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Tilt Level Monitoring and Switch Information System for Heavy Equipment of BOMAG BW 211D-40SL Series

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Abstract*—*Bomag BW 211D-40 SL is a long-term investment capital in the field of heavy equipment. This unit is used for soil compaction in the construction process or others. One of the main components in this unit is the final drive. In this section, it consists of a planetary gear arrangement. The final drive component is one of the components that often experience damage, one of the causes of the damage of this component is due to errors when operating on tilt conditions. This research uses experimental methods to design a tilt monitoring tool for the unit during operation that can send notifications in real-time (using the internet of things). The device uses an MPU 6050 sensor to detect the tilt of the unit and is combined with the GSM Module SIM800L as a data sender to the internet. The vehicle owner or foreman mechanic can monitor through Blynk. This notification is in the form of a condition of the unit's slope that is working normally, warning with slope conditions above. This data will be used as a basis for assessing the work competence of correct or incorrect operators.

Keywords*—*final drive, MPU 6050, SIM800L, internet of things, accuracy, Bomag.

I. INTRODUCTION

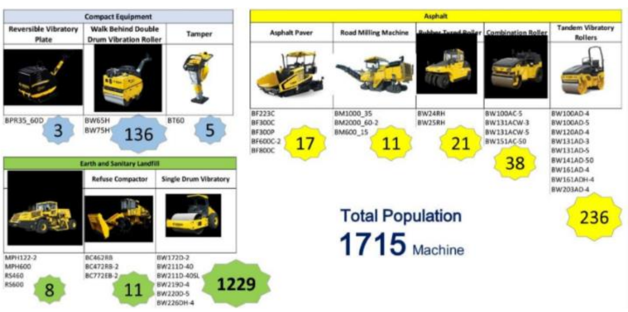


Fig. 1. Bomag population

Based on Fig. 1., it shows that the largest population of PT United Tractors' sales data in 2022 from one Bomag brand is dominated by compactor units or soil compactors, both single rollers and double rollers [1]. This also emphasizes that the article above related to the development that the Indonesian government continues to pursue is true, that can be seen from the large sales of construction units at PT United Tractors [2].

In line with the condition of increasing sales of compactor units, this is also directly proportional to the trend of problems that emerged over the unit. The problems arise with various conditions ranging from maintenance problems, incorrect operating procedures, the type of lubricant used is not right, and others.

Regarding maintenance on heavy equipment, it can be seen based on data that maintenance for the bottom of the unit (undercarriage and final drive) costs the most compared to other components, as shown by Fig. 2 Maintenance cost of heavy equipment [3].

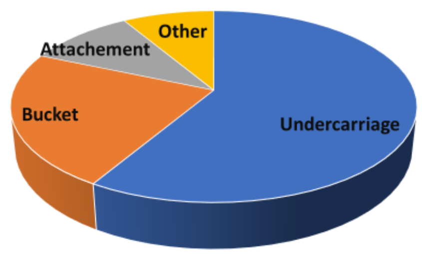


Fig. 2. Maintenance cost heavy equipment

Based on the several problems that occur above, some cases occur due to maintenance-related errors as well as problems caused by errors when operating the unit. There are several problems that become concerns to researchers and companies, namely related to damage to the final drive at one of the customers [4]. This has become a concern because, in addition to the equipment that should be strong, the price is also quite expensive.

Fig. 3. Final drive damage

Fig. 3 shows one of the findings of a problem that occurred at the customer. The picture above shows the condition of the high-level damage of the final drive. Upon the findings of the problem, PT United Tractors looked for the root of the problem [5].

Based on the results of the investigation, it was found that wrong operation was the main factor in the damage to the final drive, with the result analysis as in Fig. 4 from technical officer PT United Tractors final drive was broken [5].

Result analysis from the technical officer of PT United Tractors, which is the main factor causing damage to the final drive is caused by frequently excessive slope operation of the unit, with an average of 39% or 23 degrees. It makes the load concentrate a lot on the final drive. Based on the manual in the service manual BW 211D-40 SL as shown in Fig. 4. Table Maximum Gradeability, the limit of the unit operating on slopes is 37% [6].

Travel characteristics		
Travel speed (1)	0–4 (0–2.5)	km/h (mph)
Travel speed (2)	0–9 (0–5.6)	km/h (mph)
Max. gradeability without/with vibration (soil and weather dependent)	37/35	%

Fig. 4. Max gradeability

Fig. 4. shows the max gradeability or slope allowed on the Bomag BW 211D-40SL unit is 37% when not activating vibro and 35% when activating vibro. Based on this data, it can be converted to grade resistance by looking at Fig. 5. The number can be the maximum limit of the unit working on tilted conditions $\angle 22^o$ [7].

