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Integration of STM32 Microcontroller with Arm Cortex Architecture into the 8-Bit Measurement Circuit Customized for Real-Time Data Acquisition on Propeller Shaft to Increase Data Speed and Accuracy

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Abstract: Propeller shafts transmit torque and high-speed rotational movement from the engine to related equipment. Expected propeller shaft functions are calculated and designed by using an analytical and numerical approaches. The verification tests are significant in that they provide feedback to the design and development processes. Therefore, acquiring accurate data from power transmission equipment is becoming even more important. This paper focuses on the study of circuit boards customized for use in the validation tests of the propeller shafts. It should be noted that these measurement circuits were integrated on the propeller shafts. These measurement circuits were used to acquire data such as torque, temperature, etc. in real time. Especially with instantaneous signals such as torque, data loss can occur due to low microcontroller resolution. Therefore, it was aimed to develop to the microcontroller to 32-bit resolution from 8-bit resolution to increase data speed and accuracy. As the first step, an INA125P operational amplifier was installed to amplify the low voltage values gathered from the gages and the sensors. The gain value of the amplifier was calculated in order to provide the highest data resolution and sensitivity. And then, ADS1115 analog to digital converter circuit with a rate of 860 samples per second and 16-bit resolution was used to interpret the analog data. A low pass filter was installed to remove noise from the output signal. Embedded code was also locally developed for the hardware installed. The system was calibrated on a validated test rig. Real-time torque and temperature data were acquired from the propeller shaft. It is observed that compared to the previous 8-bit system, the data accuracy and integrity from the new 32-bit board has increased by a factor of 5 to 100 Hz. The collected data was found to be 99.4% compatible with the validated test rig data.

Keywords: STM32, 32-Bit, Propeller shaft, Microcontroller, Measurement

Introduction

In global markets, the balance between cost and profit per product has great importance, especially in mass produced industries such as automotive. Under mass production conditions, the profit or loss per product increases cumulatively and its effects can not be ignored. Therefore, the optimum product and production process are designed with precision. There are development studies for these products and production processes. Verification tests are one of the main features of the development studies (Aldemir et al., 2021).

Propeller shafts are the mechanical components which transmit power produced by the engine through transmission organs. Besides two main functions, propeller shafts are responsible for compensating angular and axial displacement caused by rear suspension. Propeller shafts have complex kinematic structure. It contains many different components. As a result, there are many different types of failure appear on this shaft working under a vehicle. For this reason, numerical calculations and analytical approaches are used during design studies (Isık, 2009).

Many verification tests are applied to propeller shafts for failure detection or development studies. Road conditions are simulated and the effects on the propeller shaft are observed in these tests. This health monitoring studies help to understand the failure modes and provide feedback for design studies. For example, torque is applied to the propeller shaft up to failure and stress values are measured instantaneously. According to the test results, critical regions can be strengthened by making design changes.

This paper focused on examination of circuit boards that customized for using on propeller shafts verification tests. These boards are used to acquire torque and temperature data in real-time. It has to be noticed that the aforementioned circuit board is designed for propeller shafts. With instantaneous signals such as torque, data loss can occur due to low microcontroller resolution. Especially in commercial applications where measurement precision is critical, the speed and accuracy of the data acquisition influences the quality of the data. Therefore, the microcontroller is replaced with 32-bit resolution from 8-bit resolution to increase data speed and accuracy. The difference in data resolution between 32-bit and 8-bit microcontrollers was shown in Figure 1 below.

