THE THIN SCALE PROJECT

Design Team
Nicholas Barsotti, Daniel Ensel, Kevin Hemberger,
Daniel Materese, Robert von der Esch

Design Advisor  Sponsor
Prof. Sinan Müftü   Lousia E. Serene
Mariah S. Chase

Abstract

Americans are increasingly becoming more health and weight conscious and as such they require a scale to track and measure their weight. While the market is full of home and bathroom scales there are currently very few options for portable scales designed for use away from the home. Patent and market research on portable and collapsible scales have shown that the designs suffer from one or more design flaws including complexity of design, weight, storage ability, aesthetic appeal and inherent clumsiness associated with collapsing and reopening the scale. These drawbacks have hindered said patents from being widely adopted in the consumer market.

The Thin Scale (TTS) designed in this project will provide an alternative to conventional weight measuring methods, through the integration of existing technologies to create an extremely light, malleable and thin weight scale such that it can be rolled up, folded or otherwise compressed into a suitcase for travel. The scale uses round protrusions, or “bubbles,” to make contact with the floor. Each bubble contains a piezoresistive sensor. The multiple sensors are connected in parallel to essentially form one, multiple input sensor. When a force is applied to the sensors they experience a change in resistance and subsequently a change in voltage, which is fed into a op-amp and then computed by a Texas Instrument computer board and converted into a weight. The board is loaded with the necessary code in order to operate as a functional scale. The sensors and wiring are embedded within an enclosure made of silicone, which was pour molded over the assembly.

Top Side     Bottom Side
The Need for Project

Provide a portable weight scale for use away from the home. Americans are increasingly becoming more health and weight conscious, and they require a scale to track and measure their weight. While the market is full of home and bathroom scales there are currently very few options for portable scales designed for use away from the home. Patent and market research on portable and collapsible scales have shown that the designs suffer from one or more design flaws including complexity of design, weight, storage ability, aesthetic appeal and inherent clumsiness associated with collapsing and reopening the scale. These drawbacks have hindered said patents from being widely adopted in the consumer market and have created the need for a new scale.

The Design Project Objectives and Requirements

The objective of this project will be to provide an alternative to conventional weight measuring methods, by creating a light, flexible and thin weight scale such that it can be rolled up, folded or otherwise compressed into a suitcase for travel. The Thin Scale (TTS) will provide an alternative to conventional weight measuring methods, through the integration of existing technologies to create an extremely light, flexible and thin weight scale such that it can be rolled up, folded or otherwise compressed into a suitcase for travel.

Design Objective

TTS has very specific design requirements outlined by the sponsors of the project. The specific requirements include the ability to weigh individuals between 3’ 4” and 6’6” height and up to 330lbs. The scale should weigh no more than 2lbs; the thickness should be no greater than 1” and the scale must be waterproof. The scale must be roll-able, foldable or otherwise compressible and / or scalable for efficient portability and storage. When stored the scale must be less than 6” thick and 25-33% of the area when lying flat. Finally the scale must appeal aesthetically to the user.
Several design concepts were considered and evaluated throughout the course of this project.

**Continuous Sensor Concept**

The design utilizes one large custom made force sensor sandwiched in between a flexible enclosure. The proposed design is the simplest one and offers the benefits of having the slimmest profile, and the fewest internal parts. However, the cost of prototyping a model is extremely prohibitive with a custom made sensor averaging $15,000. Therefore two alternative methods have been devised.

**Rib Concept**

The ribbed design utilizes multiple piezoresistive sensors connected in parallel spread out in array. The total change in voltage is summed together and then output to the circuit board and the display. The ribs in this design act to concentrate the force applied by the user on to the sensors, while still allowing the scale to roll up. In this diagram you can see the configuration of the sensors and the ribs. This type of setup will be replicated under each rib and will minimize any force leakage that may occur. The drawback to this design is the complex wire layout associated with connecting the sensors and the added weight from the ribs.

**Bubble Concept**

The bubble design again utilizes multiple piezoresistive sensors connected in parallel to sum the voltage and output it to the circuit board. The bubbles would rest on the ground with the sensors housed inside as shown in this diagram. When the user’s weight is applied to the scale all of the force would be transmitted through the bubbles and subsequently through the sensors. The advantage to his design is that we can maintain flexibility and eliminate the heavy ribs.
Recommended Design Concept

The bubble concept was chosen as the final design due to ability to achieve the design requirements, ease of manufacture and cost. The proposed designs were placed into a design matrix and evaluated based on flexibility, durability, manufacturability, waterproofness, weight, thickness, and cost. The evaluation indicated that the bubble design was the best choice.

