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COMPARISON OF DEPTH CONTROL FORM SURFACE AND BOTTOM SET POINT OF AN UNMANNED UNDERWATER REMOTELY OPERATED VEHICLE USING PID CONTROLLER

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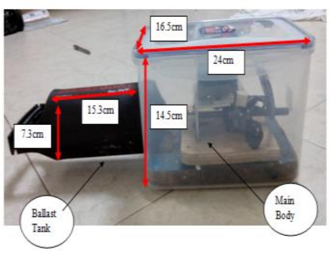
Graphical abstract



Abstract

This paper investigates the depth control of an Unmanned Underwater Remotely Operated Vehicle (ROV) based on ballast tank system using conventional PID controller. The PID Controller is applied to control the depth of the ROV from two different reference points, from the surface and from the seafloor. The concept of ballast tank system selected is piston tank type. Two different sensors are selected, which is pressure sensor for measurement from the surface, and sonar sensor for measurement from the bottom. Control method from both references point are investigated and compared to find out which feedback reference points are more appropriate in different conditions. The implementation phase will be verified through MATLAB Simulink platform. The verified algorithms will then be tested on the actual prototype ROV. And also the prospect of automated the vertical movement of a ROV.

Keywords: Depth control, unmanned underwater remotely operated vehicle, ballast tank system, piston type, PID controller

Abstrak

Kertas kerja ini mengkaji kawalan kedalaman bagi kenderaan kawalan jauh tanpa pemandu bawah air (ROV) berdasarkan sistem tangki menggunakan pengawal konvensional PID. Pengawal PID digunakan untuk mengawal kedalaman ROV dari dua titik rujukan yang berbeza, iaitu dari permukaan dan dari dasar laut. Konsep sistem tangki dipilih adalah dari jenis tangki omboh. Dua sensor yang berbeza dipilih, iaitu merupakan pengesan tekanan untuk mengukur dari permukaan, dan pengesan sonar untuk mengukur dari bawah. Kaedah kawalan dari kedua-dua titik rujukan disiasat dan dibandingkan untuk mengetahui tindak balas titik rujukan adalah lebih sesuai dalam keadaan yang berbeza. Fasa pelaksanaan akan disahkan melalui platform MATLAB / Simulink. Algoritma yang disahkan kemudian akan diuji pada prototaip ROV sebenar. Dan juga prospek automatik pergerakan ROV yang menaik.

Kata kunci: Kawalan kedalaman, kawalan kenderaan bawah air tanpa pemandu, sistem tanki ballast, jenis omboh, pengawal PID

1.0 INTRODUCTION

Unmanned Underwater Remotely Operated Vehicle (ROV) is essentially an underwater robot that is widely used in lot of underwater exploration such as industrial, marine study or work [1-2]. As the name ROV implies, which means the movement control of such vehicles are fully controlled by human remotely, but different from controlling a vehicle on the road surface, underwater vehicles need to consider a lot more movement possibilities, especially vertical movement whereas this movement are label as the vehicle buoyancy [3-4].

Buoyancy is the upward force exerted by the fluid on a body that is immersed [5-6]. Buoyant force is the force different between large pressure pushing up under the object and the small force pushing down over the object. Based on the Archimedes Principle, magnitude of the upward force (buoyant force) of an object immersed in a fluid is equal to magnitude of weight of fluid displaced by object. Underwater vehicles will float or sink depended upon on the net effect of the weight of the object and the buoyant force generated by the object.

There are basically two methods to maintain the ROV at a certain depth, which is by using a propeller or by using a ballast tank [7]. Propeller method will react according to command and causes an additional downward or upward force to move the vehicle vertically without changing the vehicle's buoyancy [8-9]. Whereas ballast tank method will changes the vehicle's buoyancy in order to move the vehicle. Propeller method has faster time response compared to ballast tank method but a constant power draw are needed as to maintain the vehicle depth, this will increase the difficulty for the operator to manage the vehicle's position and operation simultaneously [10]. Therefore ballast tank method are selected to reform the ROV into a semi-automated vehicle by replacing the vertical movement of a ROV with an automated ballast tank system to regulate the required depth set by the operator.

