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Design of Backhoe Arm Prototype with Arduino Uno Microcontroller Based Hydraulic System

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A B S T R A C T

Hydraulic is the use of fluid to move power from one point to another. In the hydraulic system the fluid used is fluid in the same liquid form as used in the old system. Fluid in the hydraulic system will continue the pressure from the hydraulic pump to the piston on the hydraulic cylinder. In the design of hydraulic systems, the props of prototype Backhoe arm carrying capacity of 1 kg of the hydraulic system are used to move the arms from the bucket, arm and boom. In planning mechanical manufacture on the excavator arm frame using a metal plate with a thickness of 3mm, using Fillet welding joints and bolt connection sizes M4 and M5. For planning the manufacture of transmission drive using a 12 V DC brushless motor with 150 W motor power, Shaft with a diameter of 18mm, bearings using the type of UCF 203, and planning a straight gear with 70, and:20 number of gears with a ratio of 35 rotation. Planning the calculation of excavator arm motion obtained results where the driving motor on the body (swing) rotates in a clockwise and counterclockwise direction to rotate 360^0, rotational speed 11160 Nmm. In the Experiment Report the method used in designing the hydraulic system on the prototype Backhoe arm is to carry out a hydraulic system planning which includes power pack planning, valve planning, servo motor planning, and cylinder planning. Based on calculations, the planning of the pump head power pack has a pressure of 633,703.24 Pa and a hydraulic pump power of 0.165 HP. The results of the calculation of the hydraulic cylinder planning are the hydraulic cylinder pressure on the bucket of 0.0015 N / mm^2, the pressure of the hydraulic cylinder on the arm of 0.0477 N / mm2, the pressure of the hydraulic cylinder on the boom of 0.159 N / mm2, and the flow of fluid flow on the hydraulic cylinder at 15,700 mm^3 / second. The results of calculation of reservoir planning are reservoir dimensions of 0,00066 m^3 and reservoir oil volume of 0.6 liters. The control system is used to control the brushless pump motor, brushed motor, servo valve. The control system uses the nRF24L01 module or with radio signal communication with a frequency of 2.4 GHz. In this control system there are transmitters and receivers, The transmitter functions to set point data from the joystick module and potentiometer that will be sent to the receiver, receiver functions as a receiver of data from the transmitter and serves to send signals to the brushed motor motor, and servo valve. From the results of testing the data transmission control system with the nRF24L01 module running well with conditions blocked by 3 walls

Keywords: Backhoe Arm, Design, Hydraulic, Mikrokontroler Arduino Uno, Prototype.

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1. Introduction

Excavator Machines have a backhoe arm where the hydraulic construction is divided into attachments consisting of a boom is an attachment that connects the base frame to an arm with a certain length to reach the loading/unloading distance, the arm is an attachment that connects the boom to the bucket, the bucket is an attachment that is directly related to the material when loading.

The excavator arm which will later be combined with the control system of the control system is useful for moving all existing systems on the excavator including rotating the pump motor, slewing drive, servo valve. The control system for the pump motor and slewing drive uses a remote control system using wireless/wireless communication using the nRF24L01 module. Broadly speaking, the workings of the control system use a potentiometer and joystick module to set point data, the data is stored and sent by the microcontroller with the nRF24L01 module. The data sent by the nRF24L01 transmitter module is received and read by the nRF24L01 receiver module and is used to drive servo motors, brushless motors, and brushed motors.

2. Theoretical Basis

Arm Backhoe is one of the most important attachments of a Backhoe. The arm must operate reliably under high load operating conditions. The boom carries lifting and landing forces. The boom is the component that connects the cab to the other attachments and is often the operating component of an excavator's arm. The boom receives energy from one or

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two boom cylinders depending on machine configuration. The arm is an extension of the boom which increases the maneuverability of the system. An arm attached to the end of the boom arm provides the digging force needed to pull the bucket through the ground. The arms receive power from one or two arm cylinders depending on the engine configuration. Bucket is located at the end of the arm, Bucket is the component that performs digging operations. Buckets have long, sharp teeth whose role is to penetrate hard soil and rock. It comes in various sizes and shapes depending on the application area. The bucket receives energy from the bucket cylinder (Pakki, et al., 2018).

