Smart cushion system for wheelchair
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Abstract: Pressure ulcers or Decubitus Ulcers are a very common existing problem in case of patients with SCI or who are completely disabled. Many kind of pressure relieving cushion systems have been developed but even the diversity of existing cushions used and reported, pressure over the bony prominences still continue to be a major problem for wheelchair-bound and bed-ridden patients. This paper introduces a novel automated pressure shifting system in order to prevent pressure ulcer or decubitus ulcers. The system consists of pressure sensor, embedded microcontroller system (PIC16F877a) and an actuation system. The work combines two systems together that is an electronic system consisting of microcontroller and a mechanical system consisting of actuation unit thereby making a complete automated system which works for shifting the accumulated pressure and distributing it throughout the region and thus preventing development of pressure ulcers. The placement of sensors in the cushion will be in such a manner that inflation and deflation of the actuators will take place when required as per the pre adjusted threshold value with the help of microcontroller. It has the potential to improve the prevention of pressure ulcer and enable the user to achieve an optimal status for his or her most satisfactory comfort while using the proposed device. The proposed system is entirely based on automated pressure shifting mechanism and helping the completely disabled patients who are in frequent need of a wheelchair or a bed for changing their positions frequently and thereby preventing decubitus ulcers due to prolonged usage of cushions for their lifetime.

Keywords: Spinal cord injury; Peripheral Interface Controller

1 INTRODUCTION
Pressure ulcers or otherwise also known as decubitus ulcers or bed sores are localized injuries of skin and underlying tissues of bony prominences, due to pressure, or pressure in combination with shear and/or friction. Most commonly affected areas are the coccyx, sacrum, hips or the heels, but other sites include elbows, knees, ankles or the back of the cranium can be affected.

Aim
The aim of our project is to develop an automated pressure shifting mechanism which can sense the pressure going beyond the set limits and thus in turn actuate the actuation unit with the help of microcontroller to shift the pressure accumulated at a particular region and distribute it throughout thereby prevent the occurrence of pressure ulcers.

The impact of this system to the clinical field will be revolutionary because it helps to reduce the threesome work of nurses where they have to change the position of each patient every 2 hours. The system being comfortable does not cause the patient any irritation either, and automatically helps to prevent bed sores.

Objectives
The objectives of our proposed work are as follows:
- Identification of the sensors
- Design of an electronic unit
- Design of a mechanical actuation unit
- Interfacing of the electronic and mechanical unit

Problem definition
The problem of pressure ulcers or decubitus ulcers are very common in patients who are wheelchair bound or bed ridden for a prolonged period of time and cannot change their positions frequently. Due to prolonged usage shear forces arise which is a force which comes into play if the part of the body tries to move itself but is unable to do so because the skin and the surface are in contact with each other which sometimes lead to frictional forces. These forces and some other factors like moisture, temperature etc. leads to rise in the mean capillary pressure of that area which is normally 17mmHg and thereby causing skin reddening, necrosis, degeneration of subcutaneous tissues and finally development of pressure ulcers. This mainly happens over the region of bony prominences. There are not many systems available to correct this and thus our work aims at developing a system which can automatically sense the pressure going beyond a level and thus correct it at that very level and prevent pressure ulcers. An estimation of around 2.5 million persons around the globe are treated every year for pressure ulcer.

The prevalence and incidence of these patients can be seen as:
- Hospitalized elders - 15%
- Nursing homes - up to 24%
- Rehab facilities - up to 25%
- Home health-care settings - 6-9%
- Orthopaedic patients - up to 19%
- Spinal cord injury patients - up to 44%

1 Introductory remarks
Every year around millions of patients die because of pressure ulcers or decubitus ulcers and despite the fact of cushions and mattresses available the prevention is not possible at early stages. Our system is an automated one which unlike other automated systems which repositions the patient every 2-4 hours works on pressure sensing mechanism and shifts the pressure only when it is sensed beyond a threshold limit and thus helps in preventing pressure ulcers.

2 LITERATURE REVIEW
There has been a lot of research on the Smart Cushion system for wheelchair ridden patients in order to prevent pressure ulcers.

2.1 MERGERY J. PETERSON AND HAZEL V. ADKINS in 1982 said that The sacral, ischial tuberosity, coccygeal area, and the lesser and greater trochanters and intertrochanteric crests receive excessive pressures when an individual stay in same position. Prolonged sitting by patients with insensitive skin and physical disability can cause pressure sores. Pressures below 20-30 mmHg is in general required to prevent occlusion of capillaries. Pressures are measured with a transducer system as the patient sits in his natural sitting posture in his wheelchair. A seat cushion is then made which will redistribute excessive pressures.

