Asian Journal of Pharmaceutical and Clinical Research
INNOVARE ACADEMIC SCIENCES
Knowledge to Innovation
Online - 2455-3891
Print - 0974-2441
Special Issue (April)
Full Proceeding Paper

INTERNET OF THINGS-BASED MULTISENSOR NON-INVASIVE TECHNOLOGY FOR ROBUST MONITORING OF TUNNELING INFRASTRUCTURE

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Received: 13 December 2016, Revised and Accepted: 03 April 2017

ABSTRACT

Objective: Tunneling is primarily one of the most expensive and uncertain endeavors in civil engineering. Hence, it is essential to explicitly quantify to consider all factors which in aid contribute toward uncertainty in terms of cost, time, and resources.

Method: This research work provides major internet of things (IoT)-based computational and analytical tools for automating the non-invasive structure monitoring methods to provide decision aids in tunneling. Such decision aids technologies for tunneling process comprises multisensory networks for monitoring of structure, smart video cameras for geo-traffic monitoring and supported excavation during accidents, and light detection and ranging technology for mapping deformations in the structures.

Results and Discussion: The presented research will reduce uncertainties, and information can be used to monitoring future risks. This work extends IoT-based multisensory network system to achieve complex tunnel systems to develop a framework which will allow the experience gained from past projects to update predictions about cost of construction in conjunction with time as the construction takes place.

Keywords: Internet of things, Tunnel infrastructure, Data fusion

 DOI: http://dx.doi.org/10.22159/ajpcr.2017.v10s1.19745

INTRODUCTION

Tunnels involve working in dark, and structures prone from structural defects causing collapse or other factors such a landslide, fire, could cause accidents during mining works. As a result of technological development with time, tunnels construction had become more commonly used as transport routes that link places, rails links, vehicles, and also as canals for water diversion is infused with heavy machinery [1-3]. These factors generally led to loss of human life. India witnesses several tunnel accidents every year. Hence, it is important and imperative to include the machine intelligence for tunnel construction and design and also for monitoring the tunnel for possible hazards or accidents [4-6]. As tunneling is prone to natural disaster, it is mandatory to analysis the roles of technology equipped with a specific focus such as to minimize the casualties and loss incurred when disaster strikes.

Tunnels are subjected to natural hazards, such as earthquakes and winds, and human-made hazards, such as fires and landslides, during their long-term use. To mitigate these hazards, monitoring these risks by sensing certain types of physical values is necessary. Here, smart sensors (mote) are used to monitor structural motion [7-12]. The Mote has on-board microprocessor and ready-made wireless communication capabilities to understand the feasibility of tunnel defect monitoring. Wireless sensor networks consist of many nodes having one or several different sensors on board. After the recording and a preliminary analysis of the data in the node, the data have to be transmitted using, for example, a radio transmission system to a base station or supervisor for further data processing or proper generation of alarm messages.

To monitor the defect in tunnel infrastructure, data have to be collected from several parts of the structure, in which light detection and ranging (LiDAR) plays a pivotal role. The core technology of the terrestrial laser scanning is the LiDAR technique, which is used to obtain the distance of each object point from the lens. The acronym LiDAR stands for light detection and ranging. The laser system produces and emits a beam (or a pulse series) of highly collimated, directional, coherent, and in-phase electromagnetic radiation [13-16]. When the light reflected by the surface of an object is received, the system can calculate the range by the flight time and acquire the reflectivity of the surface.

To ensure safety, long-term stability, and quality control in modern tunneling operation, the acquisition of geotechnical information about encountered rock conditions and detailed installed support information are required. The limited space and time in an operational tunnel environment make the acquiring data challenging. In this context, collaborative communications among the nodes play a major role with the help of smart sensors [17-21]. These coordinated activities for the rescue of victims from natural disasters are termed as crisis management system. The activities among the players have to be planned *a priori* to achieve a common task to avoid a major damage. To execute the plan efficiently, initial decision is put forth by the decision maker and roles/priorities are assigned to each player. Once the task is set, players will efficiently engage themselves alone or by grouping among themselves on the real field. To search victims, players move constantly in the field to look up for the affected people. Once the victim is found, the players take an action, and in case any help needed, players communicate with their peers for collaborated task. However, in real field, there might be a condition encountered by a player, for which the needed action is not assigned to that player due to the role and the priority of that particular player. Since the mission is critical, the player is obliged to take an action for this unknown circumstance and notify this new context/decision to its peer and chief rescue officer. Then, the whole mission will rearrange/reorder the roles and priorities of the players to adapt to this new environment.