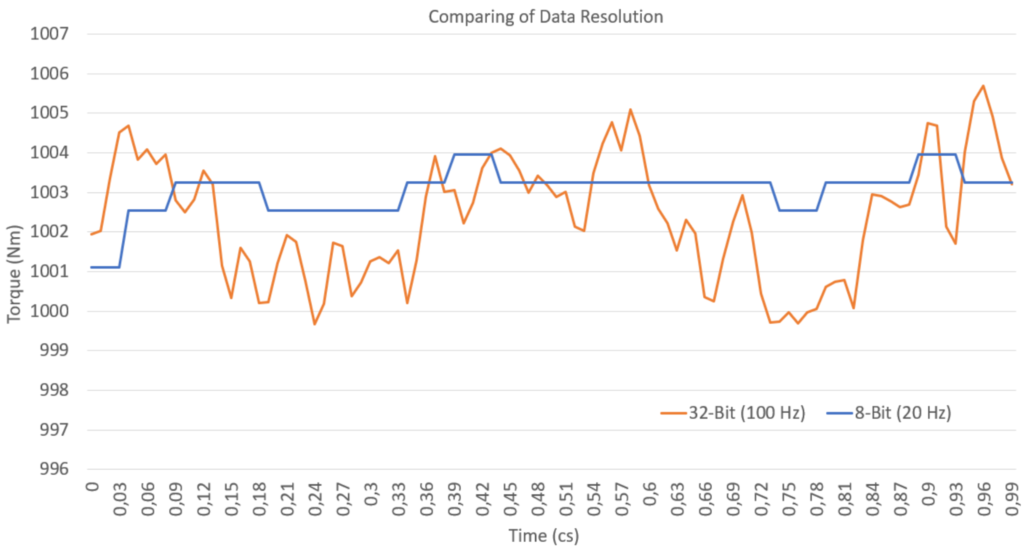

Figure 1. The difference between data resolution

Literature

Hui-fu Zhang and Wei Kang were studied on "Design of the data acquisition system based on STM32". On the study, an embedded signal acquisition system for real-time was explained. The system was involved in a three-axis acceleration sensor which has high sensitivity. It was possible to detect the mechanical failure of the rotating machines with measuring high frequency vibration. The measurement system was designed based on STM32 (Zhang & Kang, 2013).

Also, Xie et al. (2017). studied on named as "STM32-based vehicle data acquisition system for internet-of-vehicles" that includes the feasibility and effectiveness of a data acquisitions system based on STM32. The system works with the vehicle complex sensors and communications network, and it was provided cybersecurity with IoT (Xie et al., 2017).

In addition to STM32 studies, Alp İmer worked on "Smart irrigation system". The system controls an autonomous irrigation system using STM32 microcontroller. The system has different communication protocol and peripheral units. A sensor with limiter switch was used as input and a DC motor was used to drive the pulse width modulation unit on STM32. The microcontroller user interface Cube MX was mentioned on the paper (Imer, n.d.).

Hardware Method

As the first step of the study, a fundamental test setup was built for improving current circuit board. Here, it was started with applying a strain gauge on a simple steel bar and a quarter wheat stone bridge was built. Analogue signals were generated on the strain gauge by applying force to the steel bar. This is a simulation of the torque loaded propeller shaft. Then, a typical low-pass filter was used in order to prevent the noise of the analogue signals of the output.

Operational Amplifier

Strain gauges generate voltages difference at millivolt levels. These low-level voltages is needed to amplify before reading by an electronic device. The amplifying process has to be performed instantaneously. According to the research, INA125P operational amplifier is explored to be enable 0-10,000 of range a high gain. Also, this operational amplifier provides a reference voltage on high precision for mentioned bridge applications. (Burr-Brown Corporation, 1998). Traditional INA125P operational amplifier application was shared on Figure 2.

DESIRED GAIN (V/V)	R_G (Ω)	NEAREST 1% R_G VALUE (Ω)
4	NC	NC
5	60k	60.4k
10	10k	10k
20	3750	3740
50	1304	1300
100	625	619
200	306	309
500	121	121
1000	60	60.4
2000	30	30.1
10000	6	6.04

NC: No Connection.

