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MECHANICAL INTERACTION BETWEEN A CARTONBOARD PACKAGE AND A TACTILE SENSOR DEPENDING ON POSITION AND MATERIAL

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ABSTRACT

The perception of mechanical rigidity when touching a package is important for purchasing decisions. This perception will depend both on the material and geometry of the product packaging, but also on the position where the package is grasped. Both kinaestethic (globally) and cutaneous cues (locally around the fingertip) play a role in the perception of compliance, but cutaneous cues are more important. We therefore use a tactile sensor to investigate the mechanical interaction between the tactile sensor and a cartonboard package; we study the changes depending on the measuring position and the material. Using linear discriminant analysis (LDA) on the measurement result we show that we can separate these two changes for separate analysis.

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INTRODUCTION

The feeling of touching a product is important for how a consumer perceives it [1]. Cartonboard packages are no exception and are often used to package premium products, including fragrances, spirits, consumer electronics, etc. Understanding how to optimize this feeling can help consumer goods companies and packaging manufacturers to reduce resource use without compromising these attributes or even improve the required properties. The focus for this work is the perception of mechanical rigidity, sometimes referred to as *grip stiffness* in the industry [2].

The mechanical rigidity of cartonboard packages is influenced both by the cartonboard material properties and by the geometry of the package. The perception can also vary depending on the grasp position on the panels. Folds and flaps act to stiffen the package c.f. [3]. Thus, the mechanical response of cartons is dependent on both geometry and material.

Important for the perception of compressibility is the difference between what happens locally around the fingertip (cutaneous cues) and what happens globally (kinaestethic cues). We know that both kinaestethic and cutaneous cues play a role in the perception of compliance, but also that cutaneous cues are more important [4].

In this work we study the mechanical interaction with cartonboard packages using a tactile sensor that deforms upon interaction. We attempt to present a way of separating the influence of the indentation position from the material influence at analysis of the results.

In previous work we demonstrated that the biomimetic tactile sensor picks up differences in material properties [5]. We also explored the limits of repeatability for the measurement setup used here and formulated a procedure for conducting the measurements [6]. Here we build further on that work and test the interdependence of geometry and material.

We use linear discriminant analysis to find patterns in the data and introduce tactile response maps as a method for visualizing the spatial variations of the mechanical interaction with the tactile sensor. These maps can help a designer to understand the influence that material choice and geometric design have on the perceived rigidity of the package.

METHODS AND MATERIALS

Cartonboard

The cartonboard materials used for manufacturing of the packages were four ply cartonboards (sulphate plies couched together) of three grammages 290 (Material 1), 315 (Material 2), 340 g/m^2 (Material 3), see Table 1.

Table 1. Specifications of the materials used

Property	*Method*	*Material 1*	*Material 2*	*Material 3*
Basis weight	ISO 536	290 g/m2	315 g/m2	340 g/m2
Caliper	ISO 534	420 μm	465 μm	510 μm
Bending resistance				
L&W 15° MD	ISO 2493	430 mN	550 mN	680 mN
L&W 15° CD	ISO 2493	230 mN	290 mN	370 mN

Packages

The packages where of the configuration ECMA A20.20.03.01 with measurements 78 × 50 × 110 mm, see Figure 1, and were manufactured on a flatbed cutter (Esko-Graphics, Gent, Belgium). To ensure more distinct creases a creasing matrix was used. These cartons have two insert tabs, one on each short side. After having erected the package the uppermost part of one gable is constituted by a folded extension of the top panel of the package, henceforth referred to as the crease side of the top panel, while the uppermost part of the other gable is constituted by a

