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Study of direct current motor power requirement for manikin smart irrigation systems

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Abstract

Manikin Irrigation Area (I.A) has ± 3000 ha of the area, utilizes the water source from the Tefmo Dam and distributes to the Primary-Secondary-Tertiary channels with controlled by watergates that operated by lift. This mechanism has resulted in jealousy and squabbles in farmer groups because of the inequality distribution that ultimately decreases crop production. The development of Microcontroller Technology has changed the Watergate model into an automated system based on certain parameters and algorithms. One of that being developed is the smart irrigation system based on Arduino at Manikin I.A that regulates the water to land based on the time from the Real-Time Clock sensor and uses Direct Current (DC) motor as a driver to watergate. While it may work, but the system has not considered the power requirement of DC motor when the water flows in the maximum discharge and pressure affecting the motor. This study examines the power requirement of an ideal DC motor for smart watergate in 5 open channels in Manikin I.A. Based on the open channel standard parameters, a total load measurement is performed when the water given speed (V) and pressure (p) then converted to energy. The study results that on 5 different open channels in Manikin I.A, with 0.30 m^3/s maximum water discharge and 7.56 m/s^2 flow rate, a watergate control requires DC motor that has 35 to 43 Watt power (39,4 Watt average power) or 3 to 3.5 Ampere current (3,26 Ampere average Current) in order to 24-hours work.

Keywords: *arduino, DC motormanikin irrigation area, open channel, smart irrigation,*

1. Introduction

Manikin Irrigation Area (I.A) is one of the agricultural areas in Kupang, East Nusa Tenggara Province which has ± 3000 ha of area [1, 2]. Management of Manikin I.A utilizes water from the Tefmo Dam that has a 298 liters/second of water discharge [3] as an irrigation source as other irrigation areas that conceptually utilize water from dams, ponds, checks or other groundwater as an irrigation source of the farm [4–6]. The distribution of water to the irrigation area passes the primary-secondary-tertiary open channels [7] and it's controlled through the watergates at each meeting channel according to the irrigation standards from the Indonesian Ministry of Public Works [8, 9].

Generally, the operation of the Watergate in the channels is still done conventionally by lifted, shifted or rotated, based on the Watergate model and the farmer's participation [10]. However, evaluations in some places show that differences in performance between the irrigation concept and implementation [11], as in Manikin I.A which often leads to jealousy and quarrels among farmers due to uneven distribution of water and resulting in declining yields [12–14].

The development of microcontroller technology, sensors, and controls resulted in many conventional mechanical systems developed into automated systems based on certain parameters and algorithms in the form of application programming [15, 16]. Some of them are the irrigation water gate developed using Arduino for Manikin I.A [17], Smart Home Garden Irrigation System Using Raspberry Pi, reduce physical human interface, control the solenoid valve according to human's requirements and sent to the user for alert purposes either for normal or critical operations [18], Automatic Door System using a unique wireless ID by using infrared ray or Bluetooth technology and Assessment of DC Servo Motor with Sliding Mode

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Control Approach but does not assess how much power is optimal [19, 20], other smart development module for practicum activity [21] and Digital Pattern Approach to the Design of an Automotive Power Window by means of Object-Oriented Modelling, that utilizes only a DC motor without examining the ideal power required for an object being driven [22]. The smart watergate system developed to Manikin I.A, consists of 2 main parts, the mechanical, and the control part. Mechanical parts include that door frames and door plates made of steel with DC motors as a driver. While the control part consists of Arduino as a central processing and Real-Time Clock (RTC) sensors that perform the process of data transmission based on client-server [23]. RTC transmits the data time in form of voltage to the microcontroller using the scheduling method in queue data system [24]. While Arduino acts as a server that processes the data time and issues recommendations to external devices. The use of DC motors in this system is less efficient because it quickly emits heat when it has been operating for a while so it is not optimally used for a long time.

