Design an Overload Warning and Indicator Device for Stacking Corrugated Cardboard Boxes by Using the Internet of Packaging and Printed Electronics

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Abstract:

IoT technology with the cooperation of printed electronics applications can establish a tracking system to monitor the processes in real time, so improvements can be made more efficiently and losses can be decreased to an extent. IoT term may be modified to indicate a specific field like the Internet of Packaging (IoP), so it is a branch of Internet of Things, which is related to packaging industry. IoP has contributed in converting the term value chain into value network. It has several potentials and functionalities arising from its connectivity and data exchange properties. IoP targets more active objects and hence, links physical passive packaged goods to a network via embedded printed electronics like tags and smart sensors, which can collect and exchange data to provide immediate access to information. Logistics industry, which including storing and distributing packaged good, which is heavily rely on corrugated boxes for secure delivery to consumers. For example, corrugated cardboard boxes are considered the backbone of the supply chain in America. However, all the caution and measurements that be taken for preventing corrugated boxes' damages because of stacking, one of the main reasons of freight damage during storing and transporting is loading of stacking corrugated cardboard boxes. The researcher used IoT developer kits to prototype a device that can be used for tracking and monitoring the process of stacking corrugated cardboard boxes in the whole of its lifecycle, in the warehouses, and during truck loading and palletizing. The device is used to ensure that the stacking load for every box does not exceed the limit of guidelines fulfillment of used cardboard test for corrugated boxes strength.

Keywords:
Internet of Packaging – Printed Electronics-Marketing - Logistics– Packaging Quality Control

Introduction:
Although all the caution and measurements be taken for preventing corrugated boxes damages because of stacking, one of the main reasons of freight damage during storing and transporting is loading of stacking corrugated cardboard boxes. According to Gene Bodenheimer, senior vice president of retail logistics damage research at FedEx Supply Chain "as much as 11% of unit loads arriving at a distribution center have some level of boxes damage". While this number might seem small, but the consequences can be quite huge. Most damage of inner load is based on compression, the most at risk is the lowest row then the second row; otherwise, the third one is the top row since it may be damaged because of boxes loads getting out of alignment vertically or leaning. Heavy creases in the corrugated cardboard, a box with holes or other marks such as rips and tears are signs of damage. Damaged products in boxes are usually less than 1%, which means that the boxes protect the contents. However, it is possible that a huge amount of undamaged product would be rejected. (Bodenheimer.2019) The conventional solution is to label all of packages with its weight and the type of contents stack. Stack in a tower with the pallets or packages of the same dimensions and putting a sheet of corrugated cardboard or reinforcement between every three layers to help distribute weight and prevent crushing contents. However, all these solutions are not very effective and are not enough to eliminate damages completely from supply chains. (9 Corrugated Box Testing Methods to Ensure Packaging Quality). According to the technological development and the emergence of advanced Internet of packaging solutions, we must apply new methods to avoid the damage of products.

Research Problem:
Stacking load on corrugated cardboard boxes is one of the main reasons of freight damage during storing and shipping, which cause downward-pull breakage due to the gravity of stacked boxes. Although all the caution and measurements that be taken for preventing corrugated boxes damages because of stacking, there is no perfect solution for this problem.

Objectives:
Making use of modern technologies like the Internet of Packaging and printed electronics in solving the problem of corrugated cardboard boxes damage because of stacking load by modeling a device that is alarming once over-loaded.

Methodology:
The study followed the descriptive analytical method by collecting data and information related to the subject of the research then to describe and analyze the data and experimental method by conducting experiments then are using the appropriate devices to achieve the objective of the research.

