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Research Article

STM32 Based Underwater Control Card Design

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Abstract

Unmanned underwater vehicles (ROV/AUV) are robotic systems that can float underwater, are autonomous and remotely controlled. Today, unmanned underwater vehicles are used in a wide range of areas such as underwater search and rescue operations, ship underwater maintenance and repair operations, taking images from dangerous environments where divers cannot enter, military use, inspection of wrecks and underwater cleaning.

The number of ROV/AUVs with domestic hardware and software on the sector is very limited. Because of this deficiency, we worked on such a project to support nationalisation. Designed for underwater vehicles, the Control Board used the ARM-based STM32 microprocessor and auxiliary elements such as IMU, pressure sensor, communication card. Only 2% of microprocessors produced in the world are used in personal computers. The remaining 98% is inside the electronic devices in our lives. There's no way anyone familiar with the developments in electronics these days has ever did not heard of ARM. Almost all mobile devices, especially mobile phones, have processors with ARM architecture. The designed control card can be used for vehicle control and communication with the ground station in remote controlled and autonomous vehicles.

In this study, the design of the Control Board, which will perform depth and direction control of underwater vehicles using PID algorithms, was explained. Instead of automatic cruise control systems for ROV / AUV platforms that currently need to be imported from abroad, it is aimed to develop innovative automatic cruise control systems (hardware and software) and sub-components domestically.

Keywords: ARM (Acorn RISC Machine), AUV (Atonomus Underwater Vehicle), PID (Proportional Integral Derivative), ROV (Remoted Operating Vehicle), IMU (Inertial Measurement Unit)

STM32 Tabanlı Sualtı Kontrol Kartı Tasarımı

Öz

İnsansız su altı araçları (ROV/AUV) su altında yüzebilen, otonom ve uzaktan kontrol edilebilen robotik sistemlerdir. Günümüzde insansız su altı araçları su altı arama kurtarma çalışmaları, gemi su altı bakım ve onarım işlemleri, dalgıçların giremeyeceği tehlikeli ortamlardan görüntü alma, askeri amaçlı kullanım, batıkların incelenmesi ve su altı temizliği gibi çok geniş bir alanda kullanılmaktadır.

Piyasada yerli donanıma ve yazılıma sahip ROV/AUV sayısı çok azdır. Bu eksiklikten yola çıkarak yerlileşmeyi desteklemek amacıyla böyle bir proje üzerine çalışma gereksinimi doğmuştur. Su altı araçları için tasarlanan kontrol kartında ARM tabanlı STM32 mikroişlemci kullanılmış olup IMU, basınç sensörü, iletişim kartı gibi yardımcı elemanlar kullanılmıştır. Bugün dünyada üretilen mikroişlemcilerin %2 gibi küçük bir bölümü kişisel bilgisayarlarda kullanılıyor. Geri kalan %98'lik kısım hayatımızdaki elektronik cihazların içerisinde. Şu günlerde elektronik alanındaki gelişmelere aşina olan birinin ARM ismini duymamış olmasına imkan yok. Başta cep telefonları olmak üzere hemen hemen bütün mobil cihazlarda ARM mimarisine sahip işlemciler bulunuyor. Tasarlanan kontrol kartı uzaktan kontrollü ve otonom araçlarda aracın kontrolü ve su üstü istasyonu ile iletişim için kullanılabilir niteliktedir.

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Bu çalışmada su altı araçlarının derinlik ve yön kontrolünü PID algoritmaları kullanarak gerçekleştirecek kontrol kartının tasarımı anlatılmıştır. ROV/AUV platformlarına yönelik mevcut durumda yurtdışından ithal edilmesi gereken otomatik seyir kontrol sistemleri yerine, yurtiçinde yenilikçi otomatik seyir kontrol sistemleri (donanım ve yazılım) ve alt bileşenlerinin geliştirilmesi amaçlanmıştır.

Anahtar Kelimeler: ARM (Acorn RISC Machine), AUV (Atonomus Underwater Vehicle), PID (Proportional Integral Derivative), ROV (Remoted Operating Vehicle), IMU (Inertial Measurement Unit).

1. Introduction

The increasing use of ROV/AUV systems in recent years, especially in the defense industry, has led to an increase in research on ROV/AUV systems. While the first ROV developers are still unknown, the pioneers in the ROV development process are considered to be a torpedo developed by Luppis-Whitehead Automobile in 1864 and an underwater vehicle developed by Dimitri Rebikoff in 1954, called POODLE. It was the American Navy that brought the use of ROVs to an operational level. The American Navy, which started developing a kind of underwater robot to recover underwater weapons lost during sea tests, rescued an atomic bomb lost in a plane crash off the town of Palomares in Spain in 1966 and rescued the submarine crew that sank off the coast of Ireland pioneered the operational use of underwater vehicles (Moore, Bohm, Jensen, & Johnston, 2010).

