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Performance Analysis in Object Diameter Estimation based on Single and Multiple Non-Destructive and Discrete Infrared Sensors

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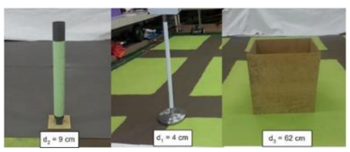
Graphical abstract



Abstract

In Simultaneous Localization and Mapping (SLAM) technique, recognizing and marking the landmarks in the environment is very important. Therefore, in a commercial farm, rows of trees, borderline of rows as well as the trees and other features are mostly used by the researchers in realizing the automation process in this field. In this paper, the detection of the tree based on its diameter is focused. There are few techniques available in determining the size of the tree trunk inclusive of the laser scanning method as well as image-based measurements. However, those techniques require heavy computations and equipments which become constraints in a lightweight unmanned aerial vehicle implementation. Therefore, in this paper, the detection of an object by using a single and multiple infrared sensors on a non-stationary automated vehicle platform is discussed. The experiments were executed on different size of objects in order to investigate the effectiveness of this proposed method. This work is initially tested on the ground, based in the lab environment by using an omni directional vehicle which later will be adapted on a small-scale unmanned aerial vehicle implementation for tree diameter estimation in the agriculture farm. In the current study, comparing multiple sensors with single sensor orientation showed that the average percentage of the pass rate in the pole recognition for the former is relatively more accurate than the latter with 93.2 percent and 74.2 percent, respectively.

Keywords: Diameter measurement; infrared sensors; autonomously detection; dead-reckoning detection; landmark detection

Abstrak

Dalam teknik *Simultaneous Localization and Mapping (SLAM)*, mengiktiraf dan menandakan tanda tempat di alam sekitar adalah amat penting. Oleh itu, di dalam ladang komersial, batas-batas pokok, garisan sempadan baris pokok dan juga pokok itu sendiri serta ciri-ciri yang lain kebanyakannya digunakan oleh penyelidik dalam merealisasikan proses automasi di dalam lapangan ini. Oleh itu, di dalam kertas kerja ini, mengesan pokok bersandarkan pada diameter diberi tumpuan. Terdapat beberapa teknik yang boleh didapati dalam menentukan saiz batang pokok termasuklah kaedah pengimbasan laser serta ukuran berasaskan imej. Walau bagaimanapun, kesemua teknik tersebut memerlukan kepantasan pengiraan dan pemprosesan data yang menjadi kekangan utama dalam pelaksanaan kenderaan udara ringan secara kendalian automatik. Oleh itu, di dalam kertas kerja ini, pengesanan objek dengan menggunakan sensor infra merah secara tunggal mahupun pelbagai pada platform kenderaan automatikdi dalam konteks pengukuran secara nomad dibincangkan. Kajian ini telah dilaksanakan ke atas saiz objek yang berbeza untuk menyiasat keberkesanan kaedah pengukuran diameter yang dicadangkan ini. Sebagai permulaan, kerja ini diuji secara *ground* di dalam makmal dengan menggunakan kenderaan omnidirectional yang kemudiannya akan dipanjangkan untuk diaplikasikan pada kenderaan udara tanpa pemandu yang kecil dan ringan bagi tujuan pengukuran diameter pokok di ladang pertanian. Dalam kajian semasa, membandingkan pelbagai sensor dengan orientasi sensor tunggal menunjukkan bahawa peratusan purata kadar lulus di dalam pengecaman tiang untuk pelbagai sensor lebih tepat berbanding yang tunggal dengan 93.2 peratus dan 74.2 peratus, masing-masing.

