ROV Depth Gauge Built from a Modified Pressure Transducer

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ABSTRACT

Remotely operated vehicles (ROVs) equipped with submersible instruments, such as depth gauges, allow marine biology researchers to collect important data needed for their projects. Accurate depth gauges are costly and deter potential projects that are limited by inadequate funding. An alternative solution to measuring ROV underwater depth was designed by modifying a standard pressure transducer to serve as a depth gauge. The operational constraints of cost, size, operating pressure, and output voltage were considered for the instrument. Following the slight modifications of waterproofing and connecting cable tethers, the senor was calibrated at depths ranging from 0 to 3 feet. The calibration results demonstrated that a pressure sensor is capable of measuring accurate voltage outputs at different depths. When the data collected from calibration was analyzed with linear regression, it rendered a linear equation to convert the output voltages to depth. The conversion equation was tested in three different swimming pools to verify accuracy and consistency. The test showed that the depth gauge provided an accurate conversion when depths within the calibration range were tested. Error became evident at depths of 3.5ft or larger, with the deepest test of 14ft providing significant amount of variation.

INTRODUCTION

Underwater remotely operated vehicles (ROVs) are frequently used in marine biology disciplines because they allow scientists to obtain data without having to endure the cost and risk of undersea diving. There are many variations of ROV's for different applications, many of which are highly accessible and low cost (Whitcomb 2000). Some marine research projects do not have sufficient funding for high-end submersible ROV instruments that their research requires (Allison et al. 1998). For many of these projects, depth measurements are an essential aspect of the experiment data analysis. Depth gauges come in many variations, but are typically bulky, expensive, and consume large amounts of power relative to ROVs and other instruments (Crowell 2006). Despite the inconvenience, their ability to provide accurate and valuable data makes them ideal for research involving ROVs. However, the shear cost of these gauges limits the number that can be employed in research areas where insufficient funding deters potential projects (Wilson 1989). There is a lack of readily available, small and lightweight, cost effective, yet accurate submersible instruments for measuring depth of ROVs.

This research outlines the construction of a depth gauge by modifying a pressure transducer to take accurate underwater depth measurements. Using a pressure transducer will allow the depth gauge to be lightweight, small, cost effective, and consume minimal power. It can also provide accurate results with little data analysis required to extract the depth readings from the instrument output. A pressure transducer requires an input voltage and returns an output voltage depending on the amount of pressure applied to the sensor. As the pressure transducer experiences greater amounts of pressure, such as venturing deeper underwater, it returns larger voltage values. Pressure transducers can be calibrated to function in diverse circumstances, but for this experiment, it will be optimized for application to a SeaPerch ROV. These ROV's typically operate at depths of 0 to 15 feet and in recreation swimming pools (SeaPerch Program 2012). With slight modifications, the depth gauge can operate in different water types, total depths, and depth resolutions as required for marine biology research. The output voltage of the depth gauge will be transmitted using a cable tether to the surface and stored on a data logger, specifically a Vernier Labquest. After calibration, the depth gauge will capable of providing depth readings of the submerged ROV.

METHODS AND MATERIALS

To construct the depth gauge, a pressure transducer was selected that met the deign constraints for operation under typical SeaPerch ROV conditions as described below. The pressure transducer was then modified and calibrated to output the ROV depth in feet, and finally tested for accuracy in local swimming pools. For a complete list of all materials and equipment see the appendix below.

Design Considerations

Different types of pressures transducers were considered based on several design factors including cost, physical size, operating pressure and temperature range, pressure measurement type, and output voltage. Cost and size were kept to a minimum while still complying with the necessary functional parameters for a SeaPerch ROV.

The operating pressure force (P) is calculated by adding atmospheric pressure (P_{atm}) to the density of the water (ρ), gravity (g), and the depth of the water above the device (d) multiplied together.

$$P = P_{atm} + \rho g d$$

Gauge pressure type measures total pressure minus atmospheric pressure and is the ideal pressure measurement type because it eliminates the need to add atmospheric pressure to the total operating pressure (Munson et al. 2013). The operating pressure is calculated using this equation coupled with the desired depth range for depth, the density of the fluid medium, and earth's gravity. For a depth range of 0 to 15 feet, a 15PSI gauge pressure range ensures proper function for varied conditions and also allows for half-foot depth resolution.