2A.G.KEY et al in 1978 said that in a survey for around 200 patients which was done in order to study the pressure distribution in the cushion and evaluate it for proper application. It was found that the soft tissues underlying the bony prominences suffer from pressure ischemia. Pressures up to 300mm Hg was measured when the subject was sitting on a wooden chair and in excess of 100 mmhgl when the
patient was sitting on a soft plastic foam cushion of a wheelchair seat. As the mean capillary blood pressure is only about 17 mm hg, this tissue loading if prolonged may lead to tissue necrosis. Also any tendency of cushion sag will result into frictional and shear forces thus further deforming the loaded tissues and causing further capillary occlusion. Cushions designed for long term sitting can be divided into two categories as active and passive. Active cushion materials being Ripple seat or alternating pressure pad and Passive materials can be flotation bags, bean bags Elastic and Viscoelastic foam cushions and custom made vacuum formed seats thus providing maximum patient support contact area.

2GEORGE VAN. B COCHRAN in 1980 discussed about a comprehensive approach to testing of wheelchair cushions and devised a detailed test protocol with estimated preferred ranges for test results that are based on the limited experience to date. Further clinical work is needed to determine the actual practical importance of each test parameter.

3FERGUSON-PELLO et al in 1986 said about a modular wheelchair cushion system intended for patients with low to moderate risk of pressure sore development. The effective prevention of pressure ulcers development over the pelvic area and subcutaneous tissue is a major concern for people with spinal cord injury. In addition to relieving pressure many other factors like physical, functional and aesthetic factors have been also taken care of in developing this system.

4G. M. PETERSON AND P.D. FISHER in 1993 said about an expert system for pressure ulcers technology entering its fourth decade of evolution and has proven successful when used as an adjunct to human non-expert way of making decisions. Pressure ulcers are identified as a health problem that is poorly diagnosed and is very expensive to be taken care of. Thus this domain may prove to be suitable approach for mapping onto an expert system knowledge base.

2KM BOGIE et al in 1995 said that the patient with spinal cord injury is at high risk of tissue breakdown at all times because of factors, like reduction in mobility and anaesthesia. It is thus essential that every patient is prescribed for an appropriate support media in case of initial rehabilitation. Changes in the response of transcutaneous gas were monitored concurrently with regional interface pressures. The results of this study indicates that spinal cord injury subjects with lesions below T6 show a progressive decrease in ability to maintain blood flow in sitting on prescribed support cushions and SCI subjects with lesions above.

3S. RAKHEJA et al in 1998 said that about the influence on dynamic human-seat interface pressure by the whole-body vertical vibration and it was investigated using a flexible grid of pressure sensors. The overall pressure distribution along with the ischium pressure existing at the human-seat interface is evaluated as functions of the magnitude and frequency of excitation caused by vibration, height and seated posture. The pressure of the seat surface is measured under sinusoidal vertical vibration of different magnitudes in the 1-10 Hz frequency range. Two methods which were proposed was based on ischium pressure and ischium force to study the influence of, posture, seat height and the characteristics of the vibration. The study revealed that the amplitude of dynamic pressure component increases with an increase in the excitation amplitude in almost entire frequency range considered. The average values of the ischium force and the ischium pressure remains constant, irrespective of the amplitude and the excitation frequency. But, the magnitudes of mean or average force and pressure at the human-seat interface, however, are dependent upon the subject’s posture and the seat height.

4TANYA ROSE PELLO in 1999 said about patients with quadriplegia using wheelchair. It helps to know the effect of tilt and recline positioning and various wheelchair cushions interface pressures on ischial tuberosity and sacrum of patients. Interface pressure under bony prominences was assessed in personal driving position. It helps occupational therapist in 15 professional judgement and proper wheelchair cushion system prescription. It also helps in proper clinical judgement and helps quadriplegia patient to reduce the formation of pressure ulcer. It contributes for better understanding of tilt and recline positioning effects on pressure ulcer development.

2YOSHIKO TANIMOTO et al in 1999 said that pressure sore remains to be a serious issue for patients with spinal cord injuries. Even after the development of different kind of pressure relieving cushions that aims to distribute the weight widely over an area pressure sores still pose a great threat. The buttock pressure distribution of 18 SCI patients on 3 kinds of wheelchair cushions was measured to evaluate the pressure distribution of cushions and select the best cushion for each SCI patient.