2.1. How the Excavator Arm Works

Backhoe backhoe hydraulic arm mechanism works with hydraulic cylinders as the driving force. The work done is through the general plane motion of each mechanism, namely the boom, arm and bucket. The rotational motion of the boom rod, arm rod and bucket rod from the longitudinal and retracted movements of the hydraulic cylinder. The longitudinal and retractable hydraulic cylinders are driven by a hydraulic pump. While the hydraulic pump works with the engine as the driving force. So basically the work being done is passing the power supplied by the engine through the hydraulic circuit. The received data is used to do work such as digging, collecting soil, moving, and so on. Schematically, the way the backhoe excavator arm mechanism works is from the engine to the hydraulic pump then to the hydraulic cylinder and then to the work equipment (Lydianingtias, et al., 2018).

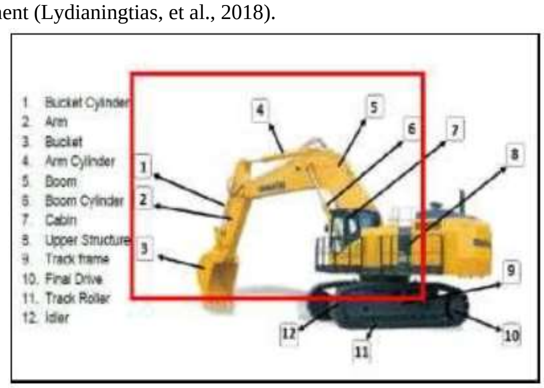


Figure 1. Arm Backhoe
Source: Lydianingtias, et al., 2018

2.2. Design of Propulsion Mechanics on the Backhoe Arm

Mechanical planning is planning carried out on the frame section of the 1kg load capacity Backhoe Arm trainer. The frame itself is a unifying element in its respective position so as to form the Backhoe Arm prototype. With the framework, the design of the Backhoe Arm prototype as a whole can be more easily connected with one component to another.

In the planning of making the drive carried out on the Backhoe Arm prototype transmission using a DC drive motor as the main drive which is forwarded to the shaft through the gears. By converting electrical energy into motion.

2.3. Hydraulic System Planning on Excavator Arm

Hydraulics is the use of fluids to transfer power from one point to another. In the hydraulic system the fluid used is fluid in liquid form, the same as that used in the old system. The fluid in the hydraulic system will transmit pressure from the hydraulic pump to the piston in the hydraulic cylinder which can then lift the load (Pakki, et al., 2018).

Table 1. Types of Hydraulic Pumps

Jenis pompa hidrolik	Keterangan
Series MH 	Has a diameter of 1.50 inches to 14.00 inches, has 13 mounting styles, compressive strength reaches 2000 psi
Series MA 	Has a diameter of 1.50 inches to 6.00 inches, can be installed with 11 mounting styles, NFPA replaceable, compressive strength up to 200 psi
Series VH 	Has a diameter of 2.50 inches to 8.00 inches, can be installed with 13 mounting styles, compressive strength up to 3000 psi
Series CHE 	Diameter from 20 to 100 mm, stroke length up to 150 mm, operating pressure up to 140 bar, 4 different rod ends.
Series MAL 	Has a Diameter of 20 to 40 mm, stroke length up to 150 mm, stroke diameter of 8 mm, operating pressure up to 9 bar, speed 50-80 mm/s.

Source: Parker, 2009

2.3.1. Hydraulic Cylinder Diameter Planning

Cylinder diameter planning is divided into 3, namely bucket cylinder diameter, arm cylinder diameter, and boom cylinder diameter. The diameter planning of the three cylinders is different because the weight on each part is different. To find the diameter of the bucket cylinder, you must first calculate the force (F). The formula is as follows:

$$F = m.a \quad (1)$$

With: m : the mass of the object
a : acceleration due to gravity (9.8 m/s2)

Next find the Pressure with the Formula:

$$P = \text{Pump pressure} + 1\text{ atm} \quad (2)$$

Pump pressure is needed to calculate the cylinder diameter because the cylinder is pushed by the pump. To find out the diameter of the cylinder using the equation formula as follows:

$$A = \pi \frac{d^2}{4} \quad (3)$$

$$d = \sqrt{\frac{4A}{\pi}} \tag{4}$$

With : A = Cross-sectional area
d = Required cylinder diameter

2.3.2. Powerpack Planning

Hydraulic Pump Unit (power pack) is a combination of oil tank, pump, motor and relief valve. In addition, hand control valves and equipment are used as needed.

