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Article

A Real-time Geo-Resilience Support Paradigm for Regional Infrastructure Sustainability using Synthetic DADO Machine Architecture

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Abstract: Swift and diligent resilience response is mandatory in sustainable geo-distributed ecosystems. The real-time geo-spatial resilience requires agility in millions of parallel and distributed data processing tasks on data acquired from regional condition monitoring(RCM) systems. These tasks include expiditous resolution of complex sustainability conflict sets, promptly anomalies characterization in chaos sets, and resilience response uniqueness. This work is an archetype of a paragon geo-resilience support system(GRSS) for regional sustainability using a novel melioration in DADO production machine. The proposed expert system capitalized the synergic strengths of RETE, TREAT, LEAPS and GATOR networks was designed and implemented as a synthetic DADO machine(SDM). The generic architecture of DADO machine was improved in this work by enrichment in rule set conditions and solution set for regional scale resilience rule set conditions. The condition left-hand side(LHS) X equal to the solution set 2X for right-hand side (RHS) was the goal achieved by working memory(WM) optimization and conflict resolution strategy(CRS) in alpha and beta networks rules. A round-trip time of 80.2 seconds for first event response set using 1492 segment size and sequence number 360,000 with maximum packets at a single geospatial structure was 21 packets/sec was a noticeable landmark in this work. LEAPS and Concurrent-read algorithm for GATOR cluster networks in the proposed synthetic DADO machine architecture was the overall implementation that enabled urban scale resilient system practically possible on physical SHM deployment.

Keywords: Sustainability; geo-resilience support system(GRSS); chaos sets; structure health monitoring (SHM); DADO machine; RETE; TREAT; LEAPS; GATOR; Internet of Things (IoT)

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1. Introduction

Chronological and random natural disasters occurring across the globe have a vital impact [1] on state-level infrastructure safety and sustainability. The desultory chaos and disasters have a direct impact on regional [2] economics, and future investment plans irradiating need for GRS to stipulate the regional sustainability. The sustainable development efforts were observed using the GDFI-Simulator [3] for Africa, America, Asia, Europe and Oceania in the 19th and 20th centuries. The GDFI-Simulator work for resilience epitomized gaps as real-time resilience system architecture requirement to optimize the trade-offs in regional development and sustainability matrix. The community resilience indicators for assessing the urban community resilience in Malaysia [4] was a substantial effort and a nascence for brisk global resilience systems(GRS). The risk interpretation and action framework for responses to natural hazards review and the role of urban actors to coordinate and contribute to sustainability [5] depicted a need for an integrated and enmeshed GRS.

In regional sustainability literature, a momentous rapture for GRSS in [6] was based on the meta-analysis of an etymological journey in resilience and disaster risk reduction from 1973, illuminated 38 cases with an obligation of dexterous GRSS. The urban resilience through regional adaptability [7] was demonstrated with systems of systems gap. The theoretical and empirical perspectives explained in [8] need to be formulated in the form of a reference model for resilience systems design. The mapping of nine narratives M1, M2, M3, N1, N2, N3, CT1, CT2 and CT3 in figure 1 [9] were very practical resilience design markup but still craved artificial intelligence and standardized geo-spatial sensing capabilities. The life sustainability and assurance elevated in [9] for disaster resilience created an obligation for usage for infrastructure safety systems as reality towards sustainability against natural calamities. This created an opportunity for infrastructure health monitoring systems i.e. SHM sensing capabilities as a sustainability assessment tool for rapid resilience response in GRSS as reliable RCM system.

The SHM system reference architectures developed on Imote2 platform and boards SHM-H and SHM-A in [10] and SHM-S and SHM-DAQ in [11] could serve as RCM tools if aided with inference engines(IE) and big data manipulation support. Recently, building information modeling(BIM) based approach by utilizing sensor data [12] gathered from actual construction projects craved for an expert system(ES) capability to assist GRSS. Moreover, this approach had lacked dynamic data buffering and interpretation framework for bridging BIM and sensor networks [13] through an IE to assist GRS. Likewise, finite element analysis(FEA), finite element modeling(FEM), and wireless sensor networks(WSNs) based analysis and methods were thoroughly compared [14] using the results of a structural analysis software through ABAQUS simulation mechanism. These methods did not feature alarms for anomalies due to the absence of IE. In all these WSNs [14-16] type of researches, the gap of an inference engine with IF-THEN rules for bounded value conditions as well as network integrated GRSS was observed.

The real-time data processing capabilities observed in the inter-storey test-bench based design and implementation approach [17, 18] using a system of remote monitoring sensor nodes being analyzed through a personal computer need to be framed as GRSS. This approach lacked parallel computing architecture for complex chaos sets matching cases and rules conflict resolution. An effort [19] that explored new horizons was an infrastructure comprised of TinyOS based sensors nodes running TinyOS Network Simulator(TOSSIM) a PC running Mathworks Matrix Laboratory(MATLAB) for data analysis and simulation. It was very effective in many aspects but still lacked expert system system architecture and work memory optimization. The passive gateway based approaches [20] using smart sensor nodes i.e. COTS+ [21] needed integration of the expert system for anomaly detection and resilience response generation.

A plethora of approaches was observed in recent years for regional sustainability and resilience automation. Information bank-based data gathering and application Bayesian networks [22] had limitation from sustainability prospect. The resilience of coupled human–digital environment systems by capitalizing SVIDT [23] method required regional infrastructure data incorporation and intelligent architecture addressed in this work. The SVIDT proposal required matching algorithms for event classification and handling. The Big data trends and vision for sustainability [24] of critical infrastructures and resilience methodologies needed to be backed by updated and realtime characterization and conflict resolution implmentation. The work proposed in [25] concluded that the AI matching algorithm RETE needed bigger working memory and α and β network hierarchy for solution space, TREAT needed an only α network. LEAPS algorithm as a superset of strengths of RETE and TREAT rule-based matching algorithms was more suitable but created a gap at state-level sample spaces i.e. LHS and solution side i.e. RHS where rules space caused big conflict sets. Trisolda, the environment [26] with TriQ RDF query language for semantic data processing and natural speech processing [27] could serve as a tangible tool in urban sustainability and resilience by interfacing with some expert systems as well as condition monitoring sensing platform.

The state-level scalable infrastructure created and implemented in [28] needed to be integrated with a bi-variable sensing mechanism for 50+ km safety assessment in [29] for regional canvas. The work [28] also required applications and optimization by distributed computing [30] capabilitiy of DADO machine architecture. The DADO machine enrichment in [31] could multiply the resilience performance of [32] agent centered model(ACM) and infrastructure centered model(ICM) for IoT and internet of everything(IoE) based scalable and sustainablility solutions. The conflict sets(CS) resolution in GRSS using dynamic programming(DP) with the GATOR [33] approach for sustainability applications of [34, 35] SHM-UCM could serve a reliable source of real-time geo-resilience.

Furthermore, regional sustainability intents observed in [1-35] had the gaps in physical and real application centered GRSS design and implementation. The regional sustainability based on cost metrics utilizing MOSPA in SHM-UCM [34] with geo-analytics capabilities would have been a huge service to geo-resilience by integarion with DADO machine as GRSS core. The improvement in limitations of [34, 35] has been accommodated in this work by improving the system architecture from regional sustainability [36] prospect by RSS i.e. SURFmap. This work is the proposition of a physical geo-resilience support system architecture(GRSSA) implemented using a novel synthetic SDM system prototype as GRSSA-SDM, discussed in two sections:

1. Real-time Geo-Resilience Support System Architecture
2. Synthetic DADO Machine System Design

In section 2, the conceptual real-time geo-resilience was actualized by symbiosis of (i) millions of geospatial infrastructure health or condition monitoring sensors nodes processed as packets of multi-variable time-series (ii) thousands of real-time parameters computed on the go from time-series variables inferred as anomalies in abnormal conditions as acknowledgement from cyber-physical geo-resilience system (iii) hundreds of chaos sets inferred from characterization of anomalies time vectors (iv) hundreds of mutually exclusive beliefs sets inferred from chaos sets (v) hundreds of rules trees derived from belief functions updates segregated as rule networks achnkowledged as packet sequence numbers (vi) geo-resilience response generation by parallel computation of rule networks resolution (vii) geo-resilience rendering as feedback to confirm regional sustainability by scanning the runtime anomalies. This all sequence required super fast problem solving architecture based on a real machine capable of handling huge data rates and integrity constraints to ensure trust worthy alarms in the nick of seconds termed as SDM.

In section 3, The phycial SDM system consisted of three blocks. In the first block, the SHM specialized sensor node clusters collected data from remore locations and filtered primary anamolies associated with electronics and communication behaviors. The node clusters were coupled at a zonal sustainability specialized system on chip(SoC) to perform tasks (i), (ii), and (iii) as distributed computing edge device with shared working memory support. In the second block, the regional sustainability specialized gateway(RSG) collected task (i), (ii), and (iii) results from shared memories of connected SoCs and implemented tasks (iv), (v), and (vi) as parallel computing edge device with public shared memory pool(PSMP). The third block was a virtual private server(VPS) hosted on a desktop or Laptop PC that had access to PSMP. The VPS loaded the results from remote PSMPs and performed tasks (vi) and (vii) globally to verify the unique resilience responses for events.

In section 4, a case study is presented with a practical implementation at the campus level that demonstrated the regional sustainability assurance capabilities of GRSSA and real-time data processing capabilities of SDM in Qatar University, Doha.

2. Geo-Resilience Support System Architecture

A Resilience Support System (RSS) is an expert system that works on the principle of Belief-Rule (BR) deductive logic called IF-THEN operations; for example, if temperature T is 38 °C then weather is hot. The intersection of multi-event confidence intervals is termed as degrees of belief; if T is 38 °C and humidity H is 75% in five days. The belief is: for all T > 37 °C implies that H >

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70%. from belief function $f_{belief}(H/T) = (75/38) = 1.973 \Rightarrow H = (1.973)T$. The belief is computed against similarity or matching all the possible combinations of events; if the temperature is between 0°C to 20°C then humidity should be between 5% to 25%; if the temperature is 20°C to 35°C then humidty will be 25% to 55%. A belief is based on belief function i.e. $f_{belief}(H/T) = (75/38) = 1.973 \Rightarrow H = (1.973)T$ derived from mathematical and logical relationships. In real world applications, there can be more than single a belief function according to Dempster-Shafer evidence theory. There has to be a unique belief function for every global event as a function of dependent variables.

At regional, zonal or city level there exist thousands of multi-sensors systems that have to justify the truthfulness in evidence of different events. The deviation of these events from sustainability belief functions and absence in resilience rules memberships is termed as “anomaly”. A set of unresolved anomalies are termed as “chaos sets” i.e. no belief function and no rule memberships exist means zero conflict support; leading to an uncontrollable event. If there are two belief functions for the same anomaly and event there rises a condition called “conflict”, and set of all such conditions is called “conflict set”. There must be rules to resolve conflict sets called “conflict support” and rules to resolve conflicting rules are called “resolution support”. The quick anomaly detection, as well as belief function update, are mandatory for runtime sustainability goals. The conceptual model for global sustainability through GRSSA is given in figure 1 as a big picture.

