Tracking of Excavators in the Artisanal Small-Scale Mining Sector in Ghana using TX 140-4G Tracker

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ABSTRACT
Tracking earth-moving and mining equipment particularly, excavators operating in all mining districts in Ghana have become necessary as the Government through the Minerals Commission seeks to regularise the Artisanal and Small-Scale Mining sector and stop the indiscriminate environmental degradation arising from the use of this equipment. To this end, the Minerals Commission has launched the Ghana Mine Repository and Tracking Control Room to monitor and track all excavators operating in mining districts in Ghana. The goal is to restrict each excavator to operate on a licensed mining concession at a time. To achieve this, a TX 140-4G Iridium tracker was pre-programmed and deployed. The TX 140-4G tracker makes use of Global Positioning System (GPS) and Global System for Mobile Communication (GSM) technology was fixed inside an excavator whose position needs to be determined and tracked in real-time. Geographic coordinates (i.e., longitude and latitude) of the excavators were received through the onboard GPS module in the control room. Communication with the tracker was established via the onboard GSM module. To ensure that each excavator operates on a concession at a time, all licensed concessions were geo-fenced and paired to all tracked excavators. Geographic Information System was used to generate buffer zones 50 meters from the actual concession boundary of each concession. A buzzer was introduced to produce a beeping sound anytime an excavator enters the buffer zone and will continue beeping until the excavator moves back into the actual concession area. Once an excavator crosses the actual concession boundary, its engine is automatically disengaged. Google Maps Application Programming Interface (API) was used to display the icons of excavators on the map in the control room.

General Terms
Small-Scale Mining, Ghana, Minerals Commission, University of Mines and Technology

Keywords
Excavator Tracking, GPS, GSM, Ghana Mine Repository and Tracking Control Room, Environmental Degradation.

1. INTRODUCTION
The level of environmental degradation associated with the activities of Artisanal Small-Scale Gold Mining (ASGM) has attracted much public outcry in recent times and must be controlled. Of particular interest is illegal ASGM popularly known as "galamsey", which has become a nuisance as its activities can be directly linked to very destructive impacts on rivers and other water bodies [1], [2], [3], as well as agricultural lands and forest reserves [4]. The problem is further exacerbated by the introduction of sophisticated Earth-Moving and Mining Equipment (EMME) such as excavators and bulldozers into the ASGM sector whose activities have led to severe environmental degradation in mining districts across Ghana [5], [6]. These nefarious activities have subsequently led to the abuse of the country's small-scale mining laws [7] as this heavy-duty mining equipment continues to wreak havoc in areas where mining abounds. As part of the Government's effort to regularise the ASGM sector and control the activities of excavators operating in all mining districts, a joint military-police task force was formed to enforce and ensure that all excavators operate only on licensed mining concessions [8], [9], [10]. However, these efforts have proved futile as illegal mining activities using excavators are carried out in remote areas and/or mostly at night, thereby continuing the cycle of environmental destruction. To reinforce the already implemented measures, the parliament of Ghana promulgated the Minerals and Mining (Minerals Operation – Tracking of Earthmoving and Mining Equipment), Legislative Instrument 2404 (L.I. 2404) in 2020 to take inventory and track the operations of all excavators used in the ASGM sector across the country. To this end, the Minerals Commission which is the Government's regulatory agency in charge of mining and allied sectors has established the Ghana Mine Repository and Tracking Control Room to take inventory, monitor and track the activities of all excavators operating in mining districts by installing trackers in them. To achieve this, the TX 140-4G Iridium GPS tracker was programmed and deployed. The proposed tracker contains all the needed subsystems and controls to track all excavators operating in Ghana. The key components of the TX 140 tracking device include; a GSM module, a GPS module, a microcontroller, a buzzer and a 24 volts relay circuit. The TX 140-4G Iridium GPS tracker also makes use of the iridium Short Burst Data (SBD) transceiver, which delivers global satellite communications in limited or no GSM signal environments.
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The paper seeks to achieve the following objectives:

1. To ensure that all excavators operating in the ASGM sector are tracked thus to comply with the regulations set out in the L.I. 2404;
2. To control the indiscriminate movement of excavators operating in the ASGM sector by pairing

them (excavators) to licenced mining concessions at a time; and

3. To monitor the operations of all excavators in real time.

The significance of the study lies in the fact that the outcome of this study would assist the Minerals Commission of Ghana to have an inventory of all excavators operating in mining districts in Ghana as well as restrict the movement of excavators to only licenced mineral rights concessions by tracking their day-to-day operations.