In this kind of scenario, the communication between the players is important for collaborative work, and this is achieved by providing reliable connection among the smart devices [21-25]. However, in real time, offering continuous availability is a real challenge due to disruption or attenuation of signal medium that results in disconnection with their peers. If there is a failure in connecting medium, the device has to shift to other medium for nonstop communication among the players. In addition to that, mission requires video streaming of intervention area, group call between the players, etc., that will deplete the battery power of devices [25-27].

Hence, the idea is to motivate a mission aware middleware that anonymously handles the difficulties for interacting and controlling the device communication infrastructure. The middleware monitors the resource context, and disruption is analyzed to identify the cause, and adaptive measures are taken to retain the communication. Predefined adaptive policies are come in handy for dynamic reconfiguration to ensure the continuity of the mission task.

The challenges in regard for sampling data in tunnel involve few challenges such as:

1. The sampling of tunneling environment and deformation sensing nodes for multiple samples
2. To investigate the dynamics of multifused tunneling data, the readings taken by different nodes must be correlated with respect to time
3. To meet synchronization requirement in tunneling scenario, the communication protocols need to work in synchronization by creating a hierarchy among the network nodes, whose clocks are then synchronized with the root's clock.

We have overcome all of this challenges in the presented research project with the real-time implementation and testing on tunneling sites in and around Chennai (India) location where we have the current development of underground metro station is an ongoing process.

METHODS

In our research proposal, we are going to focus on integrating internet of things (IoTs) with four other technological advances that play a vital role in the following aspects [28,29]:

Adaptive wireless network communication middleware (Fig. 1)

Motivated by the need for model checking, we now construct an algorithm for adaptive wireless communication middleware for verifying data fusion and form B-trees to overcome this riddle.

Thus, for every p≥N, where N is the filter's buffer window for the number of input observation to be fused. Note that N is also the number of steps taken to detect the breaking point in the trait sequence. The input dynamics of the trait sequences are given by the following function [30-32]:

update ( ){

$y(p+1)=\varphi(p)y(p)+G(p)u(p)+w(p)$

$i(p)=H(p)x+v(p)$

}

Where, φ(p) is the matrix representing the state transition, G(p) is the matrix for input transition, u(p) is the input vector from locally available drones, H(p) is the measurement matrix, and u and v are the backtrack index variables for the intervals of the trait sequences.

The initial state distribution of the primary trait vector (i.e., when K=1) is given by,

$\tau_i=P(V_1=i)$

The observation variables O_K at the end of each of the multiple drones can take one of K possible values. The probability of a certain observation at K index for state j is given by,

$b_i(o_K)=P(O_K=o_t|V_t=j)$

Taking into account all the possible values of O_K and V_K, we obtain the weighted b_k, i.e., indices trait sequences corresponding between the adjacent blocks by N matrix $b_k=\sum_{j=1}^{K} b_j(o_K)$. An observation sequence is given by $O=(O_1=o_1,\ O_2=o_2,\ldots,O_K=o_K)$. We need a symmetric flow of information in dynamic multiple drone system such that by introducing transfer entropy T to facilitate coordination by identifying the coupling between V_t and O_t on O_t's history i.e.:

$O_{t-1}=\{V_1,\ O_1,\ T_1,\ldots,V_{t-1},\ O_{t-1},\ T_{t-1}\}$

$$T(V_t > O_t, \tau) = \sum_{O_t, O_{t-1}, x_{t-\tau}} P(O_t, O_{t-1}, x_{t-\tau}) \frac{\log P(O_t | O_{t-1}, x_{t-\tau})}{P(O_t | O_{t-1})}$$

Thus, we can describe a hidden Markov chain by initializing the computing with θ = (V, O, τ) iteratively updating for local weighted maximum for θ*=argmaxP(O|θ)(Fig. 2).

Algorithm: Trait-based model injection algorithm (TBMIA)

0 Evaluate:

$$\hat{y}(p) = \frac{1}{N}\sum_{i=0}^{N-1} i(p-1)$$

update ( )

1 Initiate: $m(A_1|A_2) = \frac{\sum_{A_1 \cap A_2}^{p} m(\prod_{j=1}^{N} A_j)}{\sum_{A_1 \cap A_2}^{p} m(\prod_{j=1}^{N} A_j)}$ //(Fig. 1)

2 For each ($A_1 \oplus A_2$) do update ( )

3 Compute: $m(A_1|A_2) \leftarrow \sum_{A_1 \cup A_2}^{p} m(B_1|B_2)$

4 Check: $m(B_1|B_2) = \frac{\sum_{B_1 \cap A_2}^{p} m(\prod_{j=1}^{N} B_j)}{\sum_{A1 \cap B_2}^{p} m(\prod_{j=1}^{N} B_j)}$