Internet of Packaging (IoP) Meaning:

IoP is an application of Internet of Things. IoP has contributed in converting the term "value chain" into "value network: As Magic Add, a pioneering IoP technology company, mentioned. (IoP Definitions and Status Quo). It has several potentials and functionalities arising from its connectivity and data exchange properties. IoP aims at more active set of objects and hence, links physical passive consumer-packaged goods (CPG) packaging to a network via embedded, laminated, or printed electronics, tags, and smart sensors, which can collect and exchange data to provide immediate access to information. A package can be tracked, traced, communicated, and technical ways can be applied to facilitate decision making for diverse participants, thanks to smart devices that are integrated into packaging design. (Lydekaityte &Torben.2020) IoP is also termed as "connected packaging" to be a branch of "smart packaging" and one of its novel trends. Since traditional packaging is no longer sufficient, recent packaging modules are developed due to evaluated consumer and brand needs. Numerous types called "smart packaging" are initiated, involving computer-assisted control systems to perform several functionalities for packaged or labeled products that goes beyond simply housing a product. (Borah & Upakul. 2019)

Corrugated Cardboard Boxes Damage during Shipping:

Storing, transporting and palletizing freights are important stages of the products lifecycle, as it is necessary to obtain customer satisfaction by delivering the shipping package in good condition to ensure the safety of the product. (7 Ways to Avoid Freight Damage) Consumers today focus on the condition of the secondary packaging that is used to protect their products during shipping. UPS and FedEx shipping over 14 million packages every day, a number that is continuously increased. Logistics and shipping companies lose consumer satisfaction when secondary boxes arrive unsealed, damaged, tampered with, or impaired. Products rejected or returned, businesses lose money and market share and negatively affecting brand reputation. (Bodenheimer. 2019) Freight damage negatively affects the relationship with customers, profits and growth on the long-term and the short-term hits and cause significant losses to the producer and consequently to the shipping company. (7 Ways to Avoid Freight Damage)

Shipping warehouse workers are often overloaded, working overtime in extreme weather conditions and being pushed somehow to do more, better and faster. This can often reduce the level of care in handling parcels, especially when the supply chain is demanding; Ensuring packages are properly stacked on pallets for shipment is not always easy. This is especially true for fragile, breakable items or a pallet pointing in a certain direction, while there are various possibilities for the package to be improperly packed, dropped, stepped on, crushed or other harmful extreme weather conditions. (Dube.2020) Heat and humidity affect the strength of the packaging because 40% of the strength of corrugated cardboard is lost in the first 30 days of storage. Corrugated cardboard is 71% weaker at 95% humidity versus at 50% humidity because excessive humidity can dissolve the corrugation adhesive and cause delamination. Heat can also reduce the internal humidity of corrugated boxes, making them brittle. (Bodenheimer. 2019) Air bags, bubble wrap, foam packaging, air pillows, Foam Inserts, Stretch-wrap and paper padding are a protective packaging solution for application prone to damage from shock and vibration. Packing tape along the seal prevent box opening during transportation, as it is strong,

durable, wide, and waterproof. (Packaging Tips to Eliminate Damage and Lower Return Rates) Shock indicator sometimes can be considered as a protection solution since it changes color when being hit. (Are Damaged Goods Impacting Your Service?) Besides, choosing the right material contributing in protecting shipped products. Although all these protection methods, there are many shipments that affected by the stack loading.

Corrugated Cardboard Boxes in Logistics industry:

Logistics industry is heavily relied on corrugated boxes for secure delivery to consumers. For example, corrugated cardboard boxes is considered the backbone of the supply chain in America. When restaurants and stores shut down during the first month of COVID-19, corrugated box shipments grew by 9%, in March 2020. Shipments reached record highs, increasing industry shipments by 3.4% at the same year, the largest annual increase since 1994. The corrugated industry reached 407 billion square feet (BSF) of product shipped at the end of that year, and it was the highest level of shipments, surpassing the previous high of 405 BSF in 1999. (Kenyon.2021) Although corrugated is structurally strong to absorb the weight of other boxes when stacked, or dropped, there are specific guidelines fulfillment that decide how thick the boxes walls should be depending on the items being shipped. (Packaging Tips to Eliminate Damage and Lower Return Rates) There are corrugated strength tests like box compression test (BCT), Mullen Burst Test and Edge Crush Test (ECT).