3TANYA ROSE PELLO in 1999 said about a pilot study done for comparing interface pressure readings to wheelchair cushions and positioning. The purpose of this study was to assess the effect of tilt and recline positioning and various wheelchair cushions on interface pressures at the ischial tuberosity and the sacrum of two subjects suffering from quadriplegia with C5. Also, in addition the interface pressures existing under the bony prominences were assessed in the personal driving position, neutral, tilt of 35 degrees, 45 degrees, and maximum recline of 150 degrees.

4CARMEN P. DIGIOVINE et al in 2000 said about the ability to minimize the vibration transmitted from wheelchair to the individual during manual wheelchair propulsion. Accelerometer measured the vibration at the wheelchair transverses. Cushions designed for static pressure relief may not perform well in other potentially related to secondary vibration such as injuries. Cushions are prescribed by clinician based on cushion pressure distribution under the ischia tuberosity and sacrum.

5COURTNEY H. LYDER et al in 2000 says that pressure ulcers continue to be major health problem for hospitalized older patients. The study was done which revealed that the quality of care delivered to the hospitalized patients at risk of pressure ulcer development can be prevented by improving their nutritional conditions and changing positions frequently.

6HON KEUNG YEUN AND DONNA GARRETT in 2000 did a case study on comparison of three wheelchair cushions for effectiveness of relief from pressure ulcers. This single-subject study illustrates a research design used for the comparison of the short-term pressure-relieving performance of three different wheelchair cushions. A more ecologically valid study would be designed to investigate the longterm performance of each cushion for at least 3 hr to 4 hr (with 5 sec of push-ups for every 15 min of sitting) in a controlled clinical situation. Long-term performance of the cushions may differ from the short-term performance, as cushion performance may be compounded by the physical
property of the cushion material, which can affect the buttock-cushion interface pressure.

2ORLANDO in 2001 in his book on wheelchair seating said that Pressure ulcers are a significant healthcare problem for wheelchair users. Unfortunately, the mechanisms underlying the aetiology of pressure ulcers are not well understood. A variety of measurement techniques have been used to investigate the many factors and markers thought to be related to pressure ulcers. The interpretation of clinical research is complicated by a lack of standardized methodologies. The lack of standardized methodologies limits the strength of evidence provided by past research. The lack of evidence in the literature also is reflected in the barriers to appropriate coding policy and, therefore, clinical application of appropriate seating interventions.

3INHYUK MOON et al in 2005 said that an aerocell mattress consisting of eighteen air-cells. All these air-cells are made of porous material allowing air leakage which contributes in reducing temperature and humidity. The author also proposes an air-pressure control method of the air-cell mattress for reducing the localized external pressure. The pressure of each section of the body is independently calculated using an approximate anthropometric model, and the weight and the height of each body part.

4C. GONZALEZ et al in 2005 said about an experiment on designing a seat to evaluate the effects of random movement of its flexible base on the blood circulation of critical areas due to the application of pressure by the body. Studies related to this, states that if you remain seated for a long period of time in a wheelchair then you will be prone to the formation of pressure ulcers. The evaluation is based on a flexible seat made of neoprene affixed to a wooden box. This set forms a chamber to which air pressure is injected through inputs of different value. The air then enters through the chamber following a random pattern and generating movements on the neoprene seat.

2GUILLAUME DESROCHES et al in 2006 said about the effect of system tilt angle and seat to backrest angle changes on load sustained by shoulder during manual wheelchair propulsion. The shoulder load was estimated by joint movements. Thus, seat pressure angle can be determined with goals of user comfort and pressure modulation at the seat interface for alleviating pressure ulcer without increasing risk of overuse of shoulder injury. Wheelchair modifications include modification of wheel axle, varying backseat height, increasing hand rim diameter. One influential parameter includes distribution of mass with respect to the wheel axle. Studies show that lower and backward seat positions are more advantageous for user and reduce the risk of lower limb injury. Reducing upward force will diminish pressure on sub acromial structure but non optimal structure would lead to increase shoulder injury.

3K. VANDERWEE et al in 2006 said that repositioning patients lying on a pressure-reducing mattress alternately for 2 hours in a lateral position and 4 hours in a supine position reduces the incidence of pressure ulcers in comparison with repositioning every 4 hours. After performing the tests on around 16 patients it was concluded that more frequent repositioning on a pressure-reducing mattress does not necessarily lead to fewer pressure ulcer lesions and consequently cannot be considered as a more effective preventive measure.