Table 15 Grade resistance (%) converted from angle (°) of gradient

Angle	% (sin α)	Angle	% (sin α)	Angle	% (sin α)
1	1.8	11	19.0	21	35.8
2	3.5	12	20.8	22	37.5
3	5.2	13	22.5	23	39.1
4	7.0	14	24.2	24	40.2
5	8.7	15	25.9	25	42.3
6	10.5	16	27.6	26	43.8
7	12.2	17	29.2	27	45.4
8	13.9	18	30.9	28	47.0
9	15.6	19	32.6	29	48.5

Fig. 5. Coinvented grade resistance from angle

The above occurrence may happen because the Bw 211D-40 SL unit is not equipped with a tilt sensor, so the operator does not know the tilt condition of the unit when operating. In the current conditions, operation on the slope has not yet have an indicator that can be a reference for the operator. The maximum operation on the slope on the single roller unit based on the reference of the Operating Manual BW 211D-40 SL is at 37% [8].

In this paper, the authors researched and designed a device for tilt level monitoring tools that creates notifications in real-time using a buzzer. IOT as a notification to the unit owner sends SMS Notification and the location of the error by installing GPS on the device, so that the owner can find out the wrong condition at that time with the SMS and the location of the unit. It can improve conditions in the field. The device can install add-ons on the BW 211D-40SL unit without changing the structure. The device will use an incline sensor to detect the unit's tilt wear and combine it with an Arduino Mega and Buzzer module so that the operator will be reminded when the slope is approaching the limit with the sound of the Buzzer. The data will be stored in the cloud that later, the data will be sent to unit owners to be used as a working condition evaluation material in the field.

II. Methodology

In this study, experimental method (Fig. 6 and Fig. 7) is applied in this study. As explained in Sugiyono [9], the experimental research method is a research method used to find the effect of certain treatments. Meanwhile, the method used in this research aims to reveal the impact of a treatment [9].

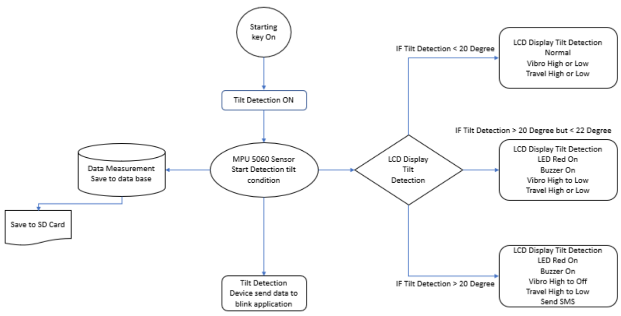


Fig. 6. Concept design

Detection	Degree	Notification	LED	Buzzer Tone	Sending SMS Notification	Blynk Monitoring
Tilt Level	$< 20^o$	Normal	OFF	OFF	NO	YES
Tilt Level	$> 20^o < 22^o$	Warning	ON	ON	NO	YES
Tilt Level	$>22^o$	Danger	ON	ON	YES	YES

Fig. 7. Logic device

There are three conditions that will be noted on this device:

1. The condition of the sensor reads a tilt of less than 20 degrees. At that time, the monitor will appear in normal conditions, travel can be high or low mode, as well as vibro working conditions can be low or high, alarm does not sound and there is no SMS notification to the unit owner.
2. The condition of the sensor reads a slope between 20 to 22 degrees. In this condition, the monitor will give a warning in the form of a warning sign with a red symbol and an alarm sound, so that the operator begins to pay attention to the working conditions carried out and this is as real time information for the operator. Currently the

work mode for travel can still be high and low. As for the vibro work mode, only low mode is allowed, so if at this time the vibro working condition is high, it will be changed to the low position and there is no notification to the unit owner.

3. The condition of the sensor reads a slope above 22 degrees. In this condition, the monitor will give a warning in the form of a warning sign with a red symbol and an alarm sound, so that the operator realizes their working conditions starts to be unsafe and this is a real time information for the operator. Currently the work mode for travel can only be low, while for vibro work mode is not allowed either low or high mode. If at this time the vibro working condition is high, it will be changed to off position, as well as if the vibro is in low condition, it will be changed to the off position. Notification in the form of SMS is sent to the unit owner so that the unit owner is aware that his unit is used in a wrong working conditions. The owner can also find out the location of the incident by reading the coordinates informed, so that if the condition is in error, the owner can instruct their members to repair it.

