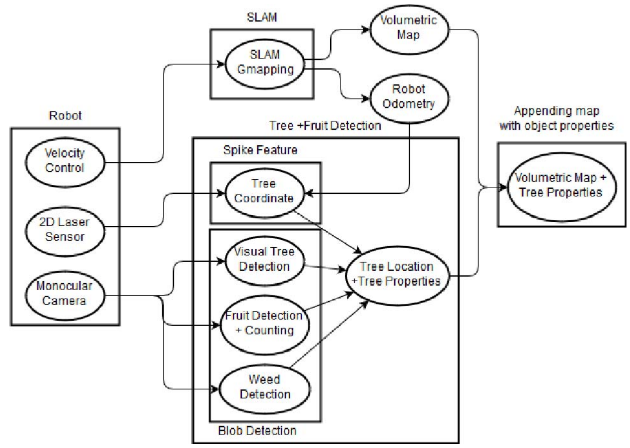


Fig. 1: Proposed methodology for combining volumetric map with tree properties information

$$p(x_t, m|z_{1:t}, u_{1:t}) \tag{2}$$

IV. Methodology

Main goal of this research is to generating 2D volumetric map of agricultural area which enriched with informations/properties for each tree. Three main component in the proposed methodology is 1) adjusting SLAM-Gmapping, which is more suitable for indoor environment, to become more compatible with outdoor environment, and 2) gathering additional informations/features contained in each tree, and 3) combining volumetric map with feature-based information into one integrated map. Details of the proposed method can be seen at figure 1.

A. Volumetric-based SLAM For Outdoor Environment

There are two established SLAM packages commonly used in Robot Operating System (ROS) : SLAM-GMapping [13] and Hector-SLAM [14]. This research used those two SLAM with fine-tuned parameters which suitable for a desired experiment fields (simulation environment in Gazebo simulator) and compared those SLAM in the term of volumetric map result. The best SLAM method will be chosen to be enriched by property of the trees.

B. Tree and Fruit Detection

Tree and fruit detection used combination between data from 2D laser scanner and monocular RGB visual sensor - Kinect. Tree detection rely from laser readings, meanwhile fruit counting used 2D RGB visual data captured from Kinect. Tree detection used a feature extracted from 2D laser readings called Spike Landmarks, which detected when two consecutive readings have a huge differences in the detected range [15], which similar to method used in [16]. Fruit detection method used combination between color and blob detection. Diagram of fruit and tree detection algorithm can be seen on figure 2.

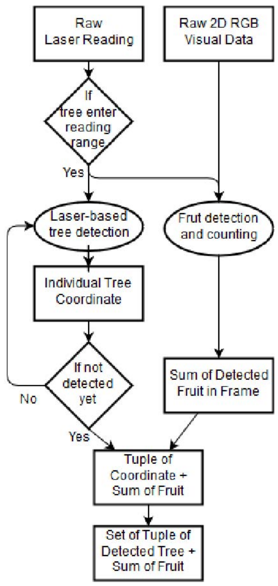


Fig. 2: Tree detection process diagram

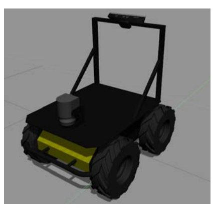


Fig. 3: Simulated Husky robot from Clearpath Robotics [19] with 2D laser scan sensor LMS1xx and monocular visual sensor Kinect

C. *Combining Volumetric Map With Tree Properties*

As Volumetric-based SLAM and tree+fruit detection run independently, last step of the proposed methodology is combining the result from both sides into one integrated map. Integration conducted with translating coordinate of trees obtained by tree+fruit detection to coordinates of grid map from the selected volumetric-based SLAM. Final result of the proposed methodology is a tuple of coordinates which associate points in grid map with amount of fruits for each tree.

V. Experiment and Analysis

Experiment of this research conducted in Gazebo simulator over Robot Operation System (ROS), and conducted in several scenarios explained below and analyzed qualitatively and quantitatively.

A. *Simulation Environment*

Simulation runs in Robot Operation System (ROS) [17] and Gazebo Simulator [18]. ROS and Gazebo runs in Linux Ubuntu 16.04. Those system runs the robot and simulation environment in a real-time.

