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Multiple Sensor on Clustering Wireless Sensor Network to Tackle Illegal Cutting

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***Abstract*— This paper is intended to purpose a designed system using Wireless Sensor Network application. It is multiple sensors to tackle illegal cutting in the stage of a timber harvesting. This paper also discusses network performance and the costs of the purposed system. In every node in the networks, the system was built using a combined sound sensor and vibration sensor in which incorporated using Xbee Pro S2C. It is considered as a communication module at each sensor node and Arduino Nano to process the data. The Wireless Sensor Network has been designed in three networks with the configuration of master and slave nodes in each network. This system was testing using several scenarios to have the data performance of the networks and the performance of the proposed system in the small forest and the opened area. The costs of the purposed system also compared related to the previous system. The result showed the optimum distance that can be applied in the WSN network as a real-time application using Xbee Pro S2C is less than 30 meters; meanwhile the time consumed to communicate between nodes is below 5 s. Therefore, the more slaves in the subnetwork will affect the performance of the system. The proposed system runs smoothly as predicted in the purposed system. All the testing is 100% completed and can be handled by the proposed system.**

***Keywords*— illegal cutting; wireless sensor network; Xbee Pro S2C; sound sensor; vibration sensor.**

I. INTRODUCTION

A rampant illegal cutting has created the destructive effects on wildlife, society and the global climate [1]. The government from various countries faces the problem of illegal cutting and its trade which associated with loss of income; meanwhile the local communities who are dependent on the forest lost their land and livelihoods. In many timber-producing countries, the majority of timber production is estimated to be illegal in various ways. Previously, most of the illegal timber was generated by selective cutting of high-value trees, while today they take the trees from the conversion of all forest areas.

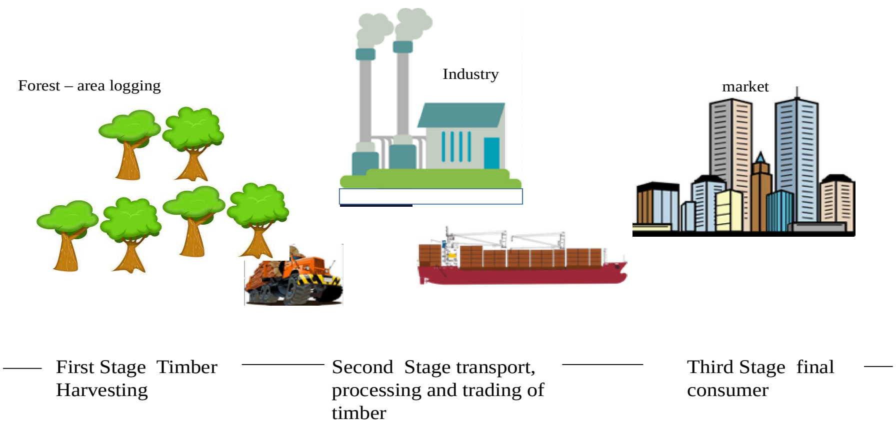

Fig. 1 Timber Supply Chains

Illegal cutting is often misinterpreted as illegal cutting by criminals in protected forests. Most illegal cutting is carried out by companies licensed in the forests that have equipped the permits, but most of the timber sourced from illegal practices is washed through ‘official’ supply chains or which are not identified as illegal since the log is openly traded not hidden trade.

Identifying and tracing illegal timber to the market requires checking different datasets and sources of information at different points along the supply chains. As seen in Fig.1, supply chains can be divided into three general stages. The first stage is a timber harvesting stage; the second stage is transport, processing and trading of timber, includes export. The last stage is the final consumer (market) [2].

Many researchers have been doing the study to tackle illegal cutting. However, even though the illegal cutting can be reduced but it can not eliminate the occurrence of illegal cutting, because the perpetrators are increasingly smart to wash the illegal timber as legal timber.

Wireless Sensor Network is a technology that is very suitable for applications that will be used to tackle illegal cutting. WSN is a technology that can be implemented at indoor and outdoor areas, consisting of many sensor nodes connected to supervise the environment of a wide range area. WSN in illegal cutting research usually used to detect, identify, tracking and monitoring the timber movement from one supply chain stage to other stages [3].