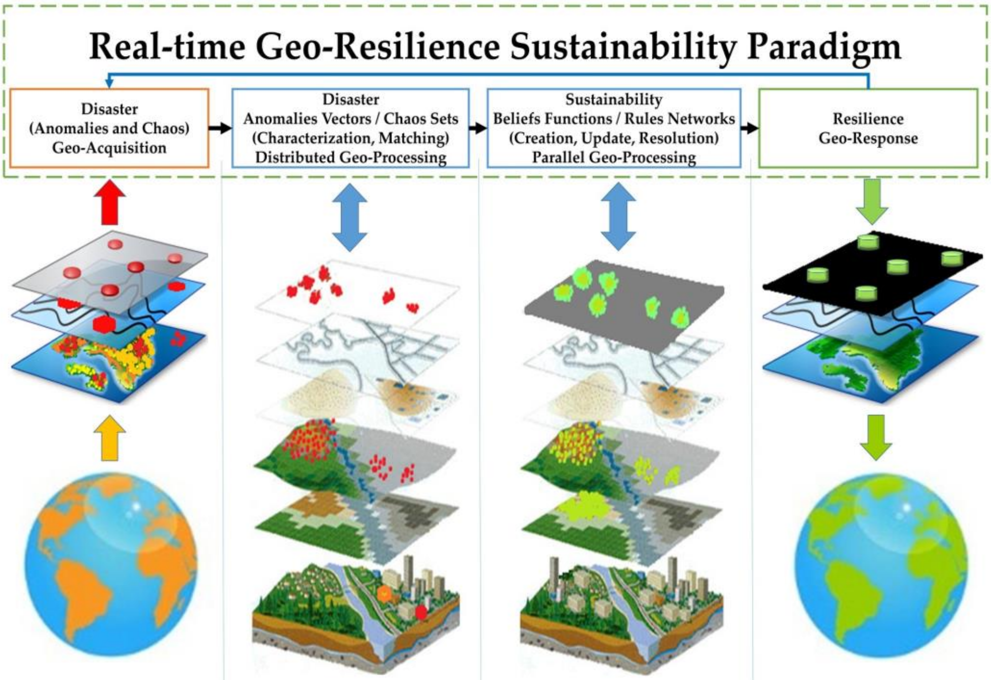

Figure 1. Simplified Conceptual Layout of GRSSA in the big picture

In figure 1, LHS as geo-acquistions and RHS as geo-response generated by proposed geo-resiience paradigm. Real-time sustainability is only possible due to rapid resilience response conceivable by application of discrete mathematics and decision-trees based mechanism instead of machine learning methods. In the machine learning approach, the computation of mathematical relationships needed artificial neural networks (ANN) that required training at first and then the generation of relationship functions. Training mechanisms were not feasible [36] for real-time applications as training a model takes time. This work proposes matching algorithms based rules engine approach that saves historical computations and works on meta-heuristics of deductive logic decision trees(DLDTs). The DLDTs are based on combinations of anomalies or event transitions like a chess game winning move problem.

Let t be the time vector for time-series variables as a set of Vectors V with n variables in a multi-sensing monitoring system with heterogeneous data rates D, vector V is given as a function of time.

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$$V(n, t) = \{V_1(n_1, t_1), V_2(n_2, t_2), V_3(n_2, t_2), \ldots\ldots V_n(n_n, t_n)\} \quad (1)$$

There exist abnormalities or anomalies as a set $A= \{A_1, A_2, A_3, \ldots. A_n\}$ in real-time magnitudes M that have an unacceptable difference of ΔA from normal or safe values N ensuring sustainability. Let us say M>N or M<N in range a = ±10% from recent value is written as:

$$\Delta A(V(n_1, t_1), V(n_2, t_2)) = (M\text{-}N)/N \quad \forall \quad \Delta A \in [-0.1,+0.1] = \{a \mid -0.1 \leq a \leq +0.1\} \quad (2)$$

Each combination of ΔAs is called chaos set $C = \{C_1, C_2, C_3, \ldots. C_n\}$. Let C_i be the instantaneous chaos set at instant i may or may not be member of C. The similarity in Ci and Vi is called belief function $f(\beta)$ and Ci and C as conflict set according to argumentation or conflict support rule R. All the members of C and should be mutually exclusive to characterize a unique event and generate unique resilience response R_{RSS}. For every event, in V and A relationship, there has to be a conflict support S_C and resolution support for S_R at time t for confidence interval I. The rule model for a real-time BR expert system for an isometric monitoring system is given as:

$$S_{Rn}(t) = \begin{cases} \text{If V has A in } n(N,t) = (0, 1, 2, \ldots N) \text{ and } a = (0, 1, 2, \ldots t) \text{ at I for } \forall\, C_i \in V \\ \text{Then C has R for I in } n(t) = (0, 1, 2, 3, \ldots t) \end{cases} \quad (3)$$

The value of I for S_R is dependent on belief degree of accurate event management β_k with a referential value i and belief update for R is given by the equation:

$$\beta_n(i_{n+1}) = \beta_n(i_n) \times \{I(i_{n+1})/I(i_n)\} \quad \text{for } i = (0, 1, 2, .. t\text{-}1) \quad (4)$$

Every β_k has any one of the five severity levels, i.e. HH=High-High, HL=High-Low, M=Medium, LH=Low-High, and LL=Low-Low in a single conditional membership. If the new $\beta_k(t)$ has I(t) > I(t-1) i.e. more confidence interval than previous it will replace the older degree of belief. This model works on all the data streams of isometric condition monitoring systems or all SHMs with same architecture, i.e. identical sensor types, number of nodes, polling rate or sampling rate, and communication infrastructure that can rarely happen at regional level due to variety of vendors and solution providers and terms of service level agreements(SLAs).

In realistic geo-resilience scenarios, there is heterogeneous sensing, heterogeneous communication, and most importantly heterogeneous CPU and memory configurations, in this case, the equations 1 to 4 will confuse the entire GRSSA. Let us modify the mathematical model for geo-resilience. Let D be set of all the data-rates at the core where all SHM systems converge such that D = [1 bit/second, 10 Gigabit/second]. The number of mutually exclusive communications buses be a set B with packet structure B_{Packet} for every unique SHM uplink. Let US be a unique set of regional structures deployed with V-SHM as a unique cluster or set of sensors variables in V sent through B. Let SHM-SENSOR be a unique set of sensors. Let the number of real-time state variables for a unit geo-event be $G_{Rss}(STATE)$ for a single SHM cloud and given as:

$$G_{Rss}(STATE) = {}^{D}C_{B} \times {}^{US}C_{V\text{-}SHM} \times {}^{V}C_{SHM\text{-}SENSOR} \quad (5)$$

The set of four equations 1 to 4 need to be framed as combinations i.e. systems of systems. In geo-resilience solutions, the milestone is to estimate the bottlenecks as:

1. The maximum number of regional anomalies with respect to the maximum number of packets P_N, given as:

$$P_N = \{ Size(G_{Rss}(STATE)) + Size(\Delta A)\} / Size(B_{Packet}) \quad (6)$$

2. The round trip time(rrt) T_β for belief function update for a respective geo-event is the difference between the time to send(TTS) first chaos set member ΔA to a matching algorithm in DADU machine and conflict resolution for last belief function by GATOR network in DADO machine, given as:

$$T_\beta = \{TTS(\Delta A) - TTR(S_{Rn}(\beta_n(t\text{-}1))\} \quad (7)$$

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3. The maximum throughput TP is achieved to satisfy minimum time T_β to generate a unit geo-resilience response by GATOR network. In the proposed design, it is computed as the size of the sum of all anomalies or one complete chaos set transferred to DADU machine working memory divided by unit T_β at an instant, TP is given as:

$$TP = size\{\Sigma_i \Delta A(i)\} / T_\beta \tag{8}$$

$$TP = size\{C\}/ T_\beta \tag{9}$$

4. The sequence or ticket numbers for every networked community alarming system based on different standards for specific area anomaly localization is used by local authorities. In this work, a sequence number mechanism has been used that has a range of $[0, 2^{32}-1]$. The least magnitude of T_β for least sequence number is the ideal most condition for RSS. The maximum allowed sequence number is 2^{32}. The overall SHM cloud dashboard is displayed after this step. The percentage health H of structures is computed as the number of variables N_V divided by the number of classified anomalies N_A multiplied by 100 and is given as:

$$H(\%) = (N_V / N_A) \times 100 \tag{10}$$

5. The live geo-analytics is the most popular tool used by local authorities is another visualization that expert systems use to assist the decision making. A simple binary operation has been used in this work i.e. load Google Maps frame in matrix G and subtracts it from Matrix RSS with geo-spatial coordinates of areas or structures with nodes having sequence numbers > 2^{16}. The empty $S_{Rn}(t)$ computed as matrix RSS-IE or GRSSA-IE, let it be termed as "condition zero". The GRSSA-IE layer is updated at every unit resilience response as shown in figure 2.

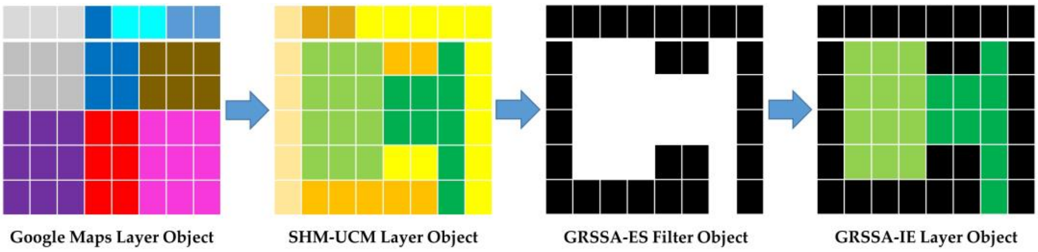

Figure 2. GRSSA-ES Adaptive Filter Subraction Process Block Diagram

The safe area on the map with active resilience will be green and waiting will be bordered green with GRSSA computation is progress and unrecoverable as black. Geo-spatial images are treated as matrixes with selected latitude and longitude bounds with each patch as a pixel for the respective color model used e.g. RGB, CMY, etc. The matrix operation subtraction needs same dimensions as R for row and C for column given as:

$$GRSSA\text{-}IE(Layer)[RxC] = G(Layer)[RxC] - RSS(Layer)[RxC] \tag{11}$$

Based on the mathematical model, we needed to design a precise architecture that had the potential of accommodating big data of rules and belief sets. The state-level parameters of GRSSA controlled the cost and time of disaster recovery while keeping the utility computing system [33] at optimum performance. The proposed GRSSA comprised of 3 layers of conceptual frameworks working in hierarchy given as:

1. SHM-GRSSA Interaction Block Conceptual Framework(SRIB-CF)
2. GRSSA-SDM Resilience Expert System Block Conceptual Framework(RESB-CF)
3. GRSSA-SDM Resilience Response Block Conceptual Framework(RRB-CF)

The geo-processing model for GRSSA is given below in figure 3.