Figure 1: boxes damage during shipping due to stacking over-load
Source: (13)

Quality Control Tests Related to Corrugated Cardboard Boxes Stacking:

Mullen Burst Test is an old standard used in the 90th for measuring box strength. It uses a pressurized diaphragm to measure how much pressure (in pounds per square inch) on the side

of a corrugated box that it can afford before it breaks. (Figure 2) Corrugators started to use a higher percentage of recycled article material, which have fibers that are shorter and less organized than the new ones. Therefore, Mullen Burst Test ratings would be lower than the new material but still can be stacked as high, with the same amount of weight, as long as the contents in the box did not move and press the sidewalls. In other words, the corrugated might burst, but it would not crush. Bursting strength is measured in pounds. National Motor Freight Traffic Association (NMFTA) changed the standard to Edge Crush Test. It measures the needed weight on the edge of the corrugated to be crushed in case of being stacked. (Reid.2022) It is measured through compressing a small piece of board on its edge between two rigid plates to the direction of the flutes until the peak load. It is measured in pounds per lineal inch of load bearing edge (lb/in), but usually reported as an ECT value (eg 44 ECT). (Figure 2)

Box compression test (BCT), also known as container compression test, a newer standard that is widely accepted and related to the strength of stacking of a box to test how much load the box can take on top of it before getting deformed. (9 Corrugated Box Testing Methods to Ensure Packaging Quality)

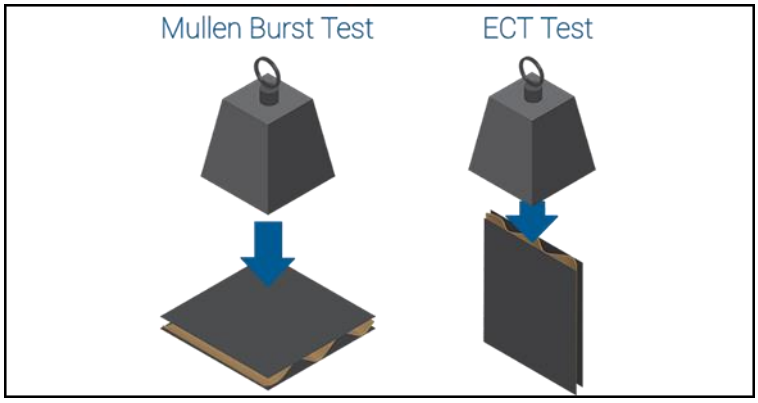

figure 2: difference between mullen burst test and ect test
source: (12)

Methodology:

The researcher modeled a device through IoP and printed electronics that can be used to indicate the over-load case via lighting a led lamp placed on the corrugated cardboard box label to alarm the workers and at the same time send an email alarm to the operator with the error.

Corrugated Cardboard Boxes Stacking Over-Load Indicator & Alarm: (Related to Product Tracking and Protection)

1- Projects' Materials:

1.1 Force sensor (FCS): The force sensor (FSR402) is Interlink Electronics product. It is a printed electronics device, lightweight, small size, and ultra-thin resistive pressure sensor. The sensor is placed in FSR film. Polymer devices reduce their resistance when pressure increases on the sensor surface. It is used to sense weight, pressure, and communication as a touch sensor. Its resistance will differ depending on the amount of stress that is applied on the sensing area, the higher the force, the lower the resistance. When there is no pressure on the FSR, its resistance will be more than 1MΩ. The FSR senses the force 100 g-10 kg of weight. (FSR1) (FSR402 Force Sensitive Resistor).

FSR is a passive device with two-terminals that decrease its electrical resistance when stressing the Sensor Sensitive Area (SSA) which is usually made of a composite of conductive polymer particles. They are randomly dispersed in a non-conductive polymer and sandwiched between two electrodes of metal. There are several researches on materials specification used in the manufacturing of SSA. Many materials have been used for producing the non-conductive material; polymers like elastomers, rubbers and poly dimethyl silicone (PDMS) are preferred. Conductive particles such as Nickel or Cooper, within the range of tens of nanometers up to a few micrometers. Carbon black and carbon nanotubes have also been used as conductive phases in the insulating material.

