

Research Article

UAV and Its Approach in Oil and Gas Pipeline Leakage Detection

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The synergy of vibration and gas sensors with unmanned aerial vehicles for a low-response-time Leakage Detection System (LDS) is explored in this work. Several pipeline accidents have occurred, most of which were triggered by untimely detection of pipe leakages in systems conveying oil and gas in many developing countries. The consequences of this include human casualties, environmental degradation, economic loss, and loss of resources. To limit the damages caused by inevitable leakages, a low-time-response system for leakage detection is required. Response time derived from the LDS is compared to the typical response time obtained from an existing system to determine the efficiency of the developed system. A comparative analysis of the response time of the designed LDS and existing systems reveals that the designed LDS response time is 1146.7% faster and having a pictorial view of the localized area of interest would go a long way to preventing unnecessary mobilization for site visits and eradicating the costly effect of false alarms.

1. Introduction

Most economies in Africa are basically dependent on crude oil and its derivatives, such as Nigeria, Angola, and Algeria [1]. Pipes, which are still the safest mode of transportation, are being used to convey these oil and byproducts. However, occasional occurrence of unintended leaks is inevitable. Human error during maintenance, sabotage, corrosion, and ageing pipes and fittings are all known to be contributing factors that cause leaks. Although pipeline leaks often start small, late detection and identification of leaks can be detrimental. For an oil and gas company, delayed detections can cause millions of financial losses, as well as damage to the reputation and environment. Within the last decade, in Africa, several pipeline accidents have occurred taking almost 3000 lives [2]. Most of these accidents were triggered by untimely detection of pipe leakages caused by bunkering activities, internal pressure, and corrosion, among others.

The pipeline right-of-way is neither secured nor guarded and is easily accessible via a 150 m dirt track off the main road. Spill occurred in 1990 in this area which has contaminated many tens of thousands of square meters. An area of 5000 square meters immediately around the spill point is devoid of vegetation, and oil crusts can be seen on the soil

surface in the surrounding areas. Also, in the year 2006, in Nigeria, an oil pipeline punctured by bunkers exploded and killed 150 people at Atlas Creek Island in Lagos State [3]. These extents of damages could have been prevented if there was a pipeline leakage detection system that could send a timely and confirmed notification of the pipeline leakages. In 2016, some researchers designed a pipeline monitoring and surveillance UAV reactive to attacks on pipelines utilizing an Arduino nano-microcontroller, force-sensitive resistor, sound sensor, piezoelectric element, radio transceiver, and GPS module [4]. This system works by listening for impact/pressure on the pipeline that exceeds the predetermined threshold value range and sends the pipeline status and GPS coordinates to the control center with the help of the radio transceiver. This system's performance was discovered to be low with the need for numerous improvements on the sensors, UAV, and the flight controller.

Saliyu Oladimeji et al. developed a multisensor approach for monitoring pipelines which is a very effective way for detecting any kind of bunkering activity considering that motion, sound, and vibration sensors are used [5]. Sapuppo et al. considered sensors based on microfluidic devices that could be arranged for various measurements, such as vibration and gas leakage; they concluded the detection in

microfluidics as a bridge between pointwise and full-field off-line monitoring systems; thus, the microoptical system could be considered as a miniaturization of expensive macro-optical systems toward portable and on-chip optical instrumentation for multicomponent microfluidics detection [6]. The sound sensor is the primary sensor which detects any movement within 15 meters of the pipeline, followed by the sound and vibration sensors which detect sounds and vibrations that come from hitting the pipes or leakages. The sensed parameters are then sent to the microcontroller which conveys them by means of a GSM module. A PIR motion sensor was utilized due to its ability to differentiate human movement from nonhuman movements. This system has produced high accuracy results but lacks a camera for immediate assessment of the site/situation as well as for evidence purposes. Bucolo et al. discussed the control of imperfect dynamical systems for vibration detection, and they designed a control strategy to ensure the optimal working conditions based on the excitation of the hidden dynamics induced by imperfections [7]. Franklin Okorodudu et al. designed a system for monitoring bunkering activities on pipelines [8]. This system consists of the power unit, comparator, microcontroller, switch, sensor wires, and transceiver. Their design involved coating the pipeline with sensor wires along its entire length. An alarm is triggered whenever a person/animal is in close proximity to the pipeline. Light-dependent resistors were used in consonance with other resistors to make them function properly at night. However, this system is prone to a lot of false alarms due to animals triggering the alarms leading to mobilization of engineers which in turn leads to wastage of resources. Also, this system works mainly to monitor the pipeline for bunkering activities.