Kata kunci: Pengukuran diameter; sensor infra merah; pengesanan automatik; pengesanan mati-perhitungan; pengesanan mercu tanda

1.0 INTRODUCTION

In certain commercial farm like papaya, rubber and palm oil, the trees are planted systematically with a uniform row's arrangement to facilitate the movement of the farmers as depicted in Figure 1. This unique condition has created many paths which allow the automated vehicle to be navigated within it. Therefore, by introducing the self-governing automated vehicle in commercial farm to assist farmers in monitoring the condition of plants can boost up the crop production as well as reduce the cost of labours in this sector. Simultaneous Localization and Mapping (SLAM) is one of the most accepted technique which enables automated vehicles build a map of the environment and at the same time can locate itself in this map to determine its location.[1] According to this technique, one of the important aspects for an automated mobile vehicle to meet its requirement is to estimate the landmark locations. Thus, in our application, individual trees are the natural landmarks that can be manipulated so that SLAM technique can be implemented in this context. In order to do that, the automated mobile robot should recognize the appearance of the landmarks by manipulating their natural or biological features. One of the tree features that can be used in this approach is the diameter of its trunk. Normally, in a well-organized plantation field, the diameter of the tree trunk is almost standardized, for example, in papaya plantation, the overall diameter of the three trunk is approximately between 20 cm and 22.5 cm for 6 months old tree.[2]

Figure 1 A well-structured plantation field in most South East Asia countries, which is consisted of a cloistered and canopied environment. (From left to right) Rubber , Palm oil and Papaya Plantation Fields

To measure the diameter of the tree trunk or any object, few techniques have been discussed by previous researchers in broad applications. A tree measurement, particularly the measurement of its diameter using 2D laser range finder for forest management and planning applications has been carried out by Jaakko *et al.* and Ohman *et al*.[3-4] In their research, they utilized two types of laser range finder, namely, 2D laser range finder for a continuous tree diameter measurement and 3D laser range finder for a reference measurement only when the measurement platform is not moving. The trunk is estimated by calculating the diameter of the tree based on the edges points of it as well as its shortest range measurement which is the middle data between the trunk and the sensor. The obtained parameters fit a circle in determining the tree diameter by manipulating the angular computation. The angle of view of the circle, which is used to calculate its diameter, is determined through the bearing angles of the edge measurements. This approach is not suitable to be implemented in our case, as our automated vehicle is moving parallel with the target tree or object and the measurements are a one-time approach which sometimes it is impossible for them to fit a circle and ideal triangle for further diameter computation. A Michael *et al.* proposed a new method to determine a diameter of a spherical object based on non-contact approach for robotic inspection fields application, particularly in the grinding operation.[5] The principle used in their method is based on laser triangulation under structured lighting, where the laser planes create lines on the target object which were captured via a charge-coupled device and connected to a PC for further computation processing. They use two methods to calculate the radius of the object, namely, the three tangent and gradient-descent methods. According to them, it is found that, the three tangent method gives a better result with relative error below 1%. On the other hand, by extracting the raw data received from the 2D and 3D laser data, the model of a tree trunk can be constructed by Meng Song *et al*.[6] According to them, there are three steps in modelling or restructuring the tree graphically through parameters extracted from the natural tree, namely, a) tree segmentation, b) circle model estimation as well as circles and axis fitting and c) tree section selections and tree trunk integration.

Vision sensor has become a handy tool in measuring size of tree trunk or any object universally. The measurement of the means of a standing tree trunk via computer vision technique has been developed by Jiangming Kan *et al.* which brings a great significance in determining the working parameters of an intelligent pruning robots.[7] In their research, there are six steps involved during the extraction of the trunks and branches from the raw data gathered through the CCD camera. Parts of these steps are pixels counting with the respect to the real size of the target object as well as intersection between branches and trunks. From their investigation, it is found that, the mean absolute error of the diameter measurement is 0.67 cm with the mean relative error of 1.9%. Nevertheless, the complex background of the image can deteriorate their detection severely. The dynamics of the fruit diameter is studied by Qingbing Zeng *et al.* to understand the plant response towards diurnal variation in water content and long-term growth conditions.[8] They proposed a non-contact diameter measurement technique based on optical method which gives an accurate measurement of the fruit in the grape field. The image of the fruit, which is gained from the CMOS camera with a telecentric lens, undergo several image processing algorithms such as filtering, image segmentation and occupied pixels calculation to calculate the exact diameter of it. They reported that their developed system has achieved a repeatable accuracy of ± 7 µm for measuring the fruit diameter. A new measurement concept for forest harvester in a cluttered environment by using 6DOF movement of laser and stereo camera to calculate the tree parameters such as height of crown base, taper, sweep and trunk dimension is designed by Mikko Miettinen *et al*.[9] In their case, a scan-correlation based method is used for short-term based dead reckoning.