The output voltage range of the pressure transducer determines at which depth intervals accurate results can be acquired. The amount that the output voltage changes as depth is varied increases with a larger output range, as changes of 10mV per foot of water are much easier to measure than a change of 2mV per foot. There is an inherent amount of noise in the measured signal, which can make it difficult to distinguish depth accurately if the output voltage resolution is too small. For the SeaPerch ROV, a minimum output range of 200mV would render a resolution of roughly 10mV per foot of depth. Typical temperature ranges of a recreational pool is roughly 20°C to 30°C, which is well within the operational temperature range of most pressure transducers.

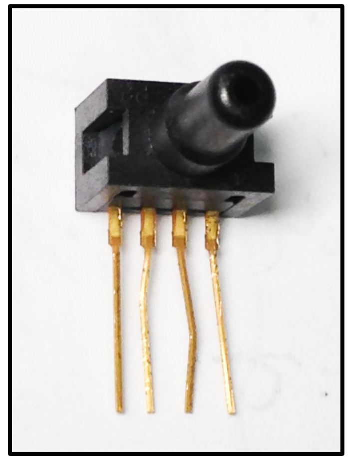

Figure 1: Honeywell pressure transducer model 24PCCFA6G.

A simple Honeywell brand pressure transducer that satisfied these conditions was identified and purchased from Digi-Key Corporation's website for roughly $25, significantly cheaper than typical depth gauges. For this experiment, the model number 24PCCFA6G was selected with an operational pressure of 15PSI, gauge pressure type, 10V input, 285mV output, as well as functionality under the appropriate operating temperature. Detailed specifications of the part can be referenced in the appendix.

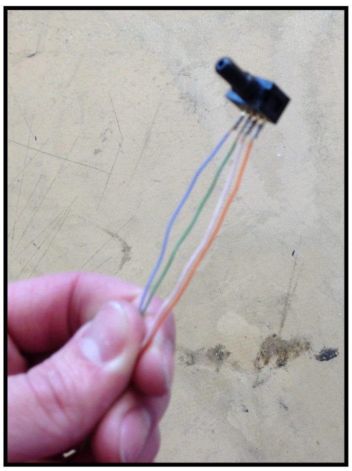

Figure 2: Pressure transducer with soldered on wire extensions.

Modifications

The bare pressure sensor, Figure 1, comes with four pins extruding out of the black enclosure. Each pin corresponds to a different function, as detailed in the appendix below on the product specification sheet. Pins 1 and 3 are for the voltage input and ground respectively, and pins 2 and 4 output either increasing or decreasing voltage output with pressure change. Pin 2 was used for this experiment and measures an increase in voltage output as pressure felt increases.

Before the pressure sensor was altered, it was tested to verify proper functionality under various sample pressures. The pressure transducer was careful retested after each subsequent step of modification to ensure it remained in working condition. To operate underwater the instrument needs sufficient waterproofing to ensure that it is not damaged over repeated use. Basic wire extensions were soldered to each of the pins, as shown in Figure 2, in order to allow for a complete waterproof seal over the key components while leaving the sensing port uncovered. Several methods can be used to waterproof such as epoxy or a spray on coating, but a white two-part casting urethane was used to give pressure transducer high durability.

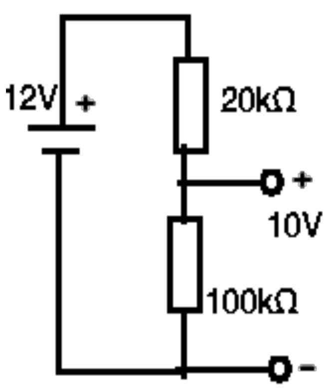

Figure 3: Circuit drawing of the voltage divider with two resistors.

The SeaPerch ROV is powered with a 12V battery source that will also power the depth gauge, which operates at 10V. Figure 3 shows how resistors of 20kΩ and 100kΩ are connected as a voltage divider to step down the 12V battery to 10V. This was accomplished with a standard breadboard connected at the surface between the 12V battery and the start of the power supply wire. The power supply wire was secured