The aim of this study is to develop a pipe leakage detection system with low response time. This is carried out by exploring vibration sensors and gas sensors synergized with an Unmanned Aerial Vehicle (UAV) for the oil and gas pipeline leakage detection. The response time of the newly developed system will be compared with that of the existing system used in the oil and gas industry in developing countries. Having a pictorial view of the localized area of interest would go a long way to preventing unnecessary mobilization for site visits. The stepwise procedure explored in this work is divided into three layers; the first is developing the basic three units such as the field unit, the aerial unit, and the control center, the second is the measurement of response time of the designed system, and the last is the comparative analysis of the response time of both systems.

2. Methodology

2.1. Material Selection. The materials used for the development of the leakage detecting UAV are two pieces of Arduino nano-microcontroller, a A2212 motor, a transceiver module, four propellers, a LiPo battery, four brushless DC motors, a GPS module, and a magnetometer. A camera ESP32-CAM is used in a series of low-cost, low-power systems on a chip microcontroller with integrated Wi-Fi and dual-mode Bluetooth. The ESP32 series employs a Tensilica

Xtensa LX6 microprocessor in both dual-core and single-core variations and includes built-in antenna switches, RF balun, power amplifier, low-noise receive amplifier, filters, power-management modules, and the ESP32-CAM camera as shown in Figure 1(a).

Another component is a piezoelectric sensor that uses the piezoelectric effect to measure changes in pressure, acceleration, temperature, strain, or force by converting them into an electrical charge as shown in Figure 1(b). Two pieces of Arduino nano-microcontroller were used as shown in Figure 1(c), which helps to gather information from the vibration sensors, gas sensors, and the GPS module and sends to the UAV through the transceiver module MQ-3 sensor. The MQ-3 sensor was used in the development of this UAV, and the MQ-3 module is suitable for detecting alcohol, benzene, CH₄, hexane, LPG, and CO. When the target alcohol gas escapes, the sensor's conductivity gets higher as the gas concentration rises as shown in Figure 2 [9]. The MQ-3 gas sensor has high sensitivity to alcohol and has good resistance to disturbance of gasoline, smoke, and vapor. This sensor provides an analog resistive output based on alcohol concentration. There is a resistance across A and B inside the sensor which varies on detection of alcohol. The more the alcohol, the lower the resistance. The alcohol is measured by measuring this resistance. The sensor and load resistor form a voltage divider, and the lower the sensor resistance is, the higher the voltage reading will be.

A printed circuit board (PCB) mechanically supports and electrically connects electrical or electronic components using conductive tracks, pads, and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a nonconductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it as shown in Figure 3.

2.2. UAV Construction. The first task is to make the frame of the UAV. We have selected SolidWorks application to draw the whole frame and generate the code of the design as shown in Figure 4. The code is sent to a 3D printer where the frames are printed.

The drone frame is a material that was 3D printed, and the material is built from quality fibre and polyamide nylon where all the electronics components are mounted [10]. It has integrated PCB connections for direct soldering of your ESCs with prethreaded brass sleeves for all the frame bolts. The arms are coloured with orientation to keep it flying in the right direction. It has a landing skid gear and large mounting tabs on the main frame bottom plate for easy camera mounting as shown in Figure 5, and the frame specification is presented in Table 1.

To assemble the motor, the four motors are each mounted on the four ends of the frame and fixed firmly to the frame with screws and a screwdriver as shown in Figure 6. After attaching the motors, the four Electronic Speed Controllers (ESCs) are fastened to the bottom of the drone's frame leaving enough free space for other components to be added to the top.

