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Conceptual FOG Based Architecture for Monitoring and Acceleration of Bone Fracture

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ABSTRACT---In the backdrop of an emerging scenario marked by a predominantly older populace, burgeoning costs of living amidst depleting resources, Cloud computing and IoT offer a ray of hope, particularly while developing e-Health system, with patient at the core of the healthcare pyramid. Telemedicine is a novel application that offers healthcare services such as diagnosis, consultation as well as treatment that reaches the most efficient levels with introduction of smart healthcare solutions. Nonetheless, IoT-driven healthcare requires to conquer multiple hurdles like complexities in data storage on cloud servers, security and privacy aspects, prohibitively high expenses incurred on perpetual data accumulation, other than energy-efficiency challenges and maintenance of sensors based out of cloud servers. In this paper, the primary focus is on devising a novel construct around the concept, Fog computing, particularly from the point of view of Tele medical IoT. As is commonly understood, Fog computing as a prototype allows cloud computing services to reach the periphery of a network. In a manner identical to cloud, Fog enables end users to receive data, computation, storage, and application services. As a case study, in this paper, an attempt has been made to develop a service-oriented architecture that monitors and accelerates healing in cases of bone fracture applying fog computing. In fact, , this architecture applies a sensing module on an energy-efficient embedded computer to perform data mining and data analytics operation on raw data that is sourced from sensing modules utilized in such telehealth operations. This embedded computer system assembles such sensed data in a time series before analyzing and discovering the identical patterns, which later stores, extracts novel patterns as well as transmits clinically-suitable data via network to the cloud based in a hospital.

Index Terms —Cloud Computing, Fog Computing, IoT, Telemedicine

I. INTRODUCTION

In contemporary times, we have witnessed revolutionary improvements in connecting people and businesses with the help of a wide network of wireless sensor networks, healthcare services, smart phones as well as multiple types of pervasive real-time monitoring systems. The introduction of Internet of Things (IoT) [1] connected people, devices and Services in a real-time and seamless way, creating great services and values for millions of people around the world. This pervasiveness has resulted in generation of huge volumes of data at lightning pace. But, IoT-driven healthcare still is plagued by certain hurdles as enumerated below. Firstly, with a growing requirement to store large amounts of data on cloud servers, it is difficult to analyze highly complex healthcare data 2) The transmitted data becomes prone to security and privacy problems; 3) the seamless and perpetual transmission of accumulated data offers no cost advantage, apart from highly energy-consuming; 4) Operation and maintenance of sensors directly from the cloud servers are fraught with danger and arbitrariness as they are non-trial operations. However, many researchers have indicated a possibility of integrating between IoTs and cloud computing for storing and analyzing this high volume data [2][3]. However, cloud computing fails to offer any credible solution to countering the delaying applications wherein the real-time needs are critical to the deployment model.

II. WHY FOG COMPUTING

The term "Fog Computing", coined by Cisco Systems [4] proposed a novel model for easing wireless data transmission among connected devices in the parlance of Internet of Things (IoT) network. Fog computing as a novel platform brought cloud computing prototype quite close to the contours of the network [5], which is like a gateway to the core network. It offers low recess, apart from being aware of location in a better way. It has the ability to transmit the required data to the cloud that in turn submits for big data analytics as well as storage applications. Apart from stellar utility in streaming and real time operations, Fog gets distributed over a wider geographical area, quite capable of handling unexpectedly high volumes, types and speed of data. Fog applications interact with mobile devices in a direct way apart from supporting diverse elements in the connected devices. Significantly, it readies the accurate data right in the proper place to be used by the IoT devices. In spite of the fact that both prototypes offer a identical services in relation to computation, storage among others, yet fog shows some advantages as it is nearer to the customer, apart from being available over a wider area as well as better mobility backing [6]. Hence, it may be noted that Fog computing is a better virtual platform endowing smartercomputational, storage, and networking applications between typical terminal devices and the conventional Cloud Computing Data centers, that are not necessarily found located at the edge of a network.

III. GENERAL ARCHITECTURE OF FOG

Fog systems usually are found to be using programming models such as sense- process-actuate and stream-

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processing. Sensors, streaming data to IoT networks help in operations that run on fog devices. After subscribing to the processed information, the accrued insights get translated into actions and finally, sent to the actuators.

