Improving IR Sensors for Use in Sensitive Robotics

I. Introduction

Tactile robots have the potential to transform robotics applications and uses by improving safety, allowing them to enter dynamic and human-populated environments. A broader range of safe and usable environments opens up numerous possibilities for economic growth in the robotics industry. In order for these robots to be economically viable, they must perform to their greatest potential, which means the sensors must be carefully created for the greatest accuracy and least noise in the signal.

The bipedal robot has arrays of compression sensors along the bottom of each foot. Each of these sensors is comprised of an IR sensor that measures the deflection of a molded silicone-rubber dome above it. To improve the signal from the IR sensor, it was necessary to determine a molding procedure that would

- Reduce light pollution from ambient light penetrating the silicone dome
- Maintain or improve the reflectivity of the interior surface of the dome
- Maintain the integrity of the silicone rubber that makes up the dome
- Maintain the approximate level of force needed to saturate, i.e. fully compress, the dome

To determine a molding procedure that would meet these criteria, two additives to the silicone rubber were tested: glass microspheres and Silc Pig® silicone pigment.

II. Determining Fluid Characteristics of Silicone Rubber

In order to increase the opacity of the dome to reduce light pollution and maintain or improve the reflectivity of the interior of the dome, it was necessary to create layers in the dome so that the interior and exterior could be altered independently of each other. Several series of tests were created to determine how to create how the fluid properties of the liquid silicone rubber interacted with the shape characteristics of the molds to derive a procedure that could be used to create the desired layers.

The silicone rubber was created by mixing a base to a catalyst in a ratio of 10:1. To simulate the additive layer, dye was mixed into a portion of the rubber. The material was then set into a vacuum chamber until all air bubbles vanished. Finally the liquid material was placed into the molds. The molding containers consisted of two parts: a lower base that had four half-sphere divots at the bottom of a shallow pool and an upper lid that had four protruding half-sphere bumps. The two parts were then screwed together and left to cure for 24 hours.

Table # lists the variations tested in three series of tests. In Series 1, it was observed that the viscosity of the rubber caused the material in the container's shallow pool that covered the divots to adhere to the bumps when the mold container components were compressed together. This meant whatever material filled the pool became the interior surface of the dome. In Series 2, several tests were run to achieve an additive layer as the interior surface of the dome. The bumps on the lid of the mold were covered with dyed plastic before being pressed into the filled base. Series 3 chose the most successful layering process from Series 2, and experimented with relationships between varying approximate amounts of material used for each layer.

Table #

	Divot Bottom	Divot Middle	Divot Top	Pool	Bumps
A1	Dyed	n/a	Plain	Plain	n/a
B1	Dye (mix in)	n/a	Plain	Plain	n/a
C1	Plain	Dyed	Plain	Plain	n/a
D1	Plain	Dry Dye	Plain	Plain	n/a
A2	Dyed	n/a	Plain	Plain	Dyed

B2	Plain	n/a	Dyed	Plain	Dyed
C2	Plain	n/a	n/a	Plain	Dyed
D2	Plain	Dyed	Plain	Plain	Dyed
A3	Dyed (l->g)	n/a	Plain	Plain	Dyed(l->g)
B3	Dyed (l->g)	n/a	Plain	Plain	Dyed(g->l)
C3	Dyed (l->g)	n/a	Plain	Plain	Dyed (l->l)
D3	Dyed (l->g)	n/a	Plain	Plain	Dyed (g->g)

*(l->g) indicates least amount to greatest

In summary, the Series 1-3 tests proved that molds could be made with distinct layers; a cross-section of the C3 mold is shown as an example in Figure # below.

Figure #

The C1 and D2 molds had three layers. In both cases the middle layer was pushed out of the dome onto the flat surrounding material or out of the mold entirely. Therefore the middle level was rejected from future tests.

III. Microsphere Molding

The microspheres used were green and yellow glass microbeads with diameters of 150-180 micrometers. The microspheres were mixed with portions of the liquid rubber silicone prior to vacuuming.