4SANDRA LOERAKKER IN HER BOOK AETIOLOGY OF PRESSURE ULCERS in 2007 says that Pressure ulcers are localized areas of tissue necrosis that tend to develop when soft tissue is compressed between a bony prominence and an external surface for a prolonged period of time. The book also discusses about the classification systems, different stages of ulcers, risk assessment, mechanical loading and damaged pathways.

5MOHSEN MAKHSOUS in 2007 said about a system which can periodically relieve ischial sitting load to decrease the risk of pressure ulcers. It was investigated that the relieving effect on interface pressure of an alternate sitting protocol involving a sitting posture reduces ischial support. It was finally concluded that a sitting protocol periodically reducing the ischial support helps lower the sitting load over the buttocks, and generally the area close to ischial tuberosity.

2LEANDRO R. SOLIS et al in 2007 said about prevention of pressure induced deep tissue injury with the help of intermittent electrical stimulation. Pressure ulcers are associated with individuals of less mobility, which are the elderly, the infirm, and people suffering from the spinal cord injury. In conclusion, IES is a potentially effective means for reducing the incidence and recurrence of Deep Tissue Injury in immobilized individuals. Using the IES technology to be applied in wheelchair-bound individuals who are long-term care, community dwellers and acute care patients.

3M.A. F CARVLHO et al in 2008 said that People with serious motor limitations have a decreased sensitivity and increased capillary pressure which leads to pressure sores. Thus by investigating the impact of extrinsic factors that result into development of pressure ulcers and leads to discomfort in disabled and bed-ridden patients and by identifying critical pressure values at different anatomical positions along with assessing the impact of specially designed support surfaces so that the level of critical values can be monitored and controlled and a system can be designed which is intended to enable the inversion in the trend of the systems developed so far when critical limits are reached and thus automatically changing the positions where risk conditions have been identified.

4ABABOU. A et al in 2008 said that Piezo resistive tactile array represents an important tool for the analysis of pressure distribution. Each site of the matrix acts as variable resistance whose value varies with normal force. The piezo resistive material uses is a force Sensing resistor from interlink corp. It is said that the pressure and tolerance of tissue play an important role in development of pressure ulcers.

5J.G. ROCHA et al in 2008 explained about a system which aims to design a system that provides people in wheelchair a relief to the level of discomfort, thereby assuring greater independence, quality of life, welfare and the prevention of illnesses or wounds. This project is based on the design and development of textile and polymer applications (cushions, mattresses and mattresses overlays) with functions of pressure and humidity monitoring in the body’s areas contacting with the surfaces supporting the structure.

6KRAPFL et al in 2008 said that continuous prolonged exposure to pressure is the major factor for occurrence of a pressure ulcer and effective preventive interventions must avoid or minimize this exposure. Thus, repositioning of the patient frequently has long been recommended as a means of preventing Pressure ulcer. Limited evidence suggests that repositioning for every 4 hours, and this combined with an appropriate pressure redistribution surface, serves as an effective treatment for the prevention of facility-acquired Pressure Ulcers as a more frequent repositioning regimen.
Hence, there is insufficient evidence to determine whether a 30° lateral position is superior to a 90° lateral position or a semi-Fowler’s position.

7HAO CHEN et al in 2009 said about developing a lain-human finite element model for cushion design to prevent bedsores by performing biomechanical analysis of interface pressure and the human model was validated by comparison of the simulation data and the experimental result.

8KERSTI SAMUELSSON et al in 2009 said about how a shaped seat-cushion and two different back supports affect under-seat pressure, comfort, and pelvic rotation. Thirty healthy subjects were tested using two differently equipped manual wheelchairs.

9JOHN YANHAO CHEN et al in 2010 said about an alternating pressure air cushion to render ulcer prevention. It helps in dealing with sufficient rest for skin tissue in contact with user’s body pressure. The design consists of six cylindrical air bags and takes care of ergonomics of user. It consists of inflation and deflation system which adopts a microcontroller IC chip to drive the pump and four associated electromagnetic valves. The software control renders a full control of system parameters such as the time period, duration of inflation and deflation, air withholding duration to enable user to adjust and readjust according to user’s comfort level.

10YUXIANG YANG et al in 2010 says that despite the diversity of wheelchair cushions available, pressure on bony prominence still continues to be a major problem for patients using wheelchair, and the incidence of pressure ulcers remains high. With a novel air-alternating wheelchair seating system discussed in this paper pressure ulcers can thus be prevented. This system consists of 9 separate air chambers, an air pressure sensor and other peripheral control parts. Every chamber is designed in a way that it fits accordingly to the major weight bearing points of human buttock and can be inflated and deflated through respective valves with the help of microcontroller.