2. LITERATURE REVIEW

In fields such as mining, quarrying, forestry and construction, EMME particularly excavators are extensively used making it necessary to track their operations. Literature has shown that tracking and monitoring of excavators can play a crucial role in measuring operational efficiency, accident prevention, enhanced security and remote monitoring [11], [12], [13]. Tracking of excavators has become crucial to the Minerals Commission in its efforts to regularise the ASGM sector and minimise the level of environmental degradation arising from the use of this heavy-duty equipment. From the literature, tracking of heavy-duty machinery can be achieved through several techniques namely; Artificial Intelligence (AI) techniques, Global Positioning System (GPS), Global System for Mobile Communication (GSM), as well as Radio Frequency Identification (RFID) [14], [15], [16], [17], [18], [19], [20]. In the work of [21], the authors developed a real-time visual tracking system for vehicle safety applications as well as introduced the concept of focus of expansion (FOE). [22] proposed a low-cost real-time tracking system that provides accurate localization of the tracked vehicle. In [23], researchers introduced a vehicle tracking system coupled with a vehicle registration number recognition system. [24] developed the GPS and GSM network hardware and software. Their proposed solution was divided into two main parts namely, the mobile unit and the controlling station. Their system ensured efficient data connection was established between the mobile unit and control stations for them to operate efficiently. The research work carried out by [25], introduced a vehicle tracking system that works using GPS and GSM technology. The system was built based on an embedded system, used for tracking the position of any vehicle via Global Positioning System (GPS) and Global system for mobile communication (GSM). Their solution continuously watches the movement of moving vehicles and reports on their status as and when. [26], the authors developed a Face Detection System which was used to detect the face of the driver and compare the outcome with a predefined face. This solution was proposed to avert the increasing spate of car theft. The Face Detection System obtains the driver images by way of a tiny web camera hidden somewhere in the vehicle and overseeing the entire circumference of the driver's face. The captured images are then compared with the already stored images. If the images don't match, the image and the location of the vehicle are then sent to the owner of the vehicle through a Multimedia Messaging Service (MMS). The rest of the paper is structured as follows: Section 3 presents the resources and methods employed to achieve the objectives of the study. The section further presents the frameworks of the proposed TX140 GPS tracker. Section 4 shows the experimental results with the discussion and interpretation, and Section 5 concludes the study and presents recommendations for future works.

3. METHODOLOGY

This section focused on the resources and methods adopted to achieve the objectives set out in this study.

3.1 Resources Used

GSM Modem - Global System for Mobile Communications (GSM) is a specialized type of modem which accepts a SIM card just like a mobile phone and operates on a mobile network operator subscription. GSM supports various services, including voice, data, and text messaging. It uses digital encryption to ensure the security of calls and messages, making it more difficult for unauthorized parties to intercept communications. The GSM modem uses a process called circuit switching. This method of communication allows a path to be established between two devices. Once the two devices are connected, a constant stream of digital data is relayed. For purposes of this study, there was a need to understand the network penetration levels in all mining districts of all the network operators working in Ghana. Figure 1 shows an image of the Motherboard with a GSM Sim Socket.

