A Survey on Bridge Health Monitoring Systems

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Abstract - *Internet of Things has always taken up a step forward towards providing solutions with great ease. One such system in which the Internet of Things is emerging as a good solution to some extent is the bridge health monitoring (BHM).Bridges are such Clementine materials which are day-night exposed to extreme climatic conditions causing their wear and tear in various aspects. These factors can be: cracks on the bridge surface, overload on the bridge, flood conditions near the bridges etc.This BHM system would use various sensors (water level sensor, IR sensor, etc.) to collect the data, an algorithm (Rapid screening algorithm, image processing) or technique can be used to solve the cracks detection problem in tough or hard to reach areas of bridge. The data can be analyzed and computed to check whether the bridge has any cracks, or has any flood like conditions near it. If at all there is something wrong with the bridge condition regarding the large number of cracks or rising water level, an alert message can be sent to the concerned person. The result of this system would be used to analyze the real time health of the bridge and to take necessary actions towards safety if there is any negative output.*

***Keywords*: Crack detection, Water level detection, Sensors, Bridge health monitoring, etc.**

1. INTRODUCTION

Bridges are our everyday means of traveling for everyone. These bridges are present in various surrounding conditions which can be extreme as well as some slow harm causing factors. The extreme conditions causing harm or degrading the bridges condition can be flooding of water waves, scorching heat, earthquake frequencies, etc. Similarly, the low harm causing factors can be highly loaded vehicles passing more often on through the bridge, Surplus usage of bridge, ignorance of timely maintenance of bridge, etc.

We can see that some bridges in our surrounding are old and safe to use conditions, while there are also some bridges which are newly built but still unsafe due to some ignored factors. This is because the health of any bridge depends on the elements and conditions considered while constructing these bridge. Every bridge has some places where a human inspector can't reach because these places are out of human reach. There needs a monitoring system which can keep an eye or track of the health at such places of bridge.

IoT system for bridge health monitoring can be a way through which the bridges can be looked after without any human intervention. An IoT system consisting of various hardware and software components along with some cloud storage system can be used over the bridge surface for this particular problem. The module built can be used to collect various kinds of data regarding the structure (in this case 'bridge'). This collected data can be analyzed and if at all the system catch holds of any anomalies, then the concerned authorities would receive the alert notification.

This kind of system would reduce many human errors caused during inspection of bridges. An early stage of damage may reduce its maintenance cost and time to be spent on it. The notification sent by the system can result in taking necessary actions towards safety measures. The system would be used for monitoring the bridges remotely without any human interference. The real-time data collected by the system would result in early and effective outcomes for avoiding future harm to many lives.

2. LITERATURE SURVEY

2.1. A case study of integrating IoT technology in Bridge Health Monitoring [1]

The paper consisted of a system consisting of four modules working in coordination and two technologies used sensor technology and fiber grating technology. The system has sub processes like demodulation, data processing, data storage and identification, safety and alert messages.

2.1.1. Algorithm

The bridge Health Monitoring system proposed [1] was an integration of following modules.

1. Sensor Module: Composed of fiber optic sensor and sensor network which was responsible for sensing and collecting the data.

2. Data collection and process module: This module had sub steps like demodulation, data processing. These processes were performed in the collected data from the sensor module.

3. Data management module: This is one of the crucial parts of the system when it comes to storing and managing the collected data and retrieve again when needed. This module was also responsible for reporting the results.

4. State evaluation module: Evaluation module had tasks like data identification, safety assessment, and notification of the updates.

All the above-mentioned modules worked in (bidirectional) coordination which made the system work with nice efficiency and good results. The integrated module had a promising direction towards the detection of anomalies and all other objective, but the complexity of the system held it back from its effective application on-site. Considering the complexity of the architecture of this module, there was lack of support and trust towards the results and outputs.

2.1.2. Advantages and Disadvantages

Advantage: The system gave accuracy, timeliness and accessible outcomes over the conventional approach of use of sensors.

Disadvantages: In spite of having the key features satisfied, the system had fewer applications due to the complexity of modules which in future might result in degradation of the outcomes.