2.30 JAICHANDAR K.S AND EDGAR GARCIA in 2010 said about a with a low cost system for bed surface temperature and monitoring patient movement that can prevent bed sores. The system contains a bed surface implanted with temperature sensors and an air flow circuit which is made to pump air into the bed to the body so as to decrease the temperature. Depending on the temperature change the microcontroller selects the rate of air inside the mattress.

3 METHOD

3.1 Identification of sensors

The initial step in designing of the system was to find a suitable pressure sensor which can sense and can give voltage outputs as these voltages are to be read by the microcontroller and then accordingly it would start the actuation unit for the pressure shifting mechanism to initiate. Thus, finding a suitable sensor was a very crucial step. There are many kinds of sensors available like piezoelectric, piezo resistive, touch sensors, vibration sensors etc. but we needed a sensor which could give static results and not change with time and thus we eliminated the piezo resistive sensors which works well with dynamic measurements like shock. After a lot of research and reviewing certain literatures we finally selected our sensor to be FSR402 from Interlink Corp which is a force sensing resistor. Force Sensing Resistors(FSR) is made of thin film polymer device, it exhibits decrease in resistance with an increase in the force applied to the active surface. Its force sensitivity is optimized for devices which involves use of control related to human touch. FSRs are not suitable for precision measurements. Since our work is mainly qualitative FSR was the best suited option and Force accuracy range from approximately ±5% to ±25% depending on the consistency of the measurement and actuation system, the repeatability tolerance held in manufacturing, and the use of part calibration.

3.2 Positioning of sensors

The next step is proper position of the sensors and this is one of the most important step because it decides the way the pressure will be sensed and shifted which means the entire process of pressure shifting mechanism depends on this stage. If the pressure is not sensed properly then the MCU will not be able to read the voltages properly which might not start the actuation unit and the whole system might fail.

Thus in order to avoid any situation like that Sensors are to be placed properly. After reviewing the literature, we found out that the bony prominences are the most prone region to suffer from pressure accumulation. Pressure prone points are mainly ischial tuberosity, greater and lesser trochanter and sacrum and hence placing the sensors in these regions would give desired results. For our work we have not actually placed the sensors in these places because of the limitation of our work to be at a small level and not in real time but if it is done for real time these would be the places where pressure sensors would be placed. Also, since our work is restricted to only developing the electronic circuit and mechanical unit at small level we cannot do its testing in real domain and thus could not place these sensors on bony prominences but instead tried it with different weights.

3.3 Designing of microcontroller unit

The third and most important step in the whole system was to design the microcontroller circuit which will be making the whole system automated. The microcontroller circuit will not only read the corresponding voltages sensed by the pressure sensor but will also drive the whole circuitry. It will be checking if the pressure which in our case is voltage is going beyond the set threshold value and then accordingly signal the actuation unit to start its working of shifting the pressure.
The MCU is acting as a switch for the whole system and also for the two rings of inflation and deflation in actuation unit consisting of solenoidal valves.

3.3.1 Initial circuit design consisting of LEDs

Initially the circuit was designed using an 8051 microcontroller but it could not serve our purpose and thus we had to look for different microcontrollers. After reviewing and researching we found out PIC16F877a would be best suited for our work. Thus, we used PIC16F877a which is a Peripheral interface controller by microchip 8-bit 40 pin microcontroller. The pin description and the internal architecture was discussed previously in the chapter hardware and software used. During the initial stages we did not have proper sensor and therefore we used potentiometer as our sensing unit and LEDs as actuation unit and developed a logic which could turn on the LEDs according to the voltages being given by the potentiometer. All the components used are already discussed in the previous chapter. The logic goes as a pre-set threshold value of voltage has been fed to the microcontroller and as soon as that threshold is reached the system should start its work and once the pressure is settled it should become normal or stop its working. At the initial stages we made the LEDs glow which depicted the actuation unit as we did not have the actuation developed till that time and according to the voltage being read by the microcontroller given by the potentiometer that particular LEDs would glow which in the final system would depict the switching on and off of the actuation unit. The process would be more clear with the results shown at the next chapters.