The spheres were placed in different layers within the domes, based on the results of the dye testing in Series 1-3. Both colors of glass microspheres, in differing ratios were tested. The combinations of sphere and plain rubber layers are shown in Table #.

Table #

	Divot Bottom	Divot Top	Pool	Bumps
A4	Spheres (y)	Plain	Plain	Spheres (y)
B4	Plain	n/a	Plain	Spheres (y)
C4	Spheres (y)	Plain	Plain	n/a
D4	Plain	n/a	Plain	n/a
A5	Spheres (y)	Plain	Plain	Spheres (y)
B5	Plain	Spheres (y)	Plain	Spheres (y)
C5	Spheres (y)	Plain	Plain	n/a
D5	Plain	Plain	Plain	n/a

A6	Spheres	n/a	n/a	n/a
B6*	Spheres (y)	Plain	Plain	Spheres (y)
C6	Spheres (g)	Plain	Plain	Spheres (g)
D6*	Spheres (g)	Plain	Plain	Spheres (g)

*B6 and D6 were set upside-down to cure

** (g) denotes green, (y) denotes yellow

To test if the microspheres settled in the silicone and sank to the bottom during curing, two molds in Series 6 were turned upside-down for the curing process. Series 6 did not demonstrate any noticeable effect of the spheres sinking and settling in the liquid silicone rubber during the curing process.

IR testing (explained in Section 5) for Series 4 did demonstrate some reduction of light compared to domes with no additives. However, it was not a significant reduction. The density of spheres was increased for Series 5 and 6 which yielded increased opacity but not to a significant level.

In Series 4-6 the ratio of spheres to rubber was judged approximately by visual inspection. In Series 8 when the ratio became crucial, the plastic and spheres were weighed separately on a scale and the exact ratio calculated (Table #). These ratios were a significant increase over Series 4-6. Instead of making a full 4-dome mold for each density, only 2 domes were allotted per density. For B8,3-4 extra spheres, which were not mixed into liquid rubber, were sprinkled on top of the filled divots before the shallow pool in the mold base was filled with plain rubber.

Table #

	Full Divot	Top of Divot	Pool	Bumps	Density of Spheres
A8, 1-2	Spheres (green)	n/a	Plain	Spheres (green)	0.168
A8, 3-4	Spheres (green)	n/a	Plain	Spheres (green)	0.324
B8, 1-2	Spheres (green)	n/a	Plain	Spheres (green)	0.727
B8, 3-4	Spheres (green)	Unmixed Spheres	Plain	Spheres (green)	0.727 + unmixed

The ratio of spheres to rubber in the B8 mold was approximately as dense as possible. This density significantly stiffened the silicone dome, changing the force needed to saturate, i.e. fully compress, the dome. To increase the density further would damage the structural integrity of the rubber and make the resulting mold prone to crumbling.

IV. Pigment Molding

Silc Prig® Silicone Pigments from Smooth-On were used to alter the color of the molds. The silicone pigment was used in two manners: painting and dyeing.

To dye the silicone rubber, pigment was mixed directly into the liquid rubber prior to vacuuming. Pigment was measured in mL through the use of a syringe. The amount of pigment used was based on the relative intensity of the hue after mixing with the liquid silicone rubber.

To paint, the pigment was mixed into Psycho Paint® Platinum Silicone Paint Base, also from Smooth-On. Two methods were tested to paint the molds. First, the paint was applied directly to the mold with a paintbrush for molds C7 and D7. Second, the paint was applied by airbrush for molds A7 and B7.

The paint needed to be thinned for use with the airbrush. It was mixed with the solvent Naptha in a ratio of 100 parts A + 100 parts B + 200 parts solvent by volume. This solvent mix was applied with an airbrush. Mixing the paint with the solvent in the recommended ratio of a 5% pigment load of the total weight (A+B) dramatically decreased the intensity of the paint hue and made the paint more translucent, which eliminated any possible reduction of light pollution. The pigment load was increased until it was of sufficient intensity by visual judgment and the paint reapplied to the molds. Each airbrushed mold received several layers of paint to improve the quality of the coating.