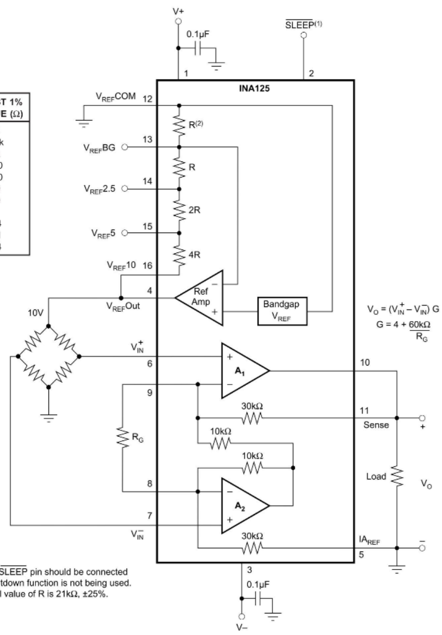

Figure 2. INA125P operational amplifier application [6]

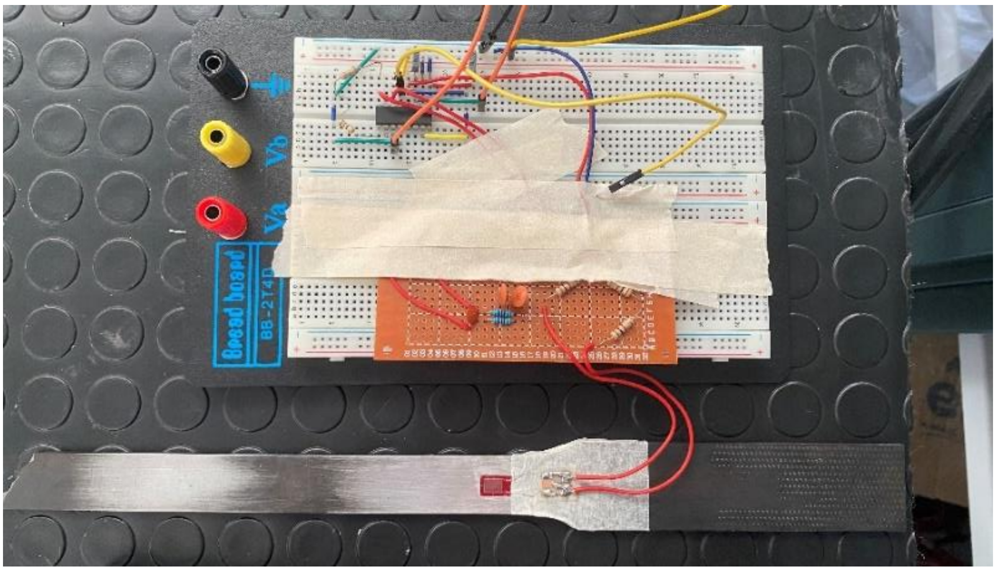

Figure 3. The picture of the test setup

The analogue signals were amplified from ±0.5 V to ±4.5 V thanks to INA125P operational amplifier. It was placed at the output of the analogue signal generator test setup. Furthermore, the INA125 gain ratio can be easily adjusted by changing the value of the gain resistor R_g. The picture of the real test setup with the steel bar, the bridge, the low pass filter and the amplifier was shown in Figure 3.

Analog Digital Converter

The mentioned analogue signals were generated on the steel bar. Electronic devices communicate using binary language. This language is explained by the digital signals such as logic 0 and 1 with a resolution of 2^n. [7] This part of the study explained the conversation of the analogue signals to digital ones. Thus, the microcontroller can able to process these digital signals. Analog digital converters that have high sampling rates were researched. The data resolution and speed were determined. Then, ADS1115 analog to digital converter with 860 SPS data sampling speed and 16-bit resolution was chosen. Thanks to ADS1115, ±4.5 V analogue torque signal range are divided into 65,536 parts and matched with digital signals. This conversion of the signals improved the data speed and accuracy.

ADS1115 footprint was printed for preparing prototype. ADS1115 and its printed footprint output were shown in Figure 4 below.

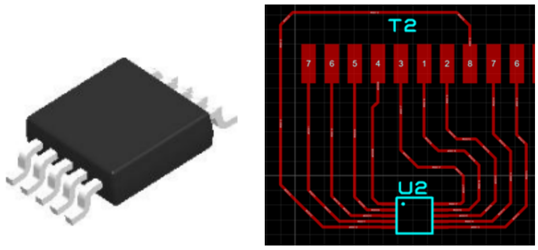

Figure 4. ADS1115 and its footprint [8]

ADS1115 prototype was placed beyond the INA125P operational amplifier. After the signal amplification, amplified analog signals was converted to digital signals.