3.3.2 Final microcontroller circuit

At the final stages one more set of 8 LEDs was employed to depict the inflation and deflation ring of the actuation unit. LCD was incorporated into the circuit for displaying the voltages accurately so that the system can be monitored properly. The sensor (FSR402) was interfaced with the microcontroller circuit in order to sense the pressure accurately and automatically. The whole system of MCU works with 5V supply which is being stepped down from 12V to 5V using IC LM7805. This 5V acts as an input for the microcontroller and at different stages of voltages from 0V to 5V different LEDs would glow according to the voltage being sensed by the pressure sensor which is in form of weights. We could not go beyond 5V as the PIC microcontroller we have used for our system would burn if voltages beyond that are given to it. The working of the electronic circuit can be explained as the pressure is being sensed by the sensor on putting weights over it and accordingly that corresponding voltages are displayed on LCD and the LED corresponding to that voltage glows in any of the two sets of LEDs which depicts inflation and deflation.

3.4 Designing of mechanical actuation unit

The aim is to design an automated pneumatic system in a bed or a wheelchair for the prevention of bed sores by sensing parameters like pressure. Pressure sores are usually seen to develop in various pressure points throughout the body and the system aims at reducing the pressure there. The pneumatic system developed inflates particular patches on the bed which are placed in accordance to the pressure points. These patches consist of outer and inner hexagonal ring capable of inflating and deflating. The outer and inner hexagonal rings of the patches are inflated and deflated alternatively such that the pressure is reduced at the point, thereby eliminating the possibility of pressure sores. So any change in undue pressure detected earlier and combined with automated pressure relieving mechanism will help to prevent the formation of pressure sore. The conventional method of treatment is by changing the position of the patients every 2 hours. Also an advanced medical system like the alpha-bed or the alternating-pressure air cushion is available in the market but it does not specifically tackle or prevent each bed sore from forming. The set up with its concentric hexagonal patches aims at preventing the formation of bed sores by controlling the pressure applied on the points. The cushion or bed will have an array of pressure sensors below a layer of concentric hexagonal patches that could be inflated and deflated. The pressure sensors are connected to a microcontroller which is interfaced with the pneumatic system. The system measures the pressure applied by the body on a particular point and if it goes beyond a threshold that is set, then the pneumatic system is switched on to deflate and inflate the concentric rings at that particular point thereby reducing the pressure. Designing such an automated system would provide a very comfortable and long lasting solution for preventing the formation of bed sores. The research in the development of this system is being done and we cannot furnish any results at this current point of time.

3.4.1 Design of cells

- **Square box design** - The initial design of the patches was made in square shape which were done so as to get maximum utility and efficiency in using these to reduce the pressure on the required points. The square shaped boxes were aligned as given in figure 5.3 so that upon deflating the inner boxes the required pressure decrease can be achieved on the skin which is contiguous with the patches.

- **Diamond design** - Next the patches were designed to be in a diamond shape so that the pressure points could be easily contained in the diamond and pressure reduction could be achieved and concentrated according to need. The design is shown in figure 5.4 But following this design there are too many blank spaces and efficient covering of the spaces could not be done. Also, these two designs were made according to the assumption that the patches would cover the entire surface of the bed.

- **Hexagonal design** - After further analysis of the previous designs of the patches it was noted that these patches were required to be on specific pressure points alone. There are 3 criteria’s which can help us decide on using a shape for designing the cells which are
  1. Geometric shape
  2. Area without overlap
  3. Area of the cell

The square, equilateral triangle and the hexagon satisfied the first two criteria’s and the third criteria was topped by the circle which has the most area but since it cannot fill an area without overlapping we had to decide between the other shapes and comparing the areas of each of the shapes to circle, the hexagon shape comes on top with 83%, which means hexagon has the highest coverage area after a circle from the lot and hence we continued to design the patch in hexagonal shape as given in figure 5.5.
Simulating the structures in Solid works lead to the following images, which clearly shows how the inner ring, deflates inwards and the outer ring, expands out.

The design of the pneumatic circuit was done in Automation Studio software. The bellows provided by the software was used in the simulation in place of the inflatable balloons. Initial stage of development consisted of a circuit with a 3/2 way normally closed solenoid valve and a check valve directly from the compressor to the circuit. The pneumatic system was to be designed in such a way that would allow the inflation and deflation of both the outer ring of the hexagonal cell and also the inner ring, hence it was clear that control valves were required for realising this function. The circuit consists of a compressor giving pressure in 1 bar pressure, 3/2 normally closed solenoid valve and check valves connected to both the inner and outer ring of the circle which is connected to the exhaust. The controls of the cells were initially made to use a 3/2 normally closed solenoid valve and also a check valve controlling the initial pump. So, when the microcontroller needs to reduce the pressure below the threshold level it initially opens the check valve controlling the inner ring using a 5V input thereby deflating the inner circle for a first level of deflation.