2.2. Bridge Safety Monitoring System using IOT [2]

In the system, the IOT wireless sensor network and smart building technologies are adopted to solve the various problems of bridge safety information transmission and management. The Monitoring devices like water level vibration sensor and weight sensor are continuously monitoring the structural health of bridge. The data Share between bridge and monitoring Centre is takes place via WI-FI module [2]. Through WI-FI module the status or condition of bridge is transmitted to the monitoring centre with the help of TCP/IP protocol.

2.2.1. Algorithm

1. Initialize vibration sensor, weight sensor, and ultrasonic sensor.
2. Ultrasonic sensor senses the water level, weight sensor detect the load of the bridge.
3. The data sensed by the sensors is send to server. If the values are above the set values notification is send to the management center.
4. The status of bridge can be continuously monitored using app.

2.2.2. Advantages

The system helps to monitor and maintain the condition of the bridges in the water bodies and to prevent the public on the bridge at the emergency situations.

2.3. Design and Implementation of Real time monitoring of bridge using Wireless technology [3]

The proposed design [3] was targeted about continuous monitoring of bridges using wireless IOT technology. The design consists of sensors which are interfaced with communication devices. The sensors collect the data from the bridge and stores in the database. The processors were used to analyze the data. The data collected from sensors are compared with the thresholds. If it crosses above the threshold then warning/alert message is sent to the server using wifi module to take actions or repair the bridge. The user can also access the status of the bridge using mobile application.

2.3.1. Algorithm

1. Initialize all the sensors
2. Collects the data of the bridge through sensors
3. Data compared with the threshold values set for bridge
4. If condition is critical, a buzzer turns on
5. Data is sent to the cloud/server
6. Alert messages are received by the server and take decisions
7. The user can access the status of the bridge using the application on mobile.

- Flex sensor: The threshold is set as 1. If the load sensor reads equal to or more than 1 then the website shows that the bridge is overweight.
- Vibration sensor: The threshold set is 165k ohm. If the bridge bends equal or more than 165 k ohm, then it shows that bridge is over bent.
- Water sensor: The threshold for the water level sensor is 20. If the level ofwater is equal or above 20 then the host shows the result as over water level.

2.3.2 Advantages

The traffic can routed to avoid major damage to the property.

The bridge damage can be detected very early. So that quick action can be taken on that situation.

2.4.Data mining algorithms for bridge health monitoring: Kohonen clustering and LSTM prediction approaches [4]

In bridge health monitoring system, as we are using different components for the system design like flex sensor, load sensor, water level sensor, arduino, GSM module, etc. The sensors are the primary and front source which collects data from surrounding. However how to effectively use these data to analyze the state of a bridge and provide the early warning about the bridge structure is an important topic in this research paper. So this research paper utilizes two data mining algorithm namely Kohonen neural network and long short-term memory (LSTM) neural network.

The Kohonen clustering method is shown to be effective for getting classification pattern in normal operating condition and is straightforward for outlier's detection. The LSTM prediction method has an excellent prediction capability which can be used to predict the future deflection values with good accuracy and mean square error, or LSTM can predict the value of a specific bridge's parameter.

2.4.1. Algorithm

1. Collecting data from different sensors, filling the missing data from range of data values and also analyzing cause of abnormal data with help of historical data and finally standardizing it.
2. Giving this processed data as input to the algorithm. Then algorithm will help to structure that data in specific form.
3. From previous structured data which collected from algorithms, monitoring new data which continuously collecting from sensors as input and giving alert if there is any outlier values.

Kohenen Neural Network:

The Kohonen network is used for self-organizing maps. This network divides the data into different categories where categories depend on type of dataset. The Kohonen network is shown in Fig-1. It includes input layer and competition layer. The training steps of network are as follows: [4]

1. Initialize neural network weights *Wij* (*I*= 1, 2,… *m*, *m* is the total number of input nodes, *j* = 1, 2,…, *n, n* is the total of number output nodes.)
2. Randomly select an input.
3. Selecting winning neuron using Euclidean distance.
4. Updates the neuron weight.
5. Repeat step 2 until training set is done.

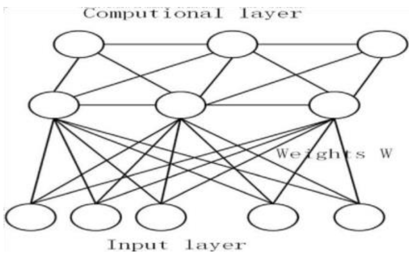


Fig-1

Long short- term memory neural network:

The LSTM neural networks are used to deal with time series problem for bridge health monitoring.