The main drawback in current underwater tasks performance is that, the components used such as thruster, lamp and camera consumed high power usage. Therefore, in order to solve high power consumption problems, one of the best ways is performing ROV operation without thruster [2]. Drawback of thruster also had proved by the research conducted by National Oceanic and Atmospheric Administration (NOAA) discover that the performance of the thruster become worst when reaching the saturated point at depth pressure is high [3]. Then, the ROV will no longer can be move downward at this saturated point. Since the thruster will not give good performance in underwater tasks, another alternative method to replace thruster is ballast tank. Ballast tank use the concept of the buoyancy force corresponds to displacement of water. When the ballast tank is filled with water, the ROV will add its weight, so the ROV will move downward. Other than that, by using ballast tank also can make the ROV travel deeper in the underwater application. Figure 1 shows the comparison of the performance.

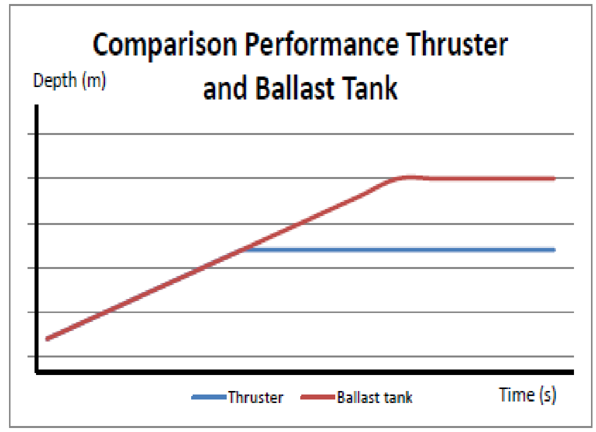


Figure 1 Comparison of thruster and ballast tank performance against depth [4]

2.0 METHODOLOGY

In order to achieve the objective, a few small experiments are done as shown in Figure 2.

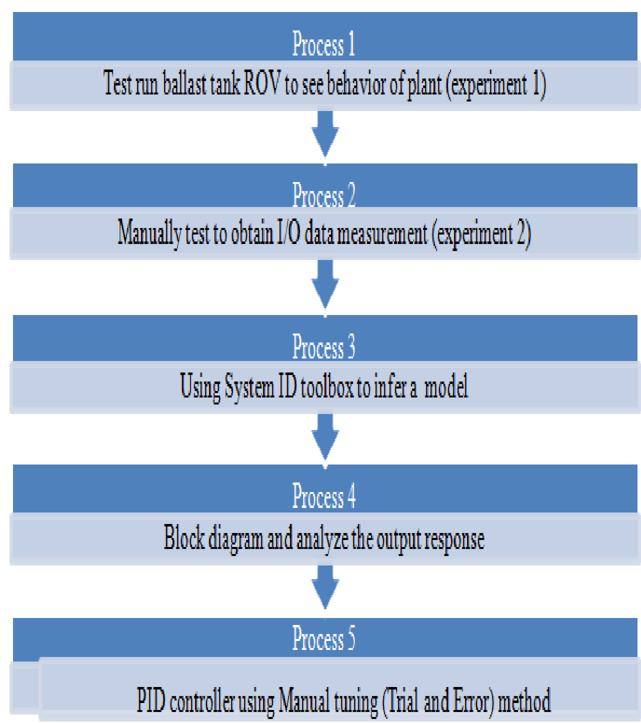


Figure 2 Flow chart

Ballast tank can be used to control buoyancy and ballast tank also has ability to hold water without any leakage [8]. Ballast tank needs to be well-designed in order to make sure that it can protect the electronic component inside. There are many type of ballast tank that can be constructed. Basically, there are three types of ballast tank used for a small project and low cost [7]:

a) Mechanical attenuated system
   i) Bellow ballast tank
   ii) Piston ballast tank
   iii) Membrane ballast tank
b) Pump system
   i) Pressure tank
   ii) Flexible tank
c) Gas operated
   i) Liquid gas
   ii) Pressurized air
   iii) $C0_2$

Table 1 shows the comparison types of ballast tank based on buoyancy control and construction.