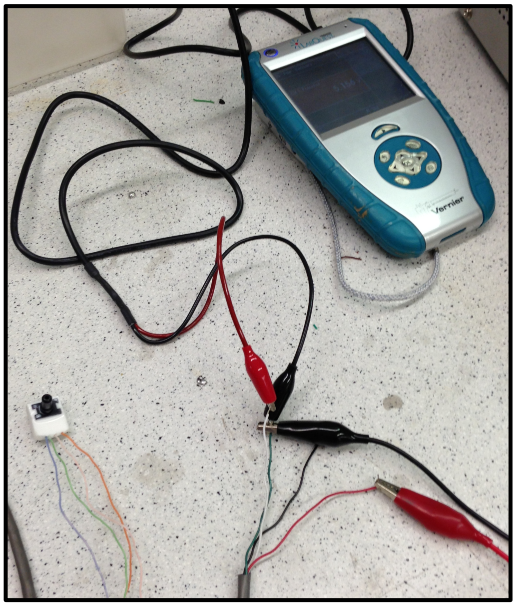

Figure 4: Vernier Labquest, used to measure output voltage, connected to the pressure transducer

to the SeaPerch's cable tether using tie wraps every five feet and attached to pin 1 of the pressure transducer.

The output voltage readings are transmitted through the available wire connection of the CAT 5 tether cable that controls the ROV's three motors. The colored and white wires are separated, as done for the SeaPerch motors, and connected to pin extensions 2 and 3. The colored wire is connected to pin 2 to transmit the voltage output and the white wire is connected to pin 3 to function as ground. To ensure wire connections were protected and secure, electrical tape was tightly wrapped around them.
At the surface the colored wire attached to pin 2 connects to a data logger capable of storing results ranging from 0V to 6V. For this experiment the output data was collected with a Vernier Labquest, shown in Figure 4, which records, stores, and displays the voltage changes. The depth gauge was attached to the SeaPerch ROV with the port facing upwards to minimize water flow into pressure sensor of the depth gauge. Pressure transducers measure the total pressure felt on the device and the dynamic pressure of the fluid flow into the port would add to the total pressure. To function as a depth gauge, the pressure transducer must measure only the pressure due to changes in depth. The highest accuracy results will occur when measurements are taken while the ROV is stationary.

Calibration

As the ROV explores underwater the pressure transducer outputs different voltages that correspond to specific pressures felt at these depths. Once calibrated, the pressure transducer will serve as a depth gauge, rendering a scale for the voltage outputs to be converted to underwater depths.

The pressure transducer was calibrated using seven known depths in a 3.5 feet deep tank filled with fresh water. The instrument was placed in the tank and submerged to measured depths of just below the surface of the water (0ft), 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 feet to determine the corresponding voltage outputs. At each depth, 100 voltage measurements were recorded by the Vernier Labquest and plotted using computer software. An average voltage was calculated at each depth and with linear regression a calibration line equation was computed. This calibration line can be extended to provide the depth of the ROV for the entire pressure range of the instrument.

Tests

The accuracy and consistency of the calibration was tested in three of the swimming pools at Brigham Young University (BYU). The bottom of each pool was referenced as a known depth and the same seven depths used during calibration were measured in each pool with a measuring tape. The output voltage of the pressure transducer was measured using the Vernier Labquest and then compared to the calibration line.