Another approach which combines the vision and non-intrusive ultrasonic sensors to detect obstacle as well as measure its size has been carried out by Muhammad *et al*.[10] Based on their approach, the size of the object is determined by computing the occupied pixels with the respect to the distance between the camera and the object as well as with respect to the real size of the object by fixing the view angle of the camera. Once the geometric similarity is identified between the real object and the image, the equivalent ratio is used to calculate the sizes, which are the width and the height of the detected object. This approach is also practiced by Sanjiv Singh *et al.* in estimating the widths of the tree by innovating the calliper device from vision sensor and laser light.[11]

All of the above techniques mentioned, has significantly contributed to the diameter measurement of an object to be implemented in the autonomous machine. Nevertheless, those approaches requires extensive matrices computation,[12] bulky sensor dimension,[3,5,12] expensive image processing time[7,10] as well as lighting condition[8] which is not suitable to be implemented on an autonomous aerial vehicle for real-time individual tree detection method in a canopied and structured environment (Figure 1). Thus, in this paper, a less complex technique based on dead reckoning approach by using infrared sensors is proposed to suit the need of real-time tree detection which in this case an omni directional wheeled vehicle is used as the testing platform.

2.0 INFRARED FOR EDGE DETECTION

In robotics, infrared (IR) sensors are widely used as proximity sensors for obstacle avoidance as well as measuring distance from the mobile robots and the target object. It is preferred than ultrasonic sensors due to lower cost and faster response times.[13] In this proposed method, an advanced IR sensor produced by Sharp, GP2Y0A02YK0F IR is used to detect the edge of the object while maintaining the distance between the automated vehicle and the target object at approximately 80 cm to keep it off from colliding with the object whenever the system failed. This sensor is selected due to its lightweight feature, which is suitable to be implemented on an automated aerial vehicle without compromising the efficiency of the diameter measurement. However, the sensor is known to be unstable under direct sunlight explosion,[14] but it is still acceptable under shady environment such as structured and canopied plantation field. In our proposed tree diameter measurement technique, the edge of the tree is detected by the IR sensors, which are attached on a non-stationary automated mobile platform. According to the datasheet of the IR sensor, the moving direction of the object and the center line between the emitter and detector must be vertically set to decrease the deviation of the measurement distance.[14] After the edge of the object is detected, the diameter of it can be computed, which will be discussed in detail in the next section.

3.0 DIAMETER MEASUREMENT TECHNIQUE

Well-structured agriculture field is one of the potential environments for small-scaled and automated aerial vehicle to be implemented in monitoring as well as scouting the development of the plants. It is structured in the sense that most of trees grow in nearly horizontal line and the trunks are almost similar in shape and size. Therefore, the diameter of the tree trunk is very essential in helping the automated aerial vehicle to spot and mark it in a constructive map, which is based on the SLAM technique. Due to this reason, there are various methods of calculating the diameter of any object as well as tree trunk by exploiting the occupied pixels, the scanned laser data as well as using circular computation based on trigonometry and triangle calculation, which have been discussed earlier. However, in our approach, which is based on the concept of dead reckoning, calculates the diameter of the pole through the edges detection of the IR sensors.

The underlying parameter that is useful in this method is the calculation of the current location from the previous known position based on the time information between these locations. This method is chosen as it offers a great advantage in enforcing real-time tree detection for an automated and nomadic aerial vehicle in the agriculture field, which is contrasted with the previous methods in the context of non-stationary diameter measurement. Furthermore, all of the tree trunks in the structured commercial farm have approximately the same size of diameter. The main idea of this method is illustrated figuratively (Figure 2a and Figure 2b). According to these figures, the diameter of the pole is calculated when the IR sensor senses the first edge, *Edge 1*. During this event, the time is captured so that the diameter can be easily computed. Once both edges (*Edge 1* and *Edge 2*) have been detected successfully, the overall diameter is determined. Further clarification of this technique is clearly depicted (Figure 3). The underlying mathematical equation used to compute the diameter of the object is written in Equation 1.

$$d = \lim_{\delta t \to 0} \frac{\delta x(t)}{\delta t} \left[(t_{n-i}) - t_n \right] \qquad (1)$$