Bantayan et al. conducted a study to detect and identify timber log using Radio-Frequency Identification (RFID) [4]. The use of RFID replaced the old technique of chemical ink and barcode that used to detect and identify the timber log [5]. The RFID was used to store the identities of each tree, such as species, forest origin, and coordinates of its location. Aboussaid et al., also researched to use RFID in identifying and detecting the timber log [6]. Similarly, Luvisi et al. conducted RFID-plants in order to have urban foresty and urban greening for management as a smart city application.

Besides RFID, another sensor can be applied to use as a detection environment in the forest, including to detect the log. The audio sensor or sound sensor is the most used since the illegal cutting corresponds with the sound of a chainsaw. If the sensor detects the sound of the chainsaw, the system can identify the occurrence of cutting trees. Cžuni et al. tried to the used sound sensor to detect the cutting trees and conducted the cutting noise of chainsaw sound using time-domain audio features [7], while Mohdiwale et al., cutting the noise using cumulative short-time Fourier transform features [8]. Kalhara et al. conducted a similar study but enhanced the system using the Application Program Interface (API) and the Internet of Thing (IoT). The noise decrease used fast Fourier transform [9], [10]. Designing WSN to detecting chainsaw also conducted by Kocharoen et al., he used a Bandpass filter to decreased the noise of the chainsaw [11].

The combine sensor nodes were studied using various sensor nodes accelerometer, microphone, and WSN to protect the forest from the cutting [12]. The WSN also conducted by Kassim et al. in the term of agriculture domain [13], [14] on monitoring the Oil Palm using Zigbee. However, according to the research studies above, in this paper, a design of a simple architecture of WSN using multiple sensors consists of a vibration sensor and a sound sensor is proposed using Zig bee as a communication module integrated with each sensor nodes. This paper aims to propose a system that can detect the cutting occurs using WSN as a technology to tackle illegal cutting. The scopes of the proposed system only in the first stage of the timber supply chain.

II. Material and Method

A. Material

The proposed architecture of sensor nodes in the WSN system can be seen in Fig. 2. The system is consists of three networks. Each network consists of four sensor nodes. Three sensor nodes in each network applied as slave nodes and one sensor nodes applied as master nodes. Each node consists of an Arduino Nano, a Vibration Sensor (gyro sensor), an Xbee Pro S2C, a sound sensor, and also a battery to supply the power at sensor nodes.

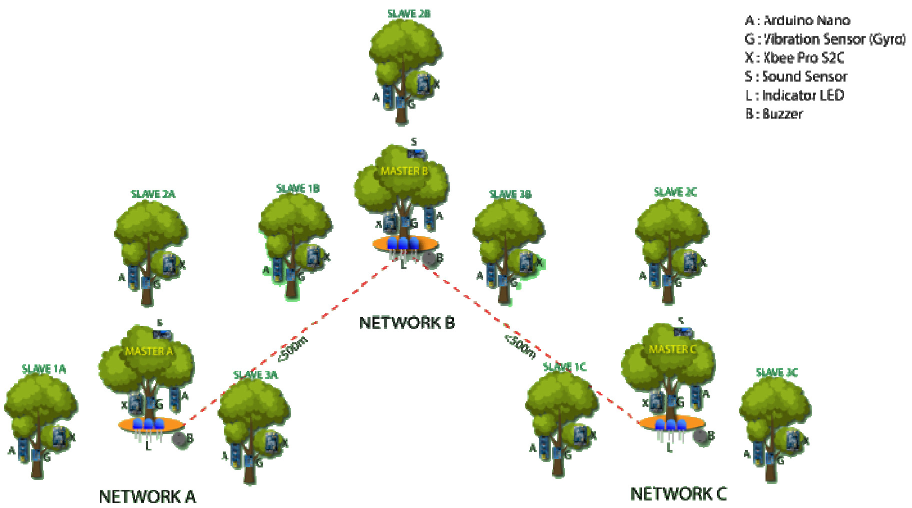

Fig. 2 Sensor Nodes Architecture

Arduino Nano used to process all data from the vibration sensor, Xbee Pro S2C, and sound sensor. Vibration sensor used to detect the falling log trees from the cutting activities while the sound sensor is used to detect the sound of the chainsaw which is coming from the cutting activities. Xbee Pro S2C used as a communication module between nodes. The distance between master nodes is placed around less than 500 meters.