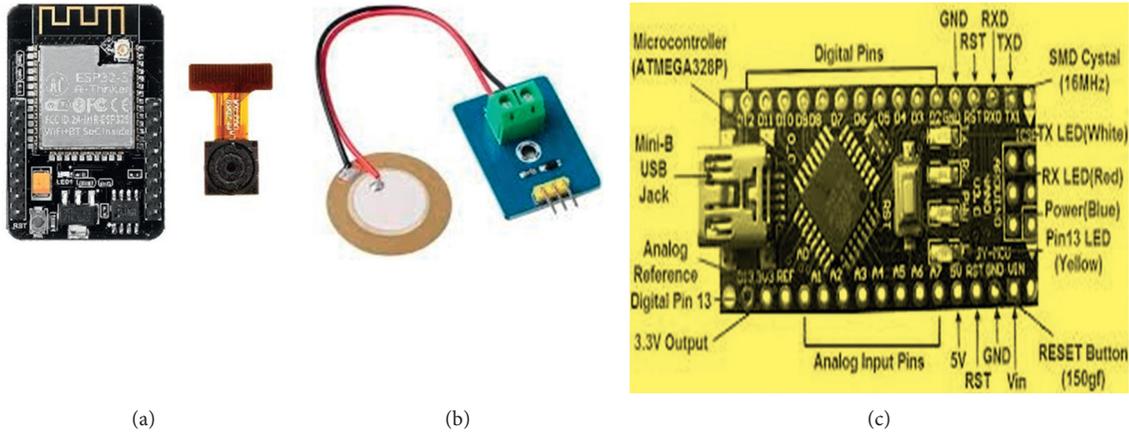


FIGURE 1: Some components of the UAV: (a) ESP32-CAM camera, (b) piezoelectric sensor, and (c) Arduino nanocontroller.

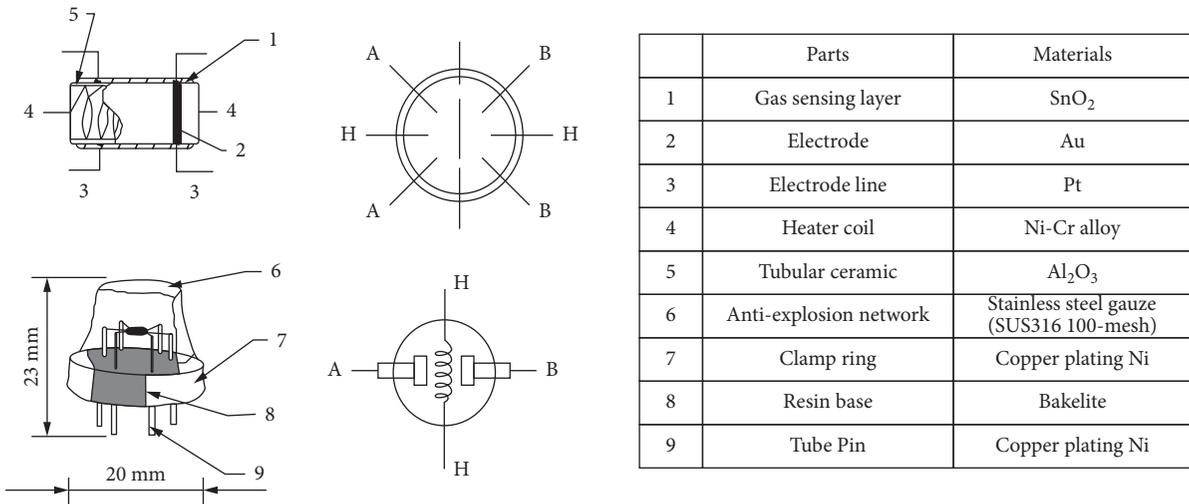


FIGURE 2: MQ-3 gas sensor parts.

