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# THE DEVELOPMENT OF UNIVERSAL MASS BALANCE

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**Abstract**

In this paper, we describe the construction of the Universal Mass Balance (UMB). The working principle of UMB has been tested through parabolic flight in microgravity, normal gravity and hypergravity environment to investigate the independency of measured oscillation frequency to the oscillated mass on gravitational conditions. The frequency was obtained by analyzing the emf signal. Later, the UMB was simplified by using optical detection. Once the UMB is calibrated, the unknown mass can be measured by slightly displacing it from equilibrium position to oscillate. As the frequency is known, the mass of the load immediately can be calculated automatically and displayed. The UMB offers potential applications in space science related field.

**Key words**: universal mass balance, optical detection, oscillation, microgravity, hypergravity

## INTRODUCTION

Mass is one of the basic physical quantity in science. Mass measurement is very important in daily life and scientific research. Among the other basic quantities, mass is one of the more difficult measurements under microgravity conditions [1]. The problem faced is that common weight balances do not function in other gravitational conditions other than earth gravity [2]. So we propose a device used to measure mass which is independently gravitational conditions [3].

In this paper, we describe the development of Universal Mass Balance (UMB) that can be used to measure the mass of a load independent of gravitational conditions. UMB employs optical detection method based on the oscillation frequency of the load. Once UMB is calibrated, an unknown load is simply put between a pair of springs and set into oscillation.

## RESEARCH METHOD

### *Development*

Universal Mass Balance (UMB) is basically designed based on the concept of simple harmonic motion is described by following relation, where *k* is spring constant:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Based on this concept, the oscillation frequency, *f* is inversely proportional to root square of mass, *m*. The relation is not linear but can approximately to be linear in very small range of measurement. So from that theory, UMB works when the object to be weighed is displaced from its equilibrium position. The measured load is attached between two identical springs that have the same value of spring constant as illustrated in Figure 1.

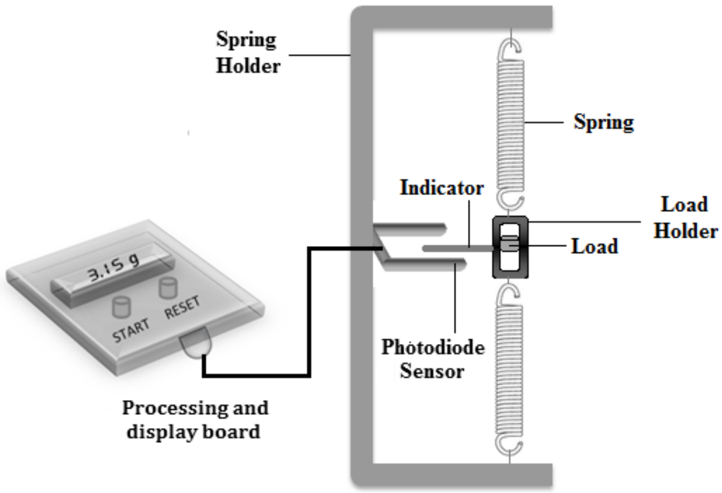


Figure 1. Schematic of UMB system.

The load is put in a holder and then the load can be oscillated in order to detect the oscillation frequency. The indicator from the load holder will intercept the signal of the photodiode sensor during the oscillations. The frequency of the oscillations can be used to calculate the mass. See Figure 1.

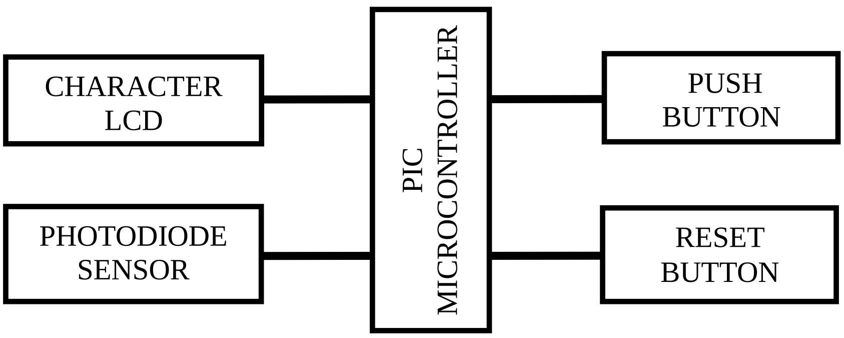


Figure 2. The block diagram of UMB.

The UMB is specially designed to use optical detection. The PIC microcontroller is specially programmed in order to make sure this system can be used. The PIC microcontroller is being connected directly to the sensor as shown in Fig.1. The processing and display board contains PIC microcontroller. The PIC is connected to the character LCD with buttons to start and reset reading, the photodiode sensor and some electronic component as simply explained through the block diagram in Figure 2.