TABLE I: Environment specification for each tree model. h is height of simulated tree, d is distance between tree, N is amount of deployed tree in the environment

Tree Type	h (meter)	d (meter)	N
Apple-Dwarf	~2.5	3	25
Apple-Semi Dwarf	~4.5	4.5	16
Apple-Standard	~6.5	9	9
Palm Oil	~7	9	10

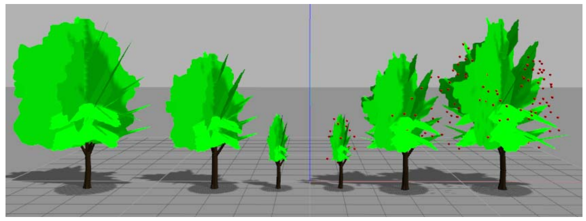
1) Robot and Sensor Used: Experiment conducted used outdoor Unmanned Ground Vehicle (UGV) Husky from Clearpath Robotics, which is a simulated 3D model compatible to ROS [19] (3D model of the Husky Robot can be seen on figure 3). For tree detection and SLAM algorithm, Husky equipped with simulated sensor of 2D Laser Range sensor LMS1xx and one visual sensor Kinect (only use 2D image, depth data is not used).

2) Simulated Tree Model: Tree model used in this simulation is created by modifying open source 3D model obtained from 3D Warehouse by Sketchup, software for 3D modeling [5]. Obtained 3D model then resized and edited in 3D model editor, Blender [20].

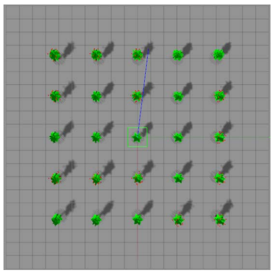
This research use two type of tree: wood-based tree (apple tree) and palm-based tree(palm oil tree). For each of them, 3D object used is using minimum amount of polygon - which the model have low shape detail but can make simulation run lighter. Tree model also only used single color for each tree component : stem in brown, leaves in light green, and fruit in red. Ground plane are not simulated, still in gray plane. Shadow and sun lighting were enabled.

1) Apple Tree
   In this research, simplified apple tree model is used. Main focus of this model is to simulate main stem and apple fruits placed in the tree's grove. Tree branch and individual leaves are not simulated. Apple tree generated in three different types: dwarf, semi-dwarf, and standard. Each type have a different height and inter-tree distance. 3D model of generated apple tree can be seen on figure 4a.
2) Palm Oil Tree
   Simulated palm oil tree equipped with leaf scars (internodes) and old leaf remainders to simulate rough and uneven palm oil trunk. Leaves used in this model are simplified in the term of shape detail to reduce simulation complexity. Palm kernels were not simulated individually but in pack, modeled as big oval shape with red color. 3D model of generated palm oil tree can be seen on figure 5a.

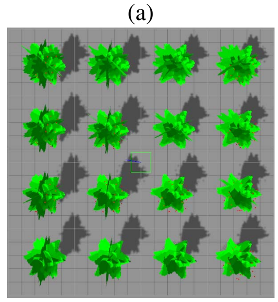
3) Simulated Agricultural Environment: Arrangement of trees in simulation field referred to real plantation rules of each tree, either apple tree or palm oil tree. Apple tree arrangement referred to [21] [22], which distance of each tree is dependent with its type and height. Palm oil tree arranged based on [23], which distance of each tree is 9 meters and arranged in a triangle pattern. Visualization of tree arrangement can be seen on figure 4b, c, and d for apple tree and figure 5b for palm



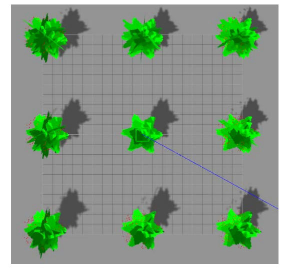
(a)



(b)

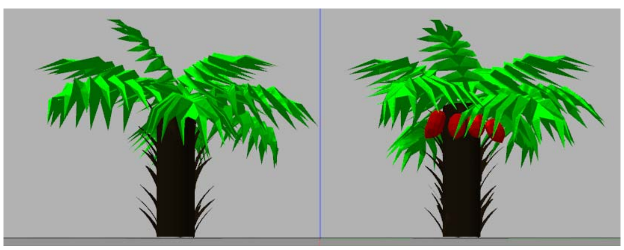


(c)