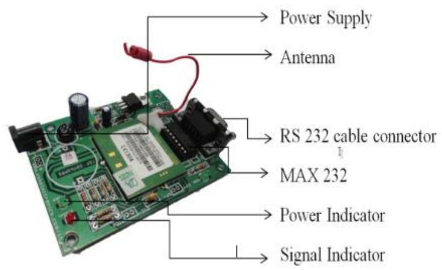

Figure 1 Motherboard with GSM Sim Socket

The GSM module consists of three major components described as follows:

Switching System (SS) – The SS is used to establish and maintain voice and data connections between mobile devices. The SS is responsible for routing calls and messages to the appropriate destination as well as subscriber-related functions. It holds five databases which are as follows; Home Location Register (HLR), Mobile Switching Center (MSC), Visitor Location Register (VLR), Authentication Center (AUC) and Equipment Identity Register (EIR). The MSC in collaboration with Home Location Register (HLR) and Visitor location register (VLR), takes care of all routing tasks for phone calls. The authentication centre (AUC) handles the security end of the system and the Equipment identity register (EIR) holds critical information regarding mobile equipment.

Base Station System (BSS) – The BSS are essentially outdoor units which are made up of iron rods and are usually of high length. They are responsible for connecting subscribers (MS) to mobile networks by way of Radio transmission. BSS is further divided into two sub-systems namely; the Base Transceiver station (BTS) and Base station controller (BSC). BTS handles communication using radio transmission with a mobile station and BSC creates a physical link between the subscriber (MS) and BTS, then manages and controls its functions.

The mobile station (MS) - MS is made up of a mobile unit and a subscriber Identity Module (SIM) card. The sim card fitted into the GSM Modem gives users more personal mobility. The equipment itself is identified by a unique number known as the International Mobile Equipment Identity (IMEI). The GSM modem used in this device is SUNROM SIM 900D. Table 1 shows the parameters and specifications of the GSM modem used.

Table 1: Proposed GSM Modem Parameters

Frequency	TX 140-4GE: FDD-LTEB1/B3/B7/B8/B20 UMTS/HSDPA/HSPA+ B1/B8 GSM/GPRS/EDGE 900/1800 MHz TX140-4GA: Tri-Band FDD-LTE B2/B4/B17 UMTS/HSDPA/HSPA+ B2/B5
Transmission Power	2 W @850/ 900 MHz 1 W @800/1900MHz
Baud Rate	9600
Power Supply	12V, 1A
Stability of Frequency	<2.5ppm
Operating Temperature	-40 °C to 85 °C

GPS Technology - The Global Positioning System (GPS) is a satellite-based navigation system that provides location and time information anywhere on or near the Earth's surface. It was originally developed by the United States Department of Defense for military purposes, but is now widely used by civilians for navigation, tracking, and other applications. The GPS uses a constellation of between 24 and 32 Medium Earth Orbit satellites that transmit precise microwave signals that enable GPS receivers to determine their location, speed, direction, and time. A GPS receiver receives the signals from at least three satellites to calculate distance and uses a triangulation technique to compute its two-dimension (latitude and longitude) position or at least four satellites to compute its three-dimension (latitude, longitude and altitude) positions. For this study, GPS technology will be employed in areas where there is limited or no GSM signal. Table 2 shows the GPS specification of the TX 140-4G Tracker.

Table 2: GPS Specification of TX 140-4G

GPS Chipset	MT3337 GPS Chipset
Receiver Accuracy	Without Aid: 3.0 M 2D-RMS DGPS (WAAS, EGNOS, MSAS, RTCM): 2.5 M
Time to First Fix	Hot start < 1 sec. Warm start < 30 sec. Cold start < 31 sec.
Sensitivity	- 165 dBm (Tracking)
Protocol	NMEA-0183
Power Requirement	3.3~5.5VDC, 50mA

24 Volts Relay - A 24-volt relay is an electromagnetic switch that is designed to operate using a 24-volt DC power source. Relays are used to control circuits by opening or closing contacts in response to an electrical signal. They are commonly used in a wide range of applications, including industrial control systems, automotive systems, and home automation systems. The 24-volt relay consists of an electromagnetic coil, a set of contacts, and a housing or mounting structure. When a voltage is applied to the coil, it generates a magnetic field that causes the contacts to open or close. This allows the relay to control the flow of current in a circuit, turning devices on or off as and when needed. In this study, the 24-volt relay was specifically chosen because the scope borders around heavy-duty earth-moving machinery. Figure 2 shows an image of a 24 Volts Relay.

