IAES International Journal of Robotics and Automation (IJRA)
Vol. 14, No. 2, June 2025, pp. 151~161
ISSN: 2722-2586, DOI: 10.11591/ijra.v14i2.pp151-161

Development and implementation of a mobile robot for grouting floor tile joints

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Article Info

Article history:

Received Oct 30, 2024
Revised Jan 27, 2025
Accepted Mar 5, 2025

Keywords:

Floor tile joints
Grout filling
Grouting
Injection
Microcontroller
Mobile robot

ABSTRACT

Many construction tasks need time and effort from people. Thus, modern technology is one of its purposes to aid task completion. These include grouting floor tile joints. It takes time and effort to complete this process. Traditional methods for grouting floor tile joints between tiles are inefficient and require the worker to stay on his knees for extended periods, which can cause health issues. Thus, mobile robots are needed to automate floor grouting. This study describes the design and development of a mobile robot model to grout floor tile joints uniformly and effectively. Compared to manual approaches, the proposed robot can clean tiles quickly and precisely. The robot fills based on user-defined workspace coordinates. Set the robot at the start location to begin grouting. The robot then follows the user-defined code and coordinates to fill the requirement. After grout filling, the robot returned to the starting position to clean. This model was evaluated and exhibited faster, more accurate grouting and a shorter injection process than manual approaches.

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1. INTRODUCTION

Technology is used in all areas of practical life these days [1], [2]. We are getting more and more reliant on the utilization of various forms of technology on a daily basis [3], [4]. Technology is now beginning to play a more significant role than ever in influencing the future, both in the lives of individuals and directly affecting the work environment [5], [6]. This technology has grown indispensable in our life, encompassing communication, transportation, information retrieval, and entertainment [7], [8]. In addition, utilization of modern technology plays a major role in the medical and educational sectors to ensure smoothness and effective operations [9]–[11]. Among these technologies is the mobile robot which has rapidly developed utilizing different technological tools [12]–[14]. All these developments aimed to realize contortedness to human and safer living environment [11], [15].

In order to achieve more comfort in the work that requires physical effort to complete, especially construction work, the trend towards using robots has begun to increase in recent decades [16]–[18]. And the use of such technology in the field of construction to improve productivity and reduce labor costs as well as to complete tasks more accurately [19]–[21]. An example of this is the process of grouting tiles as an alternative to manual injection and the resulting problems such as inconsistency due to worker fatigue in addition to the difference in the viscosity of the grout [22].

According to statistics, about 80% of people suffer from lower back pain. Also, about 1% to 3% of the population suffers from lumbar disc herniation associated with lower back pain every year. These symptoms lead to the inability to perform their various daily tasks in a normal way [23], [24]. Also, other statistics indicate a high incidence of osteoporosis in the knee, with approximately 86.7 million people worldwide suffering from this chronic disease in 2020 [25]. Consequently, there is an immediate necessity for surgical operation that necessitates substantial financial resources to fund the requisite medical care.

The main use of robots has emerged widely to help perform movements or services that are difficult for humans to perform easily, accurately and quickly [26], [27]. Many applications of robots have also spread in different areas of life to facilitate the completion of tasks and save time and effort [28], [29].

The growing utilization of service robots seeks to enhance individuals' quality of life. Their application has recently broadened to encompass fence-free settings in locations such as restaurants, factories, distribution hubs, and hospitals. The research introduced a proposed classification system for service robots, emphasizing their propulsion methods and examining their applications, advantages, and drawbacks. This is to promote the advancement of more dependable robotic solutions [30].

Robots perform functions that are pre-programmed and controlled directly by humans or by commands from computer programs. One of the most important advantages provided by robotic systems is the ability to perform difficult or dangerous tasks accurately and increase productivity [31], [32]. Hand gesture recognition facilitates the control of a wheeled mobile robot by identifying human upper body gestures across various operational contexts. The outcomes of the identified gestures are transmitted to the robot, which is maneuvered according to the data from the recognized gestures, enabling the mobile robot to be operated using hand gestures without any physical intervention [33].

In addition to using equipment efficiently and reducing labor costs by completing work in a shorter time. Robotic systems are also characterized by flexibility and ease of programming, and can be used to work in dangerous conditions that are difficult for humans to work in [34], [35]. The brain-computer interface facilitates direct communication between the human brain and its associated devices by converting electroencephalogram signals into control commands. A self-learning neuro-fuzzy controller and an obstacle avoidance controller are employed to facilitate joint control of mobile robotics by the brain, thereby improving safety, control performance, and durability. The user's intentions are tracked robustly by this controller, which ensures the safety of the mobile automaton by adhering to the necessary commands [36].

A study presented a dynamic model utilizing computational methods to enhance the stability and performance of wheelchairs for the elderly and disabled. The results of the used control systems indicated that the PSO-optimized PID fuzzy logic controller surpassed the PD controller. The minimization of settling time, overshoot, and steady-state error was accomplished, hence improving the safety and comfort of users when utilizing wheelchairs [37].

Tile grouting is the process of filling the gaps between tiles. This process is usually done by manually injecting the grout material, where the worker fills the gaps between the tiles and then returns to clean the tiles after the grout dries [38], [39]. Hence the idea of designing a robot that helps to complete this process in an easy and simple way through a specific programming of the robot that depends on choosing the work area and coordinates using a microcontroller where the starting point and work line of the robot are determined so that it walks over the gaps between the tiles and performs the grouting process [22].

