Nigerian Research Journal of Engineering and Environmental Sciences 5(2) 2020 pp. 786-796

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Review Article

The Precursory Machinery of Internet of Things (IoT) in the Platform for Harmonizing Bio-Mined Data

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ARTICLE INFORMATION

Article history:
Received 30 Oct, 2020
Revised 17 Nov, 2020
Accepted 20 Nov, 2020
Available online 30 Dec, 2020

Keywords:
Internet of Things
Biotechnology
Biomining
Data prediction
Biosynthesis

ABSTRACT

Biotechnology is an evolving field with huge prospects towards contributing to national development. As an emerging interdisciplinary domain, there are some teething challenges one of which is the provision of efficient and effective cutting edge platform for storing, disseminating, and interacting with useful models and/or data synthesized from biotechnological activities. That modern ICT solutions are indispensable to every domain of human endeavour is a generally accepted fact. Collaboration and data are two key requirements for any biotechnological research development. This review paper is an attempt at articulating and establishing the position of pervasive computing and integrated Internet of Things (IoT) in providing a single technology-driven muticulturalized window that supports biomining and other related biotechnological activities. This paper adopts an exploratory approach. Data were acquired through social and system investigations into existing practices on biomining and related activities. The proposed system is intended to relay data from biomining sites and systems for further analysis and feedbacks. The authors submit that with such a platform, biotechnologists and professionals could gain useful insights which would further boost their productivity during industrial production and research.

1. INTRODUCTION

The application of biotechnology has been recognized as a sustainable solution to several challenges facing mankind across several jurisdictions (Nyange et al., 2011). Recent advances in biotechnology have increased the integration of information and communications technology (ICT) solutions into high-throughput biotechnological methods, instruments, and systems (Gupta et al., 2017). A notable application is seen in various domains of biotechnology where sophisticated algorithms including artificial intelligence (AI) are used to modelling and evaluation of complex biological systems and their interactions. This has also led to increase the deployment of instrumentation, data science methods, access to computational resources and bioinformatics algorithms (Attwood et al., 2019).

Due to the enormous data normally generated during biotechnological activities such as biomining, the application of deep learning, a subdomain of machine learning has emerged as a powerful tool that could be used in the encoding and modeling of many more complex data (Pirih and Kunej, 2017). The internet has long become the medium for data exchange. With advances in sensor technology, connectivity has been extensively extended to biological systems. This brings to bear the concept of Internet of Things (IoT). IoT provides the facility for the interconnection of biological, physical and hybrid systems (Nwankwo, 2018).

It is noted that several channels of communication are used during biomining and access to data generated during such processes may be very costly (Salam, 2020). Therefore, having a precise or standardized communication-aware device deployed would enable consistent data exchange, auto-discovery, simplified access to data and the cost involved in the process would be reduced. The result would be innovation, market growth and competition (Ching et al., 2018).

The application of microorganisms for the extraction of metals from ores involves the harnessing of a natural process mainly for the purposes of commercialization. It has been highlighted that some beneficial microorganisms possess the capability to deposit and solubilize heavy metals available in the earth's crust since ancient times. Globally, the application of mining activities has been performed for thousands of years in order to obtain crucial metals with high industrial relevance (Jerez, 2017). Moreover, the action of mining using microorganism could be associated with sulfur and iron ores. It has been observed that anaerobic sulfate-reducing bacteria portends the capability to produce sulfides that could react with different metals to generate insoluble metal sulfides (Rawlings, 1997). These sulfides could represent electron donors for the usually aerobic sulfur-oxidizing microbes which can lead to the formation of metals from the mineral deposits. The capability of some beneficial microorganisms to solubilize metals from ores has led to the rapid development of biomining industry (Brierley, 2008). The rapid utilization of these beneficial microorganisms could be linked to some of the merits as against the traditional physicochemical techniques as this biological method require no energy during the process of extraction and does not produce any unfriendly and harmful gaseous emissions. Conversely, a very high amount of energy is required during smelting, roasting and mine tailings and wastes generated during physicochemical processes might be washed by rain water leading to water pollution and unwanted acidic water (Mohammed et al., 2011).