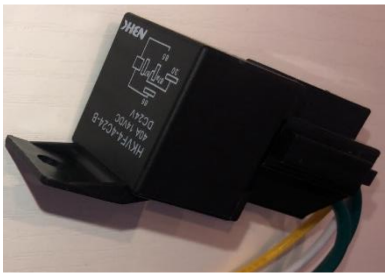

Figure 2 A 24 Volt Relay

Buzzer - A buzzer is an electronic device that is used to produce a buzzing or beeping sound. Buzzers are commonly used in various electronic applications, such as alarms, timers, and notifications. They can be found in a wide range of everyday devices, such as smoke detectors, and kitchen appliances, amongst others. Buzzers typically consist of an oscillating circuit that produces an audible sound when activated. The circuit can be activated by a variety of methods, including switches, sensors, or electronic circuits. Overall, buzzers are a simple yet effective way to provide audible feedback or alerts in a wide range of electronic applications. They are available in a variety of sizes, shapes, and configurations, making them suitable for use in many different types of devices and systems. Buzzers were employed to prompt excavator operators that they are within their buffer areas within their concessions.

Microcontroller - In this study, a 40-pin ATmega16 microcontroller made up of four-input–output ports are used. The ATmega16 microcontroller is the heart of the proposed TX 140-4G GPS Tracker. Four pins are Voltage Common Collector (VCC) pins. Pin 9 is set as the reset pin. A crystal oscillator of 12 MHz is connected to the microcontroller. RS-232 protocol was then used as serial communication between the microcontroller, GPS and GSM modem. A serial driver MAX232, the 16-pin Integrated Circuit (IC) was used for converting RS-232 voltage levels into Transistor-Transistor Logic (TTL) voltage levels. Four electrolytic capacitors were then used with the MAX232. A 9V battery was used to power the circuit. A 7805 regulator was employed to convert the 9V into 5V. The microcontroller and MAX232 were then powered by 5V. Figure 3 shows an image of an ATmega16 Microcontroller Chip.

Figure 3 ATmega16 Microcontroller Chip

3.2 Methods Used

Proposed System Overview

In this study, a novel approach is used to track and monitor the operations of excavators operating in all mining districts by way of GPS and GSM technology has been implemented. The proposed approach automatically disengages the engine of an excavator when it crosses its actual concession boundary, thereby completely doing away with any form of human intervention. The proposed tracking device installed in an excavator can receive both GPS and GSM signals by way of a GPS receiver and GSM module respectively. The GPS receives data on the current position of the excavator in the form of longitudinal and latitudinal coordinates. The positional data is then sent over a communication channel to be viewed by the control room floor operators. The interaction between the field operations and the control room is made possible because of the GSM module in the tracking device. The TX 140-4G tracker is triggered when an SMS is sent or received requesting the current location information of an excavator. Once the excavator enters the buffer area, the relay sends a message through the GSM module to the microcontroller, triggering the buzzer to start beeping. The beeping continues until the excavator is moved back into the main concession area. As soon as the excavator crosses its concession boundary, a message is sent from the relay through the GSM module to the microcontroller to truncate the flow of fuel in the excavator thereby shutting down its engine and the buzzer stops beeping. A confirmation of the 'EXCAVATOR ENGINE CUT-OFF' is sent and logged to the control room. To reconnect the engine of the excavator, the relay again sends an SMS to the GSM module thus enabling the flow of fuel to be restored and the excavator can operate again. The device also confirms this action by sending a confirmatory 'EXCAVATOR ON' text to the control room. The positional data gotten from the tracking device is been converted to degree-minutes-seconds (DD MM SS) from the QGiS software and this is been fed into a Google map application where the exact position of the vehicle can be viewed. The entire system architecture is shown in Figure 4.

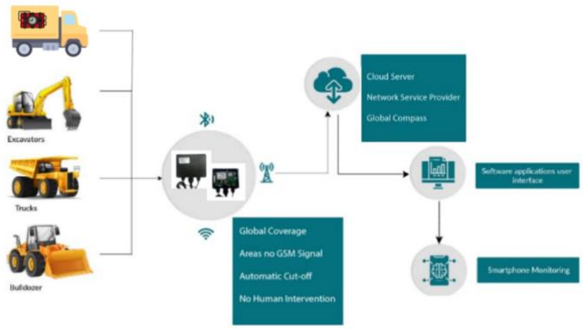

Figure 4 System Architecture of the TX 140-4G Tracker

The entire disengagement and re-connection of the excavator operations is illustrated in Figure 5.