The requirements for making a hydraulic pump unit (power pack) include the following: (Handoko, et al., 2013)

a. The oil tank must be designed to prevent the entry of dust and other impurities from outside.
b. The oil tank must be detachable from the main unit for maintenance purposes and to ensure accuracy. To free the air.
c. The capacity and size of the oil tank must be large enough to maintain sufficient levels in any step.
d. A separator plate (Bufflu plate) must be installed between the return pipe and the suction pipe to separate the impurities.
e. The return pipe and suction pipe of the pump must be below the oil level.

1. Head Losses

Flow losses occur due to the friction factor when the fluid flows with the surface of hoses, valves, hose turns and others, which affect the head that occurs or the actual head, the formula used is as follows:

a. Kerugian gesekan selang

i. Flow rate in hose

$$v = QA \tag{5}$$

With : v = flow rate in the hose (m/s)
Q = flow capacity (m^3/s)
A = cross-sectional area in the hose (m^2)

ii. Renolds number (Re)

iii. Loss coefficient (f)

$$f = \frac{64}{Re} \tag{6}$$

With: f = Loss coefficient
Re = Renolds number

b. Losses at the inlet end of the hose, wasting the hose, and at the exit of the hose

$$hf = f\,\frac{v^2}{2g} \tag{7}$$

With: hf = head loss (m)
f = hose inlet loss coefficient
v = flow speed (m/s)
g = gravity (9,81 m/s^2)

c. hose branching loss hf_{1-3}, hf_{1-2}, hf_{1-3}

d. hose bend loss

2. Total Head

Required Head or Total Head is the total head in the piping system from the suction side to the pump pressure side to the reservoir. The total head formula is:

$$H = ha + \Delta hp + ht + 12g\ v2d - v\ 2s \tag{8}$$

With: H = pump heads (m)
ha = difference in height between suction and pressure side (m)
Δhp = the difference between the static pressure heads on the suction and pressure sides (m)
ht = total head loss incurred (m)
g = gravitational force (9.81 m/s2)
vd = pressure side average flow velocity (m/s)
vs = inlet side average flow velocity (m/s)

3. Pump Head

The pump head is the energy per unit weight that must be provided to drain a planned amount of liquid according to the conditions of the pump installation, or the pressure to drain a certain amount of liquid, which is generally expressed in units of length. While the relationship between head and pressure:

$$P = \rho \times g \times H \tag{9}$$

With: P = Pressure (pa)
Q = Pump capacity (m^3/s)
H = total head(m)
ρ = fluid density (kg/m^3)

4. Hydraulic Pump Power

The pump is used to pump hydraulic fluid, this pump provides power to the fluid used to do work, the pump power must be greater than the power required. The formula used:

$$Pp = 0,163 \times Q \times H \times \gamma \tag{10}$$

with: Pp = Pump power (HP)
Q = Pump capacity (m3/s)
H = Total Head (m)
γ = Density of fluid (kgf/m3)

5. Pump Drive

The pump drive is usually an electric motor, the function of this electric motor is to act as a pump drive, the motor rotates, the motor motion is continued by the coupling that rotates the pump, the motor power and motor rotation speed affect the power and rotation produced by the pump, and also affect the hydraulic power produced . The formula used is the output power of the motor:

$$Pm = Pmoto.in \times \eta m \tag{11}$$

with: Pm = Motor output power (HP)
Pmoto.in = Motor input power (HP)
ηm = eEfficiency of the motor (%)

2.3.3. Reservoir Planning

1. Calculation of Reservoir Dimensions

Reservoir volume is determined from 3 times the required flow rate plus the room volume for expansion of 10%. Reservoir volume can be calculated by the formula:

$$V = (3 \times Q) + (3 \times Q \times 0,1) \tag{12}$$

with: V = Reservoir Volume
Q = Flow rate of the hydraulic pump

2. Calculation of Oil Reservoir Volume

The oil reservoir volume is the oil required by the system. The volume of oil in the reservoir is calculated 3 times the required flow rate. The reservoir oil volume is calculated by the formula:

$$V = 3 \times Q \tag{13}$$

with: V = Reservoir Volume
Q = Flow rate of the hydraulic pump

2.4. Arduino Uno Microcontroller Design

Selection of the microcontroller board on the Backhoe Arm prototype by comparing two microcontroller boards based on the Uno microcontroller, including:

1. The number of digital and analog output input pins as needed is 6 analog pins and 7 digital pins.
2. Using an additional power jack that can be used for power supply.
3. Using a female port so that components or shields can be directly mounted on the board.
4. The Uno microcontroller has an internal regulator and electronic fuse, so it is safer to use an external power source.

Table 2. Microcontroller Board Type

Board Type	Information
Mikrokontroler Uno *Board* 	*The Uno Microcontroller Board uses the ATmega328P chip with a DIP packaging package. To be able to use serial communication or as a USB uploader using the ATmega16U2 microcontroller chip, the microcontroller has 14 digital input output pins and 6 analog input pins and works at a frequency of 16 MHz.*
Mikrokontroler UNO SMD *Board* 	*The Uno SMD Microcontroller Board uses the ATmega328P chip with the SMD packaging package. For USB communication using the ATmega16U2 chip. On the Uno SMD microcontroller there are 14 digital input output pins and 6 analog pins.*
Mikrokontroler Genuino Uno *Board* 	*The Genuino board is the same as the Uno Microcontroller Board, using an ATmega328 chip with a DIP package. For USB communication using the ATmega16U2 chip. Genuino Uno has 14 digital input and output pins and 6 analog input pins.*
Mikrokontroler Leonardo *Board* 	*The Leonardo Microcontroller Board only uses one microcontroller which functions as the control center and also for serial communication. The Leonardo microcontroller uses the ATmega32U4 chip with an SMD package.*
Mikrokontroler Mega 2560 *Board* 	*The microcontroller board used is the ATmega2560. On the Mega 2560 microcontroller there are 54 digital input output pins and 16 analog input output pins. Flash memory contained in the Mega 2560 microcontroller is 256KB.*
Mikrokontroler Nano *Board* 	*The microcontroller board used is ATmega328. On this Nano microcontroller there are 14 digital input output pins and 8 analog output input pins. The size of the Nano microcontroller PCB or Board is smaller than other Microcontroller Boards.*

Source: Rangkuti S., 2016

The Uno/ATmega328 microcontroller uses the ATmega328 chip as its control center. It has 14 digital input/output pins, also equipped with 6 analog inputs, an external oscillator using a 16MHz crystal, a USB connector, a jack for power supply, a header for ICSP and a reset button. The ATmega328 microcontroller can be supplied with a voltage source via USB from a computer or a power supply via the power jack and can also be via the Vin and GND pins. If the electrical power needed is more than 500mA, you should use an external power supply instead of a USB terminal. The ATmega328 microcontroller has been equipped with an automatic power source selection facility (Rangkuti, 2016:7).

Table 3. Arduino Features Summary

No	Component	Information
1	Microcontroller	ATmega328
2	Working voltage	5V
3	Input voltage	7-12VDC (recommended)
4	Input voltage	6 (minimum) – 20VDC (maximum)
5	Pin digital I/O	14 pins (6 pins can be used PWM)
6	Analog input pins	6 pins
7	DC current per I/O	20mA
8	DC current for pins 3-3V	50mA
9	Flash memory	32KB (0,5KB used for bootloader)
10	SRAM	2KB
11	EEPROM	1KB
12	Clock Speed	16MHz

Source: Rangkuti S., 2016

3. Methodology

In this study the method used is the design or prototype method, which includes the stages of planning, calculating, manufacturing or assembling, and testing the machine. Where in this section is more on the control system, which includes:

1. Motion Mechanics, Propulsion Mechanics are used as a propulsion system on the Backhoe arm prototype. The power of the DC motor as the prime mover is transmitted to the shaft through the gears. By converting electrical energy into motion.
2. Hydraulic System, Hydraulic system is a system that utilizes fluid pressure as power (power source) in a mechanism. In the hydraulic system, a power unit is needed to make the fluid flow according to the needs or the desired mechanism.
3. Control System The control system is used to control the rotation of the pump motor, slewing drive and servo valve. By transferring the C++ command code from the Arduino IDE to the Uno/ATmega328 microcontroller, the actuators (brushed motors, motor brushes and servo motors) work according to the specified set point (potentiometer, joystick module).