Biomining could also be used for the purification and extraction of metals from certain low-grade ores (Nkemnaso et al., 2018). Biomining has been shown by many researchers as a sustainable technology that employ biological systems to enhance the extraction and recovery of metals majorly from their ores (Brierley and Brierley, 2013; Johnson, 2014; Johnson and Du Plessis 2015; Kucuker *et al.,* 2016). The process of biomining involves a two-stage biological process: The first stage involves extraction of metal from secondary and primary sources mainly from bottom ash, ore, waste electrical and electronic equipment, industrial and mining waste. This is called bioleaching (Kucuker and Kuchta, 2012; Gurung *et al.*, 2013). The second stage of the biomining process known as biosorption, involves the removal of heavy metals ions from industrial effluents but the detoxification of these solutions before the process of disposal is the major reason for using these techniques (Schiewer and Volesky, 2000; Vieira and Volesky, 2000; Diniz and Volesky, 2005; Kucuker and Kuchta, 2012). Biosorption has been identified as a metabolism-independent process that normally occur in the cell wall of some beneficial microorganisms such as bacterial, and fungi. Therefore, the process of biomining is an innovative methodology that is economically feasible and avoids high costs related to refining and smelting (Kucuker and Kuchta, 2012; Johnson, 2014).

Accordingly, this paper intends to articulate and establish the position of pervasive computing especially integrated IoT in providing a single technology-driven muticulturalized platform that supports biomining and other related biotechnological activities.

2. METHODOLOGY

This paper follows a secondary exploratory methodology aimed at tunneling the realm of biomining using available information including published, unpublished and site data. The activity framework for this study is presented in Figure 1. The procedure followed include:

a. Review of vital published material in various online databases
b. Selection of relevant materials
c. Identification of any local biomining activities, potential geographical sites, and infrastructure
d. Review of the relevance of booming as a biotechnological tool
e. State biomining tools and technologies

The materials of interest included in the study are those that:

a. State the precursory and implementation requirements for biomining activities
b. Specify the existing practices and technologies that support the development of biomining process chain.
c. Contain relevant data on the subject matter, its relevance and/or existing practices.
d. Highlight the usefulness of biomining
e. Identify the challenges of biomining
f. Present some innovative approaches to data access and information exchange; collaboration, and analytics as they affect biomining projects.

Following the identification of the relevant materials, special emphasis was made on the precursory requirements as well as tools that could help ameliorate the challenges currently militating against the prospects of biomining activities. Going forward, the various domains of biomining are highlighted and IoT is proposed to support global access to data, classical analytics, enquiries, feedbacks, real-life site operations.

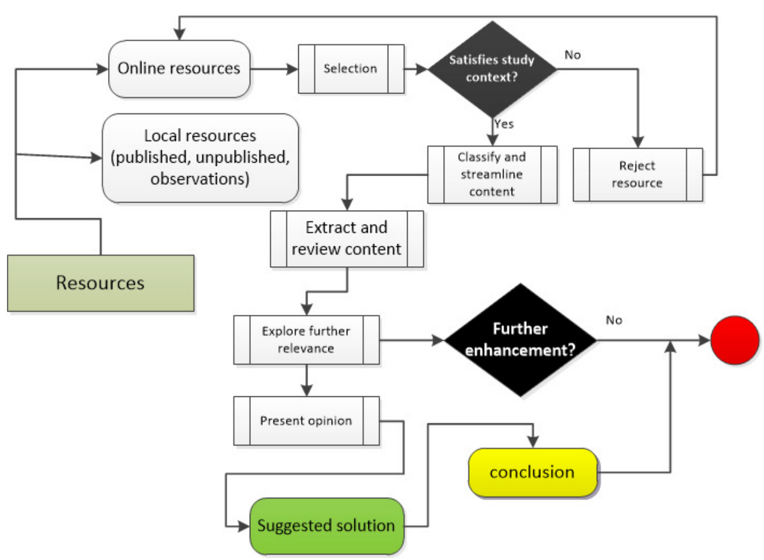

Figure 1: Research activity framework

3. DISCUSSION

3.1. The Machinery of Biomining

Biomining is considered a machinery deployed to explore the applicability of biological systems to the extraction and retrieval of metals from ores (Brierley and Brierley, 2013; Johnson, 2014; Johnson and Du Plessis 2015; Kucuker et al., 2016; Kucuker and Kuchta, 2018; Kucuker, 2018). It involves the application of microbes for the commercial mining (extraction) of profligate metals from ores and concentrates via bioleaching and bio-oxidation with slightest environmental effects (Ijaz et al., 2017; Gumulya et al., 2018). These microbes are the real agents of bioleaching and biooxidation processes for the commercial extraction of concentrates (Ijaz et al., 2017; Gumulya et al., 2018). According to Ijaz et al. (2017) and Gumulya et al. (2018), the biomining techniques are generally chosen over conventional means because of the following advantages:

a. Energy proficiency
b. Cost effectiveness
c. Environmental friendliness
d. Production of beneficial by-products

Ijaz et al. (2017) posit that diverse microbial strains such as acidophile, *chemolithotrophic, ferrimicrobium, rhodiciccus* and *sulphobacillus* at industrial scale are used in facilitating the procedures of copper and uranium bioleaching. Approximately, 20% of copper is mined globally using biomining techniques (Ijaz et al., 2017; Gumulya et al., 2018). These mining techniques comprise of the oxidation of metal sulphides that are insoluble as well as sulphates that are soluble. According to Ijaz et al. (2017) and Gumulya et al. (2018), the separation of thermophilic microorganisms for inorganic biooxidation increase the commercial mining of minerals at industrial scale. The conventional pyrometallurgical methods have some environmental apprehensions because they could result in decline of high-grade ores and release injurious gaseous (Ijaz et al., 2017; Gumulya et al., 2018). As discussed by Ijaz et al. (2017) and Gumulya et al. (2018), the microbe-aided gold mining is likely to produce double gold, as such it is desired greatly to be explored using various collection of microbes.

Bioleaching is an easy and cost-effective method for most developing nations with huge ore deposits. More than thirty strains of microorganisms have been presently discovered to possibly have influence on bioleaching (Kaksonen et al., 2017). With technological advancement in molecular genetics, physiology as well as microbial genomics, more auspicious strains with improved bioactivities are now becoming realistic. Due to the additional efforts that researchers are putting in place, there is every possibility of developing additional means for culturing various archaea and refining its genetic component for application as industrial means for commercial bioleaching.

As noted earlier, biomining is differentiated as a two-phase collective biological system. These phases are: the first phase bioleaching and the second phase biosorption (Brierley and Brierley, 2013). In order to achieve the extraction and retrieval of metals from subordinate sources like industrial waste, electronic wastes, bottom ash and scrapped automobile, the approaches presented in Table 1 are generally adopted.

3.2. Relevance of Biomining

It may be recalled that biotechnology is the technology and science of biology. Its domains revolve around the synthesis of intricate, biological based systems, which exhibit roles that naturally do not occur (Kucuker and Kuchta, 2018; Kucuker, 2018). According to Kucuker and Kuchta, (2018), biosynthesis has been of great assistance in the transformation of biological sciences for the advancement of our society in general.

Well-branded biological parts that are integrated into the framework have given rise to several biological, Biosystems, and/or biochemical products such as microbial artemisinin for malaria treatment and computerized systems for the creation of DNA-built logic circuits (Kucuker and Kuchta, 2018; Rafi et al., 2011; Johnson et al., 2013; Bano and Ashfaq, 2013). Given their long history as biotechnology work-horses, *Escherichia coli* and *Saccharomyces cerevisiae* were the natural choices for synthetic biology framework. Their use is driven by genetic engineering, broadly available genetic research tools, and deep knowledge on their biology at the molecular level (Johnson et al., 2013).

Nevertheless, several industrially useful applications of biomining involve circumstances and substrates that are unbefitting for the hosts of the conventional genetic engineering. It is advisable that before considering any biomining procedure such as the use of *E. coli* which lacks the essential major cell features and mechanisms like the capacity to endure multiple stress influences, several technically motivating but previously uncultivated organisms should be gradually examined as possible biological synthetic biology framework (Johnson et al., 2013). Although the fundamental design approaches of biological synthesis can be used irrespective of the host, the actual technique at cell level entails well-branded parts and genetic apparatuses, which are classically actual host-dependent. Resourceful means for transformation and genomic combination for knock-out/knock-in, purposeful choice markers, and inducible countenances are crucial tools for part classification. However, part classification remains a prerequisite for the design and creation of additional composite systems, which by chance might open up innovative opportunities to stunned technical challenges not decipherable with traditional technique.