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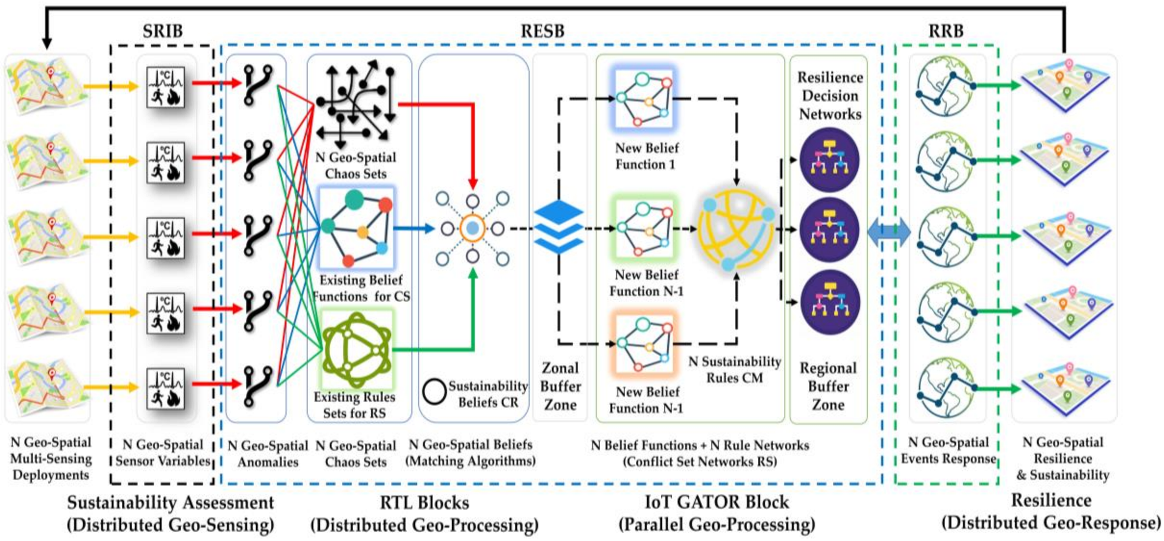

Figure 3. Detailed Conceptual Layout for GRSSA utilizing the proposed SDM

Figure 3 illustrates that the existing geo-spatial condition monitoring systems deployments were used by proposed GRSSA and SDM. The sustainability assessment is entirely based on real-time sensing variables. Following are the diagrammatic conventions used in figure 1 and 3:

- The word N is a natural number i.e. number of globally existing units.
- The dotted rectangles refer to the variable number of units and tasks in GRSSA.
- Dotted arrows show that they can be pointing to different units according to runtime conditions.
- The light gray rectangles with round edges are for sub-sections with no further processing in every major block, i.e. deployments, sensor variables, zonal buffer zone, regional buffer zone, event response, and sustainability.
- The light blue rectangles with round edges are RTL block sub-sections.
- The light green rectangles with round edges are IoT GATOR block sub-sections.
- The dotted black rectangle for GRSSA-SRIB.
- The dotted blue rectangle refers to the entire GSSRA-RESB.
- The dotted green rectangle is GSSRA-RRB
- The biggest arrow in figue is the black arrow at the top is for feedback i.e. restart the entire sequence.

Figure 3 is further explained stepwise in later sections with inner details.

2.1. SHM-GRSSA Interaction Block Conceptual Framework

The SHM-GRSSA data model was the step zero in the form of a standard entity-relation(ER) diagram in figure 4 for SHM and SDM integration for GRSSA implementation. The GRSSA interactd with the physical world with this block. The entire SHM ecosystems with structures, areas where structures were located on the map, type of structures, sensors categories for a specific strucuture, and sensors variables were the core fields with 4 entities. The first obligation for GRSSA was geo-data sources that were LHS to feed the expert system as a problem domain accomplished using SHM systems installed at remote zones. The sensor data was gathered in a single database file using SQLite database client on site SoC modules from all the connected SHM system nodes. In figure 4, it can be seen that initially, the input buffer is 36 attributes of 4 entities i.e. projects, SHM, Structures and Sensors-Grid of data rate 36 x data type size i.e. int, string, text, and date-time with minimum data rate requirement of 512kbps. The tables were designed for operational optimization of RSS so that every client does its job and keep the server dedicated to critical jobs also. This was for one site i.e. one structure in a zone and region that contributed LHS. The ER model enmeshed all the SRIB zones attributes.

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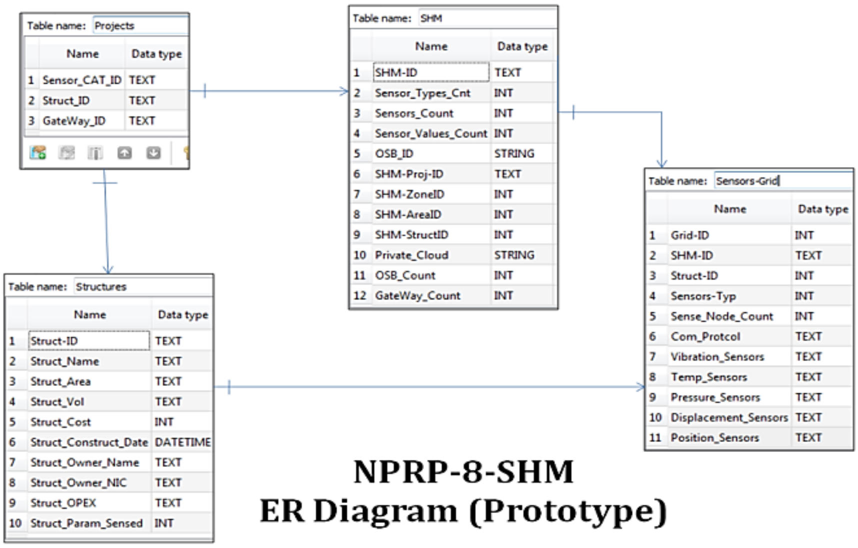

Figure 4. ER Diagram of SHM-GRSSA Interaction Block (SRIB) Prototype Database

In the ER diagram in figure 4, the zone level tasks (i), (ii), and (iii) were executed by GRSSA-SDM site block as shown in figure 8 and region level tasks (iv), (v), and (vii) were performed by the gateway as shown in figure 10.

2.2. GRSSA-SDM Expert System Block Conceptual Framework

The systematic and summarized work flow of a rule and knowledge base expert system is given in figure 5 in the light of GRSSA-SDM realization. The first step is the "Disaster Query" as real-time sensor variables enquired if there are anomalies or not. SHM inference engine is a perception engine i.e. rules and knowledge based program that processes the sensor data. It consists of a set of beleifs and rules in the form β_0 to β_k for all R_0 to R_n for S_0 to S_m where R is the set of clauses of n possibilities of the relationship of problem database and S is the set of actions or commands to update the existing database for a given $\beta_k(t)$. The "Sustainability Advice" as resilience response is the last step as well as the desired goal to be achieved.

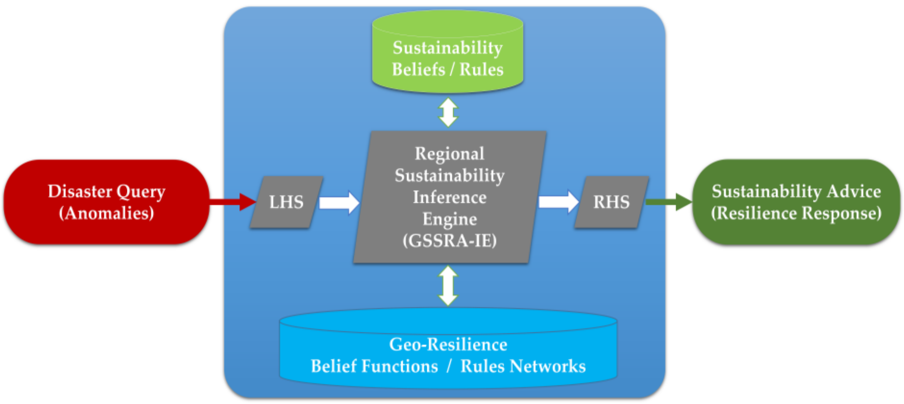

Figure 5. Simplified GRSSA-SDM ES Conceptual Frameowork

In figure 5, a regional sustainability inference engine can be observed that is the heart of GRSSA-SDM expert system. In this work, a novel inference engine has been proposed that is composed of two blocks as:

1. GRSSA-SDM Matching Alogorithms or RETE-TREAT-LEAPS(RTL) Block
2. GRSSA-SDM Resilience Network Control or IoT GATOR Block

These two blocks are explained in detail their respective sections.

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2.2.1. GRSSA-SDM Matcthing Algorithms or RETE-TREAT-LEAPS Block

In inference engine, each R is a rule network to reflect a unit relationship, i.e. can be constants and variables. Constants are evaluated directly by just SELECT command and JOIN is used for variable relationships. The operations of the inference engine (IE) proceed by evaluating one R at a time and then cyclic workflow.

The state information of a matching algorithm was evaluated as a condition of membership(CM), WMS, condition relationship(CR), conflict set support(CSS) and resolution support(RS) for details please see the table below from [12].

Table 1. State Information of Matching Algorithms in LH

Algorithm	CM	WMS	CR	CSS	RS
LEAPS					
TREAT					
RETE					

Table 1, clarified that RETE is a strong initiator, LEAPS is a good finisher and TREAT has smaller memory requirements in event management problems. Cascading these three algorithms to make a RETE-TREAT-LEAPS (RTL) block as part of a single algorithm can lead to better results. An efficient RTL block can be constructed from CM capabilities of RETE and joint WMS block to extract the best rule and CR intersection to find the best CSS set for RS.

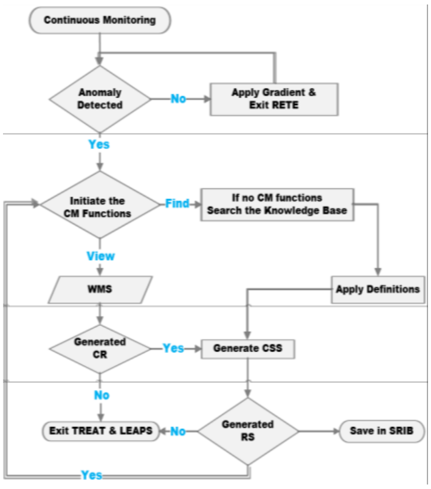

Figure 6. Comprehension of GRSSA-ES Inference Engine Working Principal

In figure 6, the gradient ΔA is introduced as a function of Newton Forward Difference(NFD) method to track the difference between past and present sensor values. If this difference is incremental means that probability of anomaly is high. The first segment of the RTL block is only triggered if either anomaly is detected or gradient is rising. If CM functions are not having the appropriate set of beleifs and rules then the knowledge base or buffer zones are searched searched, i.e. WMS and PSMP. The WMS created is dynamically accessed by TREAT and LEAPS as shared memory using concurrent read algorithm inside the RTL block. The WMS in figure 6 is created for every single anomaly. The complete anomaly vectors are generated from sensor data using β_0 to β_k and later are transformed into chaos sets on the basis of R networks and stored in WMS. All the geo-spatially created WMSs are loaded into IoT PRL PRAM for IoT GATOR block.