5 For each ($B_1 \oplus B_2$) do update ( )

6 Compute: $m(B_1|B_2) \leftarrow \sum_{B_1 \cup B_2}^{p} m(C_1|C_2)$

7 Check: $m(C_1|C_2) = \frac{\sum_{C_1 \cap B_2}^{p} m(\prod_{j=1}^{N} C_j)}{\sum_{B_1 \cap C_2}^{p} m(\prod_{j=1}^{N} C_j)}$

8 For each ($C_1 \oplus C_2$) do update ( )

9 Compute: $m(C_1|C_2) \leftarrow \sum_{B_1 \cup B_2}^{p} m(B_1|A_2)$

10 Return (p, m) co-simulation sequence.

11 end

12 end

13 end

14 Stop

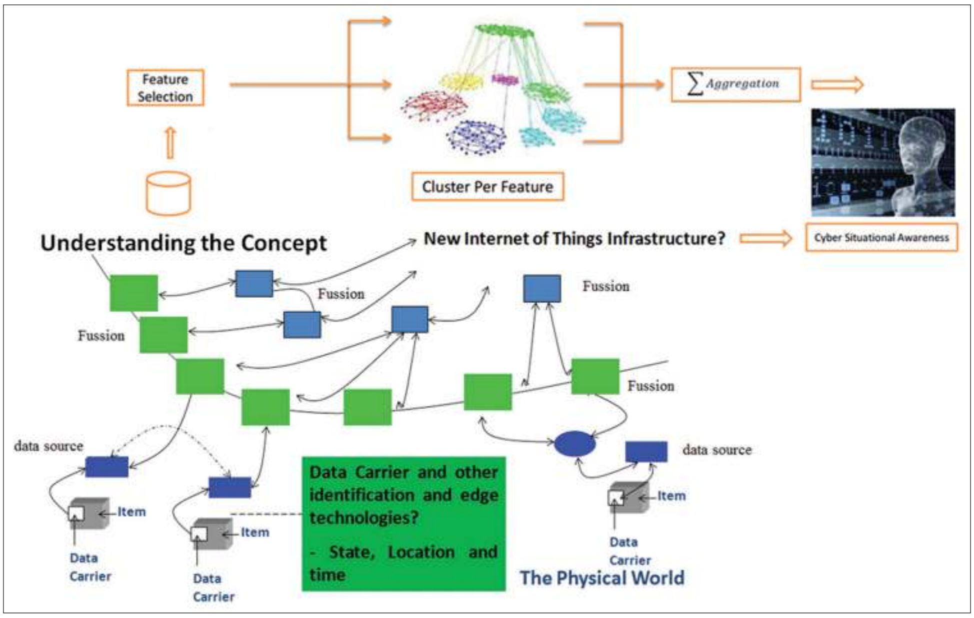

Fig. 1: Architecture of the middleware to avail information fusion while data are processing from one end to another

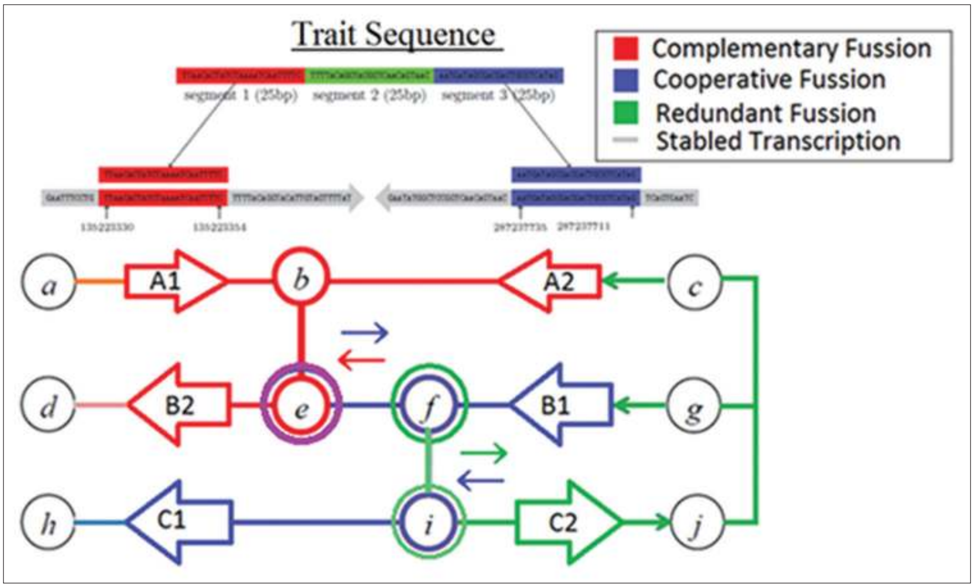

Fig. 2: Illustration of model injection types achieved from trait-based model injection algorithm from sparse trait transcription of multiple drones. Where a, d, and h represents the final state, whereas b, e, f, i, c, g, and j are the meta-states. A_1 and A_2 are the two model sequences of networked process, whereas same with B and C notations represent the subsequent fusion of trait sequences formed in due intermediately process