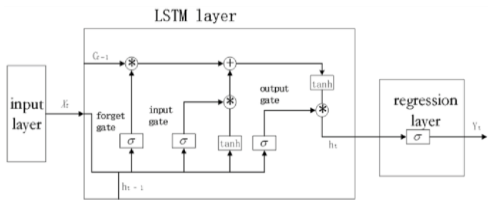


Fig- 2

The LSTM network is one of the recurrent neural networks (RNN) [4]. RNN is a feed forward network with feedback loops and internal memories. They store sequences in their internal memory for a protractor time, which is useful for creating accurate decision of the subsequent step compared with the standard feed forward networks. In this paper, the LSTM framework proposed in as is illustrated in given fig- 2,

In this way, application of those two algorithm i.e. Kohenen neural network and LSTM neural network is given which states changing trend of bridge structure by comparing predicted value with limit value under normal operation. This is initial stage theoretical work of system is given in this research paper.

2.5. IoT Based Bridge Health Smart Monitoring System [5]

This research paper gives the studied information about the implementation of bridge health monitoring system, means which components can be used or how the process will carried out is given.

In bridge health monitoring system, due to environmental effects like excess heat, flood, earthquake etc., bridge structure can damage. So, to overcome such incident, it have data-acquisition systems are used in structural projects ranging from simple beam fatigue analysis, to structural mechanics research, to continuous monitoring of large, complex structures[5]. This system provides remote, unaltered, portable way to monitor the bridges.

2.5.1. Working

1. The entire system consists of an Arduino Nano which controls the interface between the different components of the system. The board is connected to the Opto- Coupler, and angle sensor we are using accelerometer and for crack detection we are using wire mesh.
2. When the sensors sense some harm or detect values above the threshold value, it sends signals to the Arduino Board through opto-coupler.
3. The program installed in the Arduino will start to execute and according to the flow of the program it will send the signals to the respective components.
4. Arduino Board sends warning signal to the motor driver. The motor driver has been attached to a boom barrier which blocks the vehicles from moving ahead to prevent accidents from happening.
5. The real time value fetched by sensors is send to the server and android through the Wi-Fi modem to the cloud. Analyst will study that data, if there are any extreme values observed, it will give information about bridge structure.

2.5.2. Advantages and Disadvantages

Advantages: Useful to avoid accident and the status of the bridge is displayed on LCD. Disadvantages: This system is implemented on high cost.

2.6. The Detection and Recognition of Bridges Cracks Based on Deep Belief Network [6]

The paper proposed a system for detection of cracks, its length and severity using the deep belief network and support vector machine. The system has sub processes like gray processing, image enhancement, image de-noising, etc.

2.6.1. Algorithm

1. Support Vector Machine (SVM)

SVM was used for detection of cracks on the bridge surface. SVM takes in consideration both the aspects of the cases, compares the given test set with the existing case parameters and accordingly decides whether the surface has cracks or not.

2. Deep Belief Network (DBN)

Deep Belief Network is used for analysis and processing of the data. It is nothing but number of unlabeled Restricted Boltzmann Machine and a labeled Back propagation in order to predict the output based on the training set results.

3. Boltzmann Machine (RBM)

RBM is a two layered network of which one is the visible layers and the other having latent variables. These two layers of RBM are connected to each other by undirected symmetric connections.

The input had 3 types of configurations (transverse cracks, longitudinal cracks, network cracks). The input dataset consisting of 500 images (for each configuration) was provided of which 400 images were used for training and rest 100 for testing [6]. And below are the results found:

Table -1:Results

Configuration	Transverse crack	Longitudinal cracks	Network cracks
Total amplitude	100	105	100
Correct classification	94	93	93
Correct rate	94%	93%	93%

2.6.2. Advantages and Disadvantages

Advantages: The system gave automatic classifications of bridges cracks and types of fractures according to the needs.

Disadvantages: For accurate detection, large data set of images was the main need which in turn requires large storage and then the process becomes time consuming.