2.2.2. GRSSA-SDM Resilience Network Control or IoT GATOR Block

In IoT GATOR block, conflict support and response support is provided for response authentic generation. The chaos sets in IoT RTL PRAM may have similarities, if exist are resolved by GATOR

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network controller(GNC) presented in figure 7. All the regional sustainability conflicts are and event response block with N nodes, all running in parallel to generate unique resilience response against unique anomalies as shown in figure 7. All the WMSs are accessed in parallel flow by IoT RTL PRAM to feed the GATOR network controller(GNC) that generates interlocked event responses. In figure 7, the IoT GATOR block diagram shows that all RTL blocks from individual cities have their respective WMS areas mapped into zonal WMS that is shared with IoT RTL programmable RAM. The components zonal WMS and IoT TRL PRAM are acting as a private buffer zone for zonal sustainability computed from regional data.

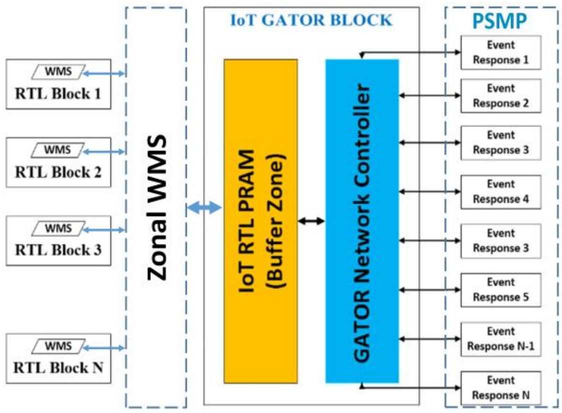

Figure 7. GRSSA-ES IoT GATOR Block Diagram for RRB

Every WMS in figure 7 is connected to WMS in figure 6. The Zonal WMS is a single memory buffer with all the RTL WMS results as an anomaly. The matching anomalies vectors from figure 4 are transformed in chaos set. The rule networks and chaos sets are the hubs of all the rules and information models master storage that governs the decisions of the inference engine.

2.3. GRSSA-SDM Resilience Response Block Conceptual Framework

The RRB consists of shared WMS access block,

The Working memory (dynamic and volatile runtime storage) has the selected variables, rules and algorithms that apply to an instantaneous case or situation only for that specific time.

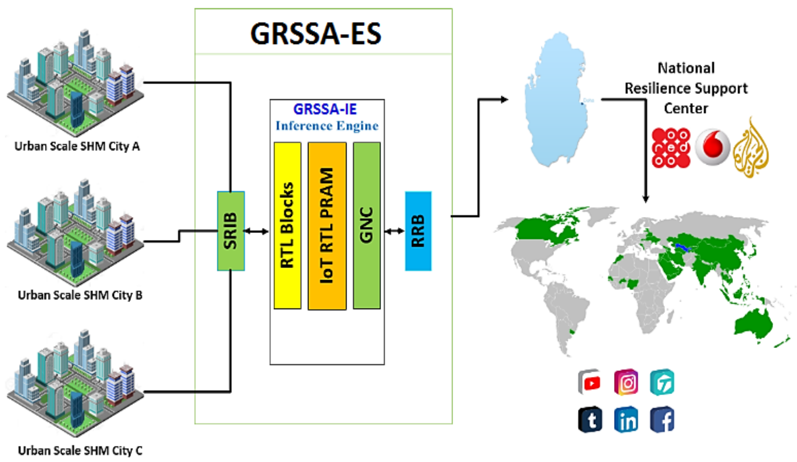

Figure 8. Description of GRSSA-ES interaction with the physical world; a) acquiring regional data from a region of 3 cities with urban scale SHM deployments, and b) generating a geo-response for regional sustainability. This layout is for Qatar as a modelled example.

In figure 8, the proposed overall GRSSA-SDM ES is displayed from LHS to RHS i.e. real-time sensing to resilience response using urban SHM sites and enabling technologies respectively.

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3. Synthetic DADO Machine System Design

DADO is a mega-scale parallel machine designed to support the swift execution of expert systems, as well as multiple, independent expert systems. The proposed SDM based on dual IE concept of the deterministic and comparitive model was implemented in GRSSA. The conceptual block diagram of the proposed GRSSA is shown in figure 3 was running on the SDM. Data processing, AI and machine learning algorithms operate in this inference engine. Real-time rules for operators and operands are being handled through working memory and hierarchy using layers of networks. Rules & SHM definitions are being adopted from the SHM knowledge base unit. SDM has two major sections the hardware or physical section and software section given below:

1. GRSSA-SDM Hardware Section.
2. GRSSA-SDM Software Section.

The sections are comprehended below.

3.1. GRSSA-SDM Hardware Section

The GRSSA tasks are executed on a physical system with three blocks given below:

- GRSSA-SDM Remote Block
- GRSSA-SDM Site Block
- GRSSA-SDM Cloud Block

Each block is explained with detail in the sections mentioned below.

3.1.1. GRSSA-SDM Remote Block

It consists of two layers RPi3 out-surface board (OSB) and CAN-Open sensors nodes, which consist of MMA8451Q(14-Bit Accelerometer) and STM32F10RBT6(32-Bit microcontroller with CAN-Open Transceiver). This is block performs geo-acquisition task presented in figure 1.

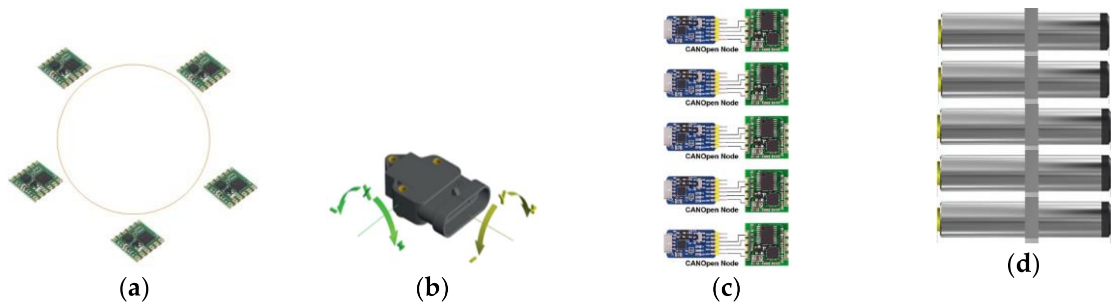

Figure 9. GSSRA-SDM Remote Block: (a) Circular Grid Topology; (b) SSN [33]; (c) Linear Grid Topology; (d) CSN [33].

Figure 9 exhibits the GRSSA-SDM remote block with event tactical sensor topology in addition to configuration options. The physical appearance [33] is shown in figure 9(a) as a seismic sensor node(SSN) and figure 9(b) cylindrical sensors node(CSN). The nodes were deployed in circular and rectilinear orientation to measure primary(P), secondary(S) and Rayleigh(R) seismic waves as a global threat to infrastructure. The topology in figure 9 serves two-fold benefits i) vibration and tilt measurement and ii) assists in the realization of seismic waves with minimum computation cost.

3.1.2. GRSSA-SDM Site Block

It has three layers; Mesh Network Layer using Wi-Fi and Bluetooth (Built-in RPi3), application gateway (Banana Pi R1), and bridge layer (wired and wireless). Two options are available for local

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and remote display and configuration i.e. first on the OSB as SSH for Raspbian OS using VNC and second on SDM-IaaS gateway as Bananian OS as shown in figure 8.

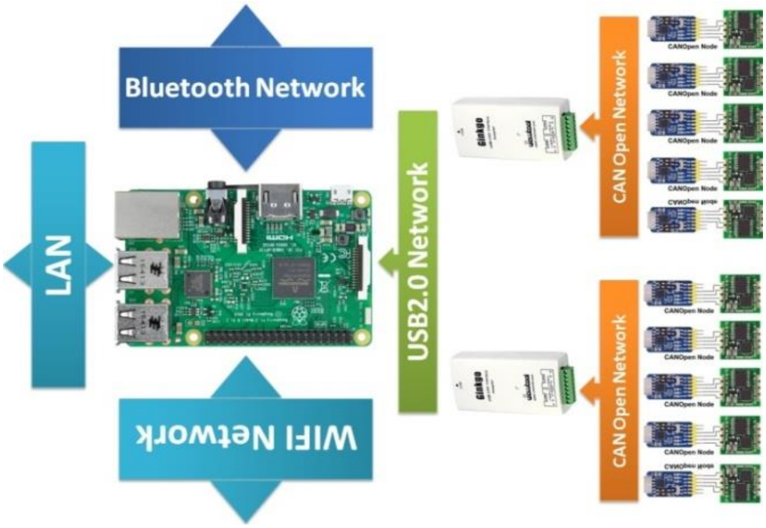

Figure 10. GRSSA-SDM Site Block [33] that performs GRSSA task (i), (ii), and (iii) as distributed computing edge node for RTL block operations with results shared in WMS.

3.1.3. SDM-GRSSA Cloud Block

SDM-GRSSA cloud block is shown in figure 11 with two clouds; the first was a customized cloud that is based on a local workstation serving as a VPS enhanced with MATLAB, Laboratory Virtual Instrument Engineering Workbench(LabVIEW), Apache2, and MySQL Server. The second is a public cloud with VPS that utilized the open-source IoTs. It connected only to ThingSpeak IoT at the time of experimentation and had options for Kaa & EmonCMS services for later implementations.

