IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 17, Issue 5, Ver. IV (Sep. – Oct. 2015), PP 01-06
www.iosrjournals.org

Development of a Force Acquisition Instrument for Orthodontics

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Abstract : *In the field of Orthodontics, various appliances and components are being utilized to facilitate tooth movement. Tissue responses range from physiologic tooth movement to irreversible damage such as pulling a tooth out of a socket. The aim of the study is to develop a force acquisition instrument which can accurately measure forces applied by orthodontic components to the tooth. Furthermore, in this paper it test and present the linearity, bias, and significant difference on the measured and true values when exposed to varying room temperature of the developed force acquisition instrument for orthodontics.*
Keywords: *force acquisition instrument, orthodontics, force measurement, ortho-components*

I. Introduction

Edward Angle, the father of Modern Orthodontics, is credited with the emergence of orthodontics as a specialty. Orthodontic treatment involves movement of malpositioned teeth. Brackets are connected to the surface of the patient's teeth and an arch wire is placed in a slot of each bracket to move the teeth [1]. Adjustments are made with the replacement of arch wires and use of elastics and coil springs.

A dynamometer is a general instrument that evaluates an applied force. In the practice of orthodontics, it measures the forces specifically applied on the tooth by orthodontic components. Current clinical dynamometer is constructed for measuring tensile and compression forces exerted by the springs and elastics for a range of 1oz-16 oz. It is calibrated with 1 oz. single line and 4 oz. double line increment. The double-ended calibrated shaft makes it possible to evaluate pull and push forces.

An Australian research that focused on the effect of a static magnetic field on orthodontic movement in the rat [2], measured the residual forces in each appliance from the induction of tooth movement and verified at the end of each experimental period using a dynamometer. In [3], it demonstrated the use of the dynamometer in their application in ensuring that the magnitude of load was always 85g from the force applied by the Ni-Ti closed-coil springs in the effects of orthodontic load on the periodontium of autogenously transplanted teeth in beagle dogs.

In general, the clinical dynamometer's capability varies on the specific application in orthodontics, ranging from simply assessing the applied force by the orthodontic appliances to estimate the tooth movement output to standardizing the thickness of adhesive material [4], among others.

The researcher had carefully studied the clinical dynamometer being used in the dental profession. From the testaments provided to the researcher by the dental faculty members and dental practitioners, no dynamometer in the market has been manufactured with precise measurement and with sufficient amount of significant numbers to accurately measure the force applied on the tooth. Dental practitioners and students use the aid of mechanical dynamometer in measuring gram-force acting on the tooth. Though inaccurate, they accept the truncated gram-force reading of the device with insufficient number of significant values in the device scale.

In this study, it aims to develop a force acquisition instrument to measure these forced for orthodontics. Specifically, it determines the acceptability of the proposed instrument, during the testing, it must satisfy the hypothesis set to test the linearity, that no offset exist between true and measured value at the specific target both for the minimum and maximum range, (Ho: a = 0) and bias, that slope between the true and measured values is equal to one, (Ho: b = 1) at the accuracy of the measurements over the full range. Likewise, no significant difference must be observed in the measurement once the instrument is exposed to varying temperature during orthodontic procedures (Ho: c = 0).

II. Related Literature

Certain situations still pose challenges in the practice of orthodontics, even with the great advancement in technology. The researcher is inspired by how engineering should be applied to a different field of study and practice. With his specialty in computer engineering, the researcher is initiated to be engaged in an interdisciplinary application between engineering and orthodontics. Thus, applying the field of biomedical engineering to enhance and improve the efficiency of orthodontic practice.

The dental profession has to address the following challenges: properly determine the nominal force applied during orthodontic tooth movement and how this will affect the efficiency of orthodontic tooth movement.

Orthodontic tooth movement is defined as "result of a biologic response to interference in the physiologic equilibrium of the dentofacial complex by an externally applied force [5]. Only small amounts of force might be required to effect this outcome, which is accompanied by remodeling changes in the periodontal ligament and alveolar bone [6].

A typical mechanical dynamometer is used to measure the force enacted by elastics, arch wires and coil springs as shown in [7]. The researcher asked Orthodontic postgraduate students in the University of the East Graduate School to use this device. The current device used is unable to provide an exact numerical value of the measured force. The students are unable to assume nor estimate the exact value due to the limitation of the device. They only consider the most significant value from the scale, i.e. if there is a scale point between 20grams-force and 40 grams-force, the user cannot include the values in between.

III. Design Methodology

In this study, a system design was created to gather and measure the force applied by the orthodontic appliances. As suggested by several research studies, a typical magnitude of force to be applied to achieved orthodontic tooth movement ranges from 25 grams-force to 1515 grams-force [8][9][10]. However, for this experimental set-up, forces from 5 to 550 grams-force were utilized.