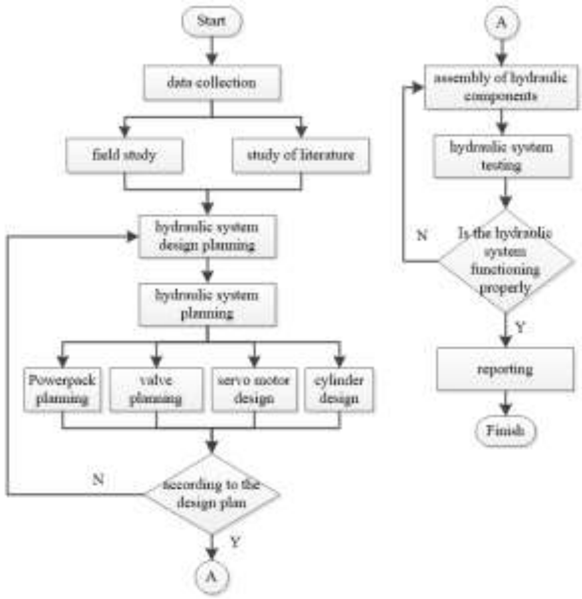
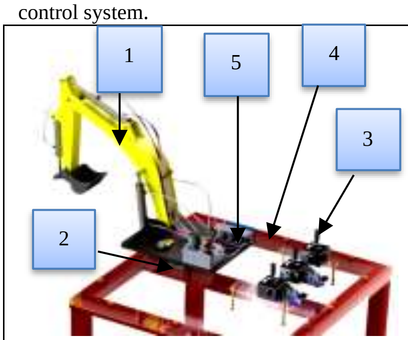


Figure 2. Flowchart Design Backhoe Arm

4. Result and Discuss

The design results of this prototype are shown in the figure below, which is a 3-dimensional design of the backhoe arm prototype with a perspective view. complete with hydraulic system, mechanical drive and control system.

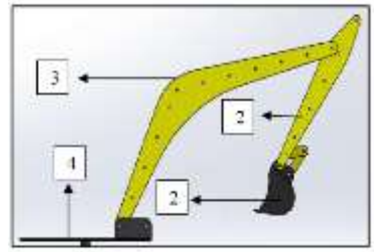


Information:
1. Backhoe Arm Frame Mechanics
2. Transmission Drive
3. Control system
4. Prototype Table
5. Hydraulic System

Figure 3. Prototype Backhoe Arm

4.1. 4.1. Drive Mechanic Design and Calculation

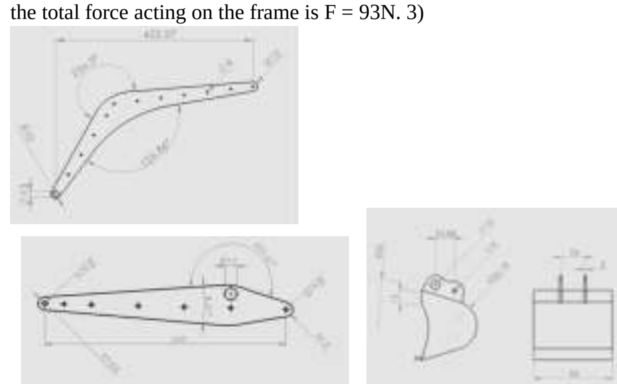
Based on the descriptions of the results of the discussion that has been carried out on the driving mechanics, the following conclusions can be drawn:



Information:
1. Bucket planning
2. Arm planning
3. Boom planning
4. Swing planning

Figure 4. Design Backhoe Arm.