STM32 Microcontroller

Generally, microcontrollers have a central processing unit, type of memories, input and output ports, etc. It can be considered as a computer with its serial communication, analog-to-digital conversion or signal processing features (Hariz et al., 2015).

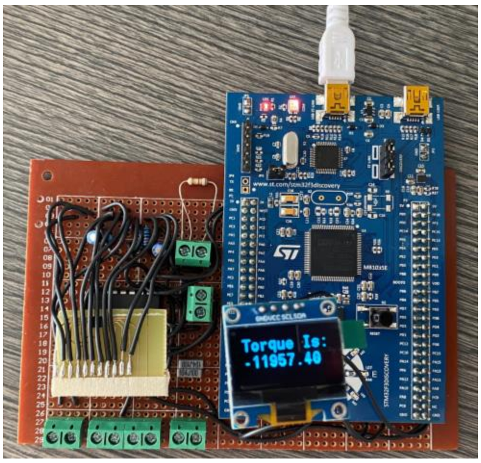

Figure 5. The first assembled prototype of the hardware

STM32 microcontrollers are signal processors with their high core speed and resolution. These controllers have different interfaces for instruction and data storage. This architecture is enabled to synchronized access to memories. This allows the microcontroller to achieve high communication speeds (Brown, 2012).

STM32F3 microcontroller has M4 core running at 72 MHz and it is customized for signal processing. It was chosen to use on this study. The DMA (Direct Memory Access) function is a bus manager in STM32F3. It has a special peripheral unit and enables to reach the limits of the data speed (ST. life augmented, n.d.).Finally, STM32F3 controller was integrated into the system. The first assembled prototype of the system was shown in Figure 5.

Software Method

In order to acquire torque data, the strain gauge electrical power without any fluctuation. This need was supplied by INA125P with its reference voltage output. Respectively, the resistance on the strain gauge was changed caused by mechanical stresses. Low level analogue torque signals were generated. These weak signals were amplified in INA125P, then they were converted into digital signals in ADS1115. These digital signals were ready to be processed on STM32F3.

CubeMX

The embedded software needs to include instructions and features for signal processing by the STM32F3 microcontroller. The instructions of input, output and function ports were assigned on Cube MX. This is a free software provided by STM32 manufacturer.

The project was started by selecting the microcontroller on the Cube MX interface. The digital input pins were defined for connecting the torque digital signals. The microcontroller serial wire programming type and core speed were defined. I^2C communication protocol and features for the monitoring system were assigned to the specified ports. An example of the Cube MX interface is shown in Figure 6.