In the guidelines of irrigation systems in Indonesia, it has recommended the size and specifications of channel and Watergate. However, when converted to an automated system, the study and selection of a DC motor as a driver needs to account so that the operation of smart irrigation systems becomes more optimal with the availability of DC motor, whereas, The speed of motor DC and other parameters affect the performance of the smart irrigation system [25, 26]. Some parts are taken to account the standardizing open channel sizes, including maximum load, friction coefficient, and channel pressure. For doors operated with a handlebar, the power can drive a force of 400 N. However, if the door has two handlebars, then each of handlebar must be calculated so that it can take 2/3 of the maximum possible load. The comparison between the height and width of the Watergate should be smaller than the friction coefficient (f) between the side of the door and the pointing groove (h/b<f), to avoid the door jams when movement [27]. The friction coefficient of Watergate materials is varies depending on the material used, whether iron, steel or wood, whether dry, wet or lubricated. All of this has an effect on the calculation of the driving load when the Watergate is used. There is a suggestion to increase the friction coefficient of various components by 40-50% for the operational efficiency of the Watergate irrigation. The final standardization of smart irrigation systems is the effect of DC motor power drives compatible with microcontrollers. To calculate a total load of all elements lifted by a DC motor, (1) is used.

$$G_{tot}=G_{(plate)}+G_{(steel\ groove)}+G_{(steel\ elbow)}+G_{(handlebar)}+P_{(swipe\ of\ watergate)} \quad (1)$$

As shown in (1) explains that heavy the Watergate irrigation depends on the weight of the Watergate plate, the weight of the groove steel, the weight of the elbow steel and the weight of the handlebar. These four elements are interconnected and will be lifted by a DC motor. When the water flows at a certain speed [28, 29], then the water pressure on the Watergate will give the friction of the door plate to the frame so that affect the lifting power of the motor [30]. Some parameters such as friction coefficient, water velocity, and water discharge will affect the calculation of DC motor power requirements [31]. The velocity of water flow and the discharge of water in the channel can be calculated by (2) and (3).

$$V=(1/n)xR^{2/3}xS^{1/2} \quad (2)$$

$$Q_{max}=AxV \quad (3)$$

The amount of water flows velocity (V) as given in (2), depending on the hydraulic radian, wet cross-sectional area and the slope at the base of the irrigation channel [32]. While the maximum water discharge (Qmax) in the channel, as (3) is affected by the wet cross-sectional area and the velocity of water flow. To determine the DC motor power used to drive the Watergate, a power equation is required which depends on the magnitude of lift, distance and lift time [33]. The total power of a DC motor is calculated using (4).

$$W=(Fxgxh)/t \quad (4)$$

As shown in 4 explains that the DC motor power is directly proportional to Effort (W) and inversely proportional to time (t). Enterprises are Style (F) with gravity magnitudes (g) and Distance (h) displacement of an object. The selection of suitable DC motors is coupled to a microcontroller-based control system, but the power specification needs to be taken into account when the system operates the Watergate on specific weight, distance and lift.

2. Research Method

This study examines the requirement of DC motor power of watergate irrigation placed on the Tertiary channels by considering the weight of the load in dry channel conditions or in the presence of water flow. There are several stages in the completion of this study, namely: calculating the velocity of water flow in each channel, calculating the weight of the Watergate without water pressure, calculating the strength of the water pressure passing through each Watergate and the friction generated to the Watergate plate when the maximum flow and water pressure occurs. The end stage is calculating the total load that responsibility of the DC motor and converting to energy to obtain the total power required. All these stages will be treated for the gates in 5 tertiary open channels. Schematically, the research stages are done as Figure 1.