A. *Hardware Design*

The hardware components (Fig. 8) are designed into three major parts namely input devices, processing devices, and output devices. There is a component description of the three assembly devices (Fig. 9):

1. Input device: Sensor MPU 6050, GPS.
2. Processing devices: Arduino Mega, GSM module
3. Output device: LCD, Buzzer, relay.

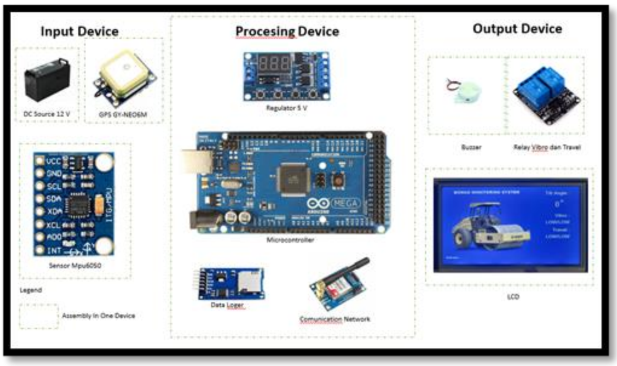


Fig. 8. Part device

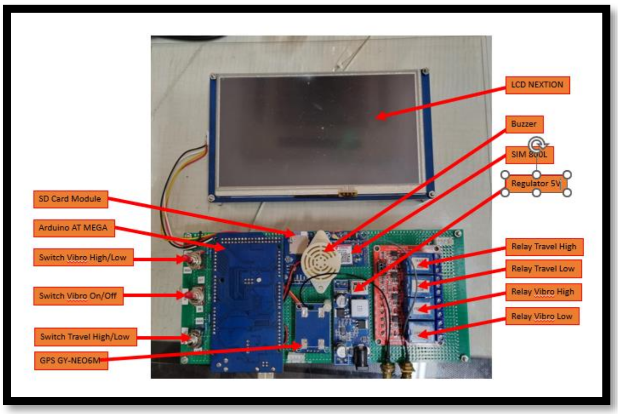


Fig. 9. Prototype device

B. *IoT Design.*

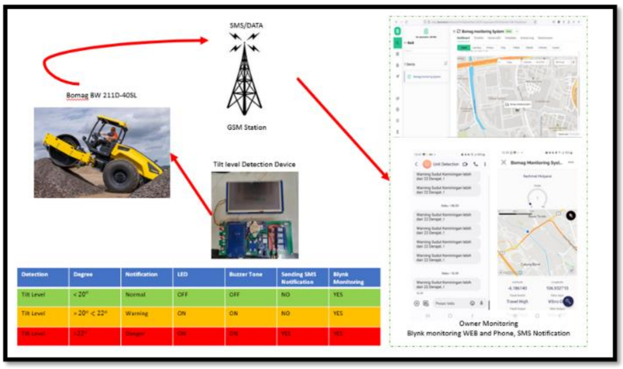


Fig. 10. IoT design

Tilt level monitoring is equipped with an internet of things system (Fig. 10). The explanation of how it works is a monitoring system using Blynk and SMS push notifications. Blynk is used to monitor the tilt of the unit when working normally and gives warning when working at an incline of more than 20 degrees but less than $\angle 22^{O}$ and the maximum limit at $\angle 22^{O}$. SMS push notifications are sent automatically to the unit owner or foreman when the $\angle 22^{O}$ tilt limit condition is reached. Io design as shown in Fig. 10.

C. *Connected Hardware, Sensor and IoT*

This device design able to 5 things:

1. Read the degree of inclination of the unit.
2. Sensor housing that can protect from noise interference, so it does not affect the performance of the sensor when taking measurements.
3. Sensor housing withstands shocks, water flushing immersion, and gravel hit.
4. Display notifications, LED lights, and bells when tilt reads as follows:
   a. If the tilt value is below $\angle 20^{O}$, LCD displays the value and normal conditions, normal LED, the sound of the bell is off, travel conditions can be high and low, vibro can be high and low and does not send SMS push notifications.

b. If the tilt value is between $\angle 20^{O} - \angle 22^{O}$ LCD displays the value and the tilt warning of the unit, LED lights up, the sound of the bell is on, travel conditions can be high and low, the vibro will be changed to the low position, and not sending any SMS push notifications.

c. If the tilt value is greater than $\angle 22^{O}$, LCD displays the value and the tilt warning of the unit, LED lights up, the sound of the bell is on, travel conditions are changed to the low position, vibro will be disabled right away, and send SMS push notification.