In our country, ROVs, which began to be used in experimental US mineseek ships in the 1970s, were first supplied from abroad in the 1990s and began to be used as a limited number of MK series in the Navy's minesweeping fleet. The Naval Forces Command, which was in search of domestic product supply due to the restrictions in its supply, first examined the SUTA (Underwater Technologies Research Institute) ROV in 1996, but later decided to work with TUBITAK on this issue. As the first serious study on this subject in our country, the ULISAR project carried out within the scope of the TUBITAK organization can be given as an example. Ulisar, a multi-purpose national Unmanned Underwater Vehicle developed by the Middle East Technical University with the support of TUBITAK, is a light-weight ROV aimed at diving up to 100 M and controlled via an acoustic link. 1 July 2006 - 1 July 2009, the project was continued on an academic basis and is the first important step in Turkey in this regard on the basis of conceptual proof. At the end of the project, the desired goals were not fully achieved. however, capable of visual navigation on them, cameras, searchlights, sonar, sonar, modem and other similar devices where acoustic sensors are installed, the relevant electronic cards are designed and prepared, where preparation of the software on these devices so as to provide convenience to the user resides on an operator console system was created (CANLI, KURTOĞLU, CANLI, & TUNA).

Underwater vehicles operating remotely or autonomously should be able to perform basic dynamic movements such as heading to a certain angle, descending to a certain depth, berthing and cruising. These movements are also expected to be successful in the against of disruptive effects such as rip currents. The increasing interest in underwater vehicles and the development of underwater vehicle technology have revealed the necessity to develop the controllers designed for these vehicles.

An integrated system formed with electronic hardware and software that takes place in any system and makes that system intelligent is called an embedded system (Gupta, 2012; Marwedel, 2006). The biggest difference of these software from the software on our computers is that they perform a single task and interact with the user indirectly. It is possible to see this system in almost all of the items which we use in our daily life. Currently, the number and use of devices using embedded CPU's tends to increase. Microcontrollers are found in almost every part of our lives and in every electronic device we use. Car, mobile phone, washing machine, dishwasher, which have become part of our daily life. Products like these are becoming programmable smart devices Day by day and shaping our lives. Microcontrollers are in constant communication and contact with the real world using sensors and actions according to the application areas in which they are used. This ensures that their potential for use is greater than that of an ordinary personal computer.

When microprocessors that have a great share in this transformation and widespread in the electronic device world are considered, it is obvious that ARM (Acorn RISC Machine) based microcontrollers designed by ARM company and produced by leading chip manufacturers have a clear advantage (BOLAT, SOLAK, & YAKUT, 2017). Until today, more than 15 billion chips using ARM technology have been produced and licenses for 640 processors have been sold to more than 200 companies. ARM is a generic name for a processor architecture that can handle 32-bit and 64-bit operations that are commonly used with low energy consumption, high speed and capacity characteristics and is designed in accordance with the RISC (Reduced Instruction Set Computer) command structure.

Recently, demand for low-cost ROV has increased by private companies, Professional Studies, University students and public organizations. The aim of this project is to design a control card for underwater vehicles using the PID approach (Åström, Hägglund, & Astrom, 2006) and the ARM-based STM32F103 development card. This work provides an effective hardware solution that enables monitoring, data collection or control of underwater vehicles for military usage.

2. Material and Method

In the application, ST brand 32-bit STM32F103 microcontroller, Bluerobotics production BAR30 pressure sensor and MPU6050 IMU and DS18B20 temperature sensor were used. In the software part, program codes are created in Keil compilers.

2.1. ARM Microcontroller

The STM32F103 series microcontroller contains a high-speed ARM Cortex-M3 32-bit RISC core operating on high-speed embedded memory, at a frequency of 72MHz. This card with 128 Kbyte flash memory and 20Kbyte SRAM has a wide variety of advanced I/O and peripherals connected to two APB buses. It offers standard and advanced communication interfaces with two 12-bit ADCs, three general purpose timers and a PWM timer. These features make the STM32F103 family suitable for a wide variety of applications such as motor drives, PC and gaming peripherals, GPS platforms, industrial applications, PLCs, inverters, printers, etc (Gay, 2018).