RESULTS

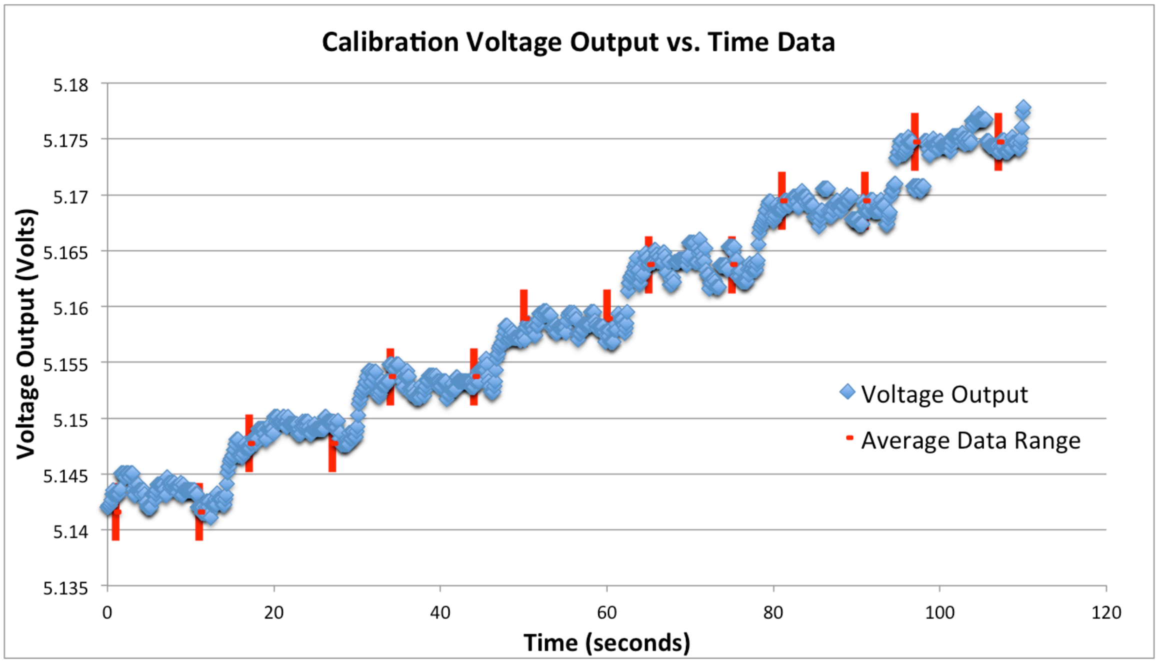

Figure 5: Plot shows the output voltage data measured at depths of 0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 feet. Red bars show the range of 100 data points taken and averaged at each depth.

In calibrating the pressure transducer, the voltage output at depths of 0, 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 feet were recorded and saved on the Vernier Labquest. The instrument was first placed just below the surface of the water at the 0 foot depth mark and then subsequently submerged a half-foot deeper every 15 seconds. The data was transmitted to a computer and analyzed in Microsoft Excel. Figure 5 shows the plot of the voltage data output for the entire calibration range. The middle 100 measurements for each depth were taken, as shown by red bars in Figure 5, and averaged to produce the output voltage for all seven depths.

The average voltage outputs are plotted with respect to their corresponding depths in Figure 6 below. A linear fit was assumed and the calibration line equation was calculated through a regression analysis of the seven data points. The standard deviations were calculated for the 100 measurements at each data point and are shown as error bars on the plot. Each error bar includes ±2 standard deviation with 95% confidence (Figliola et al. 2011). The R^2 value was also calculated to ensure the linear fit provided an accurate depiction of the data. The linear fit equation is assumed to extend the entire operational range of the SeaPerch ROV of 15ft.

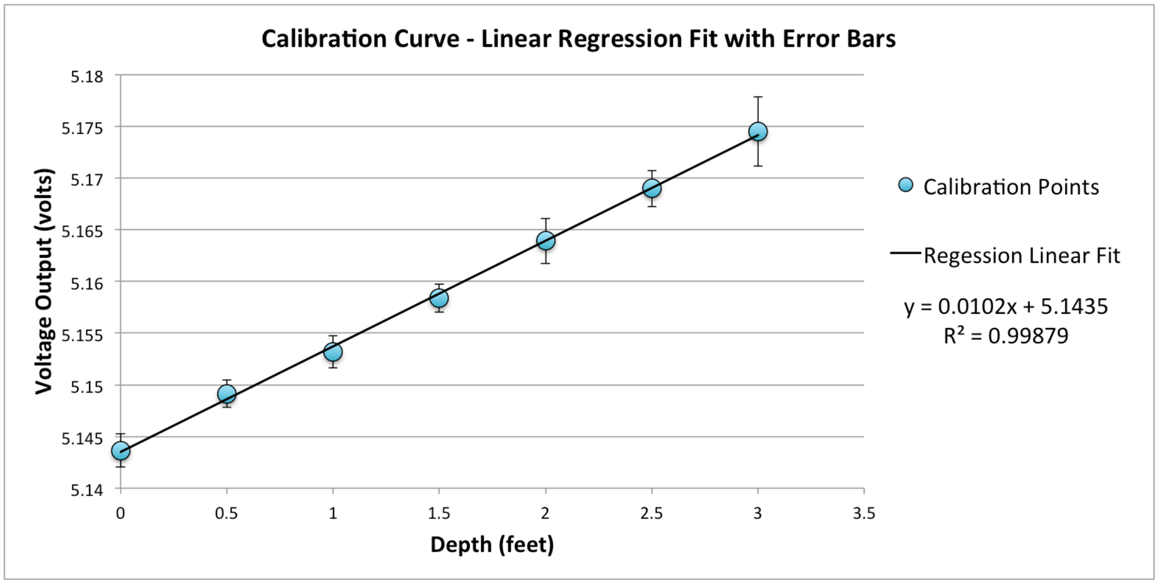

Figure 6: Voltage output plot for the seven measured depths. The data points were fit with a linear equation and calculated R^2 value. Error bars show the standard deviation at each data point.