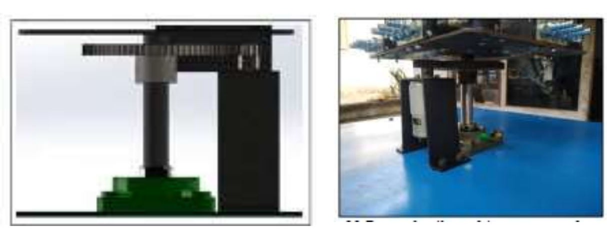
In planning the manufacture of mechanics carried out on the Backhoe arm frame using iron plate material with a thickness of 3 mm and combining the Backhoe arm frame using bolt and nut connections with sizes M4 and M5. 2) In planning mechanical calculations on the frame, the total force acting on the frame is F = 93N. 3)



(a) **(b)**

Figure 5. **(a)** Calculate Design Boom and Arm; **(b)** Calculate Design Bucket .

In planning for making the drive carried out on the Backhoe arm transmission using a brushed DC drive motor as the main drive which is forwarded to the shaft through the gears. By converting electrical energy into motion. In the planning of mechanical calculations on the frame, the results of the planning of the motor power used are 150W, the shear stress is 12V. Shaft planning using a shaft diameter of 18 mm. The design of the bearings uses UCF 203 type bearings. The design of straight gears with 20 teeth for the drive and 70 teeth for driven gears with a rotation ratio of 3.5.



(a) **(b)**

Figure 6. **(a)** Drive mechanical design; **(b)** drive mechanics.

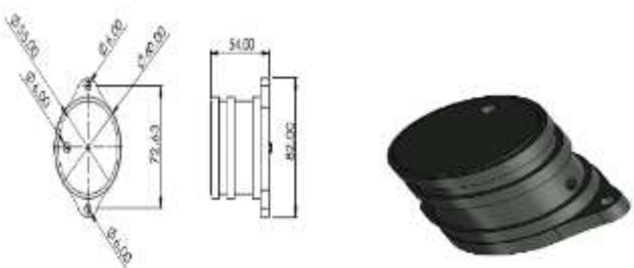
In planning the calculation of the Backhoe arm motion, the result is that the driving motor on the body (swing) rotates in the direction of movement, it can rotate clockwise if the moment of force/torque is positive and vice versa if the torque is negative, then the direction of movement is counterclockwise. So that the direction of movement to the left or right moves the body (swing) of the Backhoe arm with a range of motion that can rotate 3600, with a rotary motion speed of T = 11160Nmm. The backhoe arm movement speed can be adjusted as desired through the control system on the driving motor rotation

(a) **(b)**

Figure 7. **(a)** Design Arm Backhoe; **(b)** Prototype Arm Backhoe.

4.2. Hidrolik Hydraulic System Design and Calculation

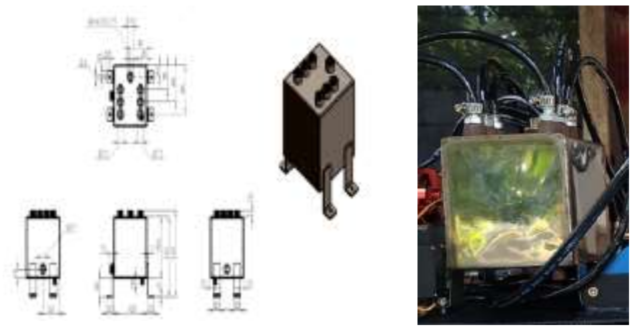
The equation in chapter 2 has shown the equation in obtaining the planning results of the components of the hydraulic system.. Hydraulic power pack planning on a prototype hydraulic system prototype arm excavator with a carrying capacity of 1 kg consists of a pump, and a pump head, which is carried out by calculating according to the formulas the formula that has been listed on the theoretical basis. The results of these calculations are a total head loss of 12.6 m, a total head of 12.85 m, a pump head of 110,679.36 pa or 1.1 bar, and a pump power of 0.36 HP or 268.45 Watt.



(a) **(b)**

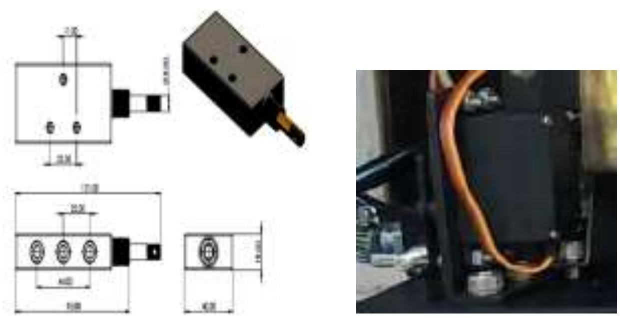
Figure 8.(a) Hydraulic pump planning; **(b)** Arm Backhoe Hydraulic Pump.