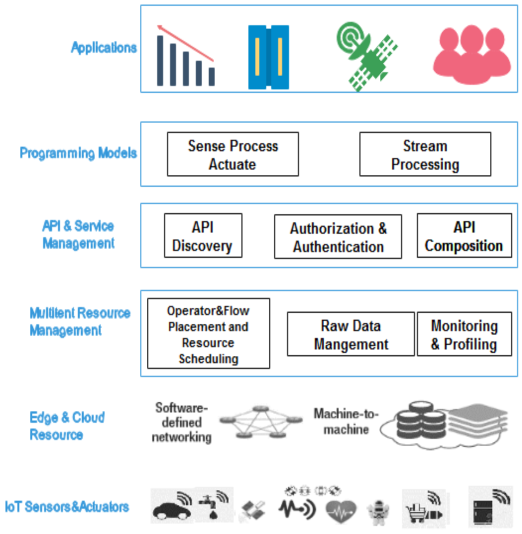

Fig1. Fog Architecture

In the bottom layer, we find end devices that include sensors and actuators apart from the applications based on their functionality. Such elements using the subsequent layer transmit via the network with peripheral devices to gain access into the cloud services. The total infrastructure is run on the resource management layer, critical to producing quality in the service that is offered. In the last stage, applications by leveraging fog-computing programming models are found to offer smart services to users.As wecan notice, Fog systems display dynamismin discovering and utilizing APIs for building complex functionalities. Elements in the resource management layer are found using data from the resource-monitoring service and monitor the condition of the existing cloud, fog, and network resources, before identifying the most suitable candidates who are good at processing the inward tasks. In multitenant applications, the resource-management elements prepare a priority list of the tasks found by the different users or programs that take part in the task. Edge and cloud resources transmit data that use machine-to-machine (M2M) protocols like MQTT (formerly MQ Telemetry Transport) and the Constrained Application Protocol (CoAP). Software-defined networking (SDN) is helpful in case of a need to efficiently manage diverse fog networks. To sum up, Fog computing is quite ideal to process data fast because of its closeness to the origin of the data, which also minimizes data pilferage from the transmission happening on the network as well as enhances data protection, finally reducing network hindrances arising out of a bigger data.

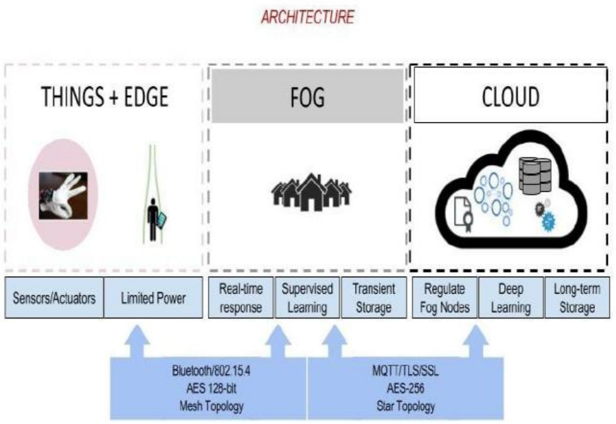

Fig2. Each of the layers shown has expected applications and system constraints

	Fog Modes closest to	**IoT Devices**	**Fog Aggregation Nodes Cloud**
Response time	Milliseconds to sub second	Seconds to minutes	Minutes, days, weeks
Application examples	M2M communication Haptics2, including telemedicine and training	Visualization simple analytics	Big data analytics Graphicaldashboards
How long IoT data is stored	Transient	Short duration: perhaps hours, days, or weeks	Months or years
Geographic coverage	Very local: for example, onecity block	Wider	Global

Table1.Explains the ability of Fog computing individually and as nodes in relation to the Network and the Cloud

IV. RELATED WORK

This section focuses on presenting the advanced devices and fog computing Monitoring and Acceleration of Bone Fracture Healing applications available globally. So far, many procedures to accelerate the healing process are in vogue that includes electrical stimulation. Electromagnetic fields (EMFs) directly impact endochondrial cells biologically before accelerating the development of callus [7]. In the present times, Ultrasound is widely applied for diagnosing osteoporosis [8]. Here, we have put a couple of ultrasound transducers on the skin on either side of the bone sample to measure the transition time of ultrasound waves. A recent work [9] has advocated for using ultrasound waves for enhancing callus formation. Moreover, our paper introduces an architectural design of a personalized wearable device that monitors and accelerates bone fracture healing by making use of ultrasound signals. The proposed wearable device gets implanted into a fixator externally before the traducers get exactly fixed on the surface of the bone. This proposed system has applications to accelerate and monitor the healing speed and status. When compared to the available techniques, like X-rays and manual sensing, this device has the capability to furnish correct and precise information about the progress in the process of healing, apart from identifying probable obstacles to non-union at the early stages of the process. Additionally, it offers many valuable support services like transmission of information to the doctor, smart data processing as well as devising alerts at any eventuality