The simulation lead to the understanding that further changes had to be made in the circuit. The current circuit had 3 check valves that was to be worked manually and only one solenoid valve. To make the system automated, we realised that all of the valves has to be electrically controlled and that’s when we came up with a new pneumatic circuit which uses 4 solenoid valves. The second phase of designing the circuit led to the creation of the following circuit. The system was to be designed in such a way that would allow the automated inflation and deflation of both the outer ring and the inner ring, hence it was clear that electrically controlled valves had to replace all the check valves also. The pneumatic system was to be designed in such a way that it could be interfaced with a pressure sensor though a microcontroller and hence make the system automated. The pressure sensor which is placed below the concentric hexagonal patches will measure the pressure exerted by the body on it. Since the primary aim is to control the amount of pressure being exerted on the body, the pressure sensor sends its value to a microcontroller. The microcontroller is fed a certain level of threshold or limit, and if the sensor sends a value above it, the microcontroller has to work with the pneumatic system to control it.

The circuit consists of a compressor giving pressure in 1 bar pressure, 2 pairs 2/2 normally closed solenoid valve is connected to both the inner and outer ring of the circle which is connected to the exhaust. The controls of the cells were initially made to be as given in figure 3.9 which uses a 2/2 normally closed solenoid valve and also a check valve controlling the initial pump. So, when the microcontroller needs to reduce the pressure below the threshold level it initially opens the solenoid valve 4 controlling the inner ring using a 5V input thereby deflating the inner circle for a first level of deflation. Now, the microcontroller checks with the pressure sensor and if further reduction in pressure is required a 5V input from the microcontroller will activate the solenoid valve 1 opening it to let the compressor inflate the outer cell of the hexagonal cell for the first level of inflation. This would cause the point of contact in the centre of the ring to experience a reduction in pressure. If the pressure still above the required threshold further deflation is carried out by opening solenoid valve 3 again, and if the pressure is still above the threshold solenoid 1 is opened for further inflation ring present in outer circle. It leads to a further depression for the body which is vulnerable to the pressure ulcer thereby reducing the pressure there. Now, to increase the pressure a bit, solenoid valve 2 is opened which acts as an exhaust letting the air out of the inflated outer tube thereby balancing the pressure difference between the two rings. Similarly, for further inflation of the inner ring, solenoid valve 3 is opened and the compressed air at 1 bar pressure fills the balloons bringing it back to the 1st level of deflation and further inflation and deflation can be got by the same logic.

3.4.2 Design of the driver system

The driver system was designed so as to couple the microcontroller unit and the pneumatic system. This was done so as to compromise on the use of different voltages by both the systems. Since the solenoid valve uses 24volts and the input given by the microcontroller unit is 5volts we require a driver circuit to the two systems. The driver circuit was designed in Proteus 8.0 since it could be simulated after being designed. The circuit consists of an IC ULN2003, which is uses 12 volts to activate 4 relays which can individually activate the 4 solenoid valves. Here, initially when a 5-volt input from the microcontroller unit is given to any of the 4 inputs of the driver circuit, the IC is activated. The IC is powered by a 12V supply and it consists of arrays of Darlington circuits which are cascaded transistors that help to drive a 12-volt supply. Now depending on the pin to which the 5V was given, the IC drives a 12V input to one of the 4 respective relays. The relay when activated switches on the coil and lets open the 24volt connection supply to the solenoid valve. When the solenoid valve is open, depending on its placement either inflation or deflation of the rings occurs. Through this system, both the microcontroller and the pneumatic circuits can be interfaced and worked. After simulating the circuit and finding it successful the driver circuit was made into a PCB and the respective relays and the ULN2003 ICU was connected and soldered into the PCB. The driver circuit is an integral part of the whole system without which the inputs from the microcontroller circuit cannot be relayed to make the solenoid valve work.