Reservoir volume is determined from 3 times the required flow rate plus the room volume for expansion of 10%. The reservoir volume can be calculated by calculating 0.6 liters.



(a) **(b)**

Figure 9. **(a)** Reservoir Planning; **(b)** Reservoir Arm Backhoe.



(a) **(b)**

Figure 10. **(a)** Hydraulic Valve Design; **(b)** Hydraulic Valve Arm Backhoe.

In planning the diameter of the hydraulic cylinder Based on the calculation results, planning the diameter of the hydraulic cylinder, namely the diameter of the hydraulic cylinder at the bucket is 7.07mm, the diameter of the hydraulic cylinder at the arm is 14.42 mm, the diameter of the hydraulic cylinder at the boom is 20.3 mm. From these calculations the diameter of the cylinder used is 20 mm.

(a) **(b)**

Figure 11. **(a)** Hydraulic Piston Design; **(b)** Piston Arm Backhoe.

4.3. Control System Design and Installation

In general, how the control system works can be seen from the functional diagram in Figure 3.2. The working system of the control system as a whole first takes the ADC joystick and potentiometer set point values, then the joystick and potentiometer ADC value set point data is sent to the receiver using (nRF24L01/Transmitter). The second (nRF24L01/receiver) receives data from (nRF24L01/Transmitter) in the form of ADC values and is processed by the Uno/ATmega328 microcontroller into a PWM signal that comes out of the digital PWM pin and is applied to the output in the form of a servo motor and ESC (electronic speed control) driver..

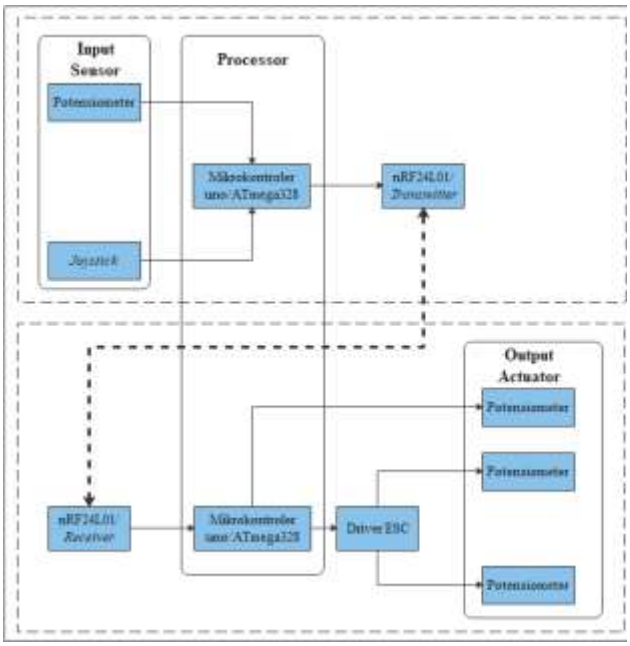


Figure 12. Control System Functional Diagram

The design of the control system is designed in such a way that it can be used with two hands. In the figure below is the design of the control system for the transmitter and receiver, front view and top view and perspective view. On the front view of the transmitter there is the nRF24L01 module and the USB port of the Uno/ATmega328 microcontroller. At the top there is a joystick module, potentiometer, UNO/ATmega328 microcontroller, switch, battery box holder, 18650 lithium battery as power supply and LED as indicator, in figure 13.

Figure 15 below shows the control system design for the front view of the receiver, top view and front perspective view. On the front of this receiver there is the nRF24L01 module and on the top there is a 18650 lithium battery box holder, 18650 lithium battery as the UNO microcontroller power supply, a switch as a connecting switch and circuit breaker and a port to connect the servo motor cable and ESC.