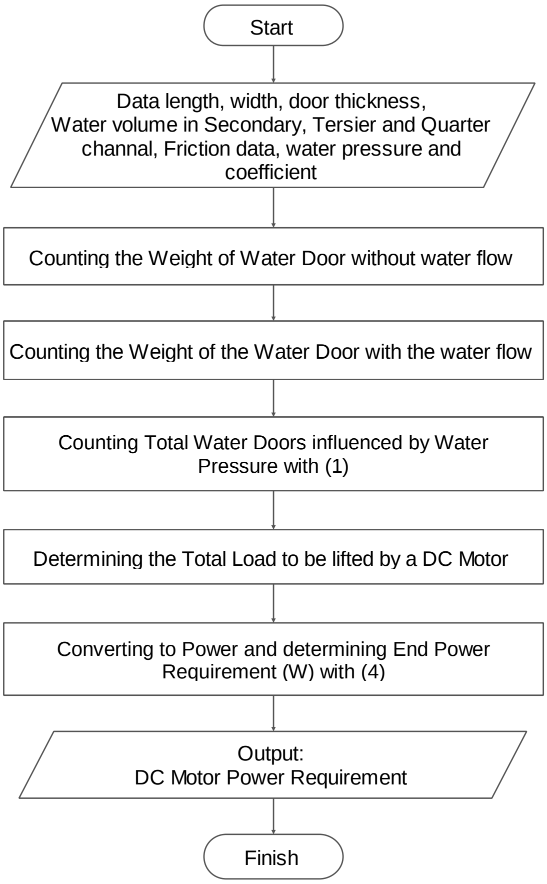


Figure 1. Phase study of DC motor power requirement on the smart irrigation system

Figure 1 shows the steps of study of DC motor power requirement before recommended to smart irrigation systems. The research begins with the collection of the channels data and the Watergate parameter according to the irrigation systems guidelines and measurement results at 5 open channels in Manikin I.A. Data collection is done by measuring the weight and volume of the Watergate. The second data is taken by measuring the lifting power with a certain speed and pressure that produces the maximum friction at the Watergate plate. The third stage is calculating the total load from the Watergate when no flow and with maximum flow. The measurement of total load can use the (1). The total load value is then converted to a power quantity with (4) (W=(Fxgxh)/t) to obtain the exact of DC motor specification for use in Arduino smart irrigation systems.

3. Results and Analysis

A smart irrigation system developed with DC motor as a driver is directed to Manikin I.A which has 5 open tertiary channels with different sizes. The specification of one of the channels is shown in Figure 2.

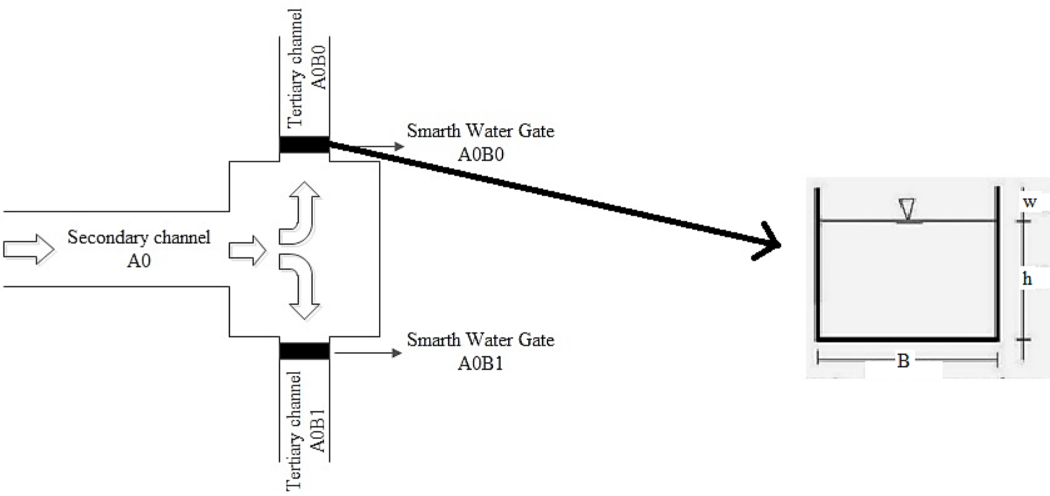


Figure 2. The open channel scheme that implements arduino smart irrigation system

The left side of Figure 2 displays the Secondary channel scheme A_0 to 2 smaller channels (Tertiary) A_0B_0 and A_0B_1 with black lines as thick as a barrier to a tertiary channel (Watergate). There is a larger rectangular area to hold water before splitting into smaller channels. The barrier will be replaced with Arduino smart irrigation system driven by a DC motor. The right side of Figure 2 is a model and size of smaller channels with bottom width channel (B) indication, height water flow (h), wavelength (w) and other indication as a standard parameter. The size of the tertiary channels is varies depending on the width of the previous channel. Figure 3 shows the measurement results of one tertiary channel with a channel width of 0.5 m and a channel height of 0.85 m.