According to Equation 1, the prior knowledge of the velocity should be known in order to implement this method. In our case, for the preliminary testing purpose, the velocity is constant at approximately, 0.215 ms^{-1}, throughout the experiment since the platform used is on a straight and even surface. Furthermore, for unmanned aerial vehicle implementation, the ground surface will have no influence to its velocity. However, once the technique is confirmed, the velocity will be acquired from the accelerometer or Inertial Measurement Unit (IMU) before adapting it on UAV. The diameter, *d*, is measured through a dead reckoning technique. In this method, the width of the object under test (pole), δx, is obtained by multiplying the velocity equation with the elapsed time, ($t_{n-1} - t_n$) of the consecutive edges detection of the object. Threshold is set to filter out the unwanted readings and produce a better diameter measurement of an object.

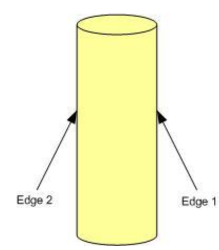


Figure 2a Edge detection based on infrared sensors

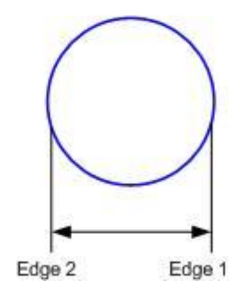


Figure 2b Tree diameter estimation based on the edge detection for a non-stationary measurement context, which the view of angle is hard to be determined through this method due to the nomadic features of the automated mobile vehicle

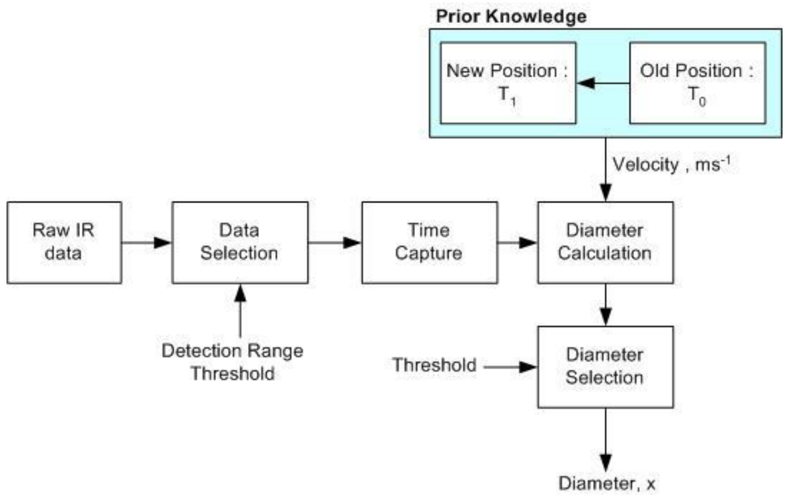


Figure 3 Programming steps involve in diameter calculation with prior knowledge of velocity of the automated vehicle platform

■4.0 HARDWARE IMPLEMENTATION SETUP

The omni directional robot is used to test the proposed detection means of tree (Figure 4). This orientation of mobile robot is applied due to its similarity of holonomic movement of an autonomous aerial vehicle such as quadrocopter. Referring to this figure, the automated omni directional robot is setup in two configurations, which are consisting of a single IR sensor and three IR sensors arrangements on the platform for pole diameter measurement. While on the other hand, the components involved in the hardware development board in testing the proposed diameter measurement technique is showed (Figure 5). It consists of a specific microcontroller from dsPIC30F family, high performance IR sensor which can provide detection range between 20cm to 150cm with 1-cm resolution, DC motors and the drivers, LCD display for showing the sensor reading values, switches, auto-calibration line following sensors (series of IR sensors) as well as XBee wireless board for online data acquisition through personal computer. On the other hand, the dsPIC30F microcontroller is equipped with a line following algorithm that allows the designed robot to move in a controlled straight line during the data capturing process. An ADC is used to convert the analog values received from the IR range finders into understandable digital values which later converted into a meaningful SI unit. For communication protocol controller between development board and personal computer, a wireless Universal Asynchronous Receive Transmit (UART) protocol is utilized. There are two interrupts used in this platform, namely, timer and UART interrupts. Timer interrupt is used to capture the interval times during sensor readings. The latter is used to send motion control signals from personal computer to the robot. A Pulse Width Modulation (PWM) is designed to provide suitable speed controller to the motor to ensure the robot can follow the provided line track and maintain its speed for robust object diameter measurement. To prove the usability of the proposed diameter measurement method for non-stationary automated mobile robot context, the experiment has been conducted on 3 different sizes of objects as shown (Figure 6).