3.5 Interfacing of MCU with actuation unit

This is the second last stage which integrates two separate units together and thus completes the whole system of automated pressure shifting mechanism. The microcontroller circuit and the actuation unit consisting of 2 by 2 NC (normally closed) Solenoid valves are interfaced together and the whole system was then tested and validated. The MCU acts as a switch for the whole system as soon as the sensor senses the pressure beyond the threshold value and then accordingly the microcontroller unit switches on the relays which works at 12V of the actuation unit which in turn on the solenoid valves which are normally closed and start the inflation and deflation process. The microcontroller checks with the pressure sensor and if further reduction in pressure is required a 5V input from the microcontroller will activate the solenoid valve opening it to let the compressor inflate the
outer cell of the hexagonal cell for the first level of inflation. This would cause the point of contact in the centre of the ring to experience a reduction in pressure. If the pressure is still above the required threshold further deflation and inflation is carried out similar to the way it was previously done. The whole system would be made more clear with the help of results on later stages.

3.6 Testing and validation
This is the final step of the whole process which involves getting the expected results and outputs from the system and to check whether the system is working properly or not. It is an important stage in the development of any system because the whole efficient working depends on its results and outputs. In order to check the proper working of our system we made use of balloons to show inflation and deflation mechanism along with the LEDs flowing for checking the actuation unit and used different weights for checking the sensor and the microcontroller unit. On sensing pressure from different weights being kept on the sensor, corresponding voltages were read by the microcontroller and if it is beyond the threshold the actuation unit was turned on through switching on of the relays and these relays will open or close the valves and as a result inflation and deflation of balloons would occur which in real time corresponds to movement of actuators in order to distribute the pressure by changing the position and thus preventing ulcer formation by shifting the pressure accumulated over a region and distribute equally. The final results and outputs discussed in the next chapter explains the testing and validation process along with the entire process properly.

4 RESULTS AND DISCUSSIONS
4.1 Circuit with potentiometer as sensing system and LED as actuating system
Microcontroller PIC16F877A with potentiometer as sensing system and LED as actuating system showing voltage division across each LED with change in potentiometer threshold value across each of them leading them to glow according to the code written in Embedded C as programming language. Two different sets of 8 LEDs were used to depict an inflating and deflating system. In the circuit incoming 5 V from the main power supply was distributed among eight LEDs. When the potentiometer is rotated, each swipe of the rotator gives input to the microcontroller which according to the written program code glows the particular LED depicting inflation and deflation mechanism, which will be incorporated in our second circuit

The circuit is interfaced with sensor FSR402 and different weights are kept on it to know respective corresponding voltage value related to each weight. Knowledge of voltage values corresponding to different weights help in giving input in actuating system for pressure distribution with inflation and deflation mechanism.

6.3 Microcontroller PIC16F877A interfaced with actuation system
PIC16F877A with sensor FSR402 is interfaced with actuation system which consists of relay system, balloon and solenoid valve unit according to the code. When the weight is put on sensor its corresponding voltage is given as input to microcontroller. If the weight is greater than 23gm which is equivalent to 20 mmHg pressure, which causes occlusion in capillary causing pressure ulcer, the deflation and inflation mechanism will start to distribute pressure uniformly. The microcontroller will give input signal to relay as ‘ON’ which in turn will open the solenoid valve leading air to rush in from compressor helping in INFLATION. The microcontroller then will check if pressure is uniformly distributed. If not, it will go for second stage which is DEFLATION and will give signal to relay as ‘OFF’. It leads to closing of valve of actuation system and deflation takes place. Thus the inflation and deflation of balloon shows the actuation system will work according to the written programme code and will check for uniform pressure distribution in the cushion. It will help in relieving pressure from vulnerable regions thus preventing pressure ulcer.

CONCLUSION
The aim of this project is to make a microcontroller based pressure shifting mechanism consisting of actuating system in order to prevent pressure ulcers. The actuating system consisting of relay and solenoid valve helps in uniform pressure distribution inside the cushion with the help of microcontroller programme code. It can be concluded that with the help of this mechanism occurrence of pressure ulcer can be prevented in initial stages helping patients and medical authority. The microcontroller will identify the pressure with help of sensor and will give input signal to the actuating system accordingly as inflation and deflation process required. It will help in relieving excess pressure from the pressure vulnerable regions. This mechanism helps in automated pressure shifting while patient is on this cushion and don’t involve regular assistance of medical staff. This cushion system can also be used in various other places like in wheelchair, bed cushion of hospital, seat system of aircraft and car. The array of sensors and pneumatic system can be made and fabricated It can be placed in pressure vulnerable regions with actuator system in future. The prototype design and fabrication on large scale can be carried for betterment of society.

ACKNOWLEDGEMENT
The authors sincerely thank and appreciate the anonymous reviewers for their kind comments.

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<td>4.37</td>
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<td>8</td>
<td>5.00</td>
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</table>


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