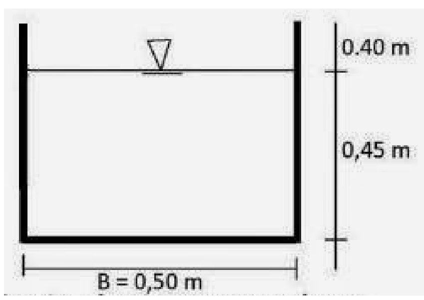


Figure 3. One of the open channels (Tertiary) in Manikin I.A

Figure 3 shows that the tertiary channel above has 0.50 meters of the floor (B), 0.45 meters of water height (h) and 0.40 meters of wavelength (w). With the 0.015 baseline slope (S) and 0.01 manning coefficient (n), the water velocity is determined in Table 1.

Table 1. Calculation of Tertiary Channel Parameters with 0.5 m Width of Floor Channel's (B)

Wide channel (A)	A=B x h=0.50x0.45	0.225 m^2
Circumferential channel (K)	K=B x 2h=0.50x2(0.45)	0.45 m
Hydrolis Radius (R)	R=A/P=0.225/0.45	0.5 m
Water speed (V)	$V=(1/n)\ xR^{2/3}xS^{1/2}$ $=(1/0.01)\ x\ (0.5)^{2/3}x(0.015)^{1/2}$ =100 x 0.63x0.12	7.56 m/s
Maximum discharge (Q_{max})	Q_{max}=A x V=0.225x7.56	1.70 m^3/s
Water pressure (P)	P=ρxgxh =997,2 kg/m^3x9,81 m/s^2x0,45 m	4402,1 p

Table 1 illustrates the calculation of Tertiary channel parameters with a 0.50 m of B, which results in a 7.56 m/s of water flow rate. With this velocity, the discharge of water can pass through a 0.50 meters open channel is 1.70 m^3/s. The water discharge at that speed always puts pressure at 4487.4 Pascal to the Watergate plate and resulted in friction between the plate and the frame of Watergate. This friction as another load (weight) of Watergate when driven by a DC motor. Completely the size of the flow rate at 5 tertiary channels in Manikin I.A as shown in Table 2.

Table 2. Water Flow Velocity at 5 Tertiary Channels in Manikin I.A

No	channels size	Parameters					
		A (m^2)	K (m)	R (m)	V (m/s)	Q_{max} (m^3/s)	P (pascal)
1	B=0,40 m, h=0,56 m	0,224	0,45	0,5	7,56	1,69	5478,2
2	B=0,50 m, h=0,45 m	0,225	0,45	0,5	7,56	1,70	4487,4
3	B=0,60 m, h=0,37 m	0,222	0,44	0,5	7,56	1,68	3619,5
4	B=0,70 m, h=0,32 m	0,224	0,45	0,5	7,56	1,69	3130,4
5	B=0,80 m, h=0,28 m	0,224	0,45	0,5	7,56	1,69	2739,1

Table 2 shows that water flows velocity from 5 tertiary channels in Manikin I.A with different bottom width channel and different pressure. From all channels have the same (almost) of the flow velocity and Maximum water flow. The water flow velocity in all channels is 7.56 m/s and the average water discharge is 1.69 m^3/s. The discharge and velocity provide different pressure on the Watergate and affect the weight of the Watergate when driven by a DC motor. Figure 4 shows a Watergate that will be placed on the Manikin open channel. The Watergate is made of steel with a handlebar and a gear connected to a DC motor. The plate of Watergate is flanked by elbow steel on both side and top.