A. Conceptual overview of the proposed architecture

In the proposed wearable system, we address the critical task to monitor and accelerate the process in which callus gains maturity in the process of bone healing in contact with external fixator. In the available methods, the crystallization of callus is recognized only in the terminating phase, wherein the cartilage tissue begins classifying before gaining visibility on X-rays film. However, after the fracture of a longer bone, some cellular and molecular events happen sequentially to conjoin the broken ends thus providing a reshape of the bone in order to reach the original structure. In fact, many factors cause slowness in healing or conjoining that includes even surgery. From the recent experience, it is possible to recognize formation of callus and its visibility on X-rays as early as only 3 weeks post surgery. Our primary focus is to introduce a method that offers better applications than the available techniques by designing a quantitative monitoring tool and an acceleration mechanism that aids the healing process with the use of ultrasound signals. This system is designed to comprise a sensing module, another module to pre-process and extract feature, apart from a decision-support module, a transmission module, an alert mechanism and finally, a centralized data storage facility. Fig.3, displays the conceptual overview of the proposed architecture.

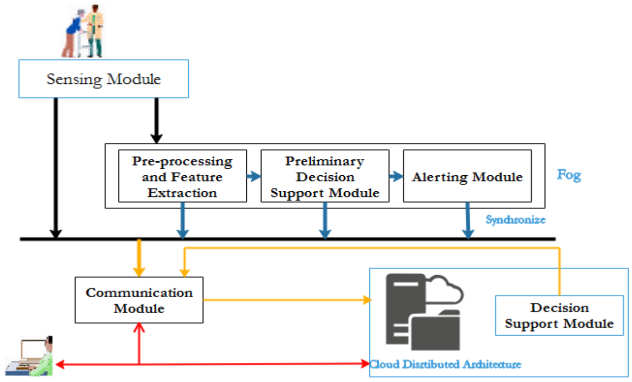

Fig.3 The conceptual overview of the proposed architecture for monitoring and acceleration of callus in bone healing

The sensing system transmits ultrasound waves right across the fracture site as shown in Fig. 4. It also uses a couple of broadband, unfocused disk transducers (5mm in diameter) having a nominal frequency of 500kHz, out of which, one acts as transmitter, whereas the other performs as the receiver. These transducers are located on either sides of the fracture, showing a straight contact with the bone.

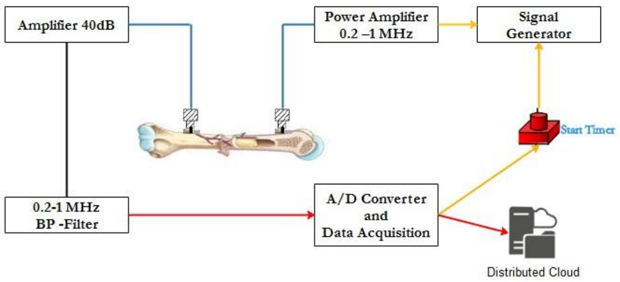

Fig.4. The conceptual overview of the proposed architecture for Sensing System

It uses ultrasound propagation speed as well as signal distortion for quantifying process in which callus gets maturity. Ultrasound wave propagation velocity has a strong linkage with bone elasticity (i.e. strength) as well as density. Callus formed in the place of fracture contains many properties, reducing ultrasound velocity to a significantly lower level. The transmitter emits a pulse that the receiver is able to detect, thus recording the time taken to transmit the signal. It also measures this at various phases in the healing process and gathers data about how the healing is happening. But, velocity measurements fail to give credible data about the architectural microstructure of the repairing bone keeps changing. Hence, it is also pertinent here to investigate how the spectral distortion of the propagating signal happens. The bone like all other biological tissues is known as a dispersive material that makes it possible to spectrally analyze how the signal records the micro structural changes happening at the place of fracture. Thereafter, it investigates the bone and callus micro structural characteristics through ultrasound signals, having a frequency range of 0.2-1 MHz. Then, the transmitter emits a pulse, wherein the spectrum of this signal is assigned a central frequency of 0.5 MHz the recorded signals that correspond to different phases of orthogenesis are applied to a data-driven smart engine to be followed by the feature extraction stage for diagnosis.