2.2. Sensors

MPU6050 is a 6-axis IMU sensor board that contains a 3-axis gyro and a 3-axis angular accelerometer. Uses the I2C protocol. Using tilt data from the sensor, PID control will ensure that the robot remains balanced under the water. Figure 1 shows the image of the MPU6050 sensor card.

Figure 1. MPU6050 IMU sensor card

The sensor selected for underwater pressure is Bluerobotics high resolution bar30 underwater pressure sensor. This sensor, which communicates with the I^2C protocol, will be used to calculate depth. It will also provide data to the PID control unit. Figure 2 shows the BAR30 temperature sensor.

Figure 2. BAR30 pressure sensor

In addition, there is a DS18B20 temperature sensor to measure the temperature of the external environment on the vehicle and an LM35 temperature sensor to monitor the vehicle temperature. Underwater vehicles can be equipped with a wide range of sensors in accordance with the tasks in which they will be used (Yildiz, Yilmaz, & Gokalp, 2009). Examples include Sonar, magnetometer, barometer, conductivity and temperature sensors.

2.3. Communication Module

The Fathom -S tether Interface Card produced by Bluerobotics was used to provide communication between the underwater and the control unit. Fathom-X Tether Interface card provides the necessary communication and video signals for the control unit and the underwater vehicle over a single communication line. Figure 3 shows the Fathom –S tether interface card.

Figure 3. Fathom -S tether interface card

2.4. Computer Interface

A computer interface is designed to control the underwater robot and read the measurement values, as well as see the camera image. This interface, prepared in Visual Studio with C# language, is transmitted via USB port to the control card via serial communication of the joystick axis information it receives using the UART protocol (Pardue, 2007). In addition, sensor information will be read through the interface. The computer interface is given in Figure 4.

Figure 4. The computer interface

2.5. PCB Desing

A PCB is a board that holds electronic components together and connects them electrically. It is the building block of any electronic design. A PCB allows signals and power to be routed between physical devices (Jones, 2004; Sharawi, 2004). The microcontroller, sensors and feeding elements in the designed control card were designed in the Eagle program and a printed circuit board was created (Aono, 2011).

2.6. PID Control

Our control card has a STM32F103 microcontroller. The task of this microcontroller is to read the information from the sensors, to control the PID, to drive the motors, to control the lighting and to send information to the above water station from underwater. The system also has an interface card for surface communication. In this way, the video image taken from underwater and the information of the read sensors can be transferred to the surface station. With this study, control algorithms that will provide automatic depth and direction control capability have been developed using PID control technique (Ang, Chong, & Li, 2005; Maalouf et al., 2013; Shen, Cao, Zhou, Xu, & Gu, 2013). Figure 5 shows a block diagram of the designed system.

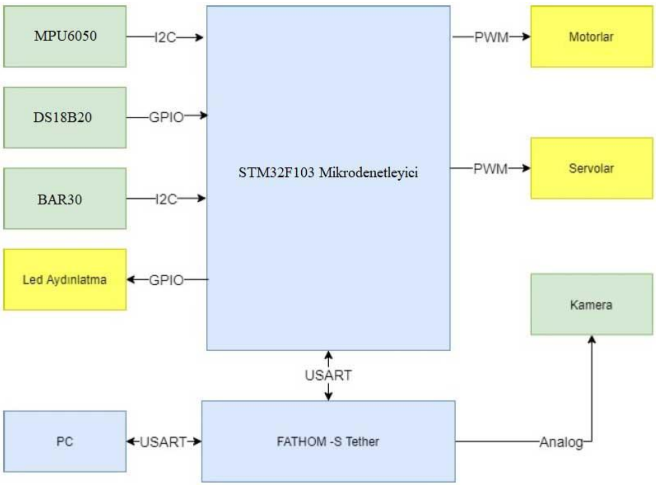

Figure 5. Block diagram of the designed system

PID control method is a feedback control mechanism commonly used in industrial control systems. A PID controller calculates an “error” value by taking the difference between the measured value and the desired reference value. The PID Controller aims to achieve the measured value to the desired reference value by controlling the process input.

PID control algorithms contain three separate fixed parameters. The proportional term aims to reduce the error in the system by multiplying it by a coefficient (Kp). This process allows the error to be corrected quickly, but there is a high probability of oscillation in the system. Integral means to find the area of the error, the error in each period is summed by multiplying by the (Ki) coefficient (Johnson & Moradi, 2005). The derivative is related to the change of time-dependent value. It detects the change in the system in advance and slows the system down so that it does not exceed the desired value. An example PID control block diagram is given in Figure 6.