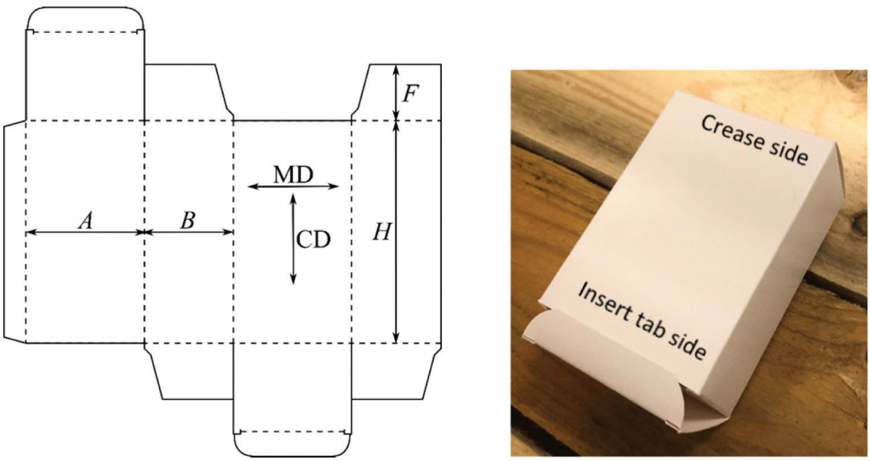


Figure 1. Left: Sketch of the package blank with drawing directions illustrated. A = 78 mm, B = 50mm, H = 110 mm. A MD crease is in this paper defined as a crease line perpendicular to the MD direction, e.g. a crease line along the long side of the package. A CD crease is correspondingly defined as a crease line perpendicular to the CD direction. Right: Erected package with insert tab not tucked in for illustration of non-symmetry.

folded extension of a tucked in insert tab that is not attached to the top panel of the package, henceforth referred to as the insert tab side of the top panel. This asymmetry means that we should not expect the mechanical response to be symmetric around the middle of the package in the MD crease direction.

Tactile Sensor

The BioTac sensor consists of an epoxy core with built-in sensors and electronics. A silicone elastomeric skin filled with a conductive fluid encloses the core. The core, the fluid and the skin mimic the bone, the soft pulp and the skin of the human finger, respectively. When the sensor makes contact with objects, the fluid is displaced, which changes the impedance for the electrodes embedded in the core. In this paper the result is presented in registered electrode values (E-values) given in bits. These values can be recalculated to impedance [7]. The main reason for studying these values is however to see their changes, which are affected by the distribution of force upon touch. A decrease in E-value indicates a decrease in the amount of fluid around the electrode i.e. an indentation, while an increase in E-value implies that more fluid is moving to the vicinity of the electrode. The pressure of the fluid also changes which is picked up by a pressure transducer. For more details on how the BioTac works, we refer to other publications, e.g.Wettels et al. [8].

Measurement Method

The methodology used for performing the experiments follows our previous article [6]. The BioTac tactile sensor (SynTouch Inc., Los Angeles, CA, USA) was combined with a uni-axial tensile tester, Lloyd LR5K (Lloyd Instruments, Fareham, UK), fitted with a 500 N load cell. We used the force and displacement data from the uni-axial tensile tester and the pressure and electrode data from the BioTac. A photograph of the setup is included in Figure 2.

Each package was probed within the elastic limit at 10 different points in a 2×5 point grid. The layout of the grid is shown in Figure 3. Measurements are performed in two lines 15 mm (A) respectively 30 mm (B) from the MD crease line. The first (1) and last (5) measurement point of a row are 8 mm from the package edge, the distance between measurement points are 24 mm. It was found that limiting travel of the BioTac to 6 mm would allow the packages to stay within the elastic limit. The BioTac made contact with the panel of the empty package, was raised 1 mm and then continued downward for 6 mm at a speed of 1 mm/min.

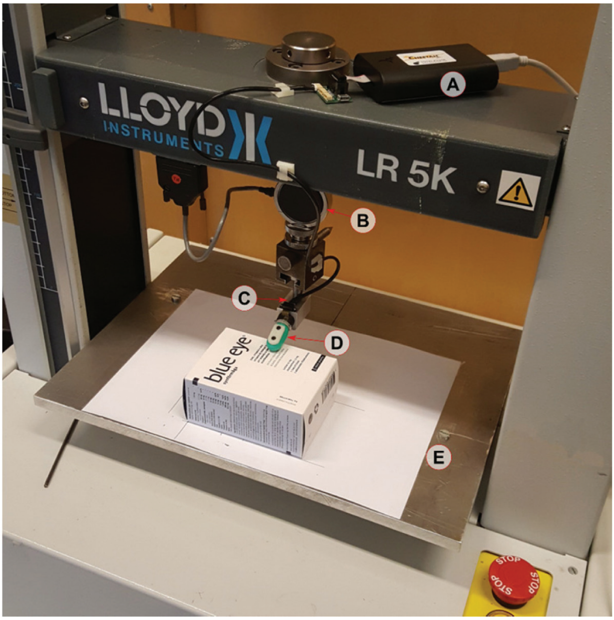
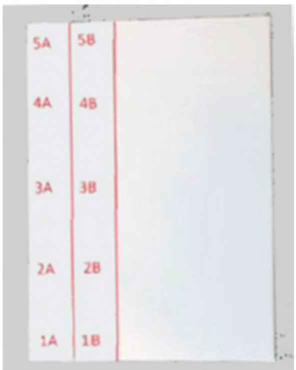