Various classification methods are applied. Our system furnishes data quantitatively about the development of the callus as well as the healing process across all stages, including early stages. It allows orthopedics to initiate precise steps in modifying a prescribed therapy as soon as a problem is identified, while allowing ultrasound signals in different frequencies to be used for accelerating the healing process [9]. Every time the progress is measured, the received signal gets corrected before being put through the process of filter, window and feature extraction. In other words, it moves across a preliminary decision support module found on the patient's wearable device.

All recorded signals, the extracted features, the result from the preliminary diagnosis module and other noting such as local temperature and heart rate get transmitted wirelessly to the centralized system. This procedure is performed by the communication module certifying a secure transmission of a patients' data to the centralized system. A second decision support module also functions in the centralized system, making use of the supplementary data about the patient's history and health status that eventually help a doctor to

V. DATA ACQUISITION

A new telemetry data acquisition unit was developed for autonomous long-term data collection. The system includes a microprocessor for real-time processing of raw sensor data. The sensor signal was scanned at the peak values using a custom-made peak detector algorithm. If we assume a maximum 3 Hz steep frequency, the sampling frequency is set to 10 Hz with an oversize of 10 Hz. Together with the stroke counter, the peak values are continuously accumulated. The results are stored at predetermined intervals. Thus, the effect of the natural deviations of the functional load is averaged. In addition, the first derivative of the raw signal is calculated in real time and the average deformation rate is calculated, which an important parameter characteristic of bone is healing. To obtain the load intensity histogram, the three peak detectors run in parallel with different amplitude thresholds to sort into a separate container according to the magnitude of the load stroke. Instead of storing and transmitting the entire sensor signal, the data is converted into a small packet of parameters of statistical significance on board (e.g., average amplitude within a specified time interval) with an ultra-low power microcontroller (MSP430AFE253).

Fig.4. Electronic unit used for on-board processing

This lean data management enables the use of energy efficient wireless data transfer technology. Downloading the calculated parameters and setting settings (if required) is done with RFID (low frequency transponder) (134.2 kHz). Downloading the data is independent of the data collection process and can be performed at selected times as required. In the current system version, the patient's skin is approached with an RFID transponder up to 3 cm for the implanted data collector. The 1-month download process for the collected data takes 12 minutes (at 6-hour logging intervals). The power consumption of the device is ~ 60 µA, which results in a battery life of about 4.5 months (3 V button battery with 210 mAh capacity). The size of the data collector and the battery is 26 mm in diameter x 7.5 mm. The principle of data collection is independent of the type of signal processed. There are two versions of a device with signal conditioning adapted to receive signals from different sensors. 1) Connecting a conventional voltmeter rosette, measuring the deformation of the implant / fixator, and 2) connecting a miniature LVDT displacement converter (linear variable differential transformer) to measure the movement of the fracture gap.

VI. BIOMECHANICAL TESTING

Both the healing and the opposite tibia were biochemically evaluated by a destructive three-point bending test. Samples were thawed at room temperature prior to testing. The samples were placed in a horizontal position against two round-shaped supports that were equally spaced from the previous break level in the 110 mm range. The mechanical head of the mechanical device has also been rounded to minimize shear stress and cutting, and the breakage is applied at a constant rate of 20 mm / min to the bone. Breaker loads were determined and load-deflection curves were obtained. The stiffness was calculated as the linear part of the load-deflection curve and the Young modulus E and η ultimate strength (breaking stress) were derived using

$$\mathrm{E} = \frac{\mathrm{F}}{d} \cdot \frac{\mathrm{L}^3}{48\mathrm{I}}$$

$$\eta = \frac{\mathrm{FLc}}{4\mathrm{I}}$$

Where c is the distance of the load head from the center of the mass, F is the applied load, d is the deflection, L is the span length, and I is the cross-sectional moment of inertia (CSMI). To avoid the commonly used approximation of the complex and irregular periosteal callus form and the circular or elliptical cross section of the bone, the position of the center. The mass and CSMI were calculated from the corresponding QCT slices using our in-house program. However, it is assumed that the neutral axis of the bend passes through the center of gravity. In addition, since Young's modulus is virtually underestimated during the three-point bending tests, due to the advanced shear stresses, the slope of the elastic range of the curve was used to approach ratio F/d.