5. Monitor tilt level condition via Blynk.

D. Validation and Experimental procedure:

1. Validation.

Before conducting experiments, the authors must validate the tilt sensor. The error value for the MPU 6050 sensor is not listed by the manufacturer so the authors need to calculate it. The validation process is based on Fig. 11.

	Tilt Conditi	Actual Value	Error	(Error/Tilt Condition)*100%
Trial 1	2	2,03	0,03	0,015
Trial 2	2	2,2	0,2	0,1
Trial 6	5	5,12	0,12	0,024
Trial 7	5	5,07	0,07	0,014
Trial 11	10	10,03	0,03	0,003
Trial 12	10	10,14	0,14	0,014
Trial 16	15	15,03	0,03	0,002
Trial 17	15	15,03	0,03	0,002
Trial 23	20	20,02	0,02	0,001
Trial 24	20	20,02	0,02	0,001
Trial 25	20	20,03	0,03	0,0015
Trial 29	21	21,01	0,01	0,00047619
Trial 30	21	21,02	0,02	0,000952381
Trial 33	22	22	0	0
Trial 34	22	22,02	0,02	0,000909091
Trial 35	22	22,02	0,02	0,000909091
Trial 39	23	23,01	0,01	0,000434783
Trial 40	23	23,02	0,02	0,000869565
Trial 44	25	25,01	0,01	0,0004
Trial 45	25	25,03	0,03	0,0012
Trial 49	30	30,02	0,02	0,000666667
Trial 50	30	30,01	0,01	0,000333333
			Total Eror	0,270869302
			Average	0,005417386
			Accuracy	0,994582614

Fig. 11. Result validation

$$\text{Error} = \frac{\text{Actual Value Device}}{\text{Value protractor}}$$

$$\text{Total Error} = \sum\left(\frac{\text{Actual Value Device}}{\text{Value protractor}}\right) \times 100\%$$

$$\text{Average Error} = \frac{\text{Total Eror}}{\text{Total Experiment}}$$

$$\text{Accuracy} = 1 - \text{Average Error}$$

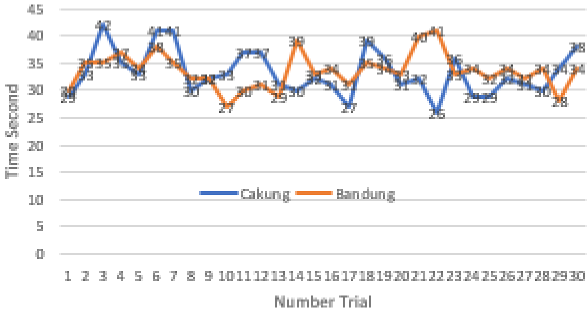
Referring to the device validation data in Fig. 11 validation, it can be seen that:

$$\text{Average Error} = 0.0055$$

$$\text{Accuracy [10]} = 1 - 0.0055$$

$$= 0.9945$$

2. Time taken for the device to communicate with the internet as shown in Fig. 12. This experiment was carried out in two places, namely Cakung and Bandung.



Location Test	Cakung	Bandung
Average (second)	33,23	33,53

Fig. 12. Time it takes for device communicate to internet

The time of 30 seconds is acceptable, because based on the guide to use the unit, it is necessary to warm up the unit for about 5 minutes before operating the unit.

3. Device accuracy during interference with noise.

Trial Numb	Tilt Condi	Actual	error	(error/derajat)*100%
1	19	18,97	0,03	0,001578947
2	19	19,01	0,01	0,000526316
3	19	18,99	0,01	0,000526316
4	19	19,03	0,03	0,001578947
5	19	18,34	0,66	0,034736842
6	19	18,94	0,06	0,003157895
7	19	19,1	0,1	0,005263158
8	19	19,21	0,21	0,011052632
9	19	18,97	0,03	0,001578947
10	19	19,04	0,04	0,002105263
18	20	20,06	0,06	0,003
19	20	20,7	0,7	0,035
20	20	20,08	0,08	0,004
21	22	22,87	0,87	0,039545455
22	22	23,01	1,01	0,045909091
23	22	22,76	0,76	0,034545455
24	22	22,98	0,98	0,044545455
25	22	22,46	0,46	0,020909091
26	22	22,23	0,23	0,010454545
27	22	22,98	0,98	0,044545455
28	22	22,89	0,89	0,040454545
29	22	22,76	0,76	0,034545455
30	22	22,98	0,98	0,044545455
			total erro	0,723605263
			Average	0,024120175
			Accuracy	0,9759