Design Description

The bubble design consists of a silicone enclosure encasing multiple piezoresistive sensors (left) that are connected in parallel. The sensors are located under cylindrical columns that contact the ground. The columns support and concentrate the user’s weight on to the sensors. The sensor’s resistance changes linearly according to the amount of force that is applied. The resulting change in resistance causes a change in the voltage. The change in voltage from the sensors is sent to the Texas Instruments developer’s board (left) which interprets the voltage signal and converts it to weight and displays it on the LCD screen for the user to read.

Analytical Investigations

The scale was modeled in ANSYS and a finite element analysis was performed to determine the optimal position of sensors inside the mold along with material thicknesses. The results indicated that the sensors should be located at the top of the cylindrical columns and be spaced no more than ¾” apart. Dimensions were optimized to include the minimal number of sensors and to minimize the thickness and overall size of the scale.

Experimental Investigations

Prototype molds were created to test the durability and flexibility of various materials to determine the proper material to be used in the mold. A design matrix was created based on these results along with material research. In the end silicone was chosen based on its ability to be pour molded, its flexibility, durability, cost, and electrical insulating properties.

The voltage signal output by the piezoresistive sensors were tested using three different types of signal conditioning devices; a Wheatstone bridge, voltage divider and an op amp. The drastic changes in resistance in relation to force applied to the sensors made the Wheatstone bridge and voltage divider unacceptable.
conditioning devices and the op amp circuit was chosen for its ability to translate these changes in voltages into a linear relationship that could be used by the developer’s board.

The piezoresistive sensors were tested utilizing the Instron machine (left) in order to measure the change in resistance and voltage in relation to force applied. The results were used to create a calibration curve for the sensors. The curve was input into developer’s board in order for the board to convert the voltage to the proper weight. The results of this test proved that the sensor’s can function in a parallel circuit and effectively function as one sensor.

Utilizing the analytical and experimental data a mold was designed and created to accurately to position the sensors, wiring, and achieve the desired silicone thicknesses in the enclosure. The final product was calibrated using a test fixture to again determine the change in resistance and voltage in relation to force applied. The results were then used to create a calibration curve that was loaded on to the developer’s board, which allowed the voltage output by the sensors to be accurately converted to the user’s weight.

**Key Advantages of Recommended Concept**

This design delivers on the primary design requirements outlined by the sponsors, the most pertinent of which are; it less than 1” thick, weighs under two pounds, has the ability to be rolled and unrolled and can support a human weight between 40lb-330lb. In addition the prototype serves as a proof of concept that a flexible scale can be created.
Financial issues

Prototyping costs prohibited the best possible design solution of utilizing one large custom sensor.

Since our product will be a consumer good, final price is very important in order to establish a large market share. In our prototype, we used a small number of sensors and silicone. All electronics were off-the-shelf solutions. The small quantities resulted in a high price per product amount.

After speaking with vendors, it was understood that at larger order quantities would reduce the cost per sensor, silicone, and electronics boards. This would allow not only for a lower cost thin scale, but also allow the use of one custom sensor instead of 40 discrete ones.

When choosing components, cost was a minor factor on the decision matrix. Accuracy, repeatability, and durability were higher in priority. Lower costing sensors were available; however, accuracy and the over-all functionality of the scale would have been reduced. The enclosure material decision process followed a similar path. Silicone was ultimately chosen because of, not only its functionality, but also its low cost, availability, and ability to be pour molded.

Recommended Improvements

A single sensor, covering the entire area or a denser array of smaller sensors would increase scale accuracy, and decrease the scales profile and weight.

Due to financial constraints, the group was limited by the size and amount of sensors that could be used. Had the budget not been so limited, a single larger sensor or a denser array, containing a larger number of smaller sensors could have been used. This would have increased the accuracy of the thin scale.

Other areas, such as the enclosure could be improved by using more sustainable material. Also, injection molding and vulcanization of the enclosure would be possible to streamline the manufacturing process.

Sensors are connected in parallel in this work and connect to a single measurement channel on the board. In a customized board each sensor would be connected to a separate channel to improve the accuracy.

Finally, an electronics solution with a custom sized board would allow the board and LCD screen to be placed in the enclosure, allowing for one standalone product.