SSA comprises multiple design parameters, such as electrode configuration, type of insulating material, and properties of the conductive particles (material and size of particles, mass ratio of the conductive particles to the insulating material). Therefore, literatures include multiple designations of these materials, but the type of insulating element is the main side for categorizing them. Hence, conductive polymer semi-conductive polymer, and rubber/elastomer/PDMS composite with conductive nanoparticles are the most common designations that can be found about the SSA. (Madrid& Carlos. 2017)

1.2 ESP 32S Development Board (ESPWROOM32):

Esp 32 is one of IoT kits for prototyping devices. ESP 32S development board has Wi-Fi/Bluetooth, 32-bit double core CPU, one for the wireless (WIFI & Bluetooth) and the other for the control and 36 PIN for project.

1.3 Resistance:

Carbon Resistor 3.3 and 10 kohm 1/4 W Resistors 10 k ohm resistance.

1.4 Bread Board “BB-01”:

A breadboard is a rectangular plastic board with a cluster of tiny holes for electronic components to be inserted for prototyping a device. Most breadboards have numbers, letters, and plus and minus signs written on them and strips marked by red and blue or red and black lines (the buses or rails), with (+) and (-) signs (ground), respectively to be connected to electrical power. There is no physical difference between the positive and negative buses and the labels to organize the circuit easily. The holes from A- E in every row is connected together and on the other "half" of the breadboard, the holes from F-J are connected.

1.5 LED:

LED 5 mm white color and may be any other color used like red, yellow or green.

1.6 Wires:

Connecting jumper wires for breadboard with different lengths and colors. It is in plastic enclosure for any type of breadboards Kits and electronic projects.

1.7 Programming Software: Arduino IDE.

1.8 USB Cable

2- The Procedures:

Connecting FCS terminals into the Bread Board E column sockets. Connecting the first terminal of the sensor to 10 kohm resistor terminal and to the GPIO 36. The other terminal of the resistor

is connected to negative distribution strips of the breadboard. The second terminal of the sensor is connected to the power 3V3 of the ESP development board.

Connecting LED terminals into the Bread Board D column sockets. Connecting LED negative terminal to 3.3 kohm resistor terminal and the other terminal of the resistance is connected to the negative distribution strips of the breadboard. Connecting the positive terminal of the LED to the GPIO 5 of the ESP development board.

Connecting ground (GND) of the ESP development board to negative distribution strips of the breadboard. Connecting the ESP development board to the PC via USB cable. (Figure 3) Then the code is written uploaded and compiled (Figure 4) by using Arduino IDE software.

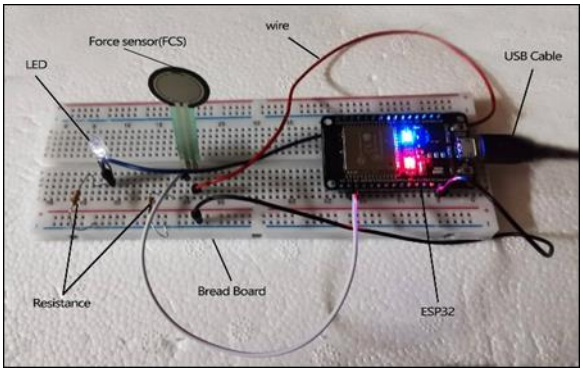

Figure 3: The overload idicator and alarm modeled device
Source: (3)