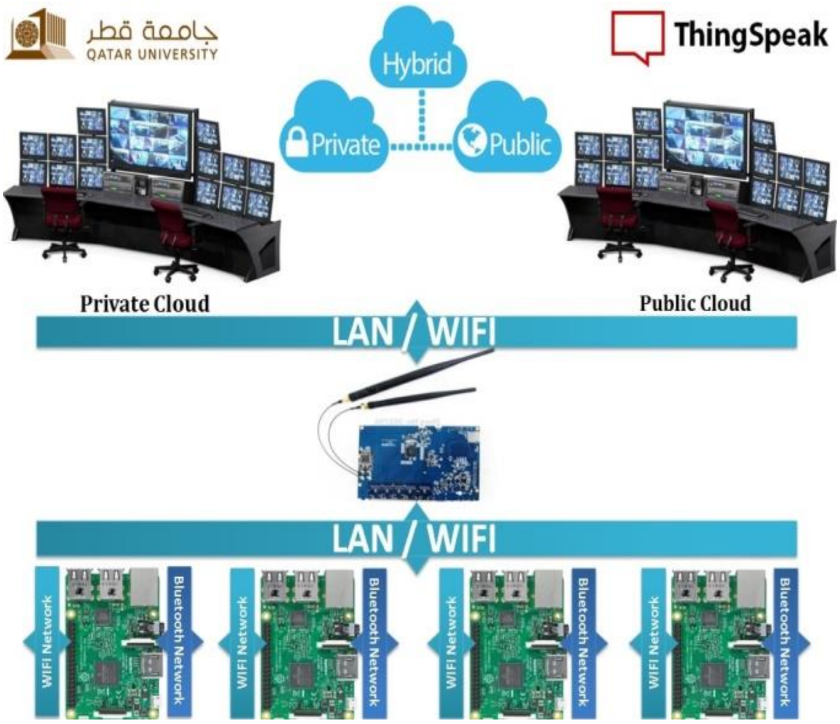

Figure 11. Description of Overall SDM-GRSSA Hardware Section Hierarchy from Site Block to VPS in form of Hybrid Cloud for enablement of GRSSA Tasks (i) to (vii).

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Figure 11 is the complete snapshot of GRSSA-SDM network infrastructure that enabled real-time geo-resilience with very promising results exhibited in results sections.

3.2. GRSSA-SDM Software Section

The robust and swift implementation of GSSRA tasks required very specific software applications combination consisting of two blocks, given below:

- GRSSA-SDM IoT Core Block
- GRSSA-SDM ES Block

Both sections are elaborated below with essential details.

3.2.1. GRSSA-SDM IoT Core Block

This block integrates the entire GRSSA-SDM hardware block shown in figure 11 to perform all GRSSA tasks will utmost agility by utilizing the full spectrum of capabilities of the underlying technology. The big picture is being orchestrated in the form of IoT client, gateway amd server in figure 12.

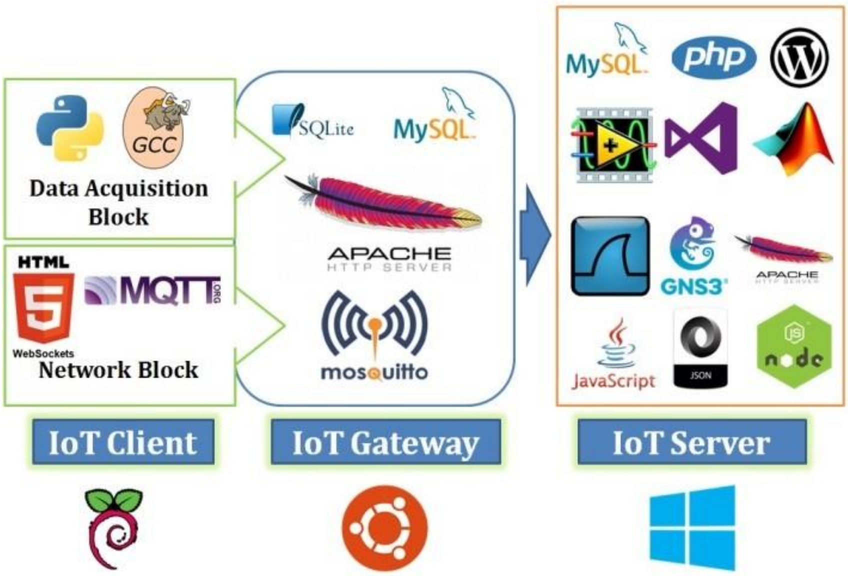

Figure 12. GRSSA-SDM IoT Core Block Architecture

Figure 12 is a mirrored silhouette of GSSRA-SDM hardware and software section. The task assignment is explained below:

1. The IoT client block as zonal distributed geo-processing software platform with CANopen driver was written in C++ and its bash shell wrapper was written in python in data acquisition block. All incoming CANopen connections and outgoing results on WiFi were handled in network block in HTML5 websockets constituting software service for RTL block as distributed geo-processor. The results were constantly uploaded to SQLite as WMS. Secondly, data was communicating between IoT server and IoT client using MQTT, i.e. with MQTT Server in IoT server responding to MQTT client in IoT client.
2. The IoT gateway block as regional parallel geo-processing software platform gathering data from SQLite processing it and saved it in MySQL client database as buffer-zone called IoT RTL PRAM. The private GNC controller was rendered in python that was saving results in PSMP in form of MySQL client database files. Moreover, the MQTT Broker, i.e. Mosquito was also handling multi-threaded two way communication between the IoT node and IoT server.

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3. The IoT server block as a global parallel geo-processing software platform that reprocessed all the results stored in PSMP generated by python and compared results generated by MATLAB with data traffic received at MQTT server interfaced with LABView. The purpose of this re-computation was to ensure the authencity and credibility of geo-response. LabVIEW was interacting with MQTT broker using DAQIO library and MySQL Server database was gathering all the data from MySQL clients on gateways as PSMPs. MySQL Server database was accessed by MATLAB. The same service was IoT server was deployed on a public cloud with Thingspeaks with built-in MQTT server and MATLAB support. The complete Hyrbid cloud hardware and software constituted the proposed geo-resilience paradigm.

3.2.2. GRSSA-SDM ES Block

The GRSSA-SDM-ES block was designed in python 2.7 to perform all the GRSSA tasks from (i) to (vii) through intelligent optimization of the GRSSA-SDM software section over GRSSA-SDM hardware section to address the challenges opted by regional sustainability. This block is a synergic integration and optimization of GRSSA and SDM to achieve geo-resilience. The synopsis of proposed geo-resilience paradigm is exhibited in figure 13.

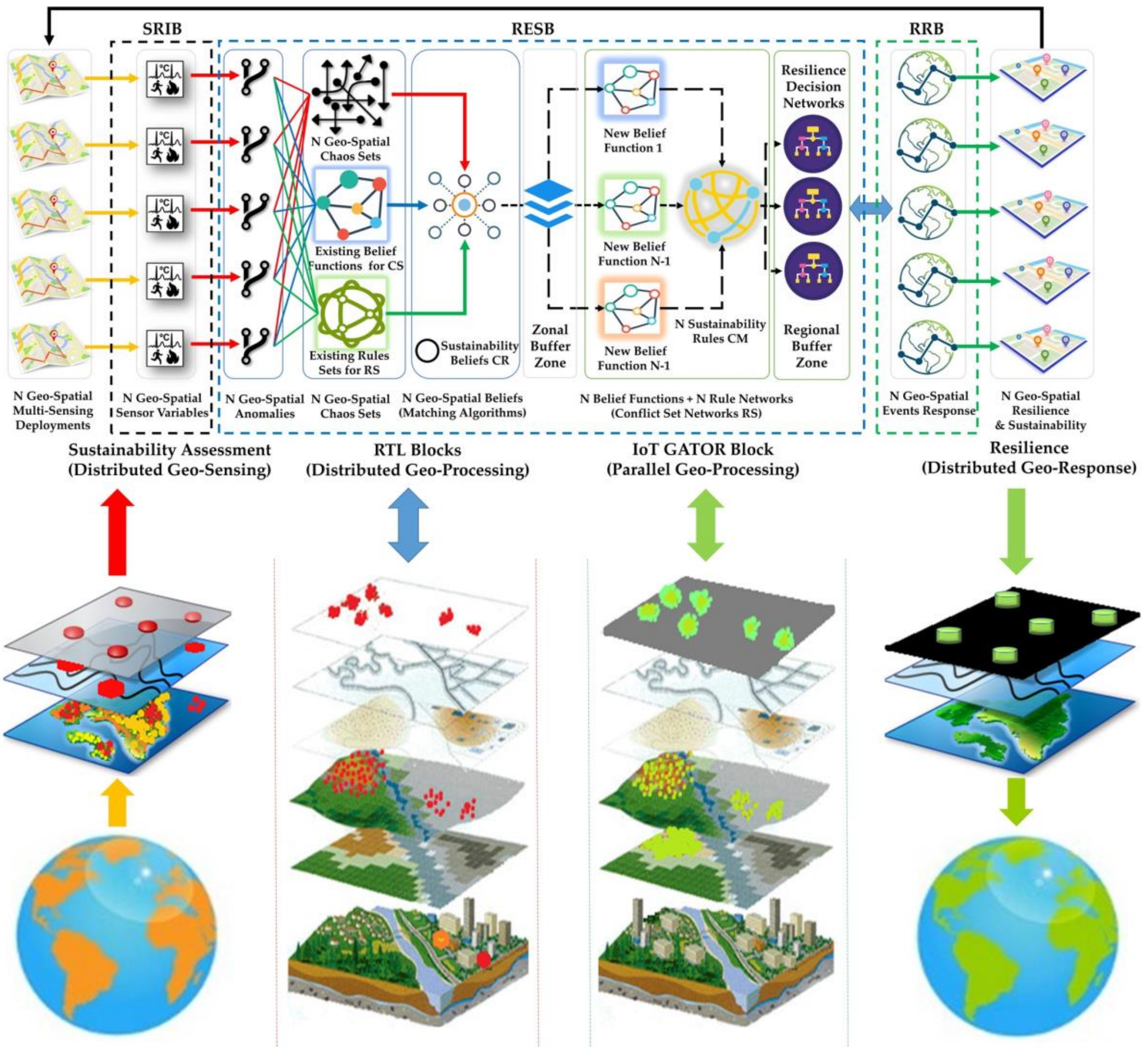


Figure 13. Complete Interaction Diagram for GRSSA-SDM ES

Figure 13 is very self-explanatory and synthesis of entire design work flow. The brownish land globe means earth with disaster challenges and greenish land means earth with sustainability.

4. Case Study: GRSSA-SDM Implementation on SHM Systems at Qatar University

The chosen case study was SHM system prediction for Qatar University (QU) as potential GRSSA-SHM study ground. Three different specification and configuration systems were installed in QU at three physically 1 km apart unique locations, namely, SHM-QU-B09 Lab, SHM-QU-CO5-Bridge and SHM-QU-H10-Research Complex. In parallel the two virtual installations i.e. SHM-QU-B03 Corridor and SHM-QU-B01 Higher Administrative Building. The SHM system details for these locations are:

- SHM-QU-CO5-Bridge SHM Site (SHM-BS) System with 5 SHM-ASSP-ZRC-SSNs
- SHM-QU-H10-Research Complex SHM site (SHM-RC) with 5 SHM-ASSP-ZRC-SSNs.
- SHM-QU-B09 SHM site (SHM-LB) with 5 SHM-ASSP ZRC-SSNs and 10 SHM-ASSP-ZRC-CSNs.
- SHM-QU-B03 Corridor (Virtual Machine Running on Project NPRP8 Laptop) simulating 5 SHM-ASSP-ZRC-SSNs.
- SHM-QU-B01 Higher Administrative Building (Virtual Machine Running on Project NPRP8 Laptop) simulating 5 SHM-ASSP-ZRC-CSNs.