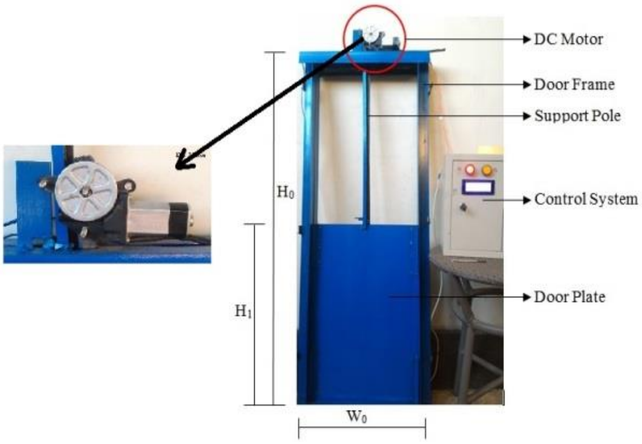


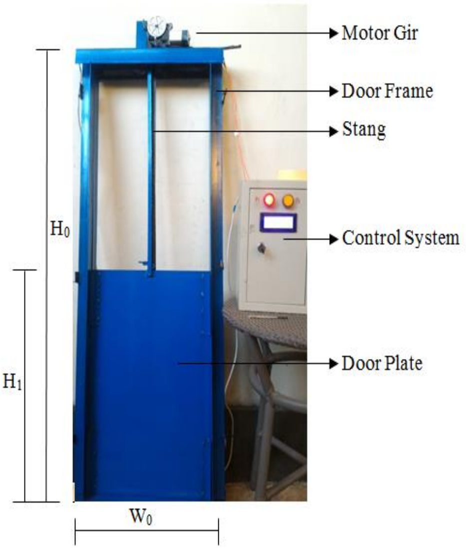
Figure 4. Watergate for Manikin I.A

The maximum capability of a DC motor is calculated when the channel is filled with water. There are 4 main components that affect the work of Arduino smart irrigation system, there is the plate of Watergate, handlebars, steel gear and elbow steel on the frame. When there is a flow of water with a certain speed and discharge, the friction between the plate and the frame becomes an additional parameter that affects to the lift capability of DC motor. Based on Table 2, the weight of Watergate is reviewed in 2 states, i.e. when the channel is empty and filled. When the channel is empty, the door weight is a heavy accumulation of 4 main components. The result of the measurement of each component in the empty channel obtained by weight of

2.75 kg+1.75 kg+5.25 kg+2.75 kg+0.75 kg=13.00 kg=13.00x9,8=127,4 Newton

this means that when the channel is empty, the door weight for the 0.5 meters wide channel is 127.4 Newton. However, while inside the drains, the weight affected by the pressure received, the friction between the door plate and frame and the density of water. For a 0.5 meters width channel, calculations are made as in Table 3.

Table 3. The Lifting Load of Doors at 0.5 m Width and 7.56 m/s of Flow Rate

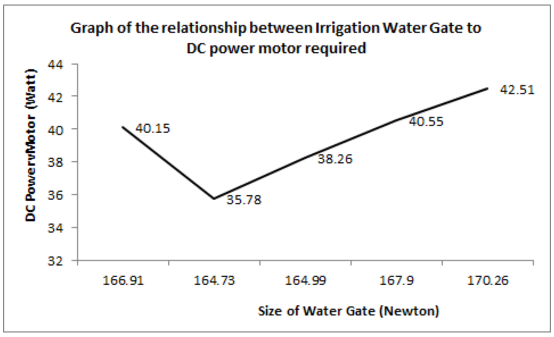
Figure	Specification	Value
	The weight of steel groove : W_0=1 x 3,00 x 0,50 x 10	15 N
	Weight of door plate: W_1=0,56 x 0,45 x 0.005 x 7,8 x 10^4	98,28 N
	Weight of elbow steel : W_2=2 x 1,50 x 0,30 x 10 W_3=1 x 0,50 x 0,30 x 10	9 N 1,5 N
	Weight of handlebar: W_4=0,70 x ¼ x 0,030 x 7,8 x 10^4j	40,95 N
	The weight of Watergate (G) :	164,73 N
	Maximum Weight Maximum with pressure: H=1/2(0,50 + 0,45) x 1,70 x 7,56 x 8,9 x 10^4	514722,6 N
	friction force: Wg=f x H=0,3 x 16159,5	154416,78 N
	Lift and Press force: Wg ± G=154416,78 + 164,74 154416,78 - 164,74	154581,52 N 154252,04 N