■5.0 DIAMETER MEASUREMENT USING SINGLE IR

Initially, the experiment of measuring the diameter of the objects is started with a single infrared sensor for edge detection. The sensor is mounted in the middle section of the body of the automated mobile vehicle for this purpose. Since the detection is made only by one sensor, the diameter of the object is calculated by using equation (1) straight away without any decision making is made upon completion of the said calculation. The selection of edge detection made by the sensor whenever it passed an object is illustratively showed (Figure 7). The sensor range is limited to 150 cm only regardless of its capability which can senses object as far as 500 cm. This limit is set so that the sensor will only sense the nearest object and any unwanted object that is out of the range in the background can be filtered out or ignored. The results obtained from utilizing a single IR sensor for object diameter measurement of 9 cm, 4cm and 62 cm can be viewed (Figure 8a – 8c and Table 1)

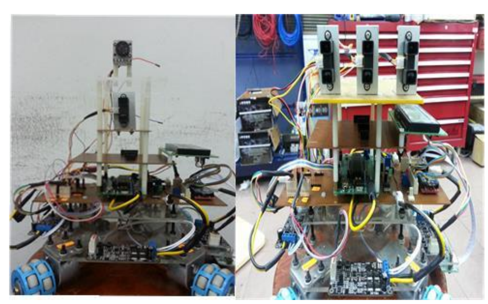


Figure 4 An omnidirectional and automated mobile vehicle platform for pole diameter measurement experiment. (Left to right) A single IR sensor and three IR sensors for diameter measurement

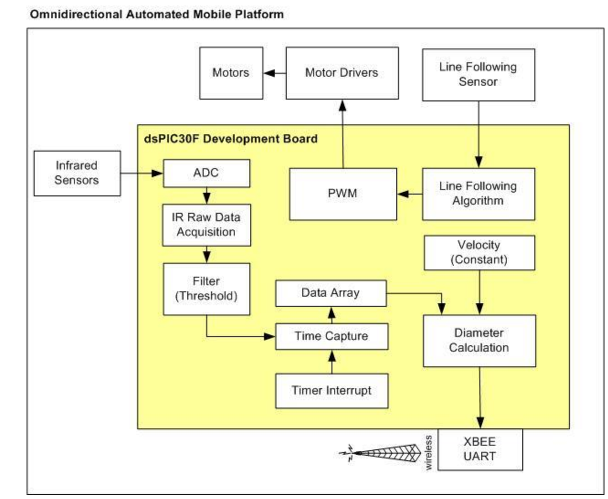


Figure 5. Component blocks of hardware and software involve in hardware development platform of omnidirectional automated mobile platforms

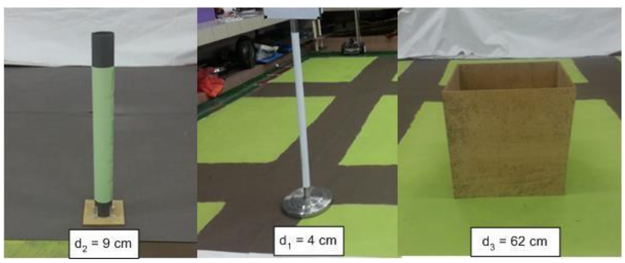


Figure 6 Three objects have been selected for Proof-of-Concept experiment of diameter measurement. (From left to right) Object with diameter of 9 cm (Object 1), 4 cm (Object 2) and 62 cm (Object 3, respectively