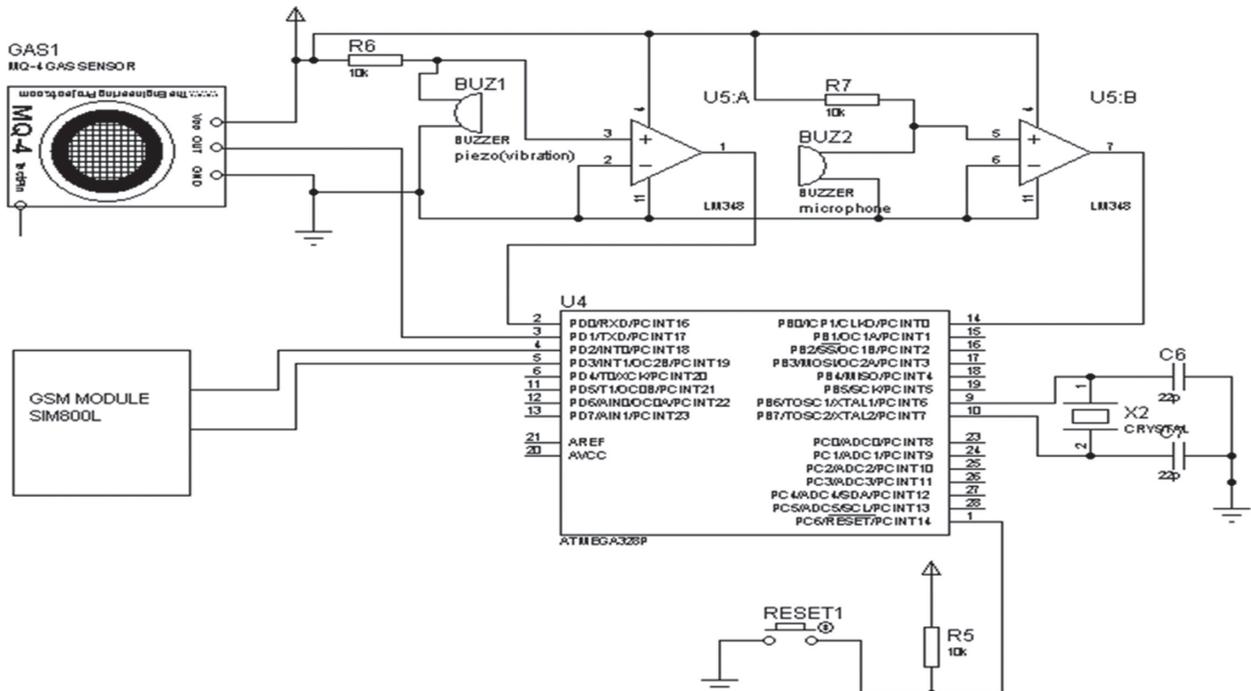


FIGURE 3: Field unit printed circuit diagram.