Tests were based on the general assumption that a white coloring would reflect light and a black coloring would absorb light. The combinations of dyeing and painting are listed below in Table #.

Table #

	Rubber Color	**Density of Pigment**	**Paint Color**	**Location of Paint**
A7	White	0.2366	Black	Exterior
B7	Black	0.2366	White	Interior
C7	Plain	0.2366	Black	Exterior
D7	Plain	0.2366	White	Interior
C8	Black	0.1446	n/a	n/a
D8	White	0.1394	n/a	n/a

*(g) denotes green

V. Light Pollution Testing

To test the opacity of the molds, a Point Grey Firefly camera with the infrared filter removed was rigged to take pictures from angles of 0°, 45°, and 90°. The domes were placed over an active infrared sensor, and the images were captured in a completely darkened room.

Initial images taken with the default camera values were unusable; they showed only a single bright, glowing mass (Figure #, Left). By decreasing the brightness, the shutter time, and the gain, the camera was able to show the domes in sufficient detail to see the individual spheres contained within the silicone rubber of mold A4(Figure #, Right).

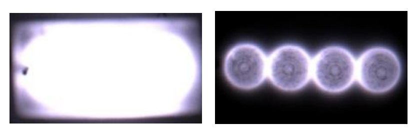

Figure #

The images allowed for a rough visual comparison of the opacity of the molds. Below in Figure # are molds C5 (left) and C6 (center). While they were more opaque than D4 (right) which contained no additives, and A4 (Figure #, right) which had a lower density of spheres, there was still significant light pollution. The camera settings were still adjusted to make the individual domes visible.

Figure #

All the molds in Series 4-6 had similar light pollution levels. Molds C7 and D7 that were normal silicone rubber with paint applied after they finished curing exhibited no significant difference in their levels of light pollution. Molds D8 and A7 made with silicone dyed white had more significant light pollution that a typical mold. A7 is shown on the left of Figure #, below. However, molds B7 and C8, which were made with silicone dyed black, blocked significant levels of light pollution. When viewed with the custom camera settings, the images appeared almost entirely black. An image of B7 is shown below in Figure # on the right.

Figure #

The camera was reset to the default values. These were the same values that made the original molds appear to be a single amorphous glowing shape. Under these values, mold B7 remained a solid black rectangle (Figure #). Some glow was visible around the edges of the mold where light leaked out from under the elevated sensor array.

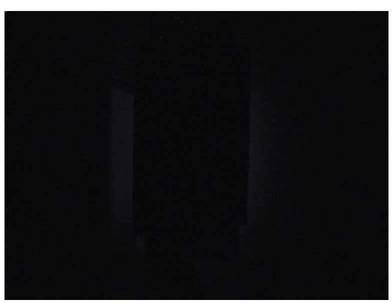

Figure #

Both molds B7 and C8 were marked for further testing to determine if their reduced pollution had any effect on the infrared sensors' ability to detect the compression of the dome.

VI. Infrared Sensor Readings

To test the ability of the infrared sensor to detect the deflection of a dome with increased opacity, an Arduino was connected to the IR sensors and programmed with Processing. The numeric values were exported into Excel.

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The data from mold #, black silicone rubber with a white painted interior was similar to the readings from a plain mold with no additives. The readings were more accurate where the interior had a thicker, smoother coat of white paint.

VII. Conclusion

The most successful molding design reduces light pollution and maintains the reflectivity, structural integrity, and force compression characteristics of the original plain molds.

The improved mold was made by adding black Silc Prig® silicone pigment to the liquid silicone rubber in a ratio of 0.14. The interior was coated with white Psycho Paint® tinted with white Silc Prig® pigment in excess of a 5% load by weight. The paint was thinned with Naptha solvent in a 1A:1B:1solvent mix ratio by volume and applied in several coats by airbrush. The quality of the infrared sensor readings in dependent on the quality of the paint coat – it should be thick and smooth, with no black showing through the white paint.

Future research should be done regarding the manufacturability of this process.