***Detection***

A specially designed Universal Mass Balance (UMB) using optical method has been constructed in Fig. 1. The photodiode sensors and the microprocessor will measure the oscillations period of an unknown mass. The processing and display board is connected to the photodiode sensor as shown in Figure 3.

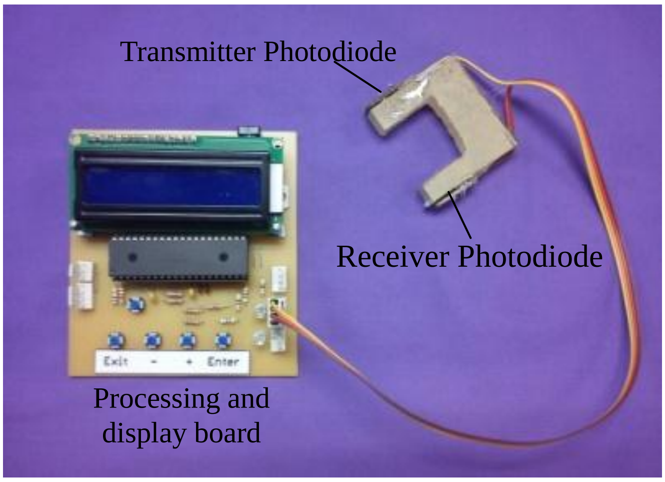


Figure 3. The processing and display board connected to the photodiode sensor

The infrared photodiode sensors will output logic 1 when the indicator, connected to the load holder, crosses the infrared beam when it is oscillating.

Once the indicator intercept the signal of the photodiode sensors, the measurement of 5 complete oscillations period is begin. The processing board and microprocessor will then calculate 1 complete oscillation period and, then calculate and display the actual mass of an unknown object. If the indicator not passing through the infrared signal, the data send as logic 0 as illustrated in Fig 4.

***Calibration***

Before the calibration was made, the load that can be used for calibration in range 0.5 g to 10 g is prepared. Second step, one of the loads is being put in load holder then set it into oscillations. The measurement of the time taken for 5 complete oscillations is being recorded directly then the average of the oscillation time for 1 complete oscillations is calculated. These steps are repeated until all loads are finished.