In Table 3, the weight of the Watergate that influence of water pressure is 154581.52 N, which means that when the 0,5 meters channel has water, a flow rate is 7.56 m/s and there 154581.52 N maximum load that must be driven by a DC motor as far as 0.6 meters so it requires an energy of 154581.52/0.6 meters=257635,867 Joule. The power to be prepared for a DC motor is (Wxh)/t=257635,867/7200 s=35.78 Watt. If The system using a 12 Volt for DC motor, so, the current capacity is 35.78/12=± 3 Ampere. Completely, the lifting load calculation of 5 open channels (tertiary) in Manikin I.A is given in Table 4.

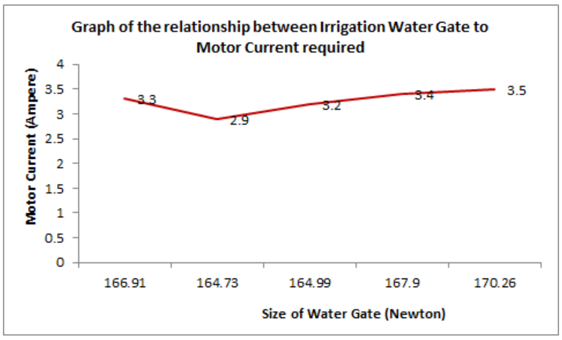
Table 4. Lifting Load Calculation on 5 Open Channel in Manikin I.A

Watergate	Parameters					
size	G (N)	H (N)	W_g (N)	W_g±G (N)	Power (Watt)	Current (A)
0,40 x 0,56	166,91	577633,14	173289,94	173456,86 | 173123,03	40,15	3,3
0,50 x 0,45	164,73	514722,60	154416,78	154581,52 | 154252,04	35,78	2,9
0,60 x 0,37	164,99	550353,75	165106,13	165271,12 | 164941,14	38,26	3,2
0,70 x 0,32	167,90	583352,28	175005,68	175173,58 | 174837,78	40,55	3,4
0,80 x 0,28	170,26	612765,00	183829,50	183999,26 | 183659,24	42,51	3,5

Graphically, the smart irrigation system power requirement in 5 open channels at Manikin I.A is given by Figure 5 (a) and Figure 5 (b).



(a)



(b)

Figure 5. Watergate weight relationship with dc power, and current
(a) watergate weight and dc power (b) watergate weight and current

Table 4 describes the calculation of DC motor power requirement for Watergate in 5 tertiary channels in Manikin I.A. Each channel (according to the size of the Watergate) has the total weight of the gate (G), the weight with the influence of water pressure (H) and the accumulated load with friction occurring between plate and the door frame. The load accumulation (weight of gate and friction) then converted to energy (Power) with the result of gate 1 requires 40.15 Watt power, gate 2 requires 35.78 Watt, gate 3 requires 38.26 Watt, gate 4 requires 40.55 Watt and gate 5 require 42.51 Watt. Because the system requires a DC voltage, which is 12 Volt, then each DC motor also get ideal current that can work on the DC motor circuit. The result of Table 4 is projected through the graph of the relationship between the weight of the door and the DC motor power in Figure 5 (a). For the wider Watergate, the DC motor power is greater required, there are 35.7 Volts on the second gate to 42, 51 Watts on the fifth gate. Similarly, Figure 5 (b) illustrates the relationship between the weight of the Watergate and the current on the DC motor circuit. The wider of the Watergate, the current required for the DC motor circuits is also greater i.e. 3.5 Ampere in the second DC motor circuit up to 3.5 Ampere in the fifth door DC motor circuit. If taken on average, the DC power requirement of Arduino smart irrigation systems in the open 5 channels of Manikin I.A is 39.45 Watt, with an average current of 3.26 Ampere to move the Watergate as far as 0.6 meters, for 2 hours in once operation within 24 hours.