A. Block Diagram

The development of the instrument was guided with the following crucial components as illustrated at Fig. 1. The full-bridge force sensor configuration was used to acquire the force applied in the sensor in an analog signal. In which it is necessary to convert the analog signal taken to a digital signal by means of an analog-to-digital converter (ADC). This is to ensure that the communication of the signal is processed in accordance to the compability of the microcontroller unit to process the gathered data. Furthermore, the ADC increases the numerical resolution of the output signal to provide the microcontroller unit to process and display a higher resolution in the display panel. And lastly, the switch acts a force voltage reference reset switch to ensure that the reference reading before any measurement is set to zero.

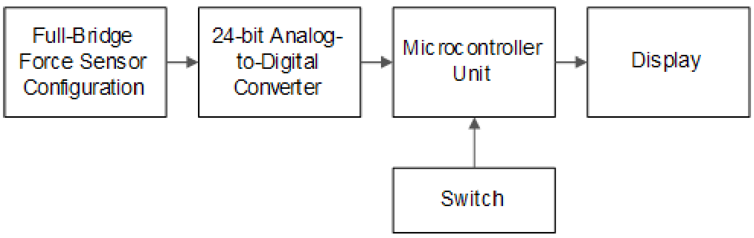

Fig. 1. Force Measurement Instrument Block Diagram

B. Hardware Components and Circuits

In this section, it further elaborates the circuit design of each hardware components.

1) Full-Bridge Force Sensor Configuration:

The force sensor is configured to have four active elements namely the: E+, S+, S-, and E-. Where, E+ and E- are the active elements measuring compressive forces while S+ and S- are the active elements measuring tensile forces. These pins (E+ and E-) are then connected to be fed with a voltage source, at a nominal 5V, from the ADC circuit and pins (S+ and S-) are analog signals that holds the corresponding values of the applied force which are then to be process by the ADC with a 1±0.15mV/V output rating.

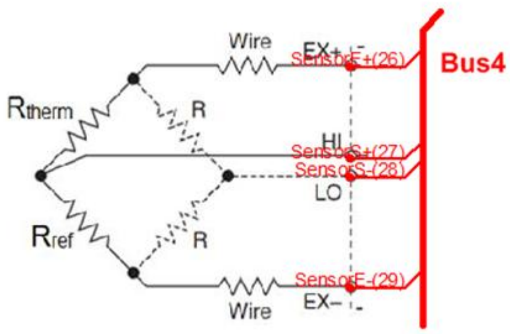

Fig. 2. Full-Bridge Configuration of the Force Sensor

2) 24-bit Analog-to-Digital Converter Circuit:

It is a 24-bit analog-to-digital converter for industrial control applications to interface with a bridge sensor. The circuit is powered with a 5V AVDD analog power supply. An SOP-16L package integrated chip was used to minimize the space it consumes during the design. The X1 pin (Pin 14) is set to ground to activate the on-chip oscillator where the output data rate when it uses the internal oscillator is 10. The PD_SCK (Pin 11) and DOUT (Pin 12) are used for data retrieval, input selection, and gain selection for the microcontroller unit.

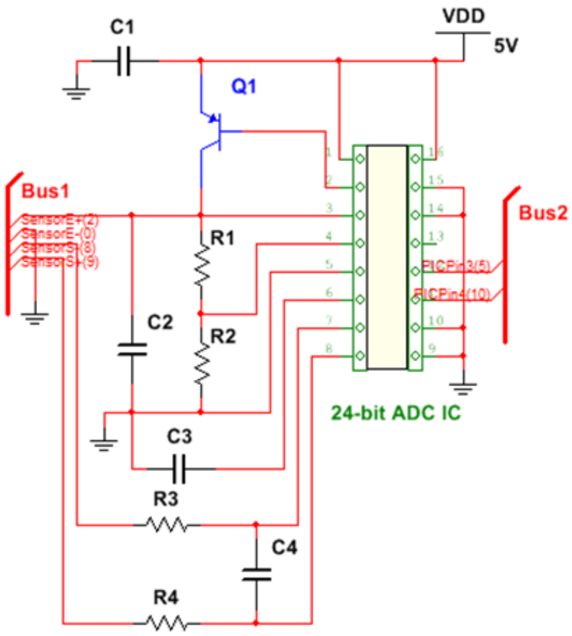

Fig. 3. 24-bit Analog-to-Digital Converter Circuit

3) Power Supply:

The normal voltage operability of the circuits generally falls within the 5V source. This circuit ensures that a stable source of 5V is fed to the entire circuitry system and prevent fluctuation of the voltage signal and regulate an external battery (V1) to an output voltage with a stable 5V analog voltage.