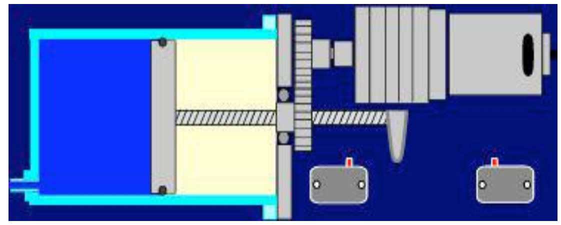
Table 1 Differences between types of ballast tank [5]

Types of ballast tank	Mechanical attenuated system	Pump system	Gas operated system
Buoyancy control	Accurate	Slightly accurate	Very accurate
Construction	Quite simple	Simple	Complex

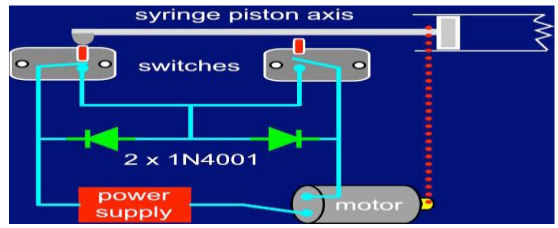
Mechanical attenuated system has accurate buoyancy control compare to pump system. Even tough, gas operated system has very accurate compared to others, but construction is complex. Besides, construction for mechanical attenuated is quite simple, thus can reduce space and safe cost. In this project, piston ballast tank is selected because easy to construct compared to bellow ballast tank and membrane ballast tank.

3.0 PISTON TANK BALLAST CONCEPT

This system, only recommended for small or medium models, uses a motorized medical syringe whose capacity is about 20 to 60 cm^3. The piston moving in the syringe body increases the submarine weight by sucking up the water. In doing this, the air is compressed inside the hull. The mechanism of displacement of the piston takes a significant place in the hull and especially as the engine must be relatively powerful to drive the piston. This system has the advantage to be of an excellent progressiveness allowing a precise control of the submarine when it dives. This syringe is commanded by electronic relays. It is necessary to use two end of run switches to stop the piston at the extreme positions of its course as shown in Figure 3.



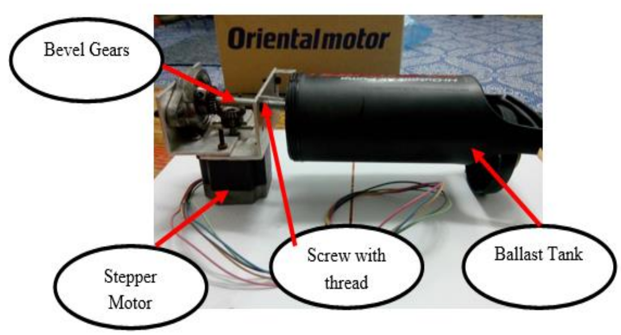
(a)



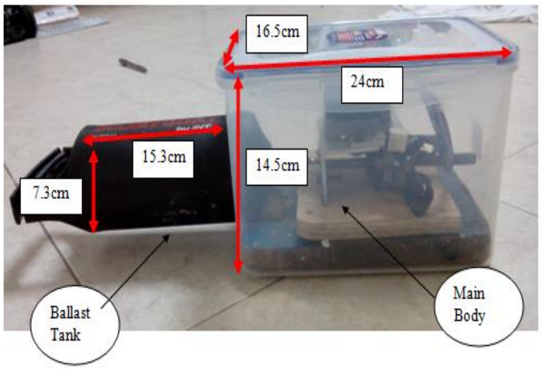
(b)

Figure 3 Piston tank System

After the ballast tank has been constructed, a few tests are implemented to get the volume, weight, and depth capability of the ballast tank. The ballast tank system is put into a water tank and weights are increase until the ballast tank are slightly positive buoyancy and very near to neutral buoyancy. The piston is then moved manually so that the ballast tank can move up and down according to the piston movement that changes the systems buoyancy. This experiment is to find out the capability of the hardware, so that further testing will be done within that range. The picture of the ballast tank is shown in Figure 4 and the characteristics of the ballast tank are shown in Table 2. Figure 5 shows the Force acting on the ROV prototype and Table 3 shows acting forces on the ROV.