Table 1: Biomining processes and instrumentation

Biomining processes	Applicable substrates/materials	Instrumentation	Extracted minerals
Agitated leaching	Crushed rocks, metal scraps/ores, chalcopyrite concentrates	Bioreactor tanks, appropriate *thermophilic* microbes, leach liquor	copper, cobalt, nickel, zinc, uranium
Heap leaching	Freshly mined ores, solid wastes	Controlled pad, stirred reactor tanks, thermophilic *or mesophilic* microbes, leach liquor	copper, cobalt, nickel, zinc, uranium
Dump leaching	Remains of mines; low-grade ores, wastes	Sealed pits; reactor tanks, *mesophilic* microbes, leach liquor	copper, cobalt, nickel, zinc, uranium
Biooxidation (Mubarok et al., 2017)	Sulfide minerals and ores	Mixed bacteria culture (*Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans, Acidithiobacillus thiooxidans*, reactor tanks, liquor to provide very acidic medium	Gold, coal desulfurization, etc.
Non-oxidative biomining (Johnson et al., 2013)	Wastes, low-grade ores, concentrates, nickel laterites, goethite, scrap electronics, metal-contaminated soils, etc	Bioreactor tanks, mesophilic acidophilic microorganisms, sulphuric acid, etc.	Cobalt, Chromium, Manganese etc.

3.3. Environmental Challenges to Biomining Projects in Developing Economies

Like every other technical project, biomining projects are also faced with some problems and challenges (Brierley, 2008). So, in selecting the technological processes involving biomining, it is important that challenges are identified. By so doing, the future prospects of biomining projects would be appropriately taken care of. Basically, there are two main issues affecting biomining; temperature and pH of the environment. According to Kucuker and Kuchta, (2018) as well as Kucuker, (2018), either the development of the microorganism is interrupted or the process (which is known as biooxidation) is interrupted during the biomining process. This is as a result of the inherent property of microbes to respond to temperature and pH (Ijaz et al., 2017). It is the intrinsic feature of microorganisms to respond to the changes in temperature and pH. Biomining is commercially productive using planned dumps, piles and enthused tanks. In most developing economies, overcoming the economic challenges of reducing costs, processing sub-standard, truncated quality and composite ores aids in understanding the activities of the microorganisms and inventive engineering (Johnson et al., 2013). Overcoming biomining commercial challenges requires enhanced mining industry and optimum commitment by the appropriate stakeholders in the biomining business. As rightly reported by Johnson and Du Plessis, (2015), the application of temperature resistive equipment's for the growing of microorganisms at bio-oxidation by biomining industries, would upsurge to enable the metal mining at industrial level. In most cases these microorganisms are sensitive to the temperature (Ijaz et al., 2018). Thus, microorganisms which can resist a very high temperature of about 80°C are therefore preferably chosen for the biomining processes. Genetic engineering of targeted microorganisms would also improve their capacity in the development of biomining apparatuses at industrial scale.

3.4. IoT and Pervasive Computing Tools

IoT is a paradigm that can change how computers and humans communicate, compute, and interact with each other. IoT is an arrangement comprising sensors, actuators and processors that interact with each other to serve a significant purpose. The IoT technology has developed in several domains including animals, hospitals, smart cities, airplane, computer, plant, office, car, etc. Consequently, the number of IoT devices is growing every day, as they provide some comfort and services to humankind (Sethi and Sarangi, 2017; Burhan et al., 2018). In order to deliver expected functionalities effectively, identifying, sensing, communication, computing, services, and semantics must be integrated. There is no single consensus on architecture for IoT. Several researchers have proposed various architectures, as shown in Table 2. The choice of an architecture may depend on the nature of the project for which IoT is considered a vital component. IoT as a pervasive computing framework offers a platform for connectedness i.e., where devices of different forms and applications such as mobile, wearable technology, sensors, etc. could become part of a more complex system (Becker et al, 2019). Transforming data from such devices into actionable knowledge, which can support the decision making of biotechnological activities, is not a trivial task. It consists of a complex process chain that includes data acquisition, data curation and storage, data analysis, and data modelling.