Figure 2. Experimental setup. Biotac mounted in the uni-axial testing machine. A: SPI device, secured with double-sided adhesive tape. B: 500 N load cell. C: Custom made fixture. D: BioTac. E: Fixed plate.

Insert tab side



Crease side

Figure 3. Overview of the package with the grid that we tested on and the labelling of the different positions.

Method of Analysis of Experimental Data

It has been shown that linear discriminant analysis (LDA) [4] can be a useful tool when analyzing the high-dimensional data collected by the BioTac sensor. The use of LDA allows to select and focus on interesting variations in the data and filter out the noise.

To best mimic the haptic perception of a human holding a package the evaluation was done at a set force level. We selected 2N as the evaluation point. This is similar in magnitude to typical manipulation forces used on a package of this size. For a discussion around manipulation forces, see for example Johansson and Flanagan [9]. The electrode and pressure values were extracted when the force first reached 2N, employing linear interpolation if 2N fell between measured sample values. We then sorted the measurements into classes, one for each material and position. We preprocessed the data using variance scaling, such that the variance of values in each component was unity. The LDA algorithm then find the directions in the data that maximize the variance between classes and minimizes the variance within classes. A more thorough introduction to LDA can be found in textbooks, e.g. Hastie et al. [10].

To perform the calculations we used the standard LDA algorithm in the python package Scikit learn version 0.22.1 [11].

RESULTS AND DISCUSSION

The weights of the first and second LDA components can be seen in Figure 4. The different electrodes have different significance for the two LDA components. It is obvious that the asymmetric geometry of the tested package makes the response asymmetric for both components.

Figure 5 shows an overview of all the samples measurements and where they get projected to with the top LDA components. Measurement position is seen to have av strong influence on LDA component 1. Separation is achieved between the positions 1A and 1B and the remaining positions. Generally, positions away from the CD crease gives higher values of LDA component 1, but close to the insert tab the movement is in the opposite direction i.e. lowering the values of LDA component 1. Low grammage gives a larger range in LDA component 1 values than a high grammage. The second component on the other hand, is primarily influenced by material. It separates samples according to material. Higher grammage of the material gives a lower value of LDA component 2. Separation is seen between material 1 and material 3, while material 2 lies in between with some overlapping of extreme measurement points.

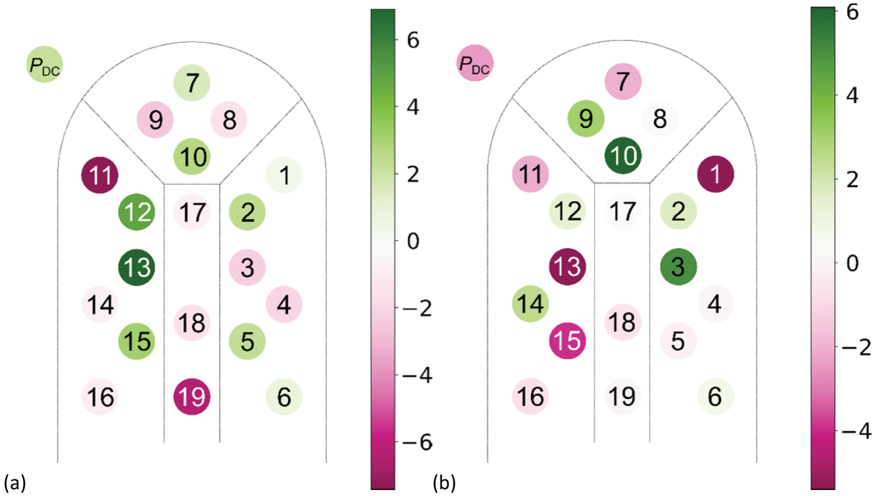


Figure 4. Presentation of the weights by electrode for the most significant LDA component (a) and the second most significant component (b). The fingerlike sensor is pictured from above with nail upwards.