VII. RESULTS & ANALYSIS

The data from this study are a sample of 464 patients, each one assigned to one of the three types i.e (Nociceptive (NP), Peripheral Neuropathic (PN) and Central Sensitization (CN). of pain by a group of experienced physiotherapists. An apriori algorithm was used to complete an association rule analysis of the data. An initial setting of 0.5 was set for support combined with a confidence level of 0.8 is set and the no of rules to returned is 32. Although the combinations of symptoms indicated existing relationships when ordered by lift the support assignment of 0.50 only considered symptoms that occurred in 50% of patients. This represented 14 (26%) of the 36 symptoms. Since the minimum number of symptoms in any patient was 8 (18%) and the mean was 14 (26%) then it was possible that taking a subset of 9 symptoms merely produced rules with symptoms that almost always occurred together due to their nature. To produce potential relationships that were unexpected it was likely that a wider approach might be required as shown in fig. 5. The group of most interesting rules according to lift (the default measure) are shown in the top-left corner of the plot fig.6.

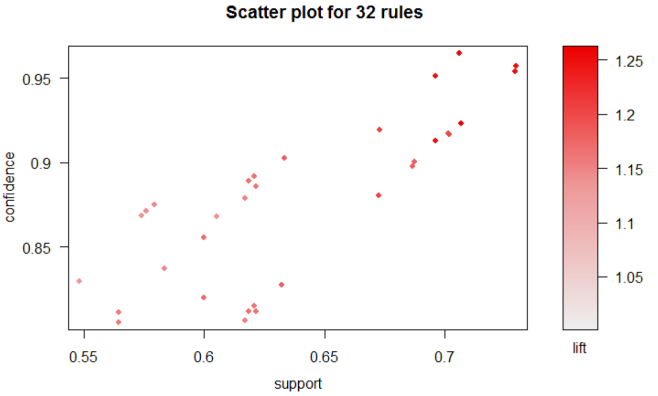

Fig.5. Support vs. Confidence for top 32 rules

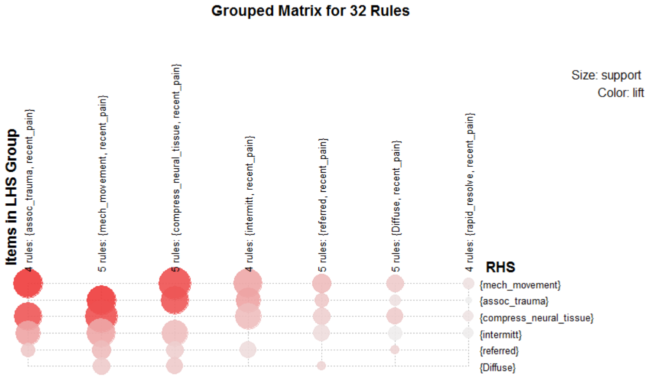

Fig.6. Grouped matrix-based visualization with 32 rules

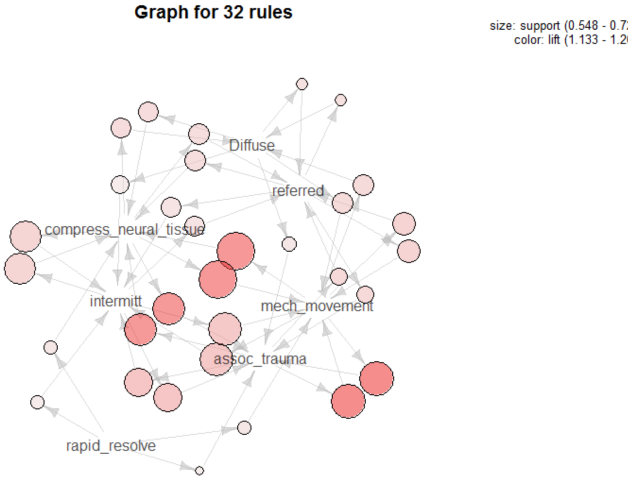

Fig.7. Graph-based visualization with items and rules as vertices (32 rules)

The setting of 0.5 was set for support combined with a confidence level of 0.8 to reduce the number of rules to 10. Although the combinations of symptoms indicated existing relationships when ordered by lift the support assignment of 0.65 only considered symptoms that occurred in 65% of patients. This represented 7 (19%) of the 36 symptoms. Since the minimum number of symptoms in any patient was 5 (13%) and the mean was 13 (36%) then it was possible that taking a subset of 7 symptoms merely produced rules with symptoms that almost always occurred together due to their nature. To produce potential relationships that were unexpected it was likely that a wider approach might be required.