The entire deployment plan for case study QU is shown in Figure 11 published in our earlier papers:

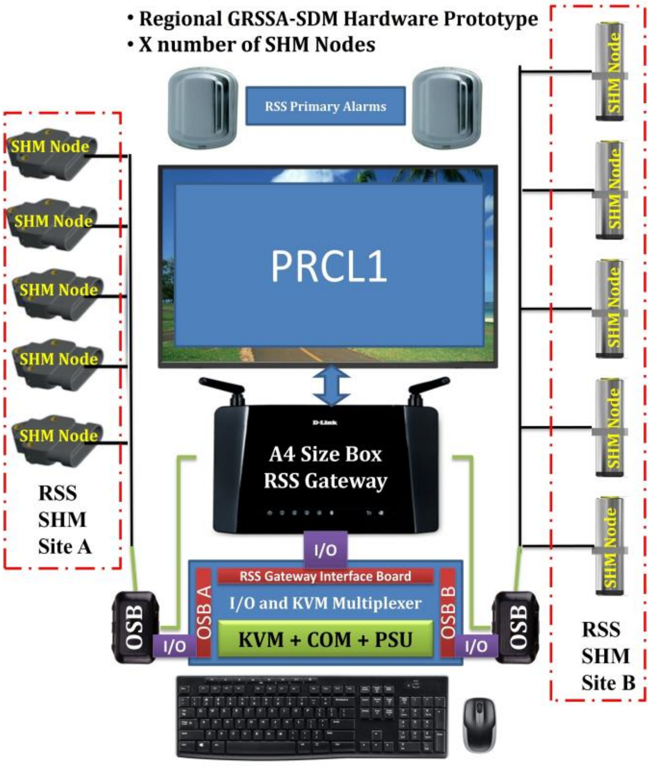
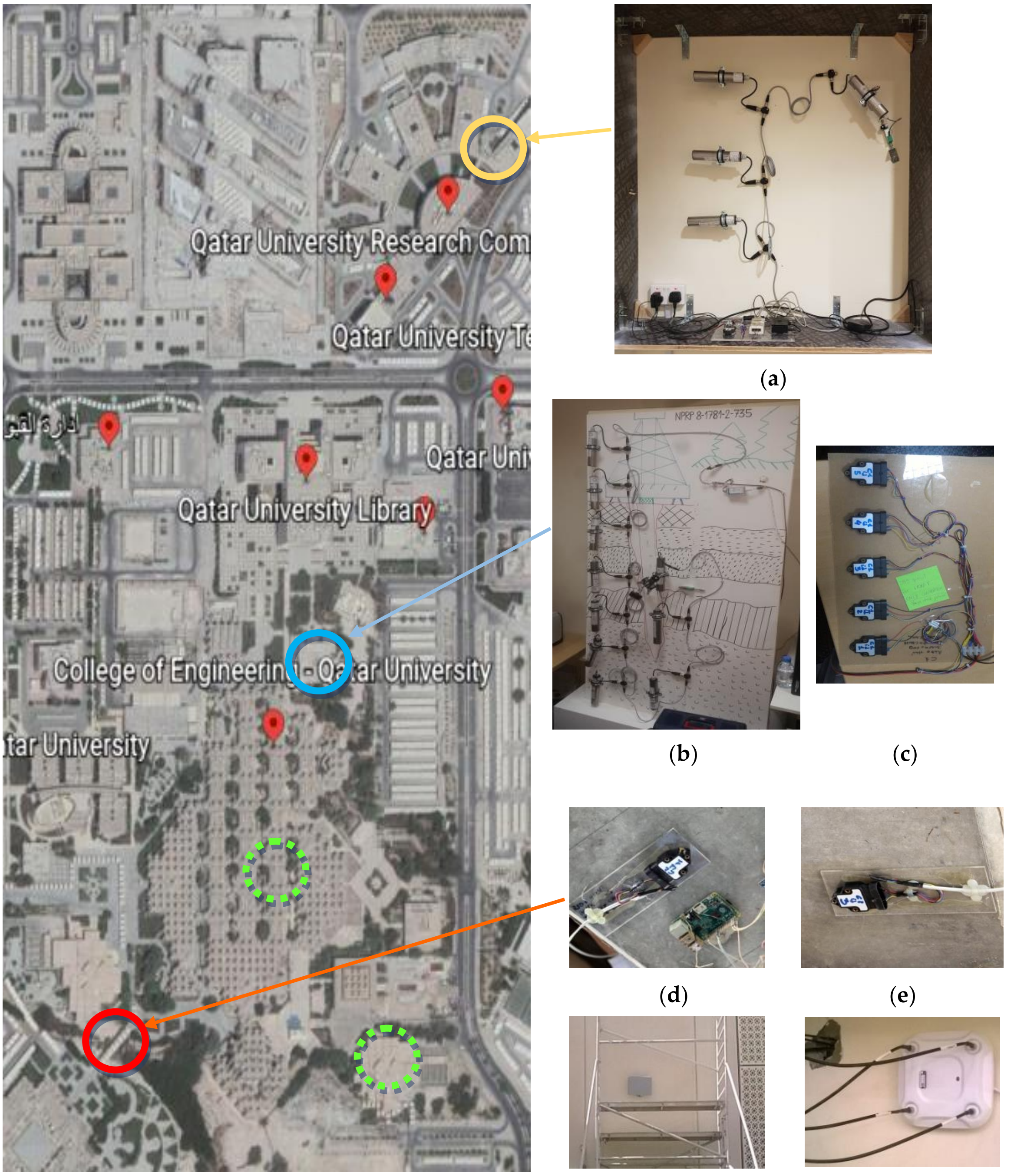


Figure 14. Realization of a Regional GRSSA-SDM Hardware Prototype

In figure 14, a very basic regional level GRSSA-SDM hardware prototype is presented i.e the 2 unique remote blocks were connected with SHM-OSB called out-surface board (OSB) with IoT node software using CANopen network with CAN-USB adapter by Gingko. The CANopen addresses were 1, 2, 3, 4, 5 on both sides. The resilience support system(RSS) sites are RSS-SHM site A with bi-axial inclinometer based nodes and resilience support RSS SHM site B with bi-axial accelerometer-based nodes. The two SHM site nodes were connected to I/O multiplexer block of RSS gateway (installed with IoT gateway software) with keyboard-video-multimedia (KVM) switch for multiple displays, communication ports and power supply unit (PSU).



(**a**) (**b**) (**c**) (**d**) (**e**) (**h**) (**f**) (**g**)

Figure 15. Case Study: QU SHM Sites Deployment Details listed as (**a**) H10 SHM site with 4 CSNs and 1 SSN; (**b**) B09 Lab with 10 CSNs on SHM stand; (**c**) B09 Lab with 5 SSNs on table; (**d**) OSB and a SSN QU Bridge Site; (**e**) SSN QU Bridge Site; (**f**) ODU for QU Bridge site mounted on outer side of boundary wall of C05; (**g**) IDU for QU Bridge site mounted on inner side of boundary wall of C05; (**h**) Overview on Google Maps for QU SHM sites.

In figure 15, the physical deployment of the SHM-QU case study is displayed that was done in C05-Bridge (red), H10-Research Complex (yellow) and B09-Lab (cyan). Two sites are for simulation purpose only i.e. the B03-Corridor (dotted-green) and B01-Higher Administrative Building (dotted-green). The purpose is only to test the model of SHM RSS in urban scale for more data and sites later with 3 physical and rest virtual SHM sites. The pictures and more details of physical sites are given in [33] as figure 9(a), 9(b) and 9(c). Core challenges in swift resilience response in regional level SHM deployments systems were resolved at campus level implementation in this work as:

1. Swift anomaly centered packet transmission P_N in SHM based implementations at a regional scale.
2. Rapid chaos set estimation through T_β as belief function update acknowledgement contributing to anomaly vectors verification matching RTL block performance test.
3. Speedy chaos sets conflict resolution by rules network estimated from the rise in gateway throughput TP as performance evaluation of IoT GATOR block.
4. Brisk resilience response estimated with consistency in packet sequence numbers, i.e. data processing stopped. No further sustainability advice needed.
5. The 15s lag in every variable on ThingSpeak is a real hurdle in real-time geo-analytics. An application-specific web-based private cloud RSS platform with the sustainability assessment capabilities was so far been absent.
6. Regional sustainability GRSS-IE layer generation mechanism was so far missing.

The physical sensor dependent data streams have a dependency on ADC sampling rate thus have lesser data rate i.e. in range of 250 kbps per node. In addition, two virtual SHM systems were deployed with higher data rate i.e. 128 Mbps per. Five different condition monitoring sites i.e. SHM systems were feeding 5 different data streams for the same ER diagram.

The network analysis and performance indicators verify the performance of real-time geo-resilience system architecture. The entire GRSSA-SDM for QU was designed and deployed with the system configuration is given in table 2:

Table 2. GRSSA-SDM SHM Network Configuration

Systems	Packet Size	Data-Rate	Protocols	Nodes Quantity
PBCL	1500 Bytes	128Mbps	IPv4	1
PRCL-N	1500 to 9000 Bytes	1Gbps	IPv4	2+
GRSSA-SDM-Gateway	2312 Bytes	1Gbps	IPv4	1+
GRSSA-SDM-Site Blocks	32-Bit to 251 Bytes	100Mbps	IPv4 & BT4.2	5+
GRSSA-SDM-Remote Blocks	8 Bytes	250kbps	CANopen	15+

The backbone of any data processing system is data processors and data buses in any definition. The databases are data processors and their size as well as the technology of storage that includes access time and read/write time play a vital role in data processing capabilities of systems. The GRSSA-SDM-ES data configuration for synthetic DADO machine is given in table 3.

Table 3. GRSSA-SDM-ES Data Configuration

Systems	Database	Role	Size on Disk	Technology
PBCL	MySQL 5.5	Server	3 TB	PCI-E SSD
PRCL-N	MySQL 5.5	Server	1 TB	m.2 SSD
GRSSA-SDM-Gateway	MySQL 5.5	Client	200GB	SATA SSD
GRSSA-SDM-SHM Site	SQLite 3.0	Client	8GB	Micro-SD-XC
GRSSA-SDM-Remote Block	NIL	Node	32KB	SPIFFS

Furthermore, the data architecture was designed in a way that whenever the hierarchy moves upward the width of data block or size of data processing clusters risen. Two core analysis mechanisms used for GRSSA-SDM implementation and performance analytics were Wireshark 3.0 and Python IDLE 2.7 with the following libraries:

- pyknow for expert systems implementation with the addition of three improvements RETE, TREAT and LEAPS programming and customization to formulate RTL block
- NetworkX, Scipy, numpy, and pyknow together to design GATOR block
- pyknow, NetworkX, Matplotlib, network2tikz, and pysocks to plot the geo-analytics of GRSSA-SDM performace analysis and operations.