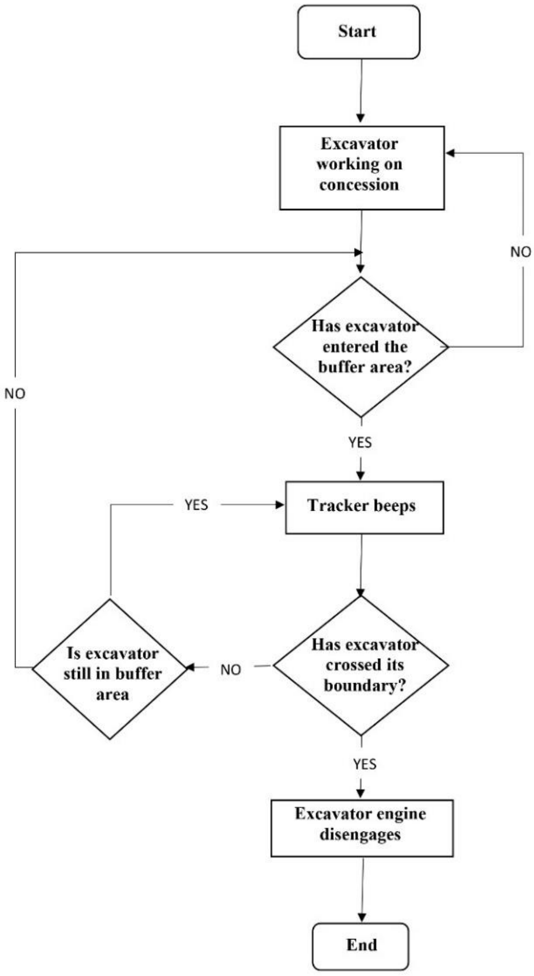

Figure 5 Excavator Disengagement Flowchart

4. RESULTS AND DISCUSSION

Results from Buffer Area Creation using QGIS

To generate the buffer area for each concession, the shapefile below (yellow area) represents the mining concession of Daakyi Mining Ventures as seen in the details panel on the right pane. To create a buffer Area of 50 meters for the concession, the geoprocessing feature of the QGIS is enabled as shown in Figure 6.

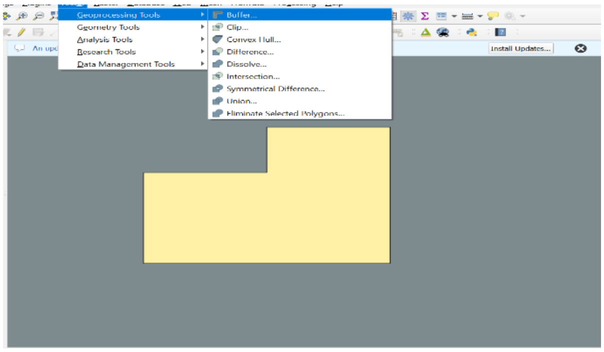

Figure 6 QGIS Enabling Geoprocessing Feature

From the Vector Menu, the Geoprocessing button was clicked to display the drop-down menu. In the dialog box, the buffer parameters were specified and in this case 50 meters (0.00045 degrees). For the buffer to be created within the actual concession boundary, -50 meters (-0.00045 degrees) were used. The end cap style, which controls how line endings are handled in the buffer is changed to flat. The other parameters are left as default as shown in Figures 7 and 8.