3.5. Usefulness of Data Generated by Biomining Activities

Data generated through biomining activities can be harnessed with the help of integrated pervasive computing technology. The excitement about pervasive computing is all about the ability to connect different systems and devices all around the world and acquire data generated by biomining activities. The use of pervasive computing helps in acquiring robust data though the deployment of intelligent systems, connectivity, and system-to-system communications combined with analytical tools designed to deliver business insights and customer value. The IoT infrastructure for biomining would generate vast amounts of data that may be analyzed to derive meaningful information for support of ongoing and future mining operations. To this end, harnessing data generated from biomining activities would require a new element of data categorization to enable big data analytics tools deliver better performance.

3.6. Harnessing Data Generated by Biomining Activities

Data generated through biomining activities may be harnessed with the help of integrated pervasive computing technology such as IoT and analytics. The excitement about IoT revolves around its potential to connect different systems and devices involved in the biomining project to enable data acquisition, remote analysis, automatic decision making, etc. This helps in the building of robust databank for future operations. IoT also brings together intelligent systems, connectivity, and system-to-system communications combined with analytical tools designed to deliver business and field insights as well as customer value. The vast data conveyed through IoT could be channeled for storage anywhere on the face of the earth thus providing a platform for central and distributed computing. IoT is an interesting vehicle to enable big data relay and subsequent data categorization using big data analytics tools. The overall result is an improved system.

Table 2: Summary of IoT architectures

Researchers	Architectures	Layers	Function
Wang et al., 2016; Yaqoob et al., 2017; Burhan et al., 2018	Three-layer architecture	Application layer, network layer, and perception layer	The architecture of three layers describes the principal concept of the internet of things. However, it is not sufficient for research on IoT because research often focuses on more elegant aspects of the IoT.
Burhan et al., 2018	Four-layer architecture	Application layer, network layer, support layer, and perception layer	In line with three-layer architecture, the four-layer architecture added security (support layer) to the IoT.
Sethi and Sarangi, 2017; Burhan et al., 2018	Five-layer architecture	Business layer, application layer, processing layer, transport layer, and perception layer	This architecture addressed the issues regarding security and storage in four-layer architecture.
Lin et al., 2017; Sethi and Sarangi, 2017; Yaqoob et al., 2017	Cloud and fog-based architecture	Transport layer, security layer, storage layer, preprocessing layer, monitoring layer, and physical layer	The aim is to do as much data preprocessing in these devices as possible, which are named at the edge of the network.
Sethi and Sarangi, 2017	Social IoT (SIoT)	Server-side (base layer, component layer, and application layer) and device side (object layer and social layer)	social relationships are considered between objects the same way as humans form social relationships
Hsieh and Lai, 2011; Yaqoob et al., 2017	3G-PLC	Perception layer, aggregation layer, network layer, and application layer	The system incorporates two advanced communication networks: Power line communication (PLC) and 3G network.

3.7. Support for Controlled Biomining Instrumentation

IoT offers unlimited support for real-time control and monitoring of experiments, production, and similar events that are subject to eventual fluctuations that may result to critical and undesirable conditions. It has been shown that controlled biomining projects produce better results compared to uncontrolled environments (Matsvayi, 2016). It is noteworthy that there are two critical intrinsic parameters in a biomining instrumentation. These are temperature and pH of the environment. These intrinsic factors are critical to the operation of the microbes. For instance, in agitated leaching used in most commercial biomining operations, thermophilic microbes which are the preferred microbes for better results must constantly be subjected to the optimal temperature otherwise the output would deteriorate (Sissing and Harrison, 2003). Similarly, for mesophilic bacteria used in dump leaching, the temperature must be optimal. The pH of the environment also affects the functioning of the microbes in a similar way as temperature. Majority of the microbes employed for catalysis and bioextraction require acidic medium and the optimal degree of acidity must be maintained to realize the expected output. Consequently, a monitoring and control solution should be in place in any of these instrumentations. As site monitoring may be highly inconvenient in high risk environments, the use of IoT would simplify the entire process. Thus, pH and temperature sensors may be used in the reactors and such IoT-enabled devices could relay continuous measurements to remote analytics centres where the transmitted live data are analyzed and feedback sent immediately to the plant for requisite control action. This would greatly aid the optimal performance of the biomining plant.