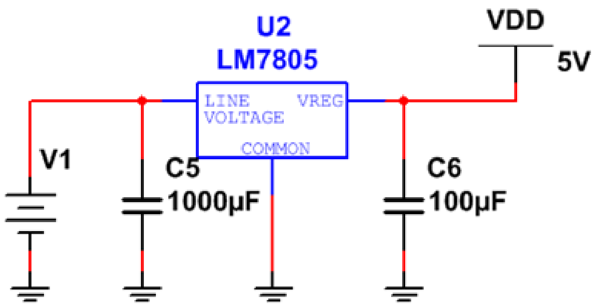

Fig. 4. 5V Power Supply Circuit

4) PIC16F876A, Force Voltage Reference Reset Switch, and Display:

The PIC16F876A an 28-pin Shrink Small Outline Package (SSOP) which is optimal to achieve compact design of the circuit and with reasonable operating clock speed, with the 4MHz crystal (X1) which is ideal for real-time data acquisition processing. The processed digital output by the ADC are then fed to the RA1 (Pin 3) and RA2 (Pin 4) to numerically program the values and display the output at the three 7-segment display. The displays are multiplex with the microcontroller unit from RB7 (Pin 28) to RB1 (Pin 22) and RC4 (Pin 15) to RC6 (Pin 17) where used to activate the particular 7-segment display and show its corresponding reading. The VDD (Pin 20) is supplied with a +5V supply while VSS (Pin 8 and Pin 9) were set to ground. In addition, the SW1 (Pin 6 and Pin 7) is introduced such that any measurement reading, before the actual measurement, is always set to zero. This is to ensure that no offset will be observed once the device attempts to conduct the measuring.

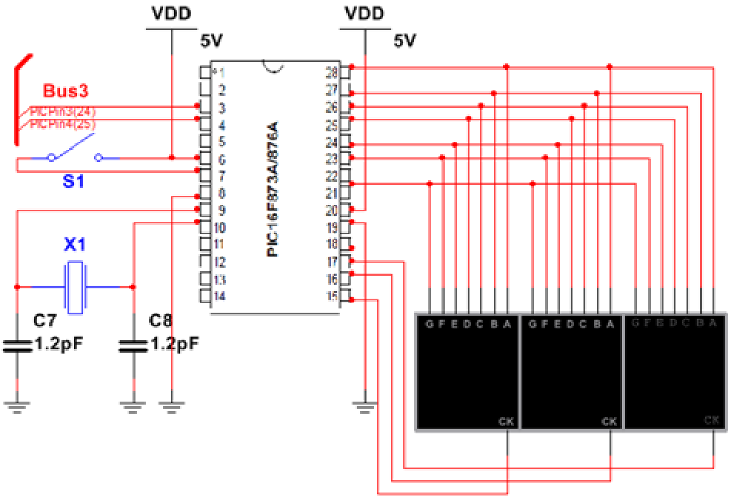

Fig. 5. PIC16F876A and 3 7-Segment Display

C. System Flow Chart

As shown in Fig. 6, it presents the flow of the operation of the force measuring instrument from how it gathers the force data, processing, and displaying the expected real-time values.