A slightly different look at the same data is shown in Figure 6. Here the values of the average LDA components are plotted in the position that represents the position of measurement. Plotting the average component values side by side like this shows geometric clustering, as positions nearby have similar values. A monotone shift with material is also seen.

Thus, it would seem as though the goal of separating material and geometry influences can be reached. If material is known the measurement position may be distinguished by aid of Figure 5 and 6. Positions is clearly distinguishable from the CD crease to about position 3 or 4 with one component. Closer to the insert tab the regression of the first component makes identification trickier. The insert tab has a weaker influence. A combination of first and second component may then be used. Similarly, if measurement position is known, it is possible to identify the material, primarily using the second component.

When, for this package geometry, measurements have been done for the different materials and measurement positions, the LDA have been calculated and the tactile response maps drawn, this can be used to identify properties of an individual measurement. If we know which materials and which measurement positions that are possible, we can with high probability identify which material and measurement position is relevant for the individual measurement.

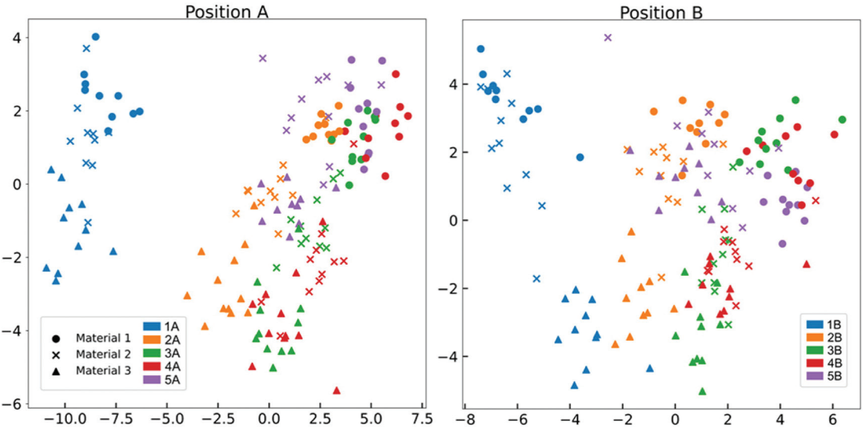


Figure 5. All measurement results in this work projected to 2D space using the two most significant LDA components. First component on the x-axis, second component on the y-axis. The measurements are made on packages of different materials (Material 1-Material 3) at different positions (1A–5B).

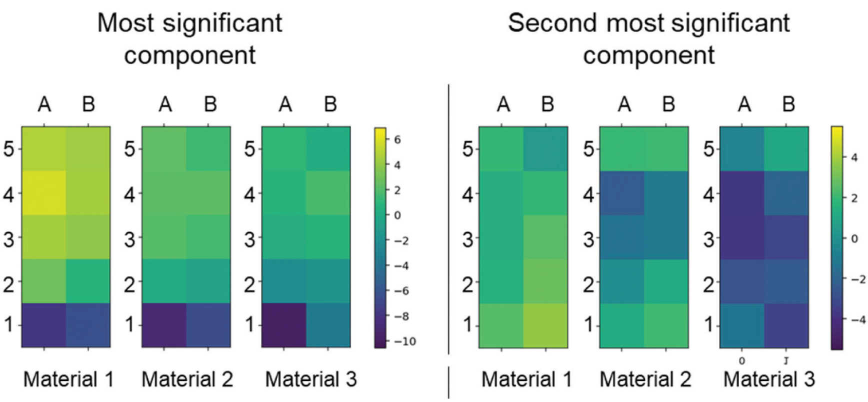


Figure 6. Averaged LDA component values by position and material.