(a)



(b)

Figure 4 Piston tank hardware prototype

Table 2 Characteristics of prototype

Item	Characteristic
Volume of ballast tank(cm³)	640.45 cm³
Weight of the whole hardware at Neutral Bouyancy(kg)	30.23 kg
Maximum Depth that the hardware can go down and come back up	110 cm

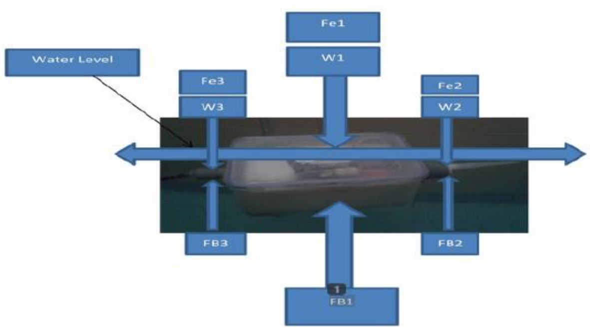


Figure 5 Force acting on the ROV prototype [5]

Table 3 Acting forces [5]

Part	Positive Forces	Negative Forces
Main Body	FB1	W1+Fe1
Ballast Tank	FB2	W2+Fe2
PVC	FB3	W3+Fe3

4.0 DEPTH SENSOR

Two different sensors are then attached and data are collected to get the transfer function of the hardware. Distance from the surface are measured using pressure sensor as shown in Figure 6. Figure 7 shows the circuit diagram for pressure sensor where based on pressure cause by depth and distance from the bottom are measured using Sonar sensor as shown in Figure 8 based on the distance to the seabed.

Figure 6 Pressure Sensor

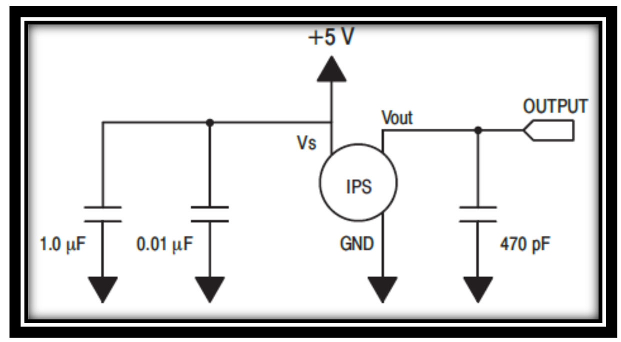


Figure 7 Circuit diagram for MPX4250GP [5]

Figure 8 Sonar Sensor

5.0 RESULTS AND DISCUSSION

The experiment results as shown in Figure 9 and Figure 10. All data are then fit into System Identifications is MATLAB Software and the transfer functions of the hardware are then determined [11]. On Model Order Selection, the second order was choose to get transfer function. After choose order type in Model Order Selection as shown in Figure 11, back on System Identification Toolbox, click on Model Output to get the output performances for this system [12]. Figure 12 shows the output for this model with best fit 71.65% which is the best that are gotten based on the handmade prototype hardware.