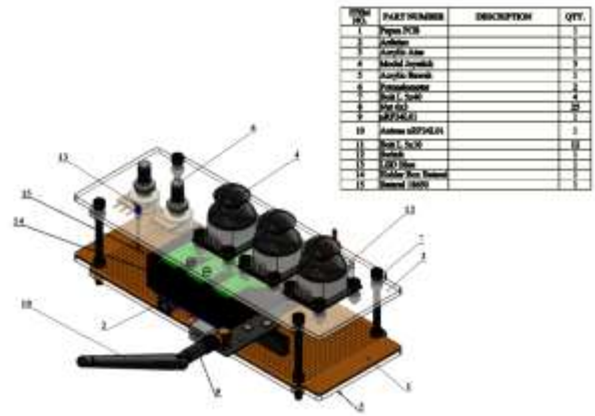


Figure 13. Front Perspective View Control System Design

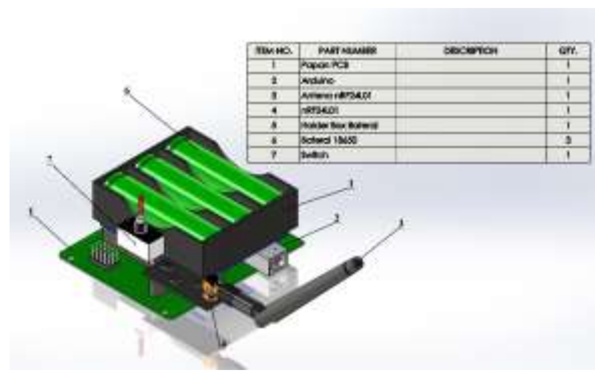


Figure 14. Receiver Front Perspective View Control System Design

Software Design in making software on the control system is enabled to program the uno microcontroller using the Arduino IDE.

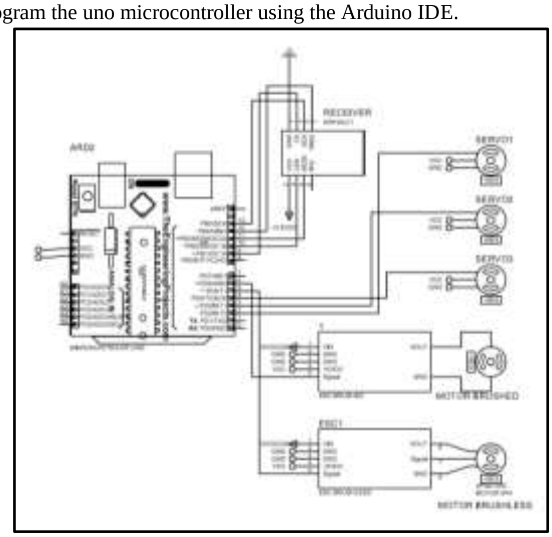


Figure 15. Receiver circuit schematic

Here is a backhoe arm prototype

(a) **(b)**

Figure 16.(a) Prototype Backhoe Arm;**(b)** Backhoe Arm Hydraulic Assembly.

4. Conclution

Based on the descriptions of the results of the design discussion that has been carried out on the driving mechanics, the following conclusions can be drawn: the Backhoe arm frame uses an iron plate material with a thickness of 3 mm. The connection uses M4 and M5 bolt and nut connections. The total force acting is 93 N. Backhoe arm transmission uses a brushed DC drive motor, the motor power used is 150 W, shear stress is 12V, shaft diameter is 18 mm, bearing type UCF 203. Straight gears with 70 teeth and 20 gears with a rotation ratio of 3.5. In the hydraulic system it can be concluded that: the diameter of the hydraulic cylinder on the bucket is 7.07 mm, on the arm is 14.42 mm, and the diameter of the hydraulic cylinder on the boom is 20. The hydraulic power pack from these calculations is a total head loss of 12.6 m, total head of 12.85 m, pump head of 110,679.36 pa or 1.1 bar, and pump power of 0.36 HP or 268.45 Watt. The reservoir consists of a reservoir oil volume of 0.6 liters. Meanwhile, the control system / micocontroller is concluded as follows: The control system uses the UNO/ATmega328 microcontroller as a data processor. The control system communication system uses the nRF24L01 module as a transmitter and receiver. The control system lever uses a joystick module and the brushed and brushless motor speed control uses a potentiometer. Brushed and brushless motor drivers use ESC (electronic speed control). Software for programming uno/ATmega328 microcontrollers using the Arduino IDE. Data transmission with the nRF24L01 communication module goes well even though it is blocked by 3 walls and there is no data loss.

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