4. Conclusion

Development of the Arduino smart irrigation system for 5 open channels (tertiary) in Manikin I.A requires a DC motor to drive the watergate when opening and closing automatically. The study of the DC motor power requirement on 5 smart watergates gets power between 35 to 43 Watt or 39.4 Watt average. If the circuit voltage is 12 Volts, then the current electric average in DC motor is 39.4/12=3.26 Ampere. Electrical power required to move the Watergate as far as 0.6 meters, lifting 2 hours (7200 seconds) in one process, for 24 hours. This power value obtained is the ideal value for each gate developed on an open channel according to the size tested. Power demand calculations on Arduino smart irrigation systems can be used for another open channels (secondary, primary, tertiary, quarter) in any irrigation area.

References

[1] Minister of Public Works and Public Housing. PUPR Minister Regulation No. 14/PRT/M/2015 concerning Criteria and Determination of Irrigation Area Status. Jakarta, 2015.
[2] Anonymous. Description of the area and potential of the Kupang Tengah sub-district. Kupang, 2015.
[3] Koreh AW. Challenges of Water Resources Management in NTT. 2016; 1
[4] Bhalage P, Jadia BB, Sangale ST. Case Studies of Innovative Irrigation Management Techniques. *Aquat Procedia*. 2015; 4: 1197–1202.
[5] Fang L, Tao S, Zhu J, et al. Impacts of climate change and irrigation on lakes in arid northwest China. *J Arid Environ*. 2018; 0–1.
[6] Prianto E, Umar C, Kartamihardja ES, et al. Management and Utilization of Embung and Weir Waters in NTT Province. *J Kebijak Perikan Indones*ia. 2018; 9: 105–114.