2.7. A continuous Water Level Sensor Based on Load cell and Floating Pipe [7]

In this proposed system a new water level sensor with a load cell and an enclosing floating pipe is used to monitor the water level. When the water touches the floating body, the buoyancy force works on the floating body and vertically pushes the load cell. In addition, the buoyant force [7] is directly proportional to the water density and the distance between the water level and the bottom of the enclosing floating pipe. Therefore, the water level can be determined by measuring the buoyant force with the load cell. The user interface operation includes the environment temperature and current water level and set the alarm level of water. When the water level reaches 30 cm, the user can immediately monitor the remote water level to determine whether it has reached the warning level.

1. Calibration of load cell

The calibration curve was obtained by plotting the load cell signal against the known standard weights (OIML Class F2) of 1-100 g. When the data obtained were linearly fitted, the resulting equation is y = 0.187x 0.043 for the calibration, where y is the load cell signals in V, and x is the applied weighting.

2. Measurements of the water level for different equipment

There is slow slope and every stage through the gate control to see the water

When the water level reaches 30 cm, the user can immediately monitor the remote water level to determine whether it has reached the warning level.

2.7.1. Advantages and Disadvantages

Advantages: The result of the preliminary study show the feasibility of the method changes in the water level of 1mm, which can be easily grasped and used to immediately control the water level.

Disadvantages: The cell calibration is susceptible to change in environment temperature.

2.8. A Rapid Screening Algorithm Using a Quadrotor for Crack Detection on Bridges [8]

The system proposed in this paper use IOT module consisting of arduino, few sensors, battery and a quad rotor. This module also has GPS and a camera tracking the location and capturing the images. It communicates via wifi to an android device running the rapid screening algorithm for crack detection. The rapid screening algorithm consists of three systems, namely: (1) Vertical scanning flight, (2) Obstacle avoidance and (3) Crack detection.

2.8.1. Algorithm

(1) Vertical scanning flight

1. Set initial position of multirotor.
2. Initiate the semi autonomous scan mode.

3. The pictures are taken and transmit to the android device.
4. User initiates the stop command.
    a) The semi autonomous scan mode stops.
    b) If not, then the obstacle is detected above the multirotor.
    c) Again, the pictures are taken and transmitted to android device.

(2) Obstacle avoidance

1. Initiate the semi autonomous scan mode.
2. Performs the crack detection algorithm on accumulated images.

(3) Crack detection

1. Original images are converted into gray level and subjected to a median filter, converted to binary level.
2. Performs masking on binary images.
3. Performs curve fit to get the result to the best threshold values based from the captured images.

A dataset of 52 images [8] was used for crack detection algorithm and resulted 92.20% of average success rate. After the training of algorithm it was implemented on new dataset of 23 images captured and resulted 95.65% precision and a recall of 83.33%.

2.8.2. Advantage and Disadvantages

Advantages: Local dark regions of an image of cracks are also located.

Disadvantage: Not every image has the same file size so the delays vary with respect to its size.

3. HARDWARE COMPONENTS

3.1. Load sensor

Load sensor converts [22] load into an electrical signal. The signal output can be voltage or current depending on amplifier circuit used. The load sensor measures the loads of the vehicles that are crossing the bridge. This sensor is attached at the bottom of the bridge to measure the load of the vehicle.

3.2. Raspberry pi 3

This module allows the users to build computer programs [21] which are complex.

3.3. Vibration sensor

Vibration sensor has a piezo sensor, a filter, capacitor and a bridge rectifier [23]. It generates an output voltage which is proportional to the applied pressure. When a natural calamity like earthquake occurs then vibrations are detected by the sensor which generates an output voltage proportional to the vibrations sensed. There is a limit for the bridge vibration, if goes beyond then the chances are that bridge may fall. This sensor is attached to the main column of the bridges.

3.4. Water level sensor

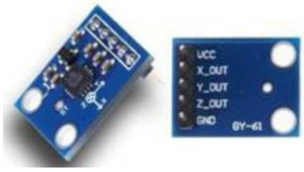
Water level sensor detects the water level. It is used in sensing the amount of rainfall, liquid leakage and water level [24]. The water level sensor is placed below the bridge. If the bridge is covered with water, then the water level tells the level of water that the bridge is held with. This sensor is fixed at the bottom of the bridge and the top of the bridge.