The accuracy test was conducted in the BYU swimming pools after the calibration of the pressure transducer had been calculated. The depth gauge was attached to a SeaPerch ROV as described above and submerged in each of the three pools. The first pool had a maximum depth of 3.5ft and was tested using hand-measured depths ranging from 0ft to 3.5ft in half-foot increments. The second pool had known depths of 4.5ft in the shallow end and 6.75ft in the deep end of the pool. The eight 0ft to 3.5ft depths from test 1 were again measured and tested as well. The third pool was a diving tank with a maximum depth on 14ft. The maximum depth along with the same eight hand-measured depths were tested as known values. The data recorded for each experiment on the Vernier Labquest was analyzed with Microsoft Excel to allow for comparison to the calculated calibration. The voltage output at each depth for all three tests together with the expected outputs from the calibration equation line are shown in Figure 7 below.

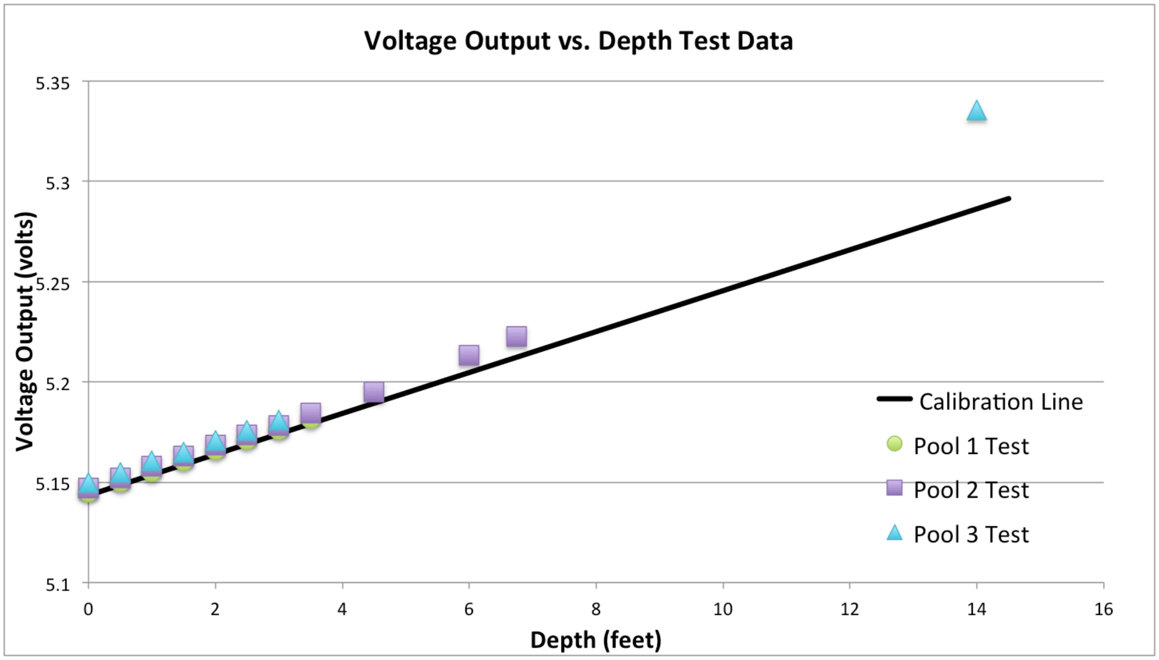

Figure 7: Voltage output plot for each tested depth in each of the three swimming pools. Test results are compared to the expected values as predicted by the calibration line.

DISCUSSION

The calibration of the pressure transducer provided an excellent linear fit as expected. The data points taken at each of the seven calibrated depths show a distinct voltage output pattern. The consistency of the data out at each step is evident in the Figure 5 plot, which shows the ROV changing depths in half-foot increments. The error bars in Figure 6 also demonstrate this consistency and show that averaged voltage outputs represent the 100 measurements well. The linear data fit of the averaged data points was exceptionally accurate, as the R^2 value shown in Figure 6 nearly approaches 1. The results from the calibration indicate that the pressure transducer is capable of operating as an accurate depth gauge with in the calibrated range.