The vibration sensor is placed at each tree while the sound sensor is placed only on the master node. This is because the sound sensor still detects the sounds of the chainsaws which occur in the tree around the master node. The use of the vibration sensor in this system is to subdue the lack of sensitivity found on the sound sensor [15].

The system in Fig. 2. above then will be implemented in a large WSN system as shown in Fig.3. All the master node in each network will be directly sent the data to the fog server. The data in the fog server will then be sent to the cloud sensor. The data in the cloud sensor can be proceed integrated with the Application Program Interface (API) and Internet of Thing (IoT) so that the user in a remote area can do the monitoring of the cutting activities.

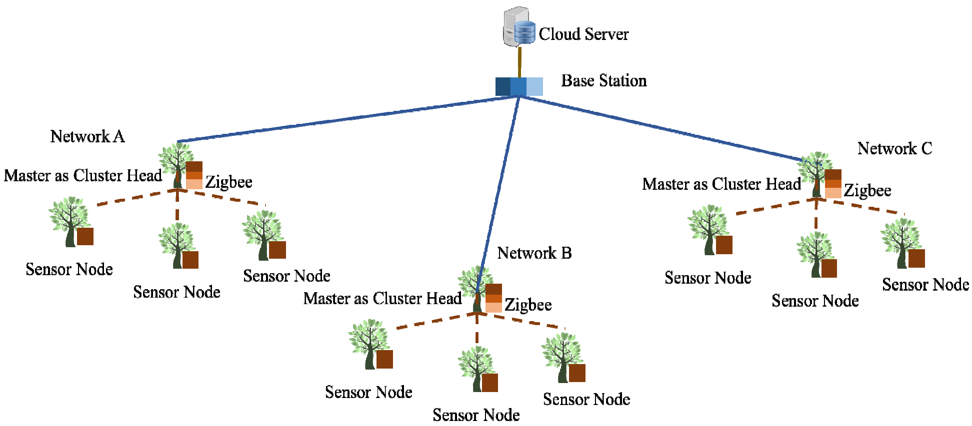

Fig. 3 WSN System Architecture

In this paper, the system will only describe the applied system in harvesting stages of timber supply chains as the first stages. It will outline the construction of the sensor nodes, the cost in each sensor nodes, the communication between nodes, and the performance in each node.

B. Method

The research method used in outlining this study is System Development Research Process adopted from Nunamaker et al. [16], as seen in Fig.4.

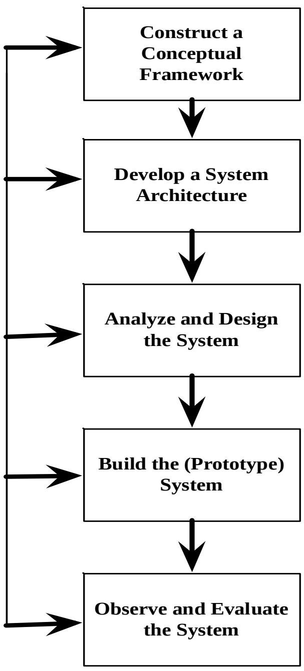

Fig. 4 System Development Research Process

Before conducting the step of construct a conceptual framework, the researchers analyzed the previous studies as the literature review in the introduction section. The construct a conceptual framework, develop system architecture, analyze and design the system, and build the (prototype) system is described in section 2. The last step is to observe and evaluate the system are explained in the result and discussion section.

C. Building System Hardware

Fig. 5 shown the construction of sensor nodes in master nodes. As aforementioned in the previous section, the configuration line between the sensor integrated and Arduino Nano microcontroller was mapped. In the master sensor nodes, the sound sensor is placed to detect the sound of the chainsaws for the trees around the master sensor nodes. Besides that, to inform the police patrol officer whether the cutting occurs, the buzzer and three LED is added into master nodes. Each led represents each network.

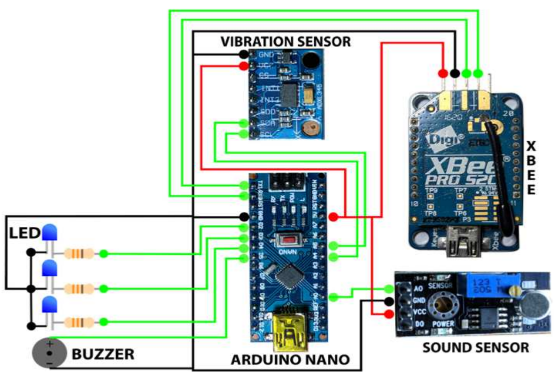

Fig. 5 Master Node Configuration

The configuration of sensor nodes applied as slave nodes can be seen in Fig. 6. At the slave sensor nodes, only the vibration sensor embed with the Arduino.