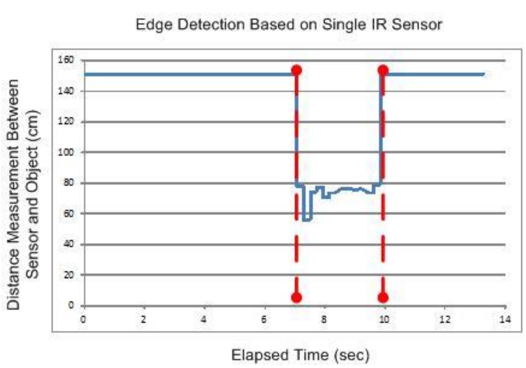


Figure 7 Edge selection from a single IR sensor detection for diameter computation

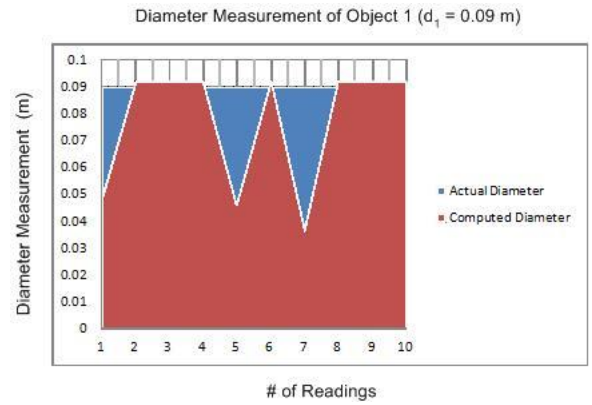


Figure 8a Result of Object 1 (d=9 cm) diameter measurement

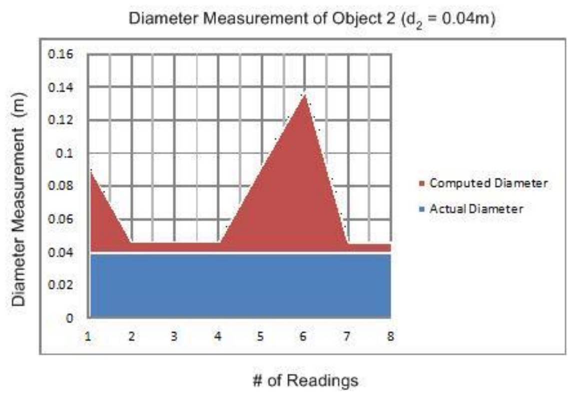


Figure 8b Result of Object 2 (d=4 cm) diameter measurement

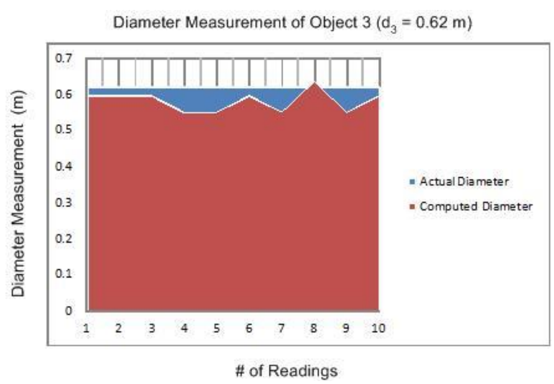


Figure 8c Result of Object 3 (d=62 cm) diameter measurement

Table 1 Result obtained for diameter measurement based on single and multiple sensors orientation

Diameter,*d* (cm)	**9**		**4**		**62**	
Sensor Orientation	**Single**	**Multiple**	**Single**	**Multiple**	**Single**	**Multiple**
Percentage of mean relative error, $\%\rho_{error}$ (%)	16	8	72	26	6	17
Percentage of object recognition (%)	70	100	62.5	93	90	84
Standard deviation, σ (cm)	2.3	0.16	3.4	1.2	2.9	2.1

Based on this experimental results, it can be observed that, the larger the object, the better diameter measurement obtained. For Object 3, which is the size of 62 cm in diameter, acquired the best result with the mean relative error percentage of 6% from its original size and standard deviation of 2.9 cm. For object 2, which is the smallest size of tested object in this experiment, gave the unfittest outcome with the largest mean relative error percentage of 72%, with the lowest pass rate of 62.5% of object recognition in obstacle test as well as a standard deviation of 3.4 cm, which is unacceptable. However, for Object 1, which is 9 cm in diameter, obtained a moderate result of mean relative error percentage of 16% as well as a reasonable pass rate of 70% in object recognition test and standard deviation of 2.3 cm. However, the object diameter measurement technique by using a single infrared sensor is unsatisfactory. This is due to the shortcomings in the edge detection such as when the mobile vehicle is not moving in straight line and the edge of the object cannot be detected properly, which can defect the overall diameter calculation inherent in this approach. Therefore, a scan-based technique by using multiple infrared sensors is developed to overcome this issue which is elaborated in details in the next section.