Fig. 13. Result interference with noise

$$\text{Error} = \frac{\text{Actual Value Device}}{\text{Value protractor}}$$

$$\text{Total Error} = \sum\left(\frac{\text{Actual Value Device}}{\text{Value protractor}}\right) \times 100\%$$

$$\text{Average Error} = \frac{\text{Total Eror}}{\text{Total Experiment}}$$

$$\text{Accuracy [10]} = 1 - \text{Average Error}$$

By referring to the device validation data in Fig. 13, it can be seen that:

$$\text{Average Error} = \frac{0{,}7236}{30}$$

$= 0.0241$

Accuracy $= 1 - 0.0241$

$= 0.9759$

4. The device is accurate if the sensor housing is shaken, hit by gravel, and doused with water.

Trial Numb	Tilt Condi	Actu al	error	(error/derajat)*1 00%
1	19	19,43	0,43	0,022631579
2	19	18,89	0,11	0,005789474
3	19	19,1	0,1	0,005263158
4	19	19,12	0,12	0,006315789
5	19	19,09	0,09	0,004736842
6	19	19,03	0,03	0,001578947
7	19	19,05	0,05	0,002631579
8	19	19,96	0,96	0,050526316
9	19	18,92	0,08	0,004210526
10	19	19,31	0,31	0,016315789
18	21	20,96	0,04	0,001904762
19	21	21,11	0,11	0,005238095
20	21	21,01	0,01	0,00047619
21	22	22,21	0,21	0,009545455
22	22	23,01	1,01	0,045909091
23	22	22,01	0,01	0,000454545
24	22	22,23	0,23	0,010454545
25	22	21,98	0,02	0,000909091
26	22	23,89	1,89	0,085909091
27	22	22,04	0,04	0,001818182
28	22	22,13	0,13	0,005909091
29	22	22,06	0,06	0,002727273
30	22	22,32	0,32	0,014545455
			total erro	0,437229437
			Average	0,014574315
			Accuracy	0,985425685

Fig. 14. Result durability test

$$\text{Error} = \frac{\text{Actual Value Device}}{\text{Value protractor}}$$

$$\text{Total Error} = \sum\left(\frac{\text{Actual Value Device}}{\text{Value protractor}}\right) \times 100\%$$

$$\text{Average Error} = \frac{\text{Total Eror}}{\text{Total Experiment}}$$

$$\text{Accuracy} = 1 - \text{Rata} - \text{Average Error}$$

By referring to the device validation data in Fig. 14, it can be seen that:

$$\text{Average Error} = \frac{0.4372}{30}$$

$$= 0.0146$$

$$\text{Accuracy [10]} = 1 - 0.0146$$

$$= 0.9854$$

5. Accuracy of the tool at low temperatures and hot temperatures.

	Tilt Condition	Actual	error	(Error/Tilt Condition)*100%
Trial 1	15	15,01	0,01	0
Trial 2	18	18,03	0,03	0,001666667
Trial 3	19	19,02	0,02	0,001052632
Trial 4	18	18,02	0,02	0,001111111
Trial 5	18	18,03	0,03	0,001666667
Trial 6	19	19,02	0,02	0,001052632
Trial 7	20	20,01	0,01	0,0005
Trial 8	20	20,01	0,01	0,0005
Trial 9	19	18,98	0,02	0,001052632
Trial 10	22	21,97	0,03	0,001363636
Trial 11	22	22,01	0,01	0,000454545
Trial 12	23	23,02	0,02	0,000869565
Trial 13	23	22,99	0,01	0,000434783
Trial 27	22	22,02	0,02	0,000909091
Trial 28	22	22,23	0,23	0,010454545
Trial 29	23	22,95	0,05	0,002173913
Trial 30	23	23,67	0,67	0,029130435
Trial 31	19	19,26	0,26	0,013684211
Trial 32	20	20,82	0,82	0,041
Trial 33	20	20,41	0,41	0,0205
Trial 34	18	17,85	0,15	0,008333333
Trial 35	19	19,03	0,03	0,001578947
Trial 36	20	20,02	0,02	0,001
			total eror	0,530557497
			rata2 eror	0,014737708
			akurasi	0,985262292