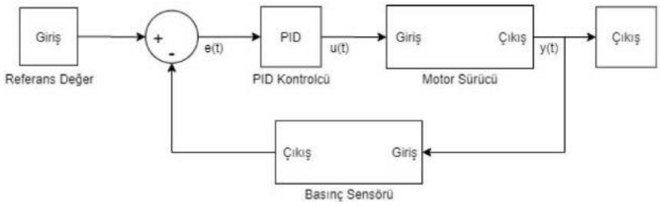

Figure 6. PID control block diagram

In order for the output of the system to follow the desired reference value in PID control, the coefficients of Kp, Ki, Kd must be adjusted accordingly. Figure 7 shows the PID control equation.

$$u(t) = K_p . e(t) + K_I \int e(t)dt + K_D . \frac{d}{dt} . e(t) \qquad (1)$$

$$e(t) = r(t) - y(t) \qquad (2)$$

Figure 7. PID control equation

In this method, the u (t) controller output is obtained by multiplying the error signal e (t) with the proportional term Kp, the integral term of the error signal with the Ki integral term, and the derivative of the error signal with the Kd derivative term. The effects of each PID coefficient on the system are given in Table 1.

Table 1. The effects of each PID coefficient on the system

Parameter Increase	Rise Time	Overshoot	Setling Time	Steady-State Error
Kp	Decrease	Increase	Small Change	Decrease
Kd	Small Change	Decrease	Decrease	Eliminate
Ki	Decrease	Increase	Increase	Small Change

In this system, the error value used for depth control consists of the difference between the value read from the pressure sensor and the reference value. Likewise, the error value used in balance control consists of the difference between the angle values read from the IMU and the reference value. The PID control system aims to bring this error value to the reference value using relevant algorithms. PID control algorithm is given in Figure 7.

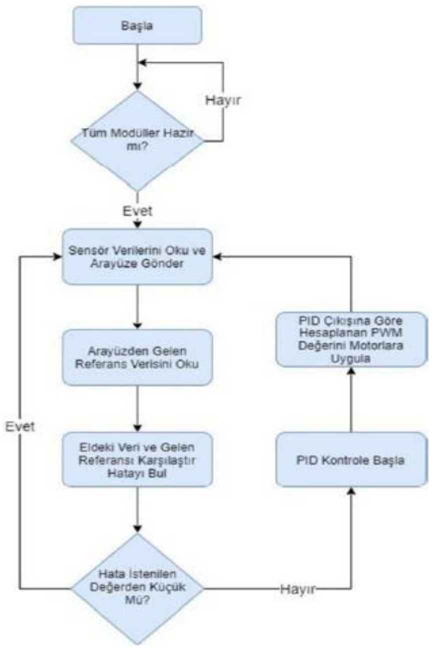

Figure 8. PID control algorithm

3. Results and Discussion

The increasing interest in underwater vehicles and the development of underwater vehicle technology have revealed the necessity of developing the controllers designed for these vehicles. When the literature is examined, it has been observed that simple control techniques such as PID are successfully applied to such systems (Ang et al., 2005; Khodayari & Balochian, 2015; Rivera, Morari, & Skogestad, 1986).

There are very few ROVs / AUVs in the market with domestic hardware and software. Based on this deficiency, it was necessary to work on such a project in order to support nationalization. It was investigated that the most suitable microcontroller for the underwater control card is the ARM based STM32F103 microcontroller card and the appropriate selection was made. Instead of automatic cruise control systems that are difficult to import from abroad in the current situation for ROV/AUV platforms, it is aimed to develop innovative automatic cruise control systems (hardware and software) and their sub-components domestically. Thanks to the designed control card, the ROV / AUV has a structure that provides its own balance against disturbing effects such as rip currents.

PID controller system consists of coefficients such as Kp, Ki, Kd. These coefficients differ for each system. The coefficients must be adjusted using appropriate methods according to the system used. In this project, PID coefficients are adjusted manually and can be changed instantly via the computer interface.

It is important to determine the control parameters in the PID control system. If the PID control parameters are not selected correctly, you can make the process you want to control even more unstable. In applications, factors such as physical, electrical, or load changes that occur during Operation change the system properties, accordingly, the adjusted gain values can negatively affect the operation of the system. Therefore, methods in which PID parameters are automatically calculated according to the dynamics of this changing system can be used (Grassi, Tsakalis, Dash, Gaikwad, & Stein, 2000; Xiaolan, Hanghui, & Debao, 2002).

4. Conclusions and Recommendations

The results obtained from this study can be used in the fields of scientific, technological and defense industries. It is believed that the results obtained at the end of this study will lead to the development of new projects related to ROV/AUV. The data obtained from this study will be a resource for future studies on this subject.

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