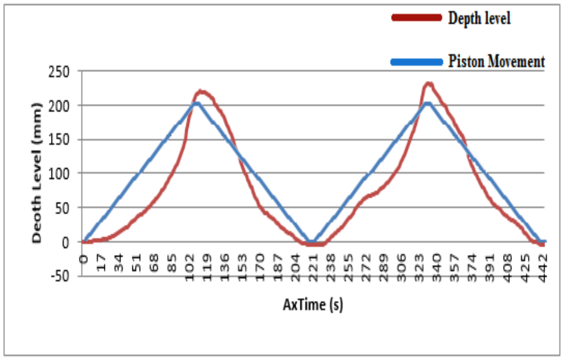


Figure 9 Graph of depth level and piston movement

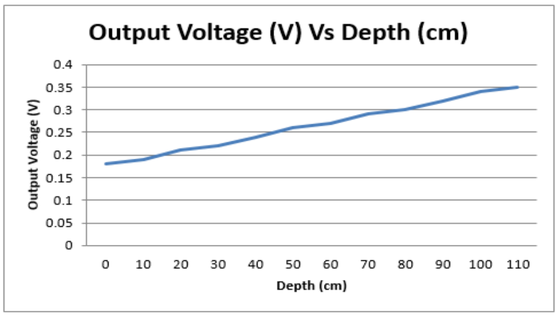


Figure 10 Graph of output voltage vs depth level

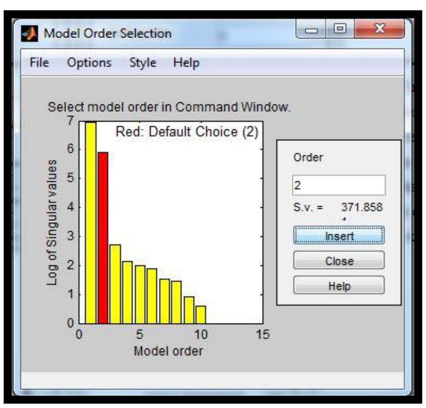


Figure 11 Model order selection

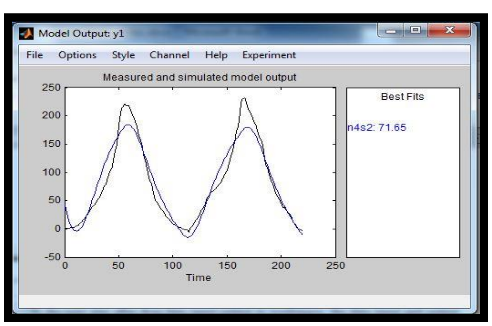


Figure 12 Best fit output performance

The transfer function obtained from System Identification is shown in Equation (1)

$$Tf = \frac{0.06818s+0.9343}{s^2+5.971s+12.5} \quad (1)$$

Once the Transfer Functions are gotten, both simulation and hardware test are done.

5.1 Simulation

PID controller is design to improve the output performance of the open loop system. The PID tuning method is used by manually tune value for Kp, Ki, and Kd until achieved desired performance. The priority that needs to be considered is overshoot, where output response must less than 6.5%. Next, priorities are rise time and settling time, where both must less than 2 s. After that, this PID controller will be applied to real hardware to see the real performance (rise time and settling time) of the ballast tank prototype. PID controller is first tested in the Simulink block diagram as shown in the Figure 13. Initially auto tune method is used to get the initial PID value range, then PID are then manually tune by trial and error to get a better responds as shown in Table 4 and the output response graph are shown in Figure 14.

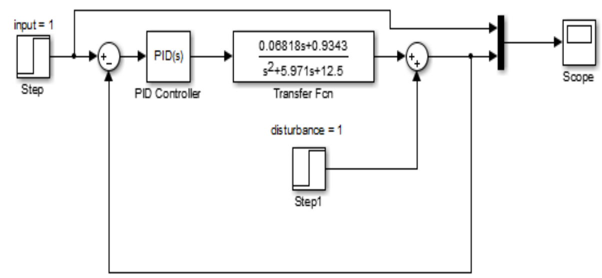


Figure 13 Simulation block diagram

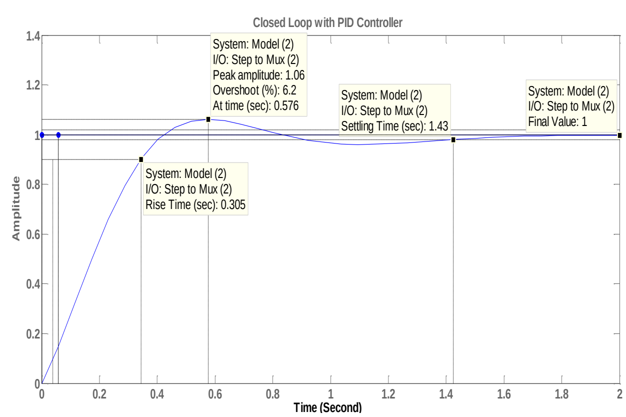


Figure 14 Close loop output response

Table 4 Tuning parameters

Method	Kp	Ki	Kd	Rise time (s)	Settling time (s)	Over shoot (%)
	Parameter of PID Controller					
Auto-Tuned	27.3	72.52	0	0.316	1.46	8.94
Trial and error Fine Tune P	0	72.52	0	0.365	8.95	57.7
	10.5	72.52	0	0.376	2.7	26.6
	28.87	72.52	0	0.37	1.43	8.2
	29.87	72.52	0	0.306	1.42	7.79
	31.87	72.52	0	0.299	1.41	7.07
Trial and error Fine Tune I	31.87	0	0	0.255	0.84	9.39
	31.87	30	0	0.454	3.54	0
	31.87	45.76	0	0.358	2.11	0
	31.87	58.77	0	0.332	1.56	2.49
	31.87	69.78	0	0.303	1.43	6.18
Trial and error Fine Tune D	31.87	69.78	1	0.35	1.4	2.84
	31.87	69.78	0.6	0.332	1.42	4.03
	31.87	69.78	0.58	0.331	1.42	4.1
	31.87	69.78	0.56	0.31	1.43	6.2