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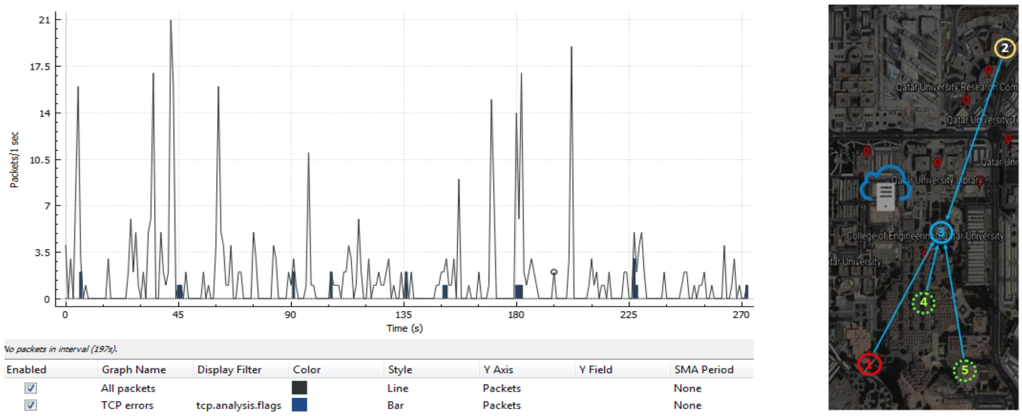
5. Results

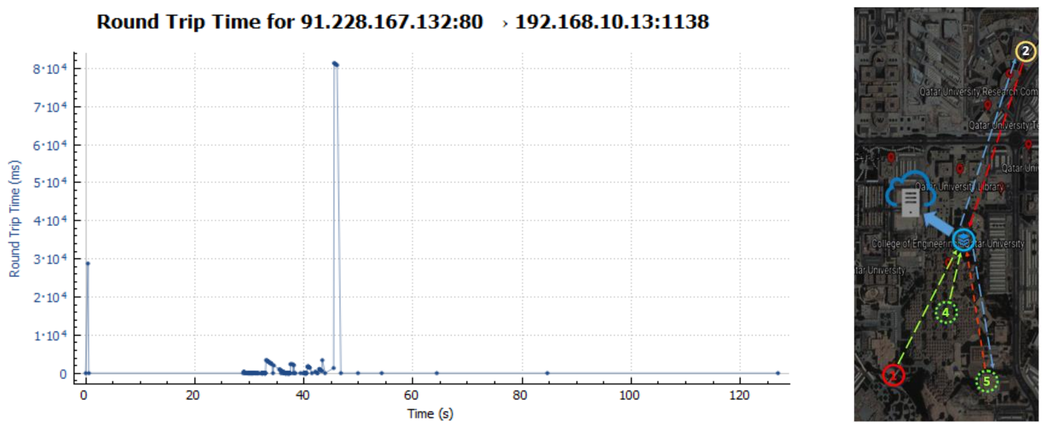
The results followed the proposed methodology steps sequence given in section 2 for regional computations. The first step was the start of transmission from remote block to the gateway as P_N trace from equation 6 in figure 16.



(**a**) (**b**)

Figure 16. Desciption of GSSRA-SDM Site to Gateway, P_N I/O Graph as (**a**) First 270 seconds trace at GNS3 running on IoT gateway in B09; (**b**) Data network establishment for the sensor to gateway uni-directional as communication of five sites.

In figure 16, we can see that the maximum 21 packets/second transmission took place from SHM Sites to RSS Gateway i.e. 48552 bytes/second or 388.416 kbps as per table 2. Only anomalies data A is transmitted upward in the hierarchy to avoid collision and data fusion scenarios. This data rate is suitable for 15 CANopen nodes with a total of 75 variables, i.e. 15 x-axis tilt-angles θ_x, 15 y-axis tilt-angles θ_y, 15 x-axis accelerations A_x, 15 y-axis accelerations A_y, and 15 temperatures. At 250 kbps for 15 nodes, it is calculated as 3750 kbps in the ideal case for CANopen 3 clusters only i.e. 58593.75 packets/second of CANopen. But when it comes to CANopen data nodes in the form of tables transferred and accessed as queries then the situation is much more complex.



(**a**) (**b**)

Figure 17. Line plot for two β_0 and β_1 belief functions update round trip time as (**a**) Two acknowledgements of anomalies at 571ms and 46s (**b**) Site 2 and 5 received packets from the gateway as well as primary alarm in dotted blue and entire WMS and PSMP accessed by PRCL.

Figure 17 shows that T_β at 46.1 seconds as the maximum round trip time in updating the belief function β_1 in the worst case in this trace computed from equation 7. The first β_0 was updated at 571ms and second at 29.4 seconds in figure 13. It can take even one complete solar day to update one belief function depending on the size of Rss(STATE).

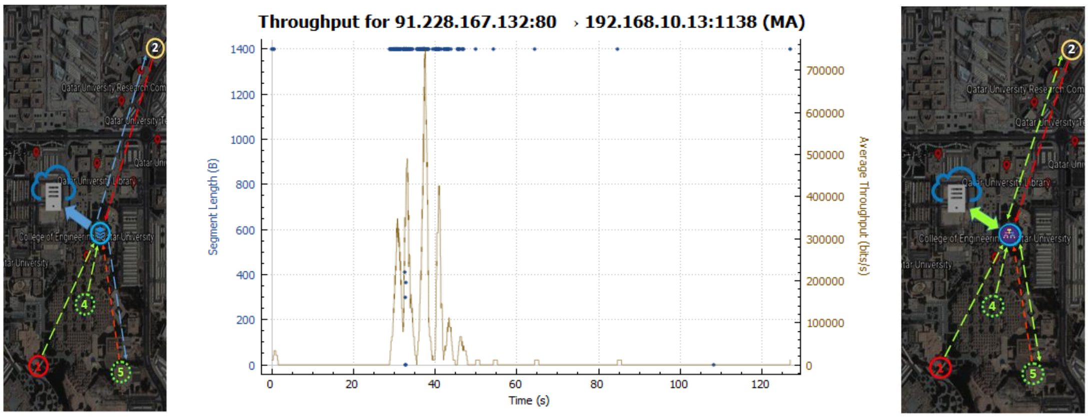


Figure 18. Description of GRSSA-SDM-gateway throughput as (**a**) Bi-directional communiation between two nodes (**b**) first 2 minutes for SHM 5 sites and 6 nodes at different MTUs; (**c**) Bidirectional communication between three nodes as new sustainability update in green lines.

The equation 8 resulted in in figure 18 plot as gateway throughput. In figure 17, the frequency of acknowledgements had increased at 29.4 seconds as throughput demand as gateway needed new more beliefs to characterize the run-time anomalies. The WMS and PSMP were updated when belief functions and rule network needed updates. Furthermore, it was observed that the maximum throughput of 749,300 bits/second was achieved 37.2 seconds with a segment size of 1482 bytes on a GRSSA-SDM gateway with MTU=1500B. Achieving event response below MTU at such a low data rate was the very competitive benchmark.

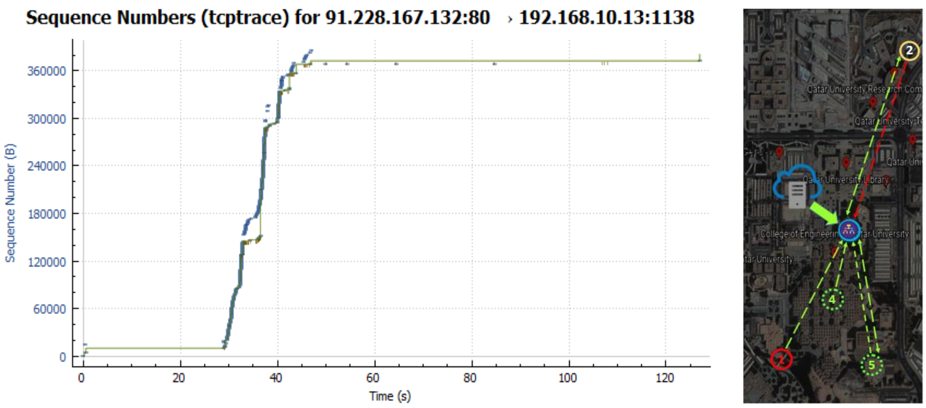


Figure 19. Description of sequence numbers generated at GRSSA-SDM-gateway as (**a**) first 2 minutes by GNC for rule network update till resilience response; (**b**) new decision tree loaded into gateway from PRCL and sustainability advice or resilience reponse conveyed to two nodes in green.

In figure 19, the equation 9 computed sequence number were illustrated i.e. GRSS-SDM 11,000+ sequence numbers generated for the first belief function update and first event response for a particular SHM variable and second at 148,586th sequence number. The horizontal green line is the time in which one belief function data stayed consistent and blue dots represent that response generation stayed constant with every next sequence. After 360000+ sequence numbers, the belief function achieved maturity as reflected by a horizontal line. The events generation stopped 372000th token at 48 seconds means no all possible rule networks and event responses calculated.