■6.0 MULTIPLE IR SENSORS FOR DIAMETER MEASUREMENT

To improve the diameter measurement based on the edge detection by infrared sensors, multiple unit of this type of sensor is used consecutively. The sensors are arranged in series, with a gap at approximately 4.5 cm at the center of the automated mobile vehicle (Figure 9). This initial setup is proposed for tree diameter measurement in between 8 cm to 9 cm, however, it can be used to measure other object diameter with certain adjustment in the diameter calculation. The results obtained from the experiments based on this approach for object with diameter of 9 cm, 4 cm and 62 cm is shown, respectively (Figure 10a to 10c as well as Table 1). The 'X' mark that crosses the bar in the graphs indicates the selected diameter measurement among others for the object with the regard to the specified tolerance value, which is ±7 % from the original value that is suitable for our application in the agriculture field. If the calculated diameter does not fall within the allowed value, the data will be discarded.

In the case of Object 1, the mean relative error dropped to 8% from the previous approach with the pass rate of 100% in the object recognition test. The standard deviation for all readings also improved to 0.16 cm. If all sensors did not calculate the diameter correctly, a corrective action is made by using data from sensor 1, '*IR#1*' and sensor 3, '*IR#3*' to compute the new diameter. This additional correction step raises a great benefit in tree trunk diameter estimation in the proposed approach. While on the other hand, Object 2 which was suffered severely in the previous experiment of single IR sensor utilization, the mean relative error percentage managed to benefit significantly reduced to 26%, more or less twice better from its original result and received pass rate of 93% in the object recognition test with the standard deviation improved to 1.2 cm. As we can see in Figure 10b, in the experiment of Object 2 diameter measurement, sensor 3, namely '*IR#3*' did not function properly. However, with the adjustment made in the diameter calculation by manipulating the edge detection made by sensor '*IR#1*' and '*IR#2*', the diameter of it can be calculated thoroughly. Meanwhile, for Object 3, which is the largest diameter of all, did not perform well in this test as the proposed technique is focusing on the tree trunk with the diameter that is extremely smaller than this. However, the results show a promising outcome for Object 3 diameter measurement with a good number of 17% in the mean relative error percentage and 84% pass rate in the object recognition test as well as standard deviation of 2.1 cm, better from the former approach.

The discrepancies of the produced results may be due to the arrangement of the multiple sensors which is specifically dedicated for the trunk with the diameter size of approximate from 8 cm to 9 cm. The inconsistent achievement in the accuracy of the produced results for other objects, which the sizes are relatively not in the range, might incur landmark position in the map (the landmark offset values or coordinates) as well as the precision of the localization problems of the vehicle. However, the small discrepancy of these offset values are significantly small, for example, for Object 3, the pass rate of the object recognition is 84%, which means that the average diameter measurement is 11 cm deviated from its original size, 62 cm. Therefore, the offset of its coordinate is ±11 cm from its original location. Nevertheless, this small deviation might not severely influence the navigation of the vehicles in the targeted environment as it will not solely depend on the landmarks.

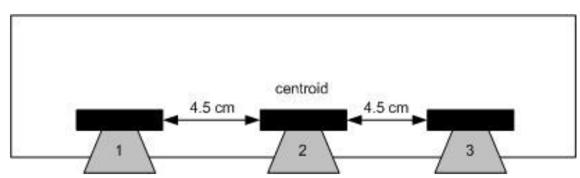


Figure 9 The arrangement of three IR sensors at the center of the automated mobile vehicle to act as a scanner in determining the diameter of an object