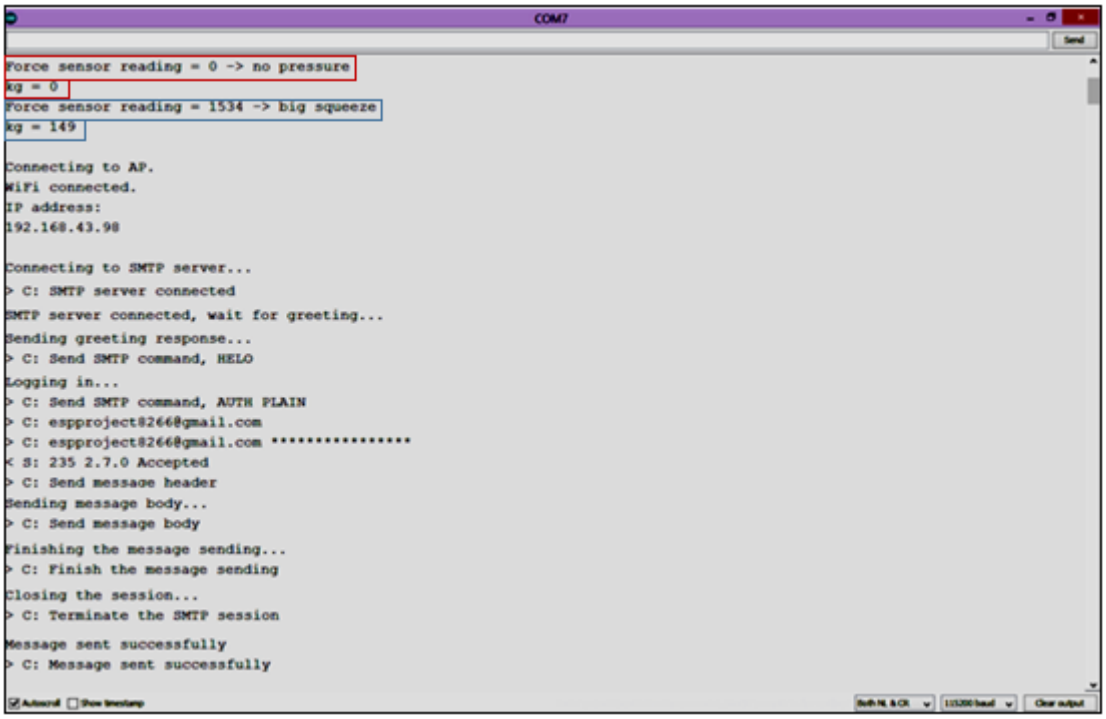

Figure 4: The serial monitor during running the code
Source: (4)

3- Results:

After compiling the code, the device has been ready for being used. When the force sensor is pressed by force lower than the defined kg limit in the code, the result is written on the serial

monitor that force sensor equal zero and there was no pressure (figure 4). Once the pressure exceeds the defined limit, the force sensor gives the alarm that there is a big pressure, the result is written that force sensor equal x and the device starting connecting to the SMTP (simple mail transfer protocol) server to send the alarm email (figure 4). The LED, which is supposed to be on the parcel package, is glowing to catch the parcel loading worker attention and at the same time an Alarm email sent to the operator that the parcel number x is overloaded to take an immediate action. (figure 5) The device may also be programmed to connect to analyzing application on the cloud to have data real-time accurate statistics.

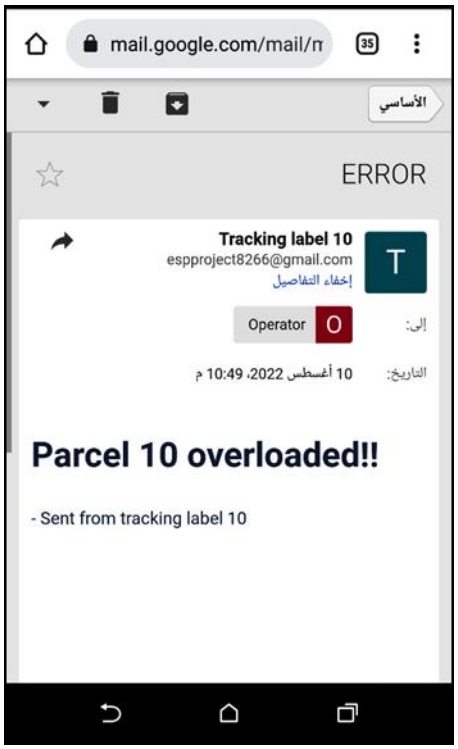

Figure 5: Alarm email that the parcel number 10 is overloaded
Source: (5)

Conclusion:

Stacking over-load is one of shipping and logistics problems that may cause losses for businesses, although all the caution and measurements that can be taken for preventing corrugated boxes damages because of it. One of the main reasons of freight damage during storing and transporting is over-load on corrugated cardboard boxes, which cause downward-pull breakage due to the gravity of stacked boxes. It is necessary to make use of modern technologies to prevent such problems. Because of that, the researcher modeled a device through IoP and printed electronics that can be used to indicate the over-load case via lighting a led lamp placed on the corrugated cardboard box label to alarm the workers and at the same time send an email alarm to the operator with the error.

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