When tested at depths over the range of calibration, the results confirmed the excellent functionality of the depth gauge. As seen in Figure 7 above, all three tests conducted at the shallow depths (0 to 3 feet) showed nearly identical values and verified this accuracy. At depths near these values, such at 3.5ft and 4.5ft, the instrument maintained its accuracy as the outputs are well with in the error bar range. It was predicted that the calibration line would capable of reliably converting voltage output to depth at depths up to 15ft. Test 3, when conducted at 14ft, revealed that calibration was not precise at greater depths. As the depth gauge was tested at known values outside of the calibration range, it began to show high amounts of inaccuracy. Although there are many potential sources of error, the calibration was consistently inaccurate at larger depths because it was not calibrated over that range. These tests suggest that if the pressure transducer was calibrated using known depth values over the entire range of desired operation, it would maintain is consistency and accuracy.

Possible sources of error include the measurement instruments used throughout the experiment, such as the hand-measured depths with the measuring tape, the Vernier Labquest, and the bottom of the pool depths as indicated by the pool facilities. The bottom of each pool was assumed as an accurate known depth, yet they were not hand-measured and there is a high possibility that these depths were not precise. In addition, it is difficult to estimate the relative vertical location of the ROV once submerged underwater. Error can be reduced by having someone in the water to verify the ROV was at the correct depth and by hand-measuring the depths at the bottom of the pool. The density variation from the fresh water in which is the calibration took place to the chlorinated swimming pool water was considered negligible.

At the start of each test, the voltage output just below the surface of the water was measured as the 0ft starting point. After the ROV surfaced following each test, the pressure transducer did not return to the original voltage corresponding to 0ft depth mark, which would consequently raise all ensuing voltage readings. This error is known as drift and is evident in Figure 7 with each progressing test between the repeated measured of 0 to 3 feet. The voltage outputs for each test follows the slope of the calibration line, but starts at a slightly higher 0ft voltage after each subsequent test. Drift can be accounted for by conducting a brief re-calibration before each submersion of the ROV. To accomplish this, the depth gauge is place just below the surface of the water and the voltage output is measured and used as the starting voltage offset for the calibration line.

CONCLUSION

This experiment demonstrated the feasibility of modifying a standard pressure transducer to function as alternative method of measuring ROV depth. Depth gauges can cost hundreds of dollars, yet with a pressure transducer a comparable instrument can be made for roughly $40. Calibrating a similar pressure transducer at known depths spanning 0 to 20 feet would confirm the assumption that when calibrated over the entire operation range, the depth gauge would maintain the accuracy it displays at shallow depths. Additional tests using pressure transducers designed for larger operational pressures can be calibrated and tested at depths ranging from 100 to 300 feet for use in lakes or oceans. Students participating in the SeaPerch program can design similar depth gauges for their ROVs, allowing them to gain valuable experience in basic instrumentation and sensor application. Furthermore, low cost depth gauges will impact marine biology research by enabling a greater variety of projects to collect sufficient data using these more readily available gauges.

REFERENCES

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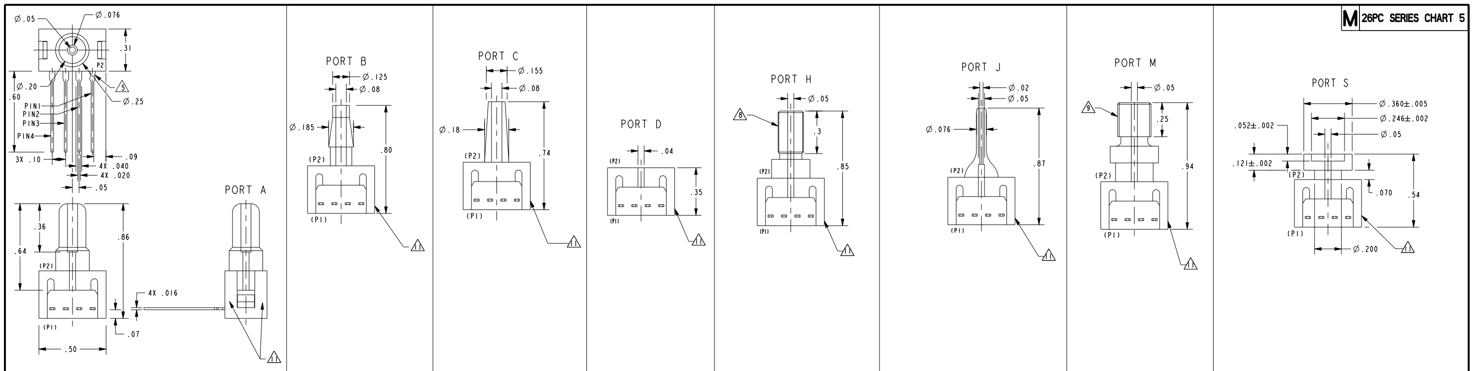
APPENDIX

Appendix 1: List of all project materials needed to build the depth gauge as outlined in the research paper.