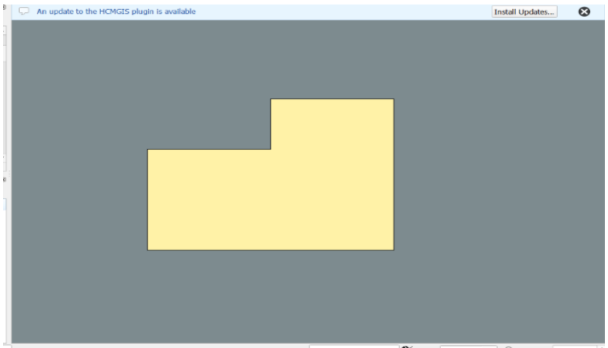

Figure 7 Setting the Actual Concession Coordinates

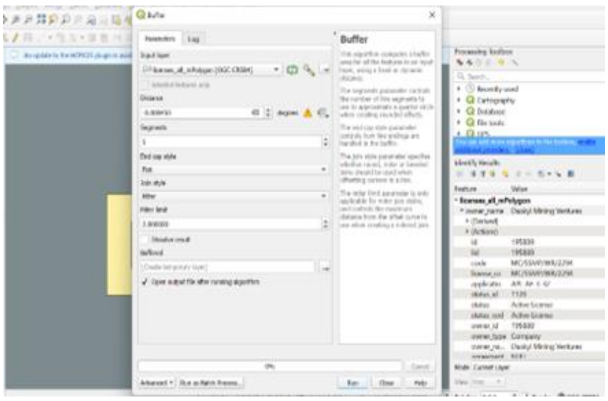

Figure 8 Defining the Buffer Area Parameters

Figure 9 shows the buffer area that has been created for Daakyi Mining Ventures.

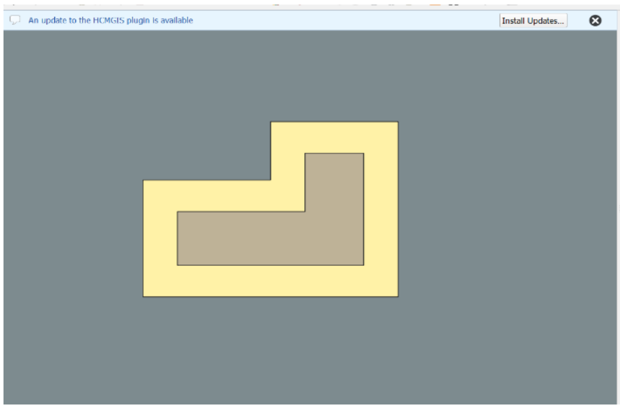

Figure 9 Generated Buffer Area Created

Results from TX 140-4G GPS Tracking Website Application

The web application for the tracking system made use of Google Map API for tracking and viewing the status of the vehicle. The GPS Module employed has National Marine Electronics Association (NMEA) 0183 Protocol for transmitting GPS information to the Ghana Mine Repository and Tracking Control Room. The status of the excavator is sent via the GSM modem, which receives the transmitted SMS to obtain GPS coordinates and status information of the excavator. The received data is processed by a python script to sort the data and save it as an Excel file. The excel file was then converted into a Keyhole Markup Language (KML) file that is compatible with the Google Earth program. Hence, the Google Earth software was used to view the location and status of the vehicle on the map. Figure 10 shows the login page of the TX 140-4G GPS tracking website interface. On this page, the login credentials of the user are taken and validated with what is in the system. If the entered username or password is wrong then the system presents an error message, otherwise, the user is directed to the next page upon successful login.

Figure 10 Login Page of the TX 140-4G Website Application

Figure 11 depicts the tracking software application after login. The interface displays three viewing panes. The left pane shows thumbnails of all the trackers, the right pane shows the actual map area showing miniature icons of all the excavators being tracked and the footer section shows the status of each excavator (i.e., mileage, positional coordinates, vehicle status, etc).