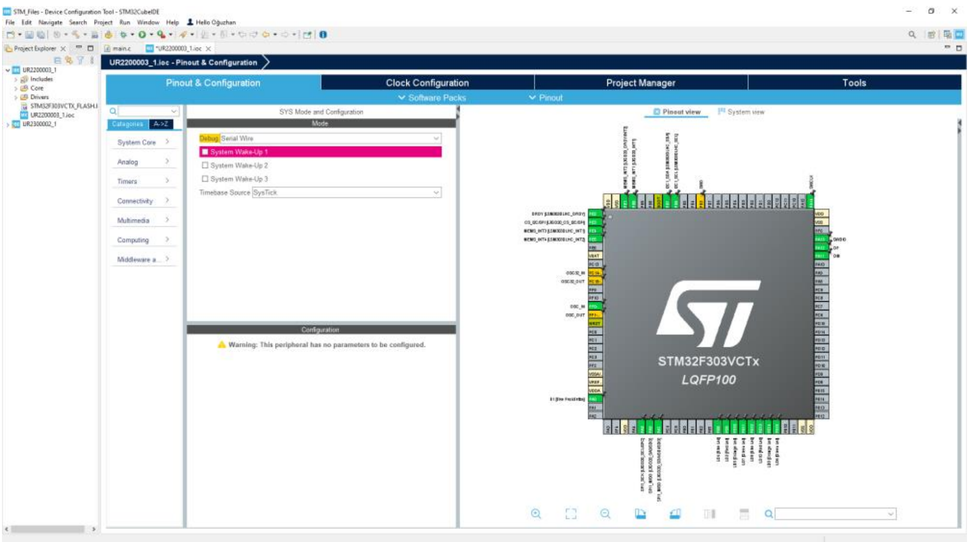

Figure 6. Cube MX user interface

After the definitions were completed, the project file was generated. Cube MX software constituted the basic version of the embedded code to be loaded into the microcontroller.

CubeIDE

C based code prepared for assigning instructions to the microcontroller. It included related libraries, variables and Cube IDE monitoring descriptions. The libraries contained typical code sets for the monitoring instructions and the input and output functions of the controller. The variables are used to assign the digital voltage levels to numerical data. UART and I^2C communication protocols were automatically implemented to the code by the Cube IDE. In addition, a sequential print loop was defined due to a variable can be written to the SWV (serial wire viewer) monitoring tab in the Cube IDE interface. These code sets are given as an example in Figure 7.

```
#include "LCD.h"
#include <stdio.h>
#include "ssd1306.h"
#include "fonts.h"
```

```
float Read_ADS1115(void);
float voltage;
```

```
  MX_GPIO_Init();
  MX_I2C1_Init();
  MX_USART2_UART_Init();
  MX_I2C2_Init();
  /* USER CODE BEGIN 2 */

  float data;
  char yazi[16] = "";
```

```
int _write(int file, char *ptr, int len)
{
  int i=0;
  for(i=0 ; i<len ; i++)
    ITM_SendChar((*ptr++));
  return len;
}
```

Figure 7. Code sets of the libraries, variables and SWV

A function was written to define and address the rules of the I2C communication protocol. In this function, the data are called by means of these addresses. Simple mathematical operations, offset values, experimentally determined calibration coefficients and printing instructions were created. Figure 8 shows the content of these functions. The prepared code was uploaded to the microprocessor via UART protocol.

```
while (1)
{
  /* USER CODE END WHILE */

  /* USER CODE BEGIN 3 */
        voltage = Read_ADS1115();
        HAL_Delay(10);

        data = voltage;
        printf("Torque is: %-.2f Nm\n", (data-10501.00)*1.3951);
        /*lcd_print(1,1, "Torque Is:");
        sprintf(yazi, "%-.2f", (data-7237.00)*1.3951);
        lcd_print(2,1, yazi);
        HAL_Delay(50);*/
     /* USER CODE BEGIN 3 */

        SSD1306_GotoXY(10,10);
        SSD1306_Puts ("Torque Is:", &Font_11x18, 1);
        SSD1306_GotoXY(10,30);
        sprintf(yazi, "%-.2f Nm", (data-10501.00)*1.3951);
        SSD1306_Puts(yazi, &Font_11x18, 1);
        SSD1306_UpdateScreen();
        HAL_Delay(1);
}
```

```
/* USER CODE BEGIN 4 */
float Read_ADS1115(void)
{
    unsigned char buffer[3];
    unsigned char i2c_addr = 0x90;
    unsigned short data=0;

    buffer[0] = 0x01;
    buffer[1] = 0xC2;
    buffer[2] = 0x85;
    HAL_I2C_Master_Transmit(&hi2c1, i2c_addr, (uint8_t*)buffer, 3, 100);


    buffer[0] = 0x00;
    HAL_I2C_Master_Transmit(&hi2c1, i2c_addr, (uint8_t*)buffer, 1, 100);
    HAL_I2C_Master_Receive(&hi2c1, i2c_addr+1, buffer, 2, 100);
    data = (buffer[0]<<8) + buffer[1];
    if(data==0xFFFF) data = 0;

    return (float)(0.5 * ((float)data));

}
```

Figure 8. Code sets of functions and transitions

Results and Discussion

Scope of the study, the aimed torque measurement system was created. The measurement system as prototype was thought to use during a static torsion test of the propeller shaft. The propeller shaft was connected to the static torsion test rig with full bridge strain gauge application on its tube. Torque was loaded on the propeller shaft. The data was acquired successfully by STM32 data acquisition system. The picture of the static torsion test was shared in Figure 9.