[7] Rogers DC, Mallicoaf D, Lindstrom S. Operation-Based Design Guidelines for Modern Irrigation Delivery Systems.
[8] Kirmanto D. Decree of the Minister of Public Works No: 390/KPTS/M/2007 Concerning Determination of Irrigation Area Status whose Management is the Authority and Responsibility of the Government and Minister of Public Works. 2007.
[9] Direktorat Jenderal SDA KPU. Irrigation planning standards. 2013; KP-01: 1–197.
[10] Sharaunga S, Mudhara M. Determinants of farmers' participation in collective maintenance of irrigation infrastructure in KwaZulu-Natal. *Physics and Chemistry of the Earth*. 2018: 0–1.
[11] Elshaikh AE, Jiao X, Yang S hong. Performance evaluation of irrigation projects: Theories, methods, and techniques. *Agricultural Water Management.* 2018; 203: 87–96.
[12] Jocom H, Kameo DD, Utami I, et al. *Air dan Konflik : Studi Kasus Kabupaten Timor Tengah Selatan. J Ilmu Lingkung* Decree of Minister of Public Works No: 390/KPTS/M/2007 Concerning Determination of Irrigation Area Status whose Management is the Authority and Responsibility of the Government and Minister of Public Works. 2007. 2016; 14: 51–61.
[13] Nthai Mukovhe Maureen. *An evaluation of irrigation water supply infrastructure to improve conveyance efficiency and water availability at Dzindi Irrigation Scheme*. 2007.
[14] Hamdy A. *Water use efficiency in irrigated agriculture: An analytical review.* Proc 4th WASAMED Work Water Use Effic Water Product. 2007; No.57: 9–19.
[15] Laumal FE. Development of Vibrating ADXL335 Sensors As A Guide To Maintenance Of Horizontal Lathe Machines. In: FE Journal (ed) National Seminar on Science and Technology Faculty of Engineering, University of Muhammadiyah Jakarta. Jakarta: Faculty of Engineering, University of Muhammadiyah. : 1–5.
[16] Laumal FE, Mone OA, Mauta JJ. Development of Arduino Based Parking Sensors and. *jurnal.umj.ac.id/index.php/semnastek*. 2017; 1–2.
[17] Laumal FE, Hattu EP, Nope KBN. Implementation of Round-Robin Scheduling Development in Real Time Central Processing Unit Data Queues. *J Rekayasa Elektr*. 2017; 13: 48–56.
[18] Ishak SN, Malik NNNA, Latiff NMA, et al. *Smart home garden irrigation system using Raspberry Pi.* 2017 IEEE 13th Malaysia Int Conf Commun. 2017; 101–106.
[19] Mahmood SH, Hassan OG, Kwad AM, et al. Auto Opening Door and Car Identification. 2016: 132–141.
[20] Qureshi MS. *Assessment of DC Servo Motor with Sliding Mode Control Approach.* IEEE First Int Conf Control Meas Instrum. 2016: 351–355.
[21] Indrianto, Indah Susantim MN, Arianto R, Siregar RA. Embedded System Practicum Module for Increase Student Comprehension of Microcontroller. *TELKOMNIKA Telecommunication Computing Electronics and Control.* 2018; 16(1): 53-60.
[22] Patalano S, Vitolo F, Lanzotti A. A Digital Pattern Approach to the Design of an Automotive Power Window by means of Object-Oriented Modelling. In: Haddar M, Abbes MS, Choley J-Y, et al. (eds) Multiphysics Modelling and Simulation for Systems Design and Monitoring. *Cham: Springer International Publishing*. 2015: 199–207.
[23] Laumal FE, Nope KBN, Peli YS. *Earthquake Early Warning Management based on Client-Server using Primary Wave data from Vibrating Sensor.* In: Journal of Physics: Conference Series. 2018. Epub ahead of print 2018. DOI: 10.1088/1742-6596/953/1/012029.
[24] Laumal FE. Jurnal Teknik Komputer Unikom–Komputika–Volume 3, No .2 - 2014. *J Tek Komput Unikom – Komputika*. 2014; 3(2): 23–28.
[25] Ahmed AM, Mohamed S. Elksasy, Amr Ali-Eldin, et al. Brushless Dc Motor Speed Control Using Proportional-Integral And Fuzzy Controller. *Int J Comput Appl*. 2015; 109: 29–35.
[26] A GR, Santha KR. Review of Sliding Mode Observers for Sensorless Control of Permanent Magnet Synchronous Motor Drives. *International Journal of Power Electronics and Drive System.* 2018; 9(1): 46–54.
[27] Directorate General of Natural Resources PU. Building Section Planning Criteria. KP-04.
[28] Gowri S, Anandha Mala GS. Efficacious IR system for investigation in digital textual data. *Indian J Sci Technol*. 2015; 8: 1–13.
[29] Yuhan H, Xiaoyan C, Fahu L, et al. Velocity of water flow along saturated loess slopes under erosion effects. *J Hydrol*. Epub ahead of print 2018. DOI: 10.1016/j.jhydrol.2018.03.070.
[30] Nittrouer JA, Shaw J, Lamb MP, et al. Spatial and temporal trends for water-flow velocity and bed-material sediment transport in the lower Mississippi River. *GSA Bulletin.* 2012; 124: 400–414.
[31] Saribulut L. A simple power factor calculation for electrical power systems. *Int J Electr Power Energy Syst*. 2014; 62: 66–71.
[32] Castaldelli G, Aschonitis V, Vincenzi F, et al. The effect of water velocity on nitrate removal in vegetated waterways. *J Environ Manage*. 2018; 215: 230–238.
[33] Tan J, Jing J, Hu H, et al. Experimental study of the factors affecting the flow pattern transition in horizontal oil-water flow. *Exp Therm Fluid Sci.* Epub ahead of print 2018; 98(June). DOI: 10.1016/j.expthermflusci.2018.06.020.