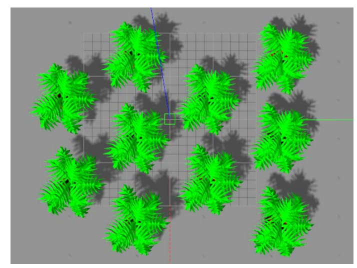


(d)

Fig. 4: Generated 3D model of apple tree (a) and each type arranged based on table I : dwarf apple in (b), semi-dwarf apple in (c), and standard apple in (d)



(a)



(b)

Fig. 5: Generated 3D model of palm oil tree (a), arranged based on table I to become (b)

oil tree. Specification for deployed tree height and inter-tree distance can be seen on table I.

B. Experiment Scenarios

Experiment conducted in several scenarios, divided into three part : 1) volumetric SLAM experiment for determining the most suitable volumetric map for designed simulation environments and 2)Fruit and tree detection experiment to measure accuracy of fruit counting and tree detection algorithm, and 3)Volumetric and feature map fusion, to combine result of volumetric SLAM and fruit+tree detection algorithm.

1) Comparing SLAM-GMapping with Hector-Slam
To get an equal comparison result, GMapping and Hector-SLAM tested with a same pre-recorded robot movement using rosbag - a recorded robot log and data generated by ROS. Rosbag record all running nodes and topics from the Gazebo simulator (all sensor readings and given robot movement command). After recorded, rosbag is played and subscribed by Gmapping and Hector-SLAM respectively. Result form each algorithm then compared qualitatively do determine which algorithm that more suitable for used simulated agriculture environment, either for apple farm or palm tree field.
2) Tree+Fruit Detection
Performance of tree+fruit detection tested separately from the volumetric=based SLAM. Accuracy determined based on differences between obtained tree coordinates from the tree+fruit detection algorithm with real coordinate of the trees in Gazebo simulator.
3) Volumetric + Feature Maps Fusion
As the used volumetric-SLAM package only provide map image as the final result, performance of the result of fusion between volumetric map with obtained coordinate + amount of fruit compared qualitatively. Result provided from the fusion compared to raw result of tree+fruit detection algorithm, selected result of volumetric-based SLAM, and ground truth of the tree location based on tree locations on Gazebo simulator.

C. Result and Analysis

As explained in previous section, experiment conducted in three part.

1) Volumetric-Based SLAM: For SLAM algorithm run in map as seen on figure 6a, SLAM-GMapping give the output in figure 6c and Hector-SLAM in figure 6d. Qualitatively, compared to ground truth in figure 6b, SLAM-GMapping give a better result than Hector-SLAM. This result occurred because Hector-SLAM heavily dependent to laser reading and used no odometry data. As seen in figure 6d, Hector-SLAM still give good visual when it near the flat and location with no repetitive pattern. However, in a repetitive area, it lost its tracking and broke the map.

2) Tree+Fruit Detection Result: In tree detection for apple tree, mean of accuracy of fruit counting for each frame captured reached 93.5% for dwarf, 95.53% for semi-dwarf, and 74.8% for standard . High accuracy obtained in dwarf and semi-dwarf scenario because fruit modeled in this experiment is very distinguishable, since leaves deployed with no gradient and texture (no visual noise) and fruit have a very contrast color (red) to the leaves (green). However, in bigger tree (standard scenario), accuracy become low because camera cannot get a visualization of upper side of tree. In palm tree, fruit detection experiment was unable to conducted because palm oil fruit not modeled individually. Result of the fruit detection can be seen in table II III IV, which Σf is real amount of fruit for each tree, $dfa + dfb$ is detected amount of fruit for each side (a as front and b as back).

3) Combining Volumetric + Feature Maps: Combination between volumetric map and feature of trees conducted qualitatively. Example of experiment conducted in palm field can be seen on figure 7.

VI. Conclusion

There are several tasks available to be solved by agricultural robotics, one of them is plant protection and weed control. Those task heavily dependent to field mapping. Two options available for map representation are 1) volumetric-based map, which give the better details of the shape and visual condition of the environment, and 2) feature-based map, which focused on a feature of specific object. To get a detailed map of a agricultural area, combination between two of them is needed.

This research proposed a tree and fruit detection system in simulated agricultural area using mobile robot which produced a enriched volumetric map with a feature-specific information for trees. Agricultural area used are simulated apple farm and palm oil field, which created from edited open-source 3D model from Sketchup and prepared in several scenarios.