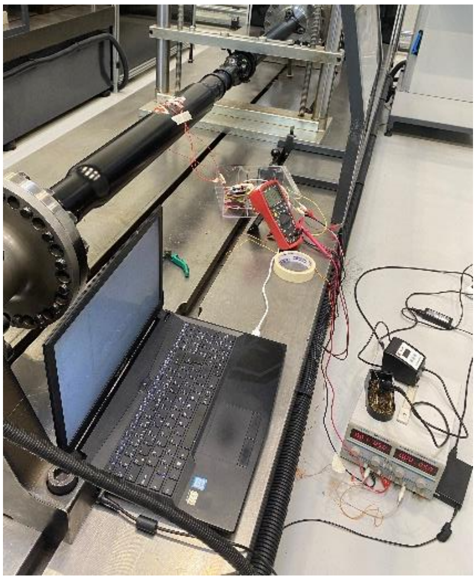

Figure 9. Data acquisition on propeller shaft

Acquired data was compared with previous data acquired with 8-bit system. It was seemed the data acquisition speed was increased 5 times to 100 Hz. This ability was contributed to prevent data loss of instantaneous torque signals. The torque that loaded to the propeller shaft was applied by accredited test rig. Accuracy of these applied torque values were compared with the data acquired by STM32. High-precision torque data were found be 99.4% consistent. The propeller shaft was gradually torque loaded in steps of 500 Nm by the test rig. The graph of the data acquired by STM32 was shown in Figure 10.

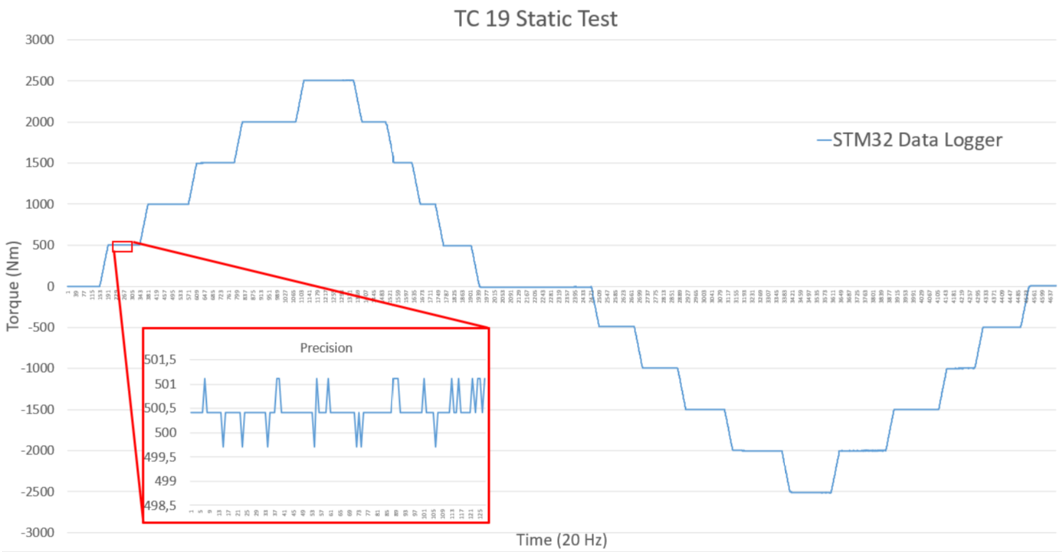

Figure 10. The graph of the data acquired by STM32

A housing was designed to protect the hardware as a mechanical and seem like a fundamentally data logger. Input/output ports and OLED display were added on the housing. Completed data logger was shared in Figure 11.

Figure 11. Data logger

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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