While the LDA gives a nice way of interpreting the results, it can nevertheless be insightful to look at individual electrodes and the values measured there. Measurements at a specific force may also not give all information about the packages. In Figure 7 the average BioTac response is shown at position 3B as electrode values (conductivity) [6]. Consumers often grasp packages in positions like 3–4 [4] and these positions seem to be useful for separation of materials. Position 3B

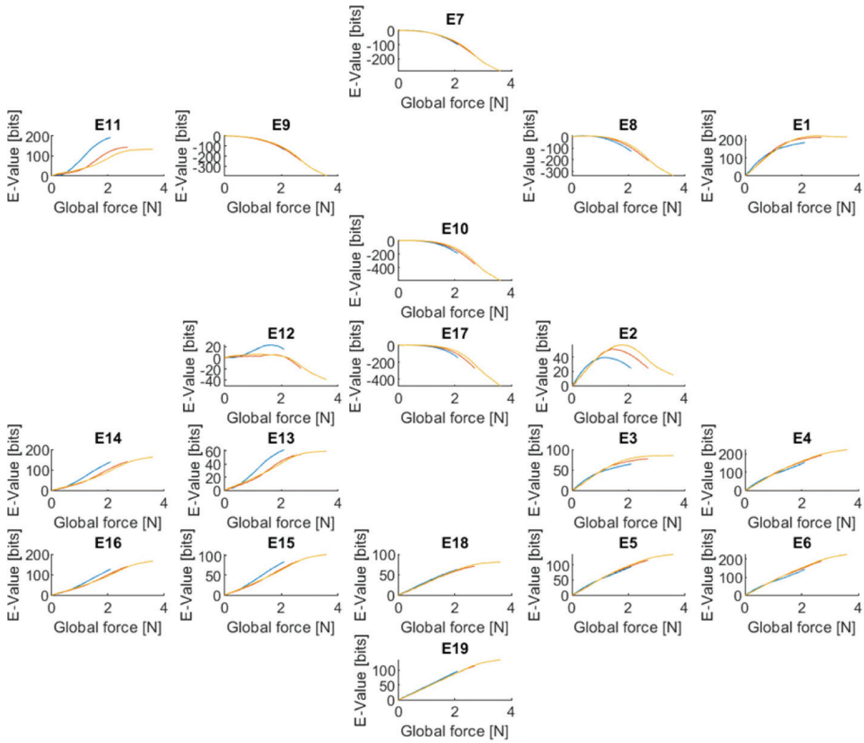


Figure 7. Average BioTac response curves by material in position 3B. The average electrode values are presented up to lowest max global force for the measurement series.

is the position furthest from the creases. Figure 7 shows that there is a clear separation of the results for the different materials for several electrodes.

The electrodes on the flat portion at the front of the Biotac E7–E10 have previously been used to discern differences in compliance [4]. Electrodes E7–E10 are situated on the fingertip and comes into first contact with the material. A stiffer material allows for less enveloping of the sensor and gives more loading on these front electrodes, which results in decreased electrode values as fluid is pressed away. This trend is visible in Figure 7. The E7–E10 electrodes were however less good for picking up the asymmetry in the loading conditions in this case and were therefore weighted less strongly by the LDA.

The asymmetry of the package is visible in the electrode results. The difference between the crease and the insert tab side of the sensor is e.g. visible in the result of electrode E2 and E12 in Figure 7. The left side (E12) has lower electrode values than the right (E2) side. The lowest grammage material 1 has higher electrode values than higher grammage materials for electrode E12 on the left side of the sensor and lower electrode values than higher grammage materials for electrode E2 on the right side of the sensor.

CONCLUSIONS

This work has shown the possibility of using the laboratory method for measurements of mechanical interaction between a tactile sensor and a cartonboard package, together with LDA and tactile response maps, to separate the influence on the mechanical interaction of position and material. With this method can be discerned the influence of indentation position and material, which may be used to optimize package material and geometry.

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Johan Alfthan RISE Research Institutes of Sweden

I am interested in mechanical properties and contact in this, so is it possible to translate these signals you get into a pressure or deformation of these fingertips that you are looking at?

Camilla Persson

The sensor, despite the electrodes, has a pressure and a temperature sensor. By looking at the electrode values we can see if fluid is leaving or coming to the position of the electrode, this gives a picture of the deformation and pressure.