3.8. Collaboration in Biomining Projects

IoT and other pervasive computing tools support collaboration in biomining projects. Collaboration is the hallmark of modern project undertakings including biotechnology projects (Brierley, 2008; Nwankwo and Ukhurebor, 2019; Nwankwo and Kifordu, 2019; Nwankwo and Ukhurebor, 2020). Inefficient and weak collaboration is one of the major reasons multi-million-dollar projects crumble (Brierley, 2008). Appropriate infrastructure should be considered as critical to the planning, implementation and sustenance of any biomining venture of economic value whether privately or publicly owned (Kifordu et al, 2019). Such infrastructure should offer unhindered secure cross-team and intra-team information flow to enable team members and decision makers communicate vital information and make appropriate decision as and when due.

IoT is a symbol of connectivity of all players in an ecosystem whether animate or inanimate. Thus, the connectivity of devices and field experts irrespective of location is a boost to any collaborative biomining project. IoT also enhances live data acquisition which ultimately influence the amount of data acquired. Processing of this vast data could be done via various information processing channels. Therefore, the integration of IoT and pervasive computing is on the verge of bringing an immense revolution in the way we interact with things (Botta et al, 2016). IoT deployment may engender the creation of a complex network with various data streams being pooled. This may also raise a question as to the security of the data traversing the entire infrastructure. It therefore follows that security considerations must not be taken with levity when implementing IoT solutions as any security loophole in the entire network would put ongoing and future biomining projects at risk of manipulation. Presumably, security has been a major concern in every project whether online or offline and project teams and key stakeholders must draw up a formidable information security plan.

3.9. How IoT promotes Platform for Biomining Projects

Technically, IoT as a platform, is one of the most influential components of pervasive computing. Its connected-orientedness at the lower level of network communication also affects the higher levels that involves human readable communication, visualization and front-end processing (de Carvalho Silva et al., 2017). The single window concept like the IoT is a globalized front-end platform that allows the design and integration of the various components of a complex domain. This allows collaborators and stakeholders of a particular project to commence any task or activity chain and conclude same on the system without having to navigate to any external system. Thus, it would enable human and non-human stakeholders across several sectors to relate in a bid to prosecute a project. The IOT platform ideally is neither a software nor a hardware but a concept that could be adopted in promoting real-time access to data, information and knowledge. The essence of this ideology in biotechnology projects is hinged on the fact there are many players from different sectors. For instance, in Nigeria, any vital biotechnology project may require inputs from different ministries and agencies and these inter-ministerial or inter-agency communication could cause such a project to fail owing to bureaucratic bottlenecks if not adequately handled (Adeoti and Adeoti, 2005). An IoT platform would create transparency in communication regardless of the agency or ministry to which the players belong to the effect that decisions could be actively made on the platform without the usual ministerial protocols. In other words, a system built on the single window concept is adaptable, intuitive, flexible, integrative, and globally accessible to all stakeholders in the system (Tsen, 2011). More so, a single window system offers security, exceptional control and tracking of resources on the system in real-time. While IoT is a low-level driving force for connectivity, a single window-based system would provide a mobile, web, enterprise or service-based software platform for the users and collaborators and would drive biomining projects from their conceptualization to realization.

4. CONCLUSION

This paper takes an exploratory look on biomining as a relevant biotechnological tool. It X-rays its relevance and existing practices. The various biomining processes were identified. The challenges posed to biomining to the development of biotechnology in a developing economy was briefly elucidated. Owing to the criticality of these intrinsic elements and the collaborative nature of most modern biotechnology projects, it is concluded that:

a. IoT's pervasive and nature would enhance the real-life monitoring and control of biomining processes in private and commercial biomining plants/laboratories.
b. IoT could serve as a great precursory tool to support the building of databases and databanks on biomining activities across a region or country and even beyond.
c. Having regards to the importance of prompt communication and collaboration to the success of most projects, IoT could enhance the construction of a single window software platform which has the potential to break all anticipated bottlenecks regarding the flow of communication and decision making across all stakeholders in a biomining project.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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