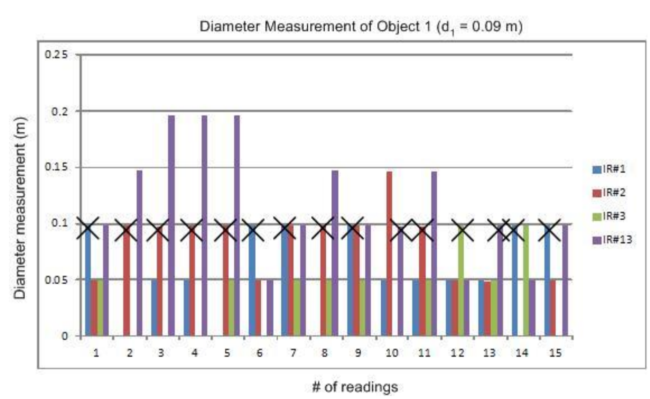


Figure 10a Multiple IR sensors for Object 1 (d = 9 cm) diameter measurement

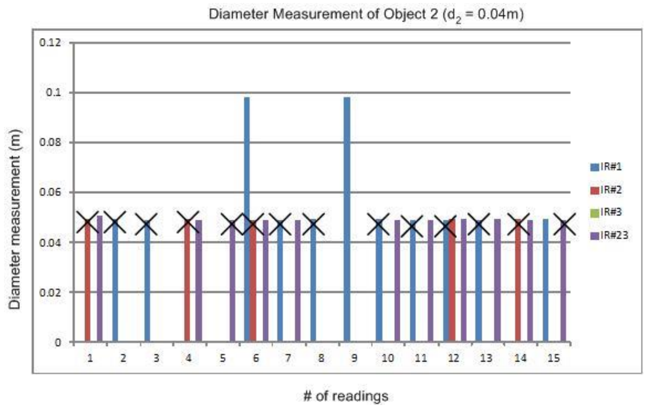


Figure 10b Multiple IR sensors for Object 2 (d = 4 cm) diameter measurement

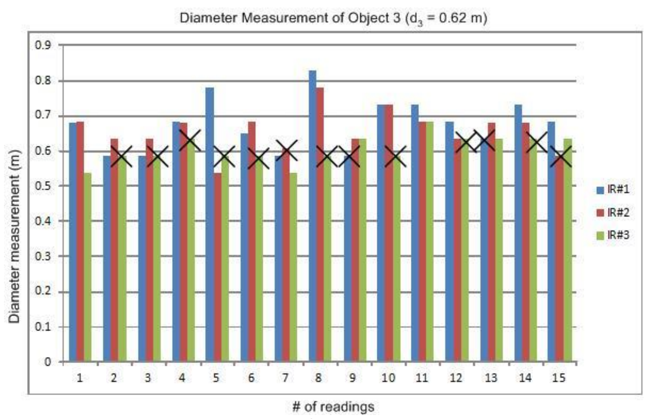


Figure 10c Multiple IR sensors for Object 3 (d = 62 cm) diameter measurement

7.0 CONCLUSION AND FUTURE WORK

Initial experiment in this current approach is utilizing a constant velocity to calculate the diameter of a tree trunk which the real velocity value is required for real-time application. However, the constant value later can be replaced with the real data of velocity that can be obtained from any other suitable sensor like accelerometer or IMU. The innovation of this approach will be considered in later phases of the project. The different between single and multiple IR sensors for edge detection is that the later approach is embedded with the innovative step to calculate the diameter measurement in the case if all sensors fail to detect the edges properly and calculate its diameter rightly. However, for end application, this approach must be innovated by adding other possible techniques to provide additional information in diameter measurement so that it will not compromise to obstacles such as vehicle deviation due to wind disturbance. It is also recommended that this technique to be tested on many objects and trees to prove its reliability and efficiency. Reported by Jakko *et al.*, they tested their diameter measurement technique on 277 trees in the cluttered environment for proof-of-concept test.[3]

Despite that, the proposed technique of diameter measurement is proven can be adapted on a small-scaled unmanned aerial vehicle as the sensors involved are lightweight and practical as the raw data received from them can be easily tuned and manipulated for better performance that is more suitable for real-time embedded system development. Nevertheless, this technique can be used to identify landmarks, in the context of identifying it through the diameter of the tree trunk, that is essential for future structured and organized commercial farm mapping systems.

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