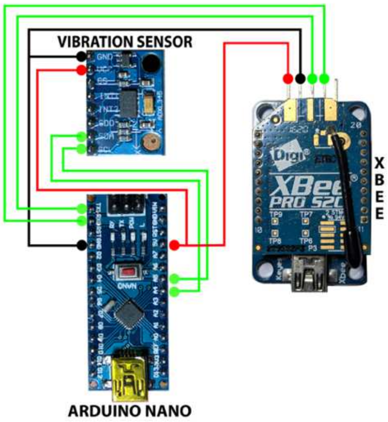

Fig. 6 Slave Node Configuration

After finishing hardware configuration in master nodes and slave nodes, the flowchart of the system can be seen in Fig.7. When all the nodes are running start, master A receives code from slaves in network A. Another master node in other networks also receives code from their slave in their networks. Each network then communicates with each other to forward the data from the sensor nodes into the head cluster, gateway, fog server, and cloud server.

When the system running start, the system supervises the environment. While the cutting occurs, the system detects the sound of the chainsaw and yield the analog value to compare to the default setting that applied if the cutting happened. The vibration sensor also senses the environment if the cutting occurs. If the analog value of the vibration sensor and sound sensor are more than the determined limit, the code illegal cutting will be sent into master nodes. The LED lamp and buzzer lighted on and informed the occurrence of cutting to the police patrol officer.

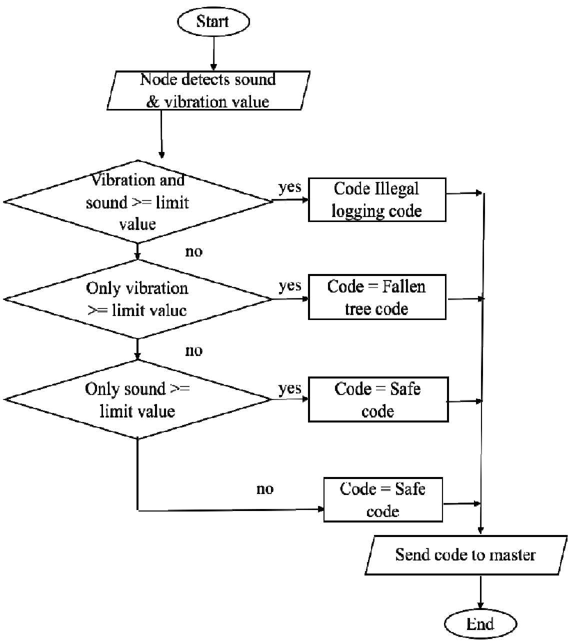

Fig. 7 Flowchart System

The communication between node and master requires a code. The code is interpreted in Table 1. The code interpreter is required in order to communicate between master and slaves. The 'x' in the table represents networks whether it is node slave in network A or node slave in network B or node slave in network C.

TABLE I
CODE INTERPRETER FOR EACH NETWORK

Network	**Part**	**Function**	**Data**	
			Code	**Code Meaning**
A, B, C	Master A,B,C	Receive code from slaves in network A, B, C	111x, 333x, 555x	Turn on a led based on code and play buzzer (cutting)
			121x, 343x, 565x	Turn on a led based on code
			222x, 444x, 666x	Do nothing
	Slave 1A,B,C	Detect vibration and chainsaw sound from 1A, B, C tree and send code based on detected condition	111x	cutting activity occurs in 1A,B,C tree
			121x	1A tree fallen
			222x	1A,B,C tree safe
	Slave 2A,B,C	Detect vibration and chainsaw sound from 2A, B, C tree and send code based on detected condition	333x	cutting activity occurs in 2A, B, C tree
			343x	2A, B, C tree fallen
			444x	2A, B, C tree safe
	Slave 3A,B,C	Detect vibration and chainsaw sound from 3A, B, C tree and send code based on detected condition	555x	cutting activity occurs in 3A, B, C tree
			565x	3A, B, C tree fallen
			666x	3A, B, C tree safe

After conducting the code for each network, the next step is conducting several testing scenario to evaluate the proposed system. The testing scenario are:

- Communication between master and slave
- Proposed *system performance*
- *Cost* Research

III. RESULTS AND DISCUSSION

In order to evaluate the result and discussion, the testing scenario should be conducted to examine the proposed system. The system is examined in the forest area and the open area in order to get a performance that suitable for the forest environment. Fig. 8 shown the place as a testing area for the proposed system.