Fig. 15. Result low temperature test

$$\text{Error} = \frac{\text{Actual Value Device}}{\text{Value protractor}}$$

$$\text{Total Error} = \sum\left(\frac{\text{Actual Value Device}}{\text{Value protractor}}\right) \times 100\%$$

$$\text{Average Error} = \frac{\text{Total Eror}}{\text{Total Experiment}}$$

$$\text{Accuracy} = 1 - \text{Average Error}$$

Referring to the device validation data in Fig. 15:

$$\text{Average Error} = \frac{0.5305}{30} = 0.0147$$

$$\text{Accuracy [10]} = 1 - 0.0148 = 0.9852$$

	Tilt Condition	Actual	error	(Error/Tilt Condition)*100%
Trial 1	5	4,97	0,03	0,006
Trial 2	22	22,42	0,42	0,019090909
Trial 3	22	22,33	0,33	0,015
Trial 4	23	23,12	0,12	0,005217391
Trial 5	23	23,32	0,32	0,013913043
Trial 6	19	19,02	0,02	0,001052632
Trial 7	20	20,16	0,16	0,008
Trial 8	20	20,31	0,31	0,0155
Trial 9	19	19,92	0,92	0,048421053
Trial 10	22	22,13	0,13	0,005909091
Trial 11	22	22,32	0,32	0,014545455
Trial 12	18	18,12	0,12	0,006666667
Trial 13	19	19,32	0,32	0,016842105
Trial 27	22	21,98	0,02	0,000909091
Trial 28	22	22,29	0,29	0,013181818
Trial 29	23	23,27	0,27	0,01173913
Trial 30	23	23,28	0,28	0,012173913
Trial 31	19	19,21	0,21	0,011052632
Trial 32	20	20,22	0,22	0,011
Trial 33	20	20,04	0,04	0,002
Trial 34	18	18,03	0,03	0,001666667
Trial 35	19	19,2	0,2	0,010526316
Trial 36	20	20,01	0,01	0,0005
			total eror	0,424068719
			rata2 eror	0,014135624
			akurasi	0,985864376

Fig. 16. Result high temperature test

$$\text{Error} = \frac{\text{Actual Value Device}}{\text{Value protractor}}$$

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$$\text{Total Error} = \sum\left(\frac{\text{Actual Value Device}}{\text{Value protractor}}\right) \times 100\%$$

$$\text{Average Error} = \frac{\text{Total Eror}}{\text{Total Experiment}}$$

$$\text{Accuracy} = 1 - \text{Average Error}$$

By referring to the device validation data in Fig. 16 :

$$\text{Average error} = \frac{0.424}{30} = 0.0141$$

$$\text{Accuracy [10]} = 1 - 0.0141 = 0.9859$$

6. The function of the device is to monitor the working condition on the slope and send SMS push notification function works when the maximum limit of the slope (IoT work Test) as shown in Fig. 17.

Detection	Degree	Sending SMS Notification	Blynk Monitoring	Buzer	Validation
Tilt Level	< 20°	NO	YES	OFF	OK
Tilt Level	> 20° < 22°	NO	YES	ON	OK
Tilt Level	>22°	YES	YES	ON	OK

Fig. 17. Result experiment IoT tst.

III. Conclusions And Recomendations

A. Conclusions

- The unit's tilt monitoring device works accurately in measuring various tilt conditions based on MPU 6050 sensor readings. The accuracy value with no interference is 99.45%, with sound interference 97.59%, vibration interference 98.54%, low temperature conditions 98.52% and high temperature conditions by drying in the sun 98.59%.
- The biggest error occurred when given sound interference is at 2.41%, but the error rate of 2.41% is considered as low.
- This tool works according to the scheme when the angle reaches 20 degrees, the alarm sounds as a warning sign to the operator and the working condition of vibro and travel can only be in low position controlled by the device. When the tilt angle reaches 22 degrees, in addition to the alarm sounds, the vibro will be turned off by the device and the travel is made low by the device and notifications are sent via SMS to the owner.
- IoT system testing and real time monitoring work according to the design, with testing done in two places, Bandung and Jakarta, using GSM providers.

B. Recommendations

- A study to examine why the MPU 6050 sensor is affected by sound interference is needed. According to previous research, there is the use of filters to eliminate sound interference from the MPU 6050 sensor.
- The test needs to be done longer to get more accurate durability data, so that it can be proven after installing this tool, there is no more damage to the Final Drive due to operating errors.

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