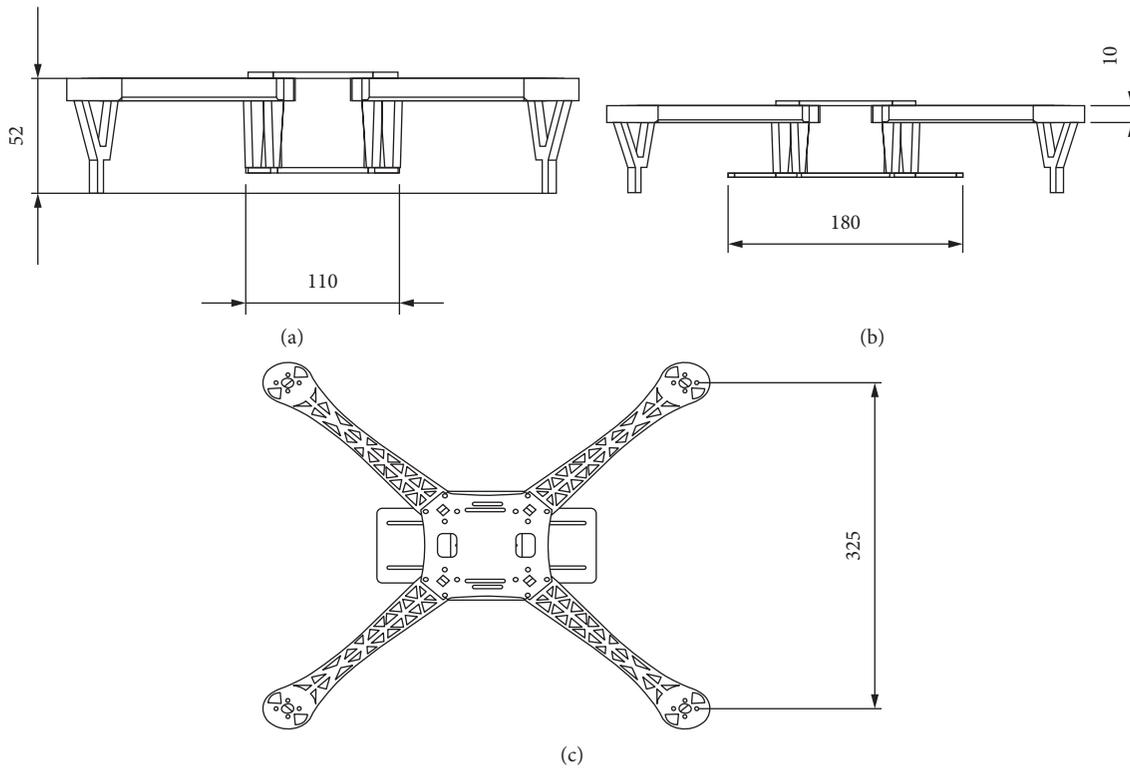


FIGURE 4: (a) UAV frame side view, (b) UAV frame with base measurement, and (c) UAV frame top view.



FIGURE 5: Landing gear.

TABLE 1: UAV frame specification.

S/N	Item	Remarks
1	Dimensions	9.96 × 5.98 × 2.17 inches
2	Weight	280 g
3	ASIN	B0776WLHX7
4	Width	450 mm
5	Height	55 mm
6	Motor mount bolt holes	16/19 mm

The landing gear is an important part when landing your UAV because it significantly reduces the shock when the UAV lands on a solid ground as shown in Figure 5. The type used in this study is the landing skid gear.

The electronic control system stabilizes the UAV in the air while flying and processes all the shifts and changes in the direction of the wind. An Arduino nano-microcontroller is chosen as our UAV controller. The flight controller,



FIGURE 6: (a) Motor mounts. (b) Mounted motor.

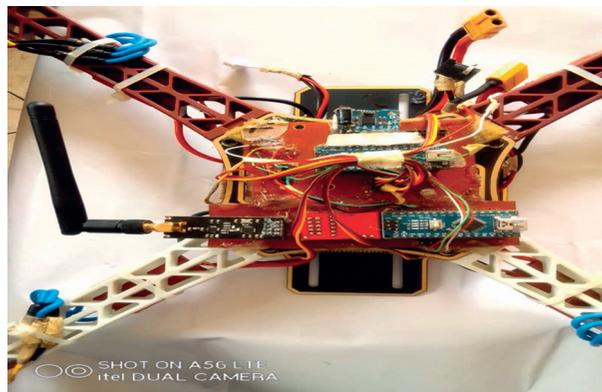


FIGURE 7: Mounted flight controller, transceiver, transceiver adaptor, GPS module, accelerometer, and magnetometer.

transceiver module, transceiver adapter, GPS module, accelerometer, and magnetometer are soldered on the PCB and placed on top of the UAV frame as shown in Figure 7 with pieces of foam attached underneath it to reduce the vibrations coming from the drone. They are all powered by 3,300 mAh. The configuration on the microcontroller is shown in Figure 8.

The two-bladed propellers are screwed on top of the motors. Once the propellers are attached, the UAV is ready for test flights as shown in Figure 9.

3. Results and Discussion

The results obtained after the successful development of the oil and gas leakage detection system are discussed as follows.

3.1. Design Measurement. At the starting, the initial weight of the UAV is 951.7 g and the thrust generated by the motors and propellers is approximately 1,903.4 g thrust according to the Omnidrone calculation app used. Thrust must be greater than the weight; hence, the UAV will be able to fly.

3.2. Effect of Vibration. During the test running, an unwanted vibration was observed, which was generated from the properly and subsequently damped by reducing the length of the propeller from 10 inches to 6 inches. Also, the circuit board was placed on a vibration damper. The accuracy of the sensors used on the UAV was tested as presented in Table 2.

3.3. Response Time of the Developed UAV. The response time taken by humans to mobilize (average of 6 mins) and get to the area of interest for physical confirmation at different distances was recorded and is shown in Table 3 in comparison to response times obtained by the designed LDS.

Table 3 shows the device has a 1146.7% lower response time than human physical investigation. With this low response time, control centre operators can act faster, thereby reducing the extent of damage to the environment which increases for each second wasted waiting for human investigation of the area of interest. This also helps control centre operators to determine if an alarm is false or true.