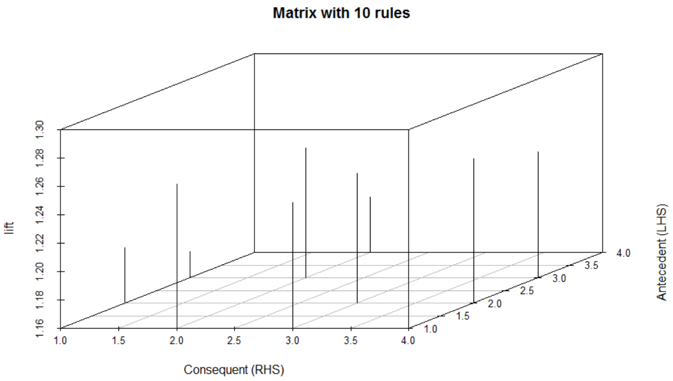

Fig.8. Matrix-based visualization with 3D with 10 rules

To reduce the number of rules further and simplify the output the support was reduced to 0.4, the confidence remained at 0.9 but the rule size was fixed to 2. Fig.9 illustrates rules plotted with Support vs. Confidence. The color indicates lift and red dots have higher lift values. The isolated plot point X8 -> X11 in the bottom left corner has relatively low support (for this set of rules) and also low confidence but also low lift. All lift values greater than 1.0 indicate the relationship between two sides of the rule has more significance than if both sides were completely independent.

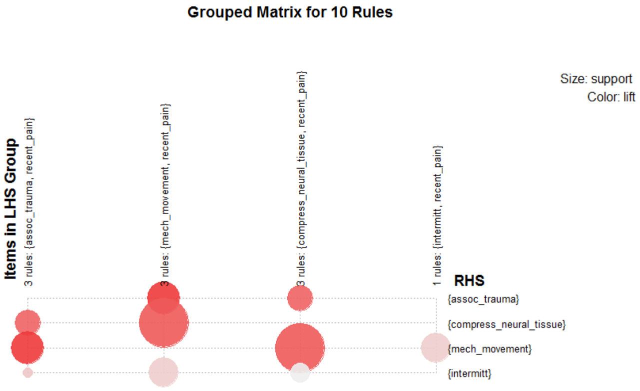

Fig.9. Grouped matrix-based visualization with 10 rules

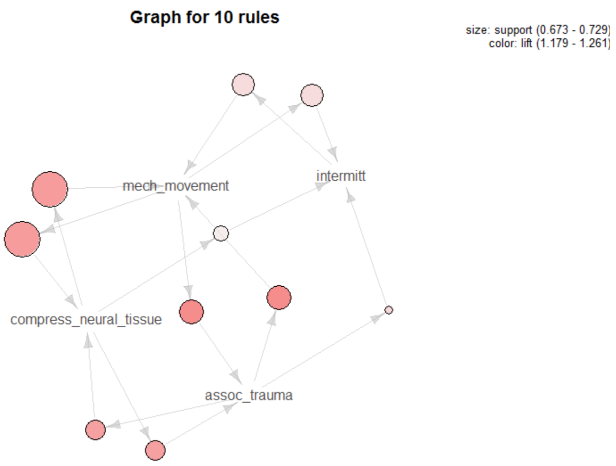

Fig.10. Graph-based visualization with items and rules as vertices (10 rules)

VIII. CONCLUSION

The proposed wearable device is engaged in collecting data from the bone healing process, including the maturity process from it interface with the human bone while pursuing and recording ultrasound amplitude. It has specific application while the fracture healing process is monitored through activation of ultrasound at lower pulses so that it is accelerated significantly. To achieve this, the transducers are brought into direct contact with the bone, preventing the possibility of signal distortion from adjoining tissues. As the proposed system is only an experimental formulation, it is yet to be implemented. However, it can be safely surmised that it is possible to effect faster and more accurate decisions compared to the available conventional methods. In fact, this formulation best performs by effectively dealing with all perceived problems and non-unions in the fracture healing process through their clear visualization at an earlier stage.

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