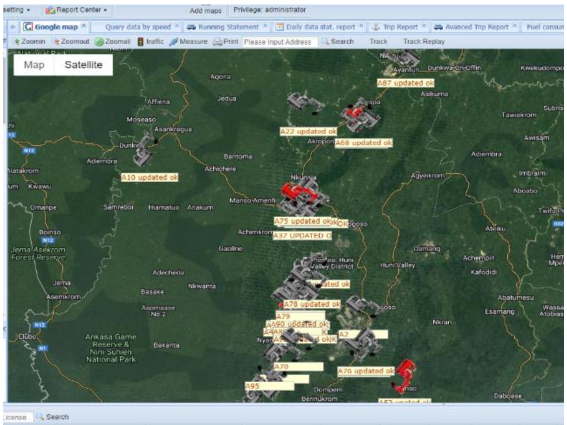

Figure 11 Viewing Area of the TX 140 Website Application

Figure 12 shows the status icons of the excavator that are being tracked. The red icons indicate the online excavators whilst the yellow icons indicate the offline excavators. All the excavators bear the names of the individuals and companies who own them.

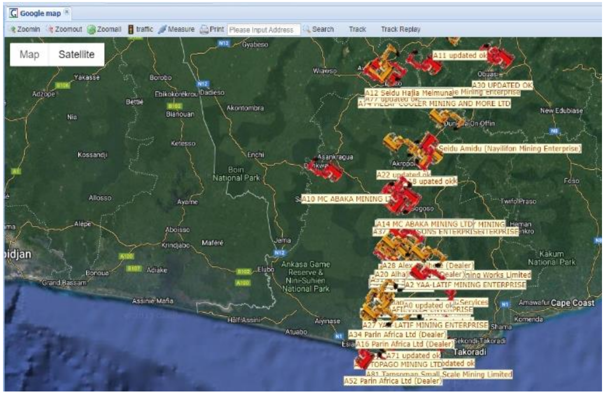

Figure 12 Status Icons of Tracked Excavators

Figure 13 depicts the created geofence and buffer area around Daakyi Mining Ventures concession. The figure further displays an excavator operating on the concession. The red border line depicts the actual concession boundary and the created geofence and the blue line depicts the commencement of the buffer area. The distance between the blue and red border lines is 50 m.

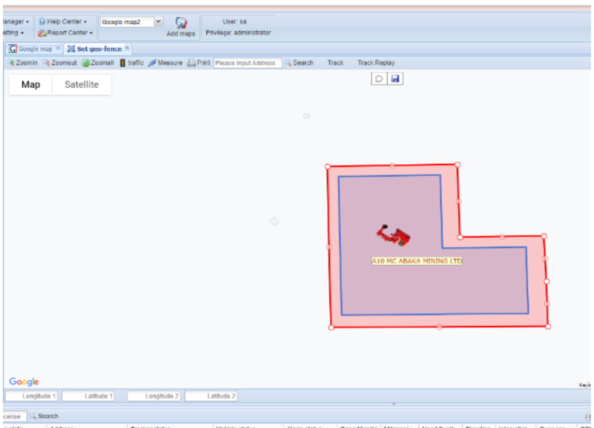

Figure 13 A Geo-fenced Concession with an Operating Excavator

5. CONCLUSION AND RECOMMENDATION

5.2 Conclusion

From the study, the following conclusions were drawn:

Even though the Minerals Commission of Ghana has implemented several interventions to regularize the ASGM sector, there exist two (2) main challenges:

i. The indiscriminate use of excavators within the sector; and

ii. Mining on concessions without an appropriate license

The challenges were attributable to two (2) main issues:

i. The lack of an enforcement policy to guide the usage of excavators within the ASGM sector; and

ii. Lack of a software system to take inventory of all excavators operating in the ASGM sector.

After the deployment of the proposed TX 140-4G GPS Tracker and the roll-out of the Ghana Mine Repository and Tracking System, the monitoring arm of the Minerals Commission was strengthened, specifically: (i) Taking inventory of all excavators and those who own them have been achieved, (ii) Monitoring the activities of all excavators from the control room have been achieved, and (iii) the general evaluation result showed that the system proved reliable as the positions of all the tracked excavators were displayed live in the control room via the Google map API.

5.2 Recommendation

From the study that has been carried out, the following are recommended:

i. The installed software packages should be upgraded periodically;

ii. Even though the upload and download capacity of 60 MB is considered sufficient, The Minerals Commission can consider increasing the bandwidth of the LAN to at least 100 MB; and

iii. The excavator operator clocking system can be looked at as a future addition to this study.

6. ACKNOWLEDGMENTS

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