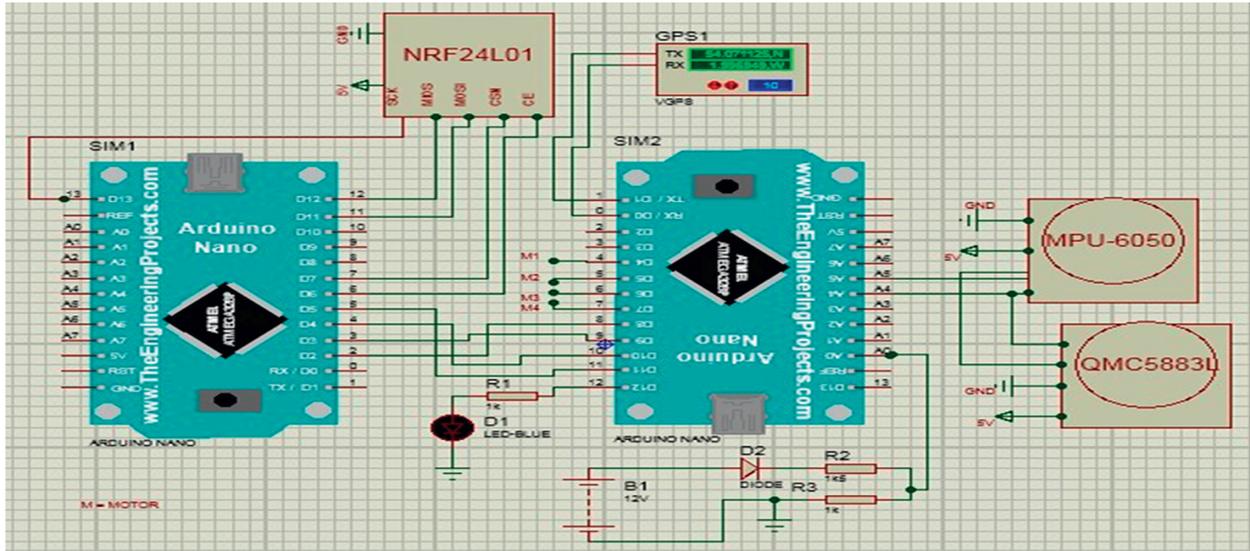


FIGURE 8: The connection with the microcontroller.

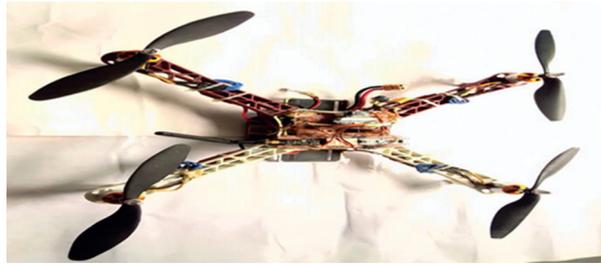


FIGURE 9: The developed UAV.

TABLE 2: Result from the modules.

Modules	First test (%)	Second test (%)	Third test (%)
GPS module	70	85	95
Vibrating sensor	80	93	97
Gas sensor	90	90	95

TABLE 3: Comparison of human response time and designed LDS response time.

Dist. (m)	Human response time (s)	Designed lds response time (s)
300	154.8	13.5
500	258.0	22.5
700	361.2	31.5
1000	516.0	45.0

4. Conclusions

The aim of this study is to develop a device that can have real-time response to pipeline leakage in the oil and gas industry. This is carried out by constructing a UAV that can autonomously fly in response to the event signals transmitted by gas and vibration sensors that is capable of monitoring both buried and surface pipelines, which helps for the purpose of providing a pictorial view of the area of interest and transmitting it to the control room for further actions. Arduino IDE is used to write the code to control roll, yaw, and pitch of the UAV. A 280 g UAV with

onboard instrumentation payload is developed for remote monitoring of oil and gas pipeline infrastructures in real time. The optimal flight altitude was established to be in the range of 4 to 15 m above ground level, and flight duration is for 15 mins monitoring time. The response time of the newly developed system was compared to the traditional leakage detection procedure, and it was concluded that the system would reduce waste of resources experienced by organizations mostly caused by false alarms raised by some of the earlier models and reduce the cost of the amount spent to mobilize the on-site and maintenance engineer.

Data Availability

The data cannot be made available at the moment, as they constitute a part of a self-sponsored ongoing research.

Conflicts of Interest

The authors declare no conflicts of interest for this study.

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