Experiment conducted to the proposed methodology give a good result. Combination between selected volumetric-based SLAM algorithm - SLAM-GMapping - with the proposed tree+fruit detection algorithm give a good accuracy compared to the ground truth of tree location an fruit amount obtained from pre-defined Gazebo simulation environment. Accuracy of tree and fruit detection reached 93.50%, 95.53%, and 74.80% for scenario dwarf, semi-dwarf, and standard respectively. Meanwhile combination between proposed tree+fruit detection and volumetric map from SLAM-GMapping is compared qualitatively and give a good result.

VII. Future Works

As this research run in a simplified simulated environment, result obtained may be different in a more detailed simulation - and may be even more compared to the real world. 3D model used in the experiment used low-polygon shape objects and no-gradient and no-texture colors and visuals for lower simulation complexity. It also run in a monochrome field with no visual and minimum terrain noise. For further research, detail of shape, color, and texture can be improved to make a simulation close to real-life condition. Moreover, more variation of SLAM algorithm that can be used to find the most suitable SLAM algorithm for the created scenarios.

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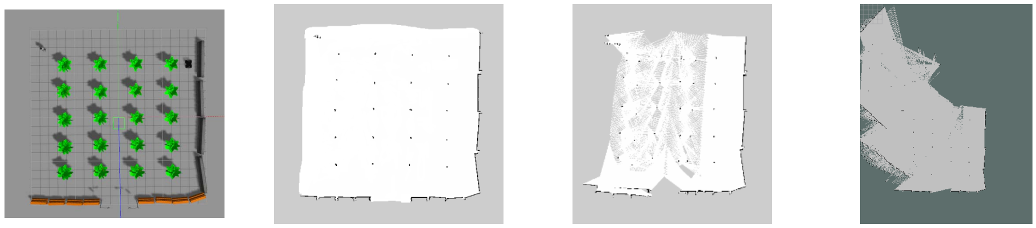


(a) (b) (c) (d)

Fig. 6: Result of SLAM-GMapping(c) and Hector-SLAM(d) when run on environment(a) compared to ground truth(b)

TABLE II: Result of fruit detection in Apple-Dwarf scenario

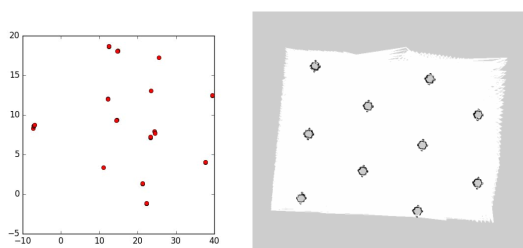
Row/Column	1		2		3		4		5	
	Σf	$dfa + dfb$	Σf	$dfa + dfb$	Σf	$dfa + dfb$	Σf	$dfa + dfb$	Σf	$dfa + dfb$
1	14	7+9	14	7+9	14	7+9	0	0	0	0
2	14	7+9	0	0	14	7+9	0	0	14	7+9
3	0	0	0	0	0	0	0	0	14	7+9
4	14	7+9	14	7+9	14	7+9	0	0	14	7+9
5	0	0	0	0	0	0	14	7+9	14	7+9

TABLE III: Result of fruit detection in Apple-Semi Dwarf scenario

Row/Column	1		2		3		4	
	Σf	$dfa + dfb$	Σf	$dfa + dfb$	Σf	$dfa + dfb$	Σf	$dfa + dfb$
1	0	0	9+19	9+19	9+19	9+19	9+19	9+19
2	0	0	9+19	9+19	9+19	9+19	0	0
3	0	0	9+19	9+19	0	0	0	0
4	26	9+19	9+19	9+19	9+19	9+19	9+19	9+19

TABLE IV: Result of fruit detection in Apple-Standard scenario

Row/Column	1		2		3	
	Σf	$dfa + dfb$	Σf	$dfa + dfb$	Σf	$dfa + dfb$
1	71	23+5	71	23+5	71	23+5
2	71	23+5	0	0	0	0
3	71	23+5	71	23+5	71	23+5



(a) (b)

Fig. 7: Result obtained from SLAM-Gmapping for palm tree scenario : tree detection using laser scanner (a), volumetric map from SLAM-GMapping (b)

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