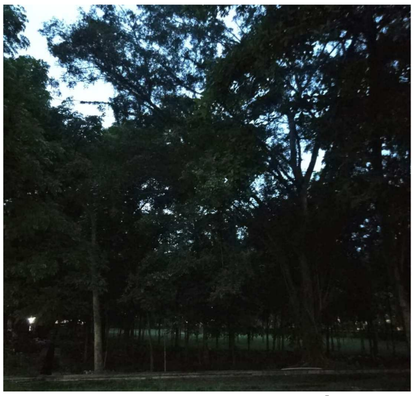

Fig. 8 Forest Environment Tested Area

A. The Communication of Master and Slave Testing

This scenario aims to examine how far the maximum range that can be reached between two module communication Xbee, to be able to communicate with each other nodes in the proposed system. Besides that, the communication of master nodes and slave nodes is examined in the term of time that used to send the message, the optimum distance, the optimum time, and the effect of a number of the slave connected to the master in a network. The testing result is defined using the google map, as seen in Fig.9.

Fig. 9 Defined Measurement Tested Area

The first is to examine the result of maximum distance communication between masters and slaves; this can be seen in Table II. The maximum distance that was obtained using Xbee Pro S2C in order to have communication between sensor nodes was at average 47.58 meters until 61.34 in the forest area and 73.31 meters until 97.75 meters for the maximum distance network in the open area. The difference occurs at the time of measurement. It is because the density of the trees at the area testing varies at each node. This data represents one cluster in the WSN network.

TABLE II
MAXIMUM DISTANCE IN THE NETWORK

Condition	**Maximum Distance (meter)**			
	S1 to M	**S2 to M**	**S3 to M**	**S4 to M**
Forest area	61.34	53.51	58.89	47.58
Open area	97.75	73.31	96.27	85.6

Table III shows the range of time when slave nodes sent a message to the master node. S stands for slave and M stands for master. In the forest area, the delivery time to send the message from slave to master is varying. It is considered average from 13.79 s until 19.77s, while in the open area the average time to send the message into the master node is 10.2s until 17.54 s. This data also represents one cluster in the WSN network.

TABLE III
TIME RESULT FOR MAXIMUM DISTANCE IN THE NETWORK

Condition	**Time (second)**			
	S1 to M	**S2 to M**	**S3 to M**	**S4 to M**
Forest area	15.62	16.78	13.79	19.77
Open area	17.54	10.2	15.88	18.1

The data in Table IV shows the optimum distance that proposes installing the slave nodes to the master node in order to have the best performance for the robust WSN network. The optimum distance that can be applied is in a radius of fewer than 30 meters in the forest area, while in the open area, the radius can reach less than 90 meters. The average time to send the message into the master nodes is 1 until 4 seconds. The optimum placement of sensor nodes influences the throughput of the system since it can allow the system in real-time system conditions because the message can be sent below 5 seconds.

TABLE IV
OPTIMUM DISTANCE VS TIME IN THE NETWORK

Condition	**Distance (meter)**				**Average Time (second)**
	S1 to M	**S2 to M**	**S3 to M**	**S4 to M**	
Forest area	<30	<30	<30	<30	
Open area	<90	<90	<90	<90	1 – 4

The performance of the communication between master and several slaves in one network affected the performance of the communication. As seen in Table V in the open area and the forest environment, the more slaves that are connected to the master node in a network, it causes the reduction performance of the network. However, this was not very significant in WSN with a small number of nodes. However, the problem arises when it used for WSN applications that require more than a hundred nodes in the system.

TABLE V
MASTER VS A NUMBER OF SLAVE IN ONE NETWORK

Condition	**Time (second)**	
	Forest area	**Open area**
1 Slave	16.01	2.12
2 Slaves	16.91	2.78
3 Slaves	17.88	3.15
4 Slaves	18.71	3.55

B. Proposed System Testing

This scenario aims to examine the work performance of the proposed system. This testing will examine the proposed system within the flowchart in Fig.7 above, and the code is shown in Table I. The testing result of the first scenario can be seen in Table VI.