Material	Quantity
Honeywell model 24PCCFA6G pressure transducer	1
Two-part casting urethane	Roughly 25ml
4” - 8” Wire extensions	4
50’ Wire/cable	1
4” Tie wraps	10
Solder and equipment	-
Electrical tape	2’-3’
Resistors (20kΩ and 100kΩ)	2
Vernier Labquest/ data logger	1
Electrical Breadboard	1
Breadboard connection wires	5

Appendix 2: Specification sheet with operating characteristics for Honeywell pressure transducer model number 24PCCFA6G.



M 26PC SERIES CHART 5

CATALOG LISTING	LASER BRAND
26PCCFH6G	6CF6G
26PCBFA6G	6BF6G
26PCCFA6G	6CF6G
26PCCFJ6G	6CF6G
26PCDFA6G	6DF6G
26PCFFA6G	6FF6G
26PCAFA6G	6AF6G
26PCBFM6G	6BF6G
26PCDFM6G	6DF6G
26PCFFM6G	6FF6G
26PCFFJ6G	6FF6G
26PCFFH6G	6FF6G
26PCAFB6G	6AF6G
26PCAFH6G	6AF6G
26PCBFB6G	6BF6G
26PCBFC6G	6BF6G
26PCBFD6G	6BF6G
26PCBFH6G	6BF6G
26PCBFJ6G	6BF6G
26PCCFB6G	6CF6G
26PCCEB6G	6CE6G
26PCCFC6G	6CF6G
26PCCFD6G	6CF6G
26PCDFB6G	6DF6G
26PCDFD6G	6DF6G
26PCFEB6G	6FE6G
26PCGFA6G	6GF6G
26PCGFM6G	6GF6G
26PCAFM6G	6AF6G
26PCCFM6G	6CF6G
26PCCEA6G	6CE6G
26PCDFJ6G	6DF6G
26PCGNM6G	6GN6G
26PCFFS6G	6FF6G
26PCBFS6G	6BF6G

26PC_F_6G

STYLE
(G) GAGE
TERMINATION
(6) 1 X 4 (.60 IN.)
PORT
(A) STRAIGHT
(B) BARB
(C) LUER
(D) MODULAR
(H) 5mm THREAD
(J) SMALL NEEDLE
(M) 1/4-28 THREAD
(S) MANIFOLD MOUNT
SEAL
(F) FLUOROSILICONE
(E) EPDM
(N) NEOPRENE
PRESSURE
(A) 1 PSI
(B) 5 PSI
(C) 15 PSI
(D) 30 PSI
(F) 100 PSI
(G) 250 PSI

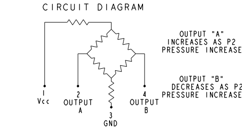
GENERAL OPERATING CHARACTERISTICS
(ELECTRICAL PERFORMANCE AT 10.00±0.01 VDC EXCITATION, 25°C)

PRESSURE RANGE (PSI)	0 - 1			0 - 5			0 - 15			0 - 30			0 - 100			0 - 250			
	MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	UNITS
SPAN (P2>P1) 1	14.7	16.7	18.7	47	50	53	97	100	103	97	100	103	95	100	105	143	150	157	mV
NULL OFFSET	-1.5	0	+1.5	-1.5	0	+1.5	-1.5	0	+1.5	-1.5	0	+1.5	-2.0	0	+2.0	-2.0	0	+2.0	mV
		TYP	MAX		TYP	MAX		TYP	MAX		TYP	MAX		TYP	MAX		TYP	MAX	UNITS
LINEARITY (BFSL, P2>P1)		0.25	0.5		0.4	0.5		0.25	0.5		0.1	0.2		0.4	0.6		0.5	0.7	%SPAN
NULL SHIFT (0 TO 25°C, 25 TO 50°C) 2		±0.5	±1.0		±0.5	±1.0		±0.5	±1.0		±0.75	±1.5		±1.0	±2.0		±1.0	±2.0	mV
SPAN SHIFT (0 TO 25°C, 25 TO 50°C) P2>P1 2		±1.0	±2.0		±1.0	±1.5		±0.75	±1.5		±0.75	±1.5		±0.5	±1.5		±0.5	±1.5	%SPAN
REPEATABILITY AND HYSTERESIS		±0.5			±0.2			±0.2			±0.2			±0.2			±0.2		%SPAN
OVERPRESSURE (P2>P1; P1>P2)			20			20			45			60			200			500	PSI