5.2 Hardware

When the PID value of Kp = 31.87; Ki = 69.78; Kd = 0.56 are applied to the hardware and test are done in an indoor tank by varying different distance from both the surface and bottom as shown in Figure 15. Both main parameters considered are Rise time and settling time. All results are shown in Table 5. Table 6 shows the weight estimation for ballast tank using mathematical equation.

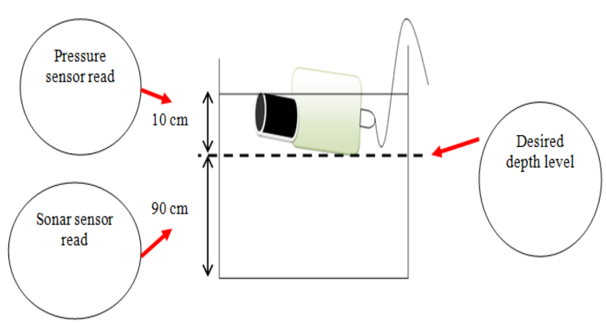


Figure 5.25 Experiment setup

Table 5 Comparison results of both sensor as feedback

Characteristic	System control level from surface Setpoint = Distance from Surface	System control level from bottom Setpoint = Distance from Bottom
Type of sensor	Pressure sensor	Ultrasonic sensor
Closed-loop system (with PID controller)	▶ Setpoint = 10 cm Tr = 80s, Ts = 88s	▶ Setpoint = 90 cm Tr = 239s, Ts = 269s
	▶ Setpoint = 20 cm Tr = 147s, Ts = 155s	▶ Setpoint = 80 cm Tr = 126s, Ts = 224s
	▶ Setpoint = 30 cm Tr = 96s, Ts = 151s	▶ Setpoint = 70 cm Tr = 120s, Ts = 195s
	▶ Setpoint = 40 cm Tr = 82s, Ts = 119s	▶ Setpoint = 60 cm Tr = 35s, Ts = 55s
	▶ Setpoint = 50 cm Tr = 73s, Ts = 146s	▶ Setpoint = 50 cm Tr = 13s, Ts = 40s

Table 6 Weight estimation for ballast tank

Type	Weight (N)
Main body	26.89
Ballast tank	3.34
Total	30.23

6.0 CONCLUSIONS

To summarise the results, it seems that the bigger the distance from the set point the bigger the rise time and settling time for both cases, from surface or from bottom. Therefore it is suggested that when designing feedback scheme, location depth aspects will play a big factor. And also if buoyancy level of ROV can be automated by setting a predefined distance first, then controlling ROV will be a lot easier. In order to improve this project, there are 5 recommendations that have been recognizing through this project. First, the intelligent controller such as fuzzy logic can be implemented to observe the performance of the ballast tank system compared to the conventional controller. Second is selecting the suitable o-ring for piston and need to be really fixed with the ballast tank. The reason is to avoid leakage into ballast tank and can destroy the stepper motor. Besides that, to prevent the leakage also can be done by using a proper sealing technique that is suitable patch from underwater specification. Third recommendation is regarding on the body of the ballast tank. Instead of using the Tupperware, it us much more suitable and proper to fabricate a fiber glass or use aluminum material as the body if there is an extra budget. Since, the Tupperware can release the air inside the body through the cover when it is compressed at high pressure. The fourth is regarding on the cable used for reading signal from the pressure sensor. In this project, the electrical wire is used to read the signal from the sensor toward the Arduino's analog pin. However, this wire produces noise and delay when it is attached to ballast tank. Therefore, the signal cable for underwater application is recommended in order to obtain the consistent signal from the pressure sensor. The fifth is a supply cable used for stepper motor also must from the underwater cable which is neutral buoyancy. This is because the current cable gives the effect (additional weight) on the buoyancy of the ballast tank.

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