3.5. Flex / Tilt sensor

Flex sensor [25] measures the tilt in several axes with respect to the reference plane. An electrical signal is produced proportional to the angular movement. It has three pins of power supply, the output of flex/tilt sensor and ground. The tilt sensor sends the data of the amount of bending of the bridge. The sensor data if crosses threshold then there are chances of falling of bridge. This sensor is fixed at the side of the bridge.

3.6. Acceleration sensor

An acceleration sensor is also called as accelerometer. An acceleration sensor measures the motion of the object. Acceleration includes acceleration caused by the movement of objects and acceleration caused by gravity.



3.7. Servo motor

Servo meter is used for closing the gates of the bridge. The Servo meter is used for accurate linear positioning of structure. It uses Pulse Width Modulation (PWM) as a control signal.

3.8. Optical fiber grating sensor

Optical fiber grating sensor measures the parameter by detecting wavelength changes of light signal reflected by each grating.

4. CONCLUSION

This paper reviews the techniques to detect the damage for bridge structures. Structural Health Monitoring in the field of Bridge Engineering is still at a developing stage. New sensing technologies and methodologies for analysis of the data gathered are constantly being introduced. Most of the advances originate in fields other than Bridge Engineering. Bridges are expensive and critical part of infrastructure. So, they are built with high safety factors. But still, the failure of a bridge can take long time to develop. Most of the SHM strategies are only validated in laboratory experiments, and only a few are deployed and implemented as long term monitoring. There are a number of onsite problem to be solved while implementing a system on a real bridge. Although real practical applications in damage detection are far from being able to replace the traditional inspection based maintenance plans. By structural health monitoring, it has been a great help.

5. REFERENCES

[1] Zu and Xingyu Xu Qiaohong, “A Case Study of Integrating IoT Technology in Bridge Health Monitoring”, School of Logistics Engineering, Wuhan University of Technology Wuhan, Hubei, China (2020).

[2] B Dhanalakshmi, A Prakadeesh, R Roshan Kumar, “Bridge Safety Monitoring System using IOT”, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-9 Issue-6, (April 2020).

[3] Mr. Pradeep kumara V H, Dr.Shubhangi D C, “Design and Implementation of Real time monitoring of bridge using Wireless technology”, Proceedings of the Second International Conference on Inventive Research in Computing Applications (ICIRCA-2020).

[4] Aiping Guo, Ajuan Jiang1, Jie Lin, Xiaoxiao Li, “Data mining algorithms for bridge health monitoring: Kohonen clustering and LSTM prediction”, the Journal of Supercomputing (2020).

[5] Akshata Dhuri, Snehal Kadam, Pratiksha Jogale, Latika Kawade, “IoT Based Bridge Health Smart Monitoring System”, International Journal of Engineering Research & Technology (IJERT) (2020).

[6] Wang Xuejun, Zhang Yan, “The Detection and Recognition of Bridges’Cracks Based on Deep Belief Network”, Department of Computer Science and Technology, Shijiazhuang Tiedao UniversityShijiazhuang, China, IEEE International Conference on Computational Science and Engineering (CSE) and IEEE International Conference on Embedded and Ubiquitous Computing (EUC) (2017).

[7] Sheng-Wei Wang; Chen-Chia Chen, Chieh-Ming Wu, Chun-Ming Huang, “A Continuous Water-Level Sensor Based on Load Cell and Floating Pipe”, Conference: 2018 IEEE International Conference on Applied System Innovation (ICASI), National Chip Implementation Center 7F, No. 26, Prosperity Rd. I, Science Park Hsinchu City, Taiwan (2018).

[8] Bridges Elmer R. Magsino, John Robert B. Chua, Lawrence S. Chua, Carlo M. de Guzman and JanVincent L. Gepaya, “A Rapid Screening Algorithm Using a Quadrotor for Crack Detection on Bridges”, Electronics and Communications Engineering Department De La Salle University-Manila, Philippines (2016).

[9] System Charushila D. Bhadane1, Sonali K. Borade1, Priti M. Borse1, Prof. R. S. Pagar2, Prof. D. Y. Thorat3, “IOT based Bridge Safety Monitoring”,ISSN : 2456-3307.

[10] Survey Victoria J. Hodge, Simon O’Keefe, Michael Weeks, and Anthony Moulds, “Wireless Sensor Networks for Condition Monitoring in the Railway Industry: A Survey”,(IEEE).