Johan Alfthan

Yes, I was guessing this would be so, but that is good to know, because I think this is an interesting topic.

Discussion

Camilla Persson

I think it's interesting and I think this can be used to model deformation; for instance, a computer model can be used and then you check against what you measure. This isn't in this presentation.

Janet Preston Imerys Minerals Ltd

I was wondering if this model 'finger' could be used to investigate special effect finishes for example soft touch surfaces? Have you correlated it with panels of people feeling a surface to determine a special tactile effect? I think that would be another interesting area of study.

Camilla Persson

We haven't performed that study yet. You could of course measure with a sensor and then ask a test panel to judge the same packages and then try to get some correlation between the two. When I talk about my research today I am not talking about how you feel it, what I measure is the interaction, not the feeling. But of course, the interaction can give feelings.

There are measurements where the sensor is drawn against surfaces to measure the surface interaction or friction. However, here we focus on the interaction upon "point loading" as during touch.

Janet Preston

This is possibly an idea for the future and may be an interesting way to use your model finger.

Ryen Frazier North Carolina State University

I was curious, when you showed the finger, or the kind of sample finger that you were just describing, are there any different sizes? Is it based on the average male or female? I am curious as to the size and obviously how that affects the force and the area that it covers as well. You mentioned that you chose a specific force out of all your experiments or that you can choose to look at a specific force and develop these graphs, and then look at the positions based on that. So I am curious secondarily if you saw with each different force you chose similar responses in positions?

Camilla Persson

This biotech sensor, it has a fixed dimension. It's manufactured to be similar to a thumb, I guess an average thumb. I don't think it's available in different sizes, but I am not absolutely sure, but it is true it has a certain dimension of the deformable thumb.

Ryen Frazier

Yes, so I guess either why did you choose that specific force or did you look at other forces as well?

Camilla Persson

We chose a common force to get no slip when you lift this kind of package.

Ryen Frazier

My overall question based on these two things is, do you think it will differ in response a lot if the size of the finger or the force applied is different, or do you think it will mimic the same thing?

Camilla Persson

Now, I must just guess. I think that if I would have chosen another force, it would still be possible to distinguish different materials and different positions. I think that will be possible. We have also done one other work dealing with how to manage the data. We had some students and they came up with the idea, what if we just take the mean of these graphs and look at the mean values and try to see if we can do something with that. Maybe some separation may be seen. And we said, okay let's do that. They could draw conclusions, so there are different ways of analysing the data here and that is one other way of doing it.

Steve Keller Miami University

Just a suggestion and that is, it looks like there is directionality with this artificial finger and with the package. So, the recommendation is to collect data rotated at 90 degrees, 180 degrees then take a look at the data to see how the finger responds to rotation. If the results are not the same then it's the finger geometry that is causing the differences in the results and not the package itself.

Discussion

Camilla Persson

If you rotate the finger you will get closer to or further away from the crease with the different sides of the finger. So, you will expect to get a difference in the graphs and we have already performed, but it's unpublished, measurements with the finger inclined in different angles.

Ville Leminen Lappeenranta-Lahti University of Technology LUT

I was just thinking that you have a lot of different graphs and lots of different force values. Would it be possible maybe to also just use a little bit simple sensor instead of this finger and acquire the same data which is a ball-shaped sensor or some other that you could acquire the same force?

Camilla Persson

Earlier we used these metallic spheres, then we only got a force displacement graphs and we didn't have any sensors on the sphere. There are different tactile sensors available in the market. We have just used one type of tactile sensor. I am not sure if that is the answer to the question.

Ville Leminen

Maybe my question is that what is the additional data that you can acquire by using this method compared to these older methods?

Camilla Persson

Let's try to answer the question. The difference in the data that I get from this measurement method and the other one is that I with the tactile sensor, where there are more measurement positions on the sensor, I can see the enveloping. I can see the differences in the different positions around the finger. If I have only the force, then I have the force when I use the tactile sensor also.

Ville Leminen

Maybe I would phrase it that you get more resolution on a local scale by using this?

Camilla Persson

That's true, that is a good way to put it.