The testing conducting in many times, but the table only has shown the resume of the several tested. In the first test, the codes are determined as the falling tree in the area of network A at nodes 3. The slave nodes 3 sent code 565A to the master node. The master node interpreter as tree fallen in Network A at nodes 3. When the tree was fallen, the sound of buzzer and the LED was lighted on to inform the forest officer. A similar act was also conducted in the second test. When the falling tree happened at node 2 in network C, the code 343 C was interpreted as tree fallen in Network C at nodes 2.

The third test, if the sound of the chainsaw and the tree is falling, the slave nodes sent the code 111B into the master node in network B. The buzzer and the LED in the master node will lit. It informs the forest officer since there is a cutting activity that occurs in network B at node 1.

TABLE VI
WORK PERFORMANCE OF THE PROPOSED SYSTEM

No	Network	Slave	Code	Buzzer	LED	Information
1	A	3	565A	on	Led3 on	Tree Fallen at Network A nodes 3
2	C	2	343C	on	Led2 on	Tree Fallen at Network C nodes 2
3	B	1	111B	on	Led1 on	Cutting Activity occurs in Network B nodes 1
4	A	2	444A	off	off	Tree safe at Network A nodes 2

The fourth test conducted with doing nothing since the fourth test is the default condition of the proposed system. The buzzer and the LED are in off condition. All the tests conducted in this section are the master nodes that can interpret 100 %.

Another testing is conducted in order to examine the performance of the proposed system. At Table VII, the performance of the proposed system when much cutting happened at the same time in the same network. Based on the table, all the cutting happened can be interpreted by the proposed system and informed the forest officer, precisely 100%.

TABLE VII
THE PERFORMANCE OF CUTTING TREE IN A NETWORK

No	Network	Slave	Code	Buzzer	LED	Information
1	A	3	555A	on	Led3 on	Tree Fallen at Network A nodes 3
2	A	1	111A	on	Led1 on	Cutting Activity occurs in Network A nodes 1
3	C	1	555C	on	Led1 on	Cutting Activity occurs in Network C nodes 1
4	C	2	333C	on	Led2 on	Cutting Activity occurs in Network C nodes 2

C. Cost Research

Another discussion that can be evaluated in this section is the cost of the purpose system. According to the previous study [6], Aboussaid et al., using passive RFID to tackle illegal cutting. As seen in Table VIII, the total cost that has been drafted by Aboussaid et al. is $ 856.99 while the total cost of the proposed system is $ 45.6. According to that condition, it can be concluded that the price of the total cost in one node of the RFID system is equivalent to the use of WSN as much as 19 sensor nodes.

TABLE VIII
COST COMPARISON OF SENSOR NODES

Sensor Nodes		Cost	Total
RFID	Passive RFID tags	$ 2	$856.99
	Antenna	$ 54.99	
	Handheld Reader Device	$ 800	
WSN	Arduino Nano	$ 4.3	$ 45.6
	Vibration Sensor	$ 1.5	
	Sound Sensor	$ 1.8	
	Zigbee	$ 38	

IV. CONCLUSION

This research proposed a basic system of a Wireless Sensor Network that can be applied in illegal cutting domain research. Since the area of the forest that will be supervised by the system is a vast and comprehensive range, so it needs a clustering in order to have a robust, stable, potential network. The use of the combined sensor of vibration sensor and the sound sensor is in order to have better quality since the sound sensor has limited performance in detecting the sound of the chainsaw. So, the lack of the sensor can cover the use of the vibration sensor.

Clustering the WSN as a sub-network A, B, C can gain the performance of the purposed system, since the load of the operational of the network can be divided by each network. The optimum installed nodes can be done by range distance less than 30 meters for forest area environment. The more slaves that are connected in one network will cause network performance. Although it is not significant, network performance should be considered to get the optimum results.

For future works, the system can be enhanced to do tracking and monitoring besides detection and identify the illegal cutting activities. By using an integrated Global Positioning System, the coordinate of every tree in the forest can be located and save it into the cloud server. API and IoT also can be applied in the system and give the high interface performance for the user for tracking and monitoring the cutting system using the WEB browser remotely.

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