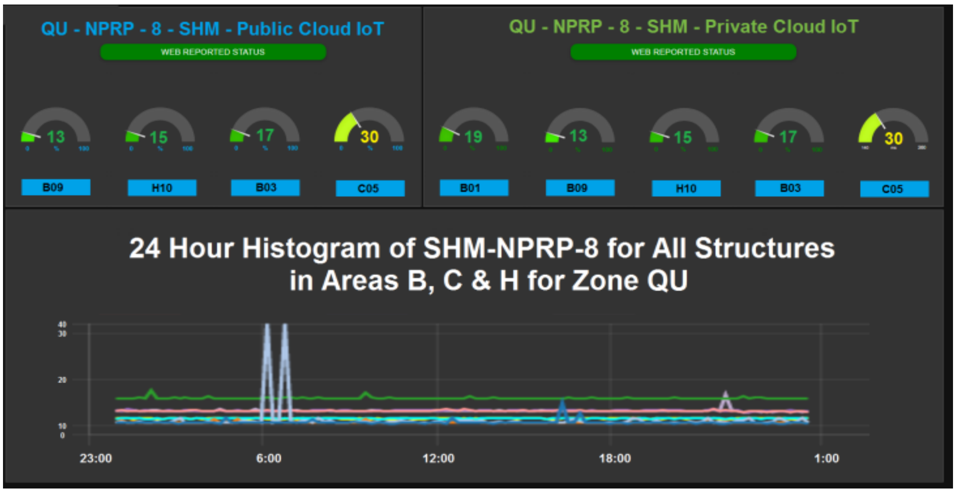
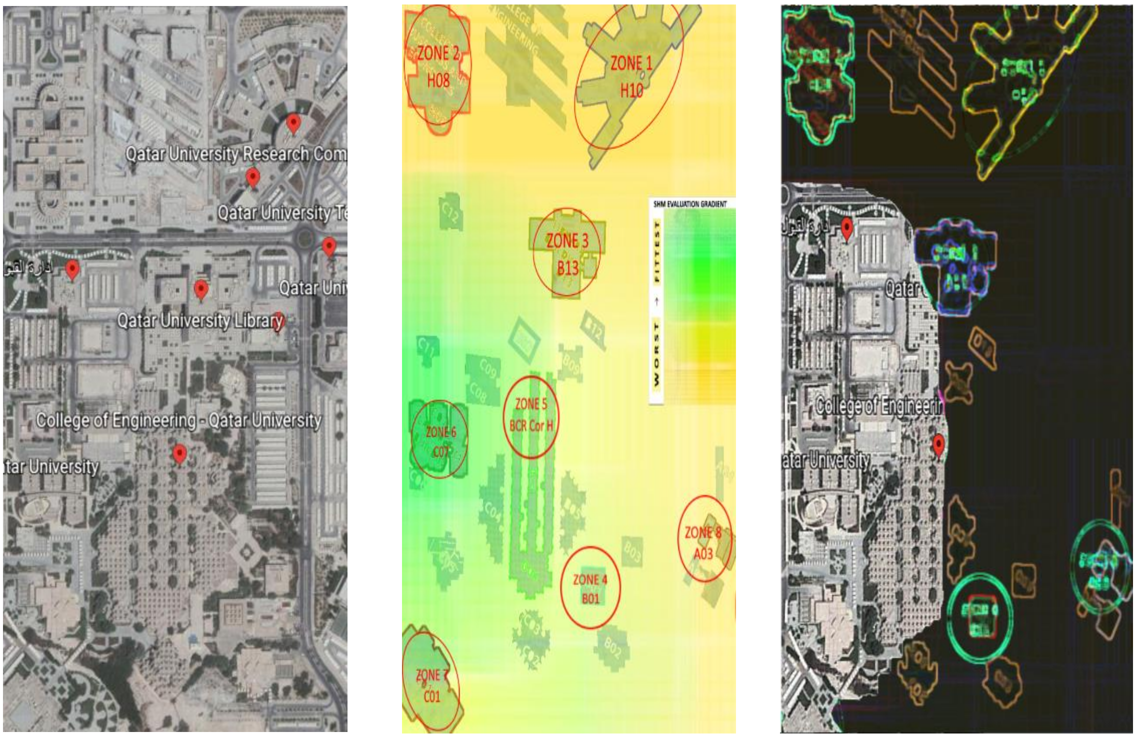


Figure 20. Line plots and speedometer charts illustrating the health of structures in QU as per deployment details are given in figure 11 in form of Real-time QU-RSS Dashboard for Hybrid Cloud

Step 4 is H(%) estimated by equation 10 is displayed on the RSS-SHM Dashboard as speedometers. In figure 20, we can see RSS dashboard as a holistic overview of the system. The green-colored speedometer charts show zero resilience needed. There occurred a condition at 6:00 am for SRIB to transmit 40kb/s and at 6:30 am again to depict the mass employee or staff movement due to change in duty shifts. Absence of color speedometer charts on the dashboard means the system is fulfilling the safety integrity level (SIL) parameters and conditions. The line graph in the bottom displays the number of belief functional values updated in 24 hours that are only 40.



(**a**) (**b**) (**c**)

Figure 21. The SHM-RSS Events Response Layer are shown as (**a**) Google Earth View; (**b**) SHM-UCM Layer (MOSPA); (**c**) GRSSA-SDM-IE Layer.

The final step geo-spatial plot is estimated as by subtracting Figure 21(b) from Figure 21(a) as well as applying "the condition zero" defined in step 5 in section 2. Figure 21(a) is the actual view without application of GRSSA-SDM-ES as acquired from Google Earth. In figure 21(b) we have used

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a machine learning algorithm MOSPA for urban scale geo-informatics and SHM analytics presented in [33] as an applied algorithm for testing. The belief functions in RTL block in figure 17(c) optimized WMS by deleting the green area from conflict sets, the green area guided the citizens are a safe location to move till the brown area was set for recovery that took the time of 80.2 seconds to mark H08 and B01 as recoverable zones. The yellowish area turn is in WMS and GATOR networks generated only safe exit response for inhabitant till the areas get back to normal. The cost of damage is the parameter of assessment in MOSPA whereas in RSS-IE the number of independent parameters for unit events in minimum time is the degree of merit. Maximum cost leads to maximum resilience needed. Cost refers to the real-time damage estimated and predicted lifetime damage of structures and human resource.

6. Discussion and Limitations

6.1. The Problem/Challenge

Regional events are happening in parallel at different geospatial locations. The resilience delay due to the tendency of similarity between these events is very high. The runtime sensing and classification of these events is domain-dependent as resilience parameters vary from domain to domain i.e. environmental, structural, geological, utility grid, and water supply, etc. The real test of any geo-resilience is generating a unique and swift resilience response with minimum resources and time to handle heterogeneity or a variety of zones and regions.

6.2. The Contribution of Proposed GRSSA-SDM Paradigm

An organization level GRSSA-SDM was designed to test this RSS machine by using inputs from three physically deployed SHM systems visible in figure 15. The sensor dependent data streams have a dependency on ADC sampling rate thus have lesser data rate i.e. in range of 250 kbps per node. In addition, two virtual SHM systems were deployed with higher data rate i.e. 128 Mbps per also visible in figure 15. Five different condition monitoring sites i.e. SHM systems were feeding 5 different data streams for the same ER diagram. The step-wise operations of RSS are given below:

1. Step 0: All the SHM nodes set sensor data as variable vector V given in equation 1. The data was continuously monitored for unsafe conditions M and safe range N and anomalies vector ΔA was estimated from equation 2. Equation 3 and 4 were only for ideal RSS system.

2. Step 1: The diversity and variety expected at urban-scale were computed from equation 5 as resilience system state Rss(STATE). The first factor in equation 5, ${}^{D}C_{B}$ = 2 i.e. two unique data rates were used. The second factor, ${}^{US}C_{V\text{-}SHM}$ = 10 i.e. 3 SHM sites were unique out of 5. The third factor, ${}^{V}C_{SHM\text{-}SENSOR}$ = 595 i.e. 2 unique out of 35 total sensor nodes. The Rss(STATE) for the given case study was computed as 11900 from equation 5. The data size fed to GRSSA-SDM machine by SHM sites was 11900 x size of data-type. In our case was integer i.e. 11900 x 4 bytes = 47600 bytes. Means 11900 event states fed to RSS. The data rate was 48552 bytes/second meant all sent to RSS and number of packets required for end to end communication were 20.5882 packets but results shown 21 packets/seconds as displayed in figure 16.

3. Step 2: The T_{β} estimated by equation 7 had to be ideally in milliseconds taking into account the capability of Corei7 processors by in reality was totally dependent on GRSSA-SDM network infrastructure and quality of communication channels. The value 571ms was too ideal whereas 29.4 is near to realistic as shown in figure 17.

4. Step 3: The RSS system achieved its goal at lesser MTU i.e. 1492 as shown in figure 14. It had shown its fitness and robustness for handling heterogeneity at urban-scale.

5. Step 4: The sequence numbers in figure 19 are quite promising i.e. 11,000+ and 148,586 for first two belief functions means the system was ready to broadcast resilience response in less than imposed condition zero i.e. 2^{16}.

6. Step 5: The figure 20 shown the application of equation 10 as H(%) for the given case study. The structures with N>M were green as per anomaly conditions in equation 2.

7. Step 6: The GRSSA-SDM-IE live geo-analytics layer was generated by equation 11 shown in figure 21. The area with better health had fewer anomalies and less belief function update times thus were green. Whereas areas with a higher number of anomalies or zero installation of SHM system had unknown conditions both turned black.

The porposed RSS had four limitations that were observed during the implementation phase and are given below:

1. The limitation of this work in implementation on urban structures was the requirement of a thoroughly tested and functional RTL framework.

2. Data integrity in WMSs was mandatory for RTL framework was a second limitation.

3. Minimum of 749,300 bits/second TP was mandatory for fast read/write capabilities of IoT RTL PRAM to enable the GATOR network to operate at full potential for every 45 sensors sets was the third limitation.

4. Regional sustainability documentation with standardized beliefs, rules, anomalies, chaos definitions need to be defined by regional authorities and knowledge experts in infrastructure monitoring and resilience response domain. The identification of sustainability parameters for infrastrucute itself is a separate and complete study.

Regional sustainability, infrastructure monitoring and geo-resilience are very vast fields. In this work a new concept of systems of systems for geo-resilience was introduced as a cyber-physical system assist automated resilience capability incorporation in state agencies. There should be an international commission for setting the global resilience standards that must be verified by resilience solution designers.

7. Conclusions

The pioneered GRSSA-SDM platform leverages thriving significance in swift geo-resilience and regional sustainability approaches. The desideratum of regional infrastructure sustainability was to express resilience response and ascribable platform parameters. GRSSA-SDM is a conjunct optimization of an intelligent AI implementation architecture amalgamated with regional infrastructure monitoring systems. The adequacy of GRSSA-SDM in assisting regional authorities as a reliable infrastructure sustainability tool was demonstrated in the presented case study as:

1. Tangible regional disaster model parameters as anomalies, anomalies vectors, and chaos sets computed from geo-distributed sensor variables capitalizing equations (5) to (11).
2. Intrinsic regional sustainability axioms as beliefs, belief functions, rules, and rule networks ciphered from self-configurable inference engine i.e. achieved in RESB by optimization of synergic strengths of RETE, TREAT and LEAPS matching algorithms as RTL block with shared WMS to assist further summarization in networks by GATOR algorithm through RTL PRAM.
3. Indisputable and indigenous resilience response stored in RRB as an outcome of conflict resolution and conflict support axioms in IE.
4. ER diagram reflecting a regional data model for managed data integration of infrastructure monitoring systems to assist GRSSA-SDM processes.

5. Swift resilience support through geo-distributed and geo-parallel computing platform as GRSSA-SDM software/hardware co-design platform with perform the tasks (i) to (vii) along with the governance of equations (5) to (11).
6. The achievement of maximum desired TP below the rated MTU=1500 as 1492 visible in figure 18 was possible due to buffer zones. The regional and zonal buffer zone design through client-server database system models using SQLite-MySQL client for WMS for zonal results and parallel computing input support and MySQL client to MySQL server for PSMP for regional parallel computing support.
7. The resilience response tracking as network operations analysis by utililizing Wireshark as well as geo-analytics, as shown in the results section.
8. A resilience response using sequence number stability and GRSSA-SDM IE layer generation to assist regional authorities as easiest sustainability eloquent benchmark.

Adaptive and comprehensive geo-resilience tools for regional sustainability authorities in the form of physical hardware and software as a novel multi-objective edge computing solution was the service rendered in this work.

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