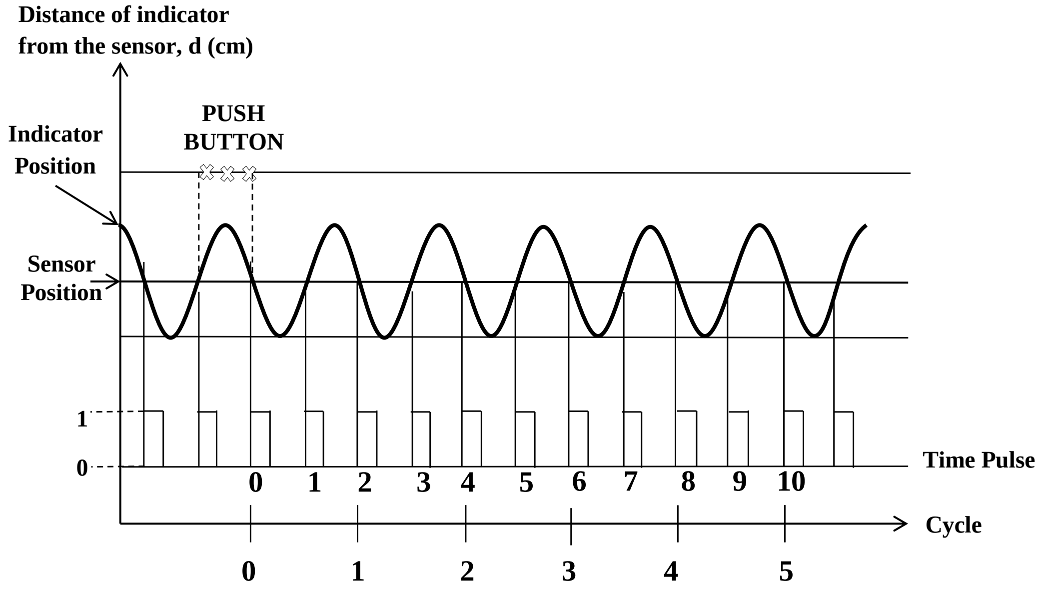


Figure 4. The time pulse according to the distance of indicator from the sensor

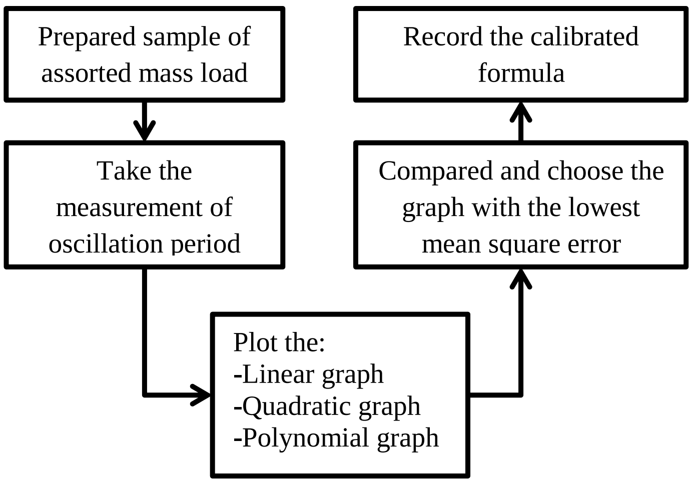


Figure 5. The flow for calibration process of Universal Mass Balance (UMB)

Then the graph between this two parameters is plotted. The parameter of time taken for 1 complete oscillation is plotted as the y-axis and the value of actual mass load is plotted as the x-axis. This graph is plotted using data analysis software. 3 types of graph are plotted together using the same data which are linear, quadratic and polynomial graph. The best fit graph is the graph that has the lowest value of mean square error. In this experiment, the polynomial type of order 3 is the most suits for this UMB development has lowest mean square error compared to the linear and quadratic graph types. The calibrated formulae derived from the polynomial graph would be in this pattern, $ax^3+bx^2+cx+d$.

The unknown mass of load to be weighed later should be limited in this range of mass value. If it exceeds this range, the measurement is being not really accurate. The measurement range of the mass load also can be adjusted by using the correct pair of spring. So this is why the calibration of UMB is necessary and being as a part of step in this development.

***Measurement Process***

In order to get the data of the load mass, firstly load should be put in the load holder and then set it into oscillations. The system will detect 5 complete oscillations and the measurement of the time taken for 5 complete oscillations is being recorded directly. After that the system will calculate the average of the oscillation time for 1 complete oscillation. As the value of the time average for one complete oscillation is known, the system will substitute it into the calibrated formula. Then, the value of the load mass is calculated by the system. The system of our UMB will display the value of the load mass through the LCD.

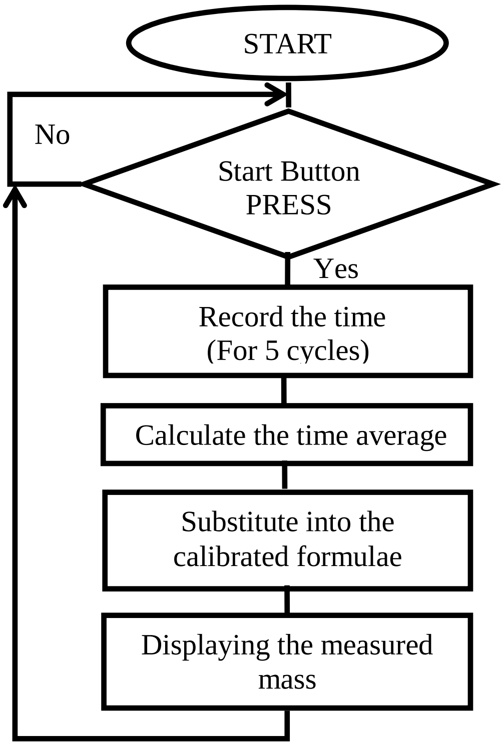


Figure 6. The flow process for the UMB software

***Performance Test***

Several sample (unknown mass load), with different masses have been tested using this UMB then the results compared with the common mass balance (A&D GF-300, made in Japan). The result indicates that when using this UMB there only slightly percentage error compared to the normal mass balance. The percentage of error is about 0.02 % (can be neglected because too small).

Table 1 The data for different load in mass and time taken for 1 complete cycle of oscillation using UMB

| **Reference Load Mass, g** | **Load mass using UMB, g** | | **Average time, s** | |
|---|---|---|---|---|
| | | **±(×10$^{-3}$)** | | **± (×10$^{-5}$)** |
| 0.983 | 0.98188 | 7.71 | 0.11549 | 7.37865 |
| 1.186 | 1.18648 | 7.15 | 0.11743 | 6.74949 |
| 3.449 | 3.45426 | 6.25 | 0.13746 | 5.16398 |
| 3.635 | 3.64908 | 8.19 | 0.13907 | 6.74949 |
| 6.037 | 6.04048 | 5.73 | 0.15768 | 4.21637 |

## CONCLUSION AND SUGGESTION

We described the development the prototype of Universal Mass Balance (UMB) which can be used for mass measurement independent of gravitational field. UMB concept has been tested in simulated microgravity environment through parabolic flight. The simplicity of the UMB lies on the used of a pair of spring for the oscillation of mass being measured. The measurement range of UMB is adjustable by selecting the correct values for the spring pairs. For futher extension, we would like to miniaturize the system to be practically used in space.

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