[11] V.Kavitha, J.V.Aishwarya , A.S.Aisshwaryapriya, M.Harini Associate Professor, “Development of an IoT-Based Bridge Safety Monitoring System”, Department of CSE, Sri Sairam Engineering College, Chennai(IJERCSE).

[12] LIYAN ZHANG, GUANCHEN ZHOU, YANG HAN , HONGLEI LIN, AND YUYING WU, “ Application of Internet of Things Technology and Convolutional Neural Network Model in Bridge Crack Detection “, Laboratory of Engineering Computing, North China University of Science and Technology, Tangshan, China (hanyang@ncst.edu.cn).

[13] Prof.N.W.Dangare1 , Ghadge Sonali2 , Khandge Tejas3 , Pathare Nisha4 , Patil Laxman5, “Survey on IOT Based Bridge Monitoring System”, Dept. of Computer Engg, keystone School of Engg, Savitribai Phule University, Pune, India(Website: www.ijircce.com).

[14] J.J. McCullagh , T. Galchev, R.L. Peterson, R. Gordenker, Y. Zhang, J. Lynch, K. Najafi, “Long-term testing of a vibration harvesting system for the structural health monitoring of bridges”, Department of Electrical Engineering, Center for Wireless Integrated MicroSensing and Systems (WIMS2), University of Michigan, EECS Building, 1301 Beal Ave., Ann Arbor, MI 48109-2122, USA.

[15] Jin-Lian Lee2 , Yaw-Yauan Tyan3 , Ming-Hui Wen1 , Yun-Wu Wu2, “Development of an IoT-based Bridge Safety Monitoring System”, Department of Commercial Design and Management, National Taipei University of Business, Taiwan Department of Architectural Design, China University of Technology, Taiwan Department of Civil Engineering and Hazard Mitigation Design, China University of Technology, Taiwan

[16] Yu Yan,1,2 Xingquan Mao,3 Xu Wang , 1 Xianfeng Yu , 4 and Lei Fang 2 1, “Design and Implementation of a Structural Health Monitoring System for a Large Sea-Crossing Project with Bridges and Tunnel”, School of Civil Engineering, Chongqing Jiaotong University, Chongqing, China; Hong Kong–Zhuhai– Macao Bridge Authority, Zhuhai, Guangdong, China; Highway Consultants Co., Ltd., Beijing, China; School of Civil Engineering & Transportation, South China University of Technology, Guangzhou, Guangdong, China.

[17] Snehal Sonawane, Nikita Bhadane, Sayali Zope, Ashitosh Pangavhane and V. S. Tidake, “ Design of Bridge Monitoring System based on IoT”, Department of Computer Engineering, NDMVPS’s KBTCOE, Savitribai Phule Pune University, Pune.

[18] Luis Daniel Otero , Senior Member, IEEE, Mark Moyou , Adrian Peter , and Carlos E. Otero, Senior Member, “Towards a Remote Sensing System for Railroad Bridge Inspections: A Concrete Crack Detection Component”, IEEE Department of Engineering Systems, Florida Institute of Technology, Melbourne, FL, USA; Department of Electrical and Computer Engineering, Florida Institute of Technology, Melbourne, FL, USA.

[19] Prateek Prasanna, Kristin J. Dana, Nenad Gucunski, Basily B. Basily, Hung M. La, Member, IEEE,Ronny Salim Lim, and Hooman Parvardeh, ““Automated Crack Detection on Concrete Bridges”,IEEE.

[20] Snehal Sonawane, Nikita Bhadane, Sayali Zope, Ashitosh Pangavhane and V. S. Tidake, “Design of Bridge Monitoring System based on IoT”, Department of Computer Engineering, NDMVPS’s KBTCOE, Savitribai Phule Pune University, Pune.

[21] https://maker.pro/raspberrypi/tutorial/an-intro-to-raspberry-pi-and-itsfundamentals.

[22]https://circuitdigest.com/microcontrollerprojects/raspberry-pi-weight-sensing-automatic-gate.

[23] https://www.instructables.com/id/Vibration-SensorSW-420-Raspberry-Pi/.

[24] https://www.hackster.io/shafin-kothia/water-levelmonitor-with-raspberry-pi-d509a2.

[25]https://circuitdigest.com/microcontrollerprojects/raspberry-pi-flex-sensor.