In the event of catastrophic incident caused by natural disaster, a rescue team is set up to help the victims who trapped inside the tunnel. Thanks to incorporated smart devices, the rescue team cooperates with each other to attain a mutual task in the mission. The efficient collaboration is ensured by providing the reliable connection and communication among the smart devices. However, the mission evolves continuously and tasks assigned to the players' changes abruptly that force the communication infrastructure to reform the connection sources. Furthermore, incessant access to network connectivity between the devices is very intricate within the framework of a wireless environment. To tackle these challenges, the research work focuses on mission-aware middleware architecture which is capable of dispensing a dynamic infrastructure for uninterrupted communication between the rescue team. The middleware monitors the mission context for any deviation, and reconfiguration action is executed if there is an abnormality. Semantic modeling facilitates the middleware to comprehend the different mission contexts, and semantic web rule language instructions are used to understand the degree/severity of context. Providing generic resolutions for automated self-reconfiguration is motivated by rule-based reconfiguration policies using ontology [33,34]. With this adaptive communication middleware, we will not only able to connect sensors, establish communication, under tunneling lines but also we will be able to dispatch several essential sensors data free flowing across the mining lines. It paves the way forward for the other monitoring infrastructure to be laid out in tunnels for monitoring purposes.

RESULTS AND CONCLUSION

One of the key techniques to ascertain the safe and smooth implementation of the tunnel construction is tunnel monitoring. We presented the development of IoTs enabled infrastructure for

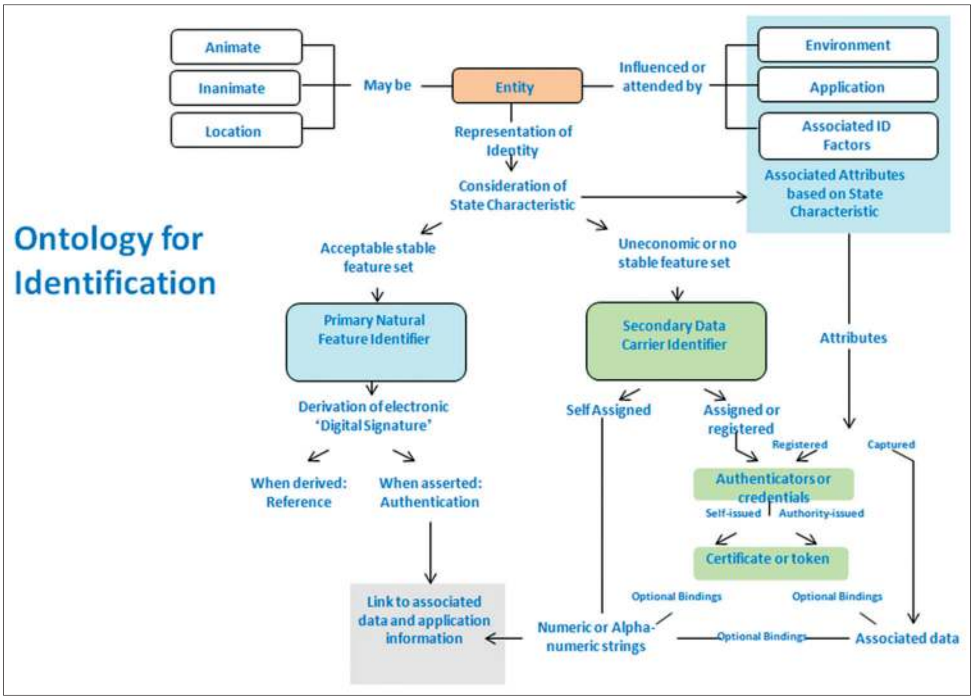

Fig. 3: Architecture of the presented system for data fusion

monitoring of tunnel construction for its features and advantages. Optimization of tunnel construction has become the incipient research and development orientation in recent years.

The research will eliminate the tunnel or mining incidents in India

- Bilaspur tunnel tragedy, September 2015 and
- Himachal tunnel collapse, September 2015.

This study, in turn, will eliminate the tunnelling or mining hazards by prognosticating the structural deformations. The architecture of the presented data fusion for the system as shown in Fig. 3 is incipient. This give an edge for developing IoT-enabled research application in settings of the tunnelling project. This summarizes the principle and framework of application, presents its addressed quandaries and superior performance in comparison with the traditional subsisting monitoring system, meanwhile expects to optimally accommodate tunnel project, and expedites and ameliorates the development of IoTs by prognosticating the future research direction

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