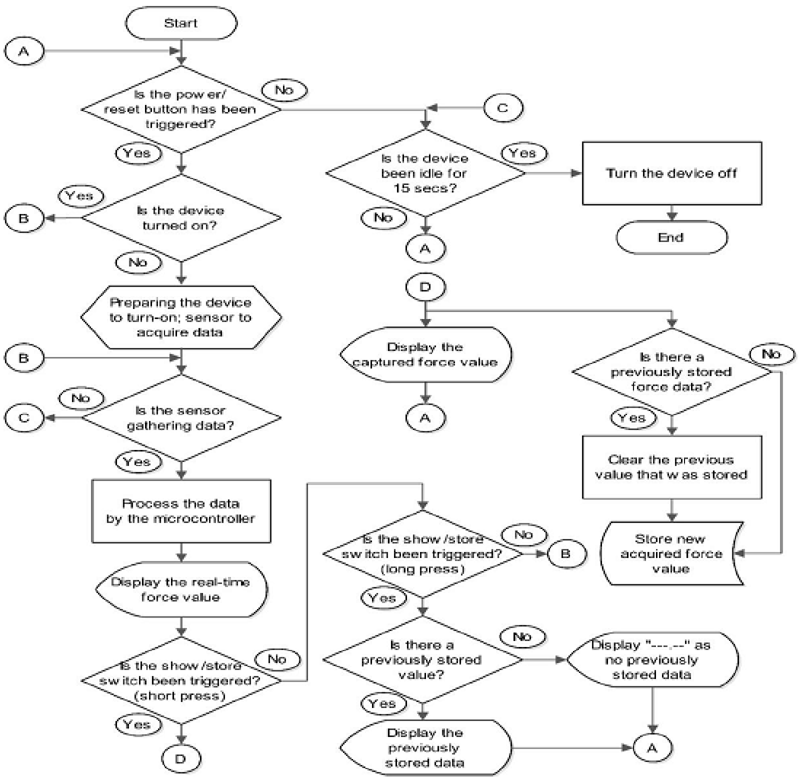

Fig. 6. Force Measurement Instrument Flow Chart

D. Test Procedures

The instrument underwent numerous testing to ensure that the measurement reading is stable. The measured and true values are linear or at most nearly close to each other. And the measurement will not be affected by the given range of room temperature. The instrument were tested using the Universal Testing Machine (UTM) where it applied forces ranging from 40 grams-force to 550 grams-force. These force ranges are divided into two: the minimum and maximum range of measurement, with 40-80 grams-force and 300-550 grams-force, respectively. Under each force increment in the testing, each was given with 10 test sample. The applied force by the UTM is considered the true value in which it will then be compared with the reading taken by the instrument which is the measured value.

IV. Results

In this study, it was tested that the hypothesis set in the research satisfies the followings: (1) no offset exist between the true and measured values; (2) the slope between the true and measured values is equal to one; and (3) the measured values with respect to the true values were not affected when exposed to various levels of room temperature.

Using the SPSS, a statistical software, the gathered data are transformed which supports to validate the hypothesis set in this study. The followings are the results taken after the testing procedure.

Table 1. t-Test on the Significance Between the True Value and Measured Value from 40 grams-force to 80 grams-force for the Minimum Force Measurement

	Measured Value				
	g-f	**Mean**	**SD**	**t-value**	**P-value**
True Value	40	39.8	0.422	-1.500	0.168
	45	44.8	0.422	-1.500	0.168
	50	49.8	0.422	-1.500	0.168
	55	54.8	0.422	-1.500	0.168
	60	59.7	0.483	-1.964	0.081
	65	64.9	0.316	-1.000	0.343
	70	69.7	0.675	-1.406	0.193
	75	74.8	0.422	-1.500	0.168
	80	79.9	0.316	-1.500	0.343

Table 2. t-Test on the Significance Between the True Value and Measured Value from 300 grams-force to 550 grams-force for the Minimum Force Measurement

	Measured Value				
	g-f	**Mean**	**SD**	**t-value**	**P-value**
True Value	300	299.5	0.707	-2.236	0.052
	325	324.4	0.843	-2.25	0.051
	350	349.3	1.16	-1.909	0.089
	375	374.7	0.483	-1.964	0.081
	400	399.5	0.707	-2.236	0.052
	425	424.5	0.707	-2.236	0.052
	450	449.9	0.732	-0.429	0.678
	475	474.5	0.972	-1.67	0.138
	500	498.8	3.521	-1.078	0.309
	525	524.4	0.843	-2.25	0.051
	550	549.5	0.972	-1.627	0.138

Table 3. Model Summary for the Linearity of forces from 40 gram-force to 550 gram-force

Model	R	R2	Adjusted R2	Std. Error of the Estimate
1	1.000	1.000	1.000	2.05523

Table 4. One-Way ANOVA on the Significant Difference in the Measurement on the 50 grams-force When Exposed to Varying Temperature

Source	SS	df	MS	F-value	P-value
Columns	0.787	7	0.112	0.612	0.744
Error	13.228	72	0.184		
Total	14.015	79			

Table 5. One-Way ANOVA on the Significant Difference in the Measurement on the 500 grams-force When Exposed to Varying Temperature

Source	SS	df	MS	F-value	P-value
Columns	15.350	7	2.193	0.716	0.659
Error	220.599	72	3.064		
Total	235.949	79			

V. Discussions

Referring to Table 1 and 2, the P-value calculated shows values which are greater than the 0.05 level of confidence. This also suggests that the hypothesis set (Ho: a=0) is accepted. The test range is true from the minimum measurement range of 40-80 grams-force and for the maximum measurement range of 300-550 grams-force.

A model summary, in Table 3, was generated to determine if the true and measured values produce a slope equal to one. Using the test values taken from 40 grams-force to 550 grams-force, with 10 test samples for each incremented forces, the R^2 value is equal to one (Ha: b=1). Statistically, it suggests that there is a perfect correlation between the values of the true and the measured force.

Lastly, under the exposure of varying temperature during testing, it determines if there is a significance in the measured values and the true values. Using one-way ANOVA, under Table 4, the test sample at 50 grams-force when exposed from 18°C to 32°C shows a P-value of 0.744. While in Table 5, at a 500 grams-force sample, it exhibit a P-value of 0.659. Comparing the computed P-value, the instrument's reading were comparable with the true values when exposed to various level of room temperature.

VI. Conclusion

In this study, it was tested that the hypothesis set in the research satisfies the followings: (1) no offset exist between the true and measured values; (2) the slope between the true and measured values is equal to one; and (3) the measured values with respect to the true values were not affected when exposed to various levels of room temperature.

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