ALL PRESSURE RANGES	MIN	NOM	MAX	UNITS
EXCITATION VOLTAGE		10	16	VDC
INPUT RESISTANCE	5.5K	7.5K	11.5K	OHMS
OUTPUT RESISTANCE	1.5K	2.5K	3.0K	OHMS
RESPONSE TIME			1.0	ms

TEMPERATURE RANGES	
STORAGE	-55°C TO +100°C (-67°F TO +212°F)
OPERATE	-40°C TO +85°C (-40F° TO +185°F)
COMPENSATED	0 TO +50°C (+32°F TO +122°F)
OPERATE 10	-20°C TO +85°C

CIRCUIT DIAGRAM



NOTES
1 SPAN IS THE ALGEBRAIC DIFFERENCE BETWEEN OUTPUT AT MAXIMUM RATED OPERATING PRESSURE AND OUTPUT AT 0 PSI
2 TEMPERATURE ERROR IS CALCULATED WITH RESPECT TO 25°C
3 - INPUT MEDIA LIMITED ONLY TO THOSE MATERIALS THAT WILL NOT ATTACK SILICON, THE HOUSING MATERIAL OR SEAL MATERIAL
4 - TERMINALS ARE PLATED FOR SOLDERING (LIMIT SOLDERING TO 315°C FOR 10 SECONDS MAXIMUM)
5 PIN 1 IS IDENTIFIED BY NOTCH IN LEAD
6 - SENSOR IS OPERATIONAL OVER VACUUM PRESSURE RANGE
7 - RATIOMETRIC TO SUPPLY VOLTAGE
8 M5 THREADED PRODUCT
RECOMMENDED TORQUE FOR SEALING: 4 IN-LBS
DO NOT EXCEED 6 IN-LBS OF TORQUE
SIZE 007 O-RING
O-RING COUNTERBORE DIMENSIONS
Ø.300±.003 X ↧.040
9 1/4-28 UNF THREADED PRODUCT:
RECOMMENDED TORQUE FOR SEALING: 8 IN-LBS
DO NOT EXCEED 12 IN-LBS OF TORQUE
SIZE 009 O-RING
O-RING COUNTERBORE DIMENSIONS:
Ø.360±.003 X ↧.040±.002
10 THIS IS FOR CATALOG LISTINGS WITH EPDM SEALS ONLY
11 CATALOG LISTING AND DATE CODE HERE. ALTERNATE FORMAT OF CATALOG LISTING BRAND IS THE ENTIRE CATALOG LISTING

METRIC	INCHES
0.41	.016
0.51	.020
1.02	.040
1.3	.05
1.8	.07
1.93	.076
2.0	.08
2.3	.09
2.5	.10
5.1	.20
6.4	.25
7.9	.31
9.1	.36
12.7	.50
15.3	.60
16.3	.64
20.4	.80
21.6	.85
21.8	.86
22.1	.87
23.9	.94

THIRD ANGLE PROJECTION
SCALE 3 : 1
DO NOT SCALE PRINT
UNLESS OTHERWISE SPECIFIED TOLERANCES ARE
ONE PLACE (.0) ±.030
TWO PLACE (.00) ±.015
THREE PLACE (.000) ±.005
ANGLES ±
WEIGHT 2 OZ.

MICRO SWITCH a Honeywell Division
BRIDGE PRESSURE SENSOR
CATALOG LISTING 26PC SERIES CHART 5
ANSI Y14.5M-1982 APPLIES

ISSUE 37 DRAWING NUMBER M 26PC SERIES CHART 5 PAGE 1 OF 1
RELEASE NO. CO-74532 RS 15APR09 RS 07JAN09 SAV 17FEB93 J A F 16FEB93 PTC/CAD 20

Appendix 3: Part specifications for Honeywell pressure transducer model number 24PCCFA6G as given by Digi-Key corporation website at Digikey.com.

Standard Package	5
Category	Sensors, Transducers
Family	Pressure Sensors, Transducers
Series	24PC
Pressure Type	Gauge
Operating Pressure	15PSI
Port Size	-
Output	285mV
Voltage - Supply	10V
Termination Style	PC Pin
Operating Temperature	-40°C ~ 85°C
Package / Case	4-SIP, Side Port
Factory Setting	-
Dynamic Catalog	24PC Series
Other Names	480-2501