The grout process requires a lot of time and effort from the worker to fill the gaps between the tiles and also to clean them again from the grout residue. Hence the importance of employing robotic systems to solve this problem and save time and effort in addition to accuracy in work. The main goal of the project is to reduce human intervention by completing some tasks that may be difficult, such as grouting. The worker places the robot at the beginning of the area and gives it the coordinates of this area, then the robot works alone and completes the work with less effort, less energy, less manpower and less cost. In addition to higher accuracy, the tasks required for all spaces are executed according to the coordinates used.

The proposed system for the grouting process works in three stages. The first stage is the pre-grouting tiles joint cleaning from dust and concrete residues between the tile's joints. Then, grouting filling in which the spaces between the tiles are filled with the grouting material. The last stage is the post-grouting cleaning. In this stage, the robot cleans the floor surface of the working area after the completion of the tile grouting process. Figure 1 presents a diagram that illustrates the grouting process.

First, the robot is placed at the beginning of the work line, then we enter the tile coordinates (width). Then we turn on the machine, the robot starts walking on the edge of the tile and puts the grouting inside the empty space between the tiles, where the on/off sensor stops the robot from working if it is not pumping the grouting and turns it on if it is pumping the grouting. During the tile grouting process, when reaching a dead end, the distance sensor senses the distance between the robot and the obstruction, the robot changes its direction and completes the process.

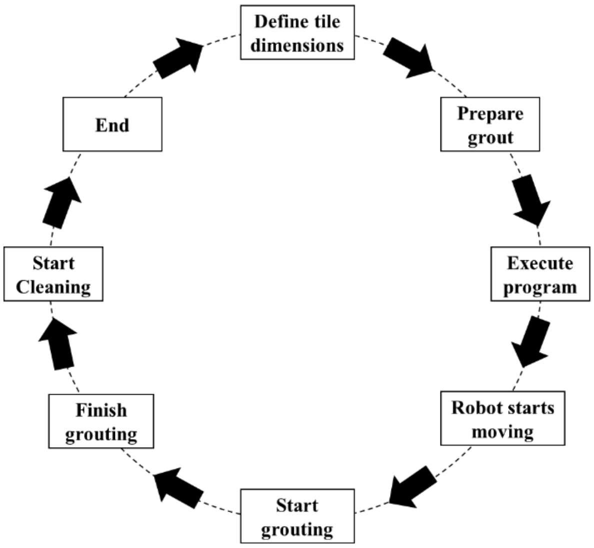

Figure 1. Grouting process

2. PROPOSED SYSTEM IMPLEMENTATION

Figure 2 shows the hardware architecture for the proposed robot. The inputs are keypad and ultrasound sensors. The outputs are LCD, DC and servomotors. The controller used in the developed robot is Arduino Mega. The proposed robot consists of electronic, electrical and mechanical components. The descriptions of the major components are presented below with further details.

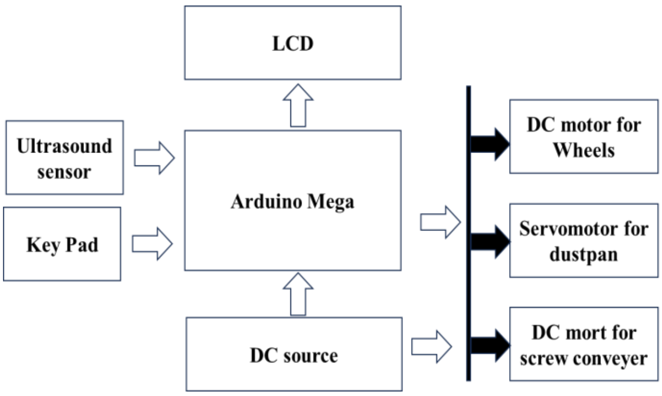

Figure 2. Proposed system architecture

2.1. Electrical system

The developed device is composed of a set of electrical and electronic parts that need energy for the intended performance tasks.

a. Arduino Mega 2560: This is a microcontroller device based on the ATmega2560 that has 54 digital input/output, 16 analog input/output, and 4 UART ports as shown in Figure 3.
b. Liquid crystal display (LCD): This is a display screen that displays the values entered through the keyboard used. These values are entered when using the robot to set up its operation according to the requirements of the tiles used in the place. This screen is there to verify the correct input values for the robot's working area before starting the work.
c. The keypad: It is a set of buttons arranged in a pad which have digits and symbols. The keypad is used to insert the tile dimensions for the further process with the system microcontroller
d. DC Motor Encoder: It is a transducer device used to measure the direction and rotation speed of the motor then send to the microcontroller to standardize the speed of the wheel.

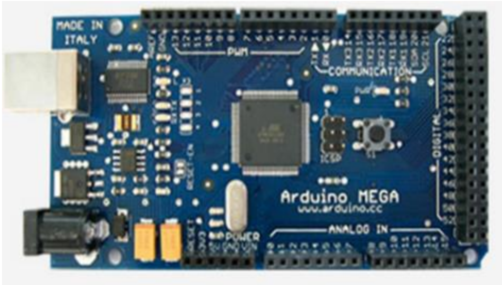

Figure 3. Arduino Mega 2560

e. L298N Driver: it is an integrated circuit that has a dual full-bridge driver designed to drive the DC motors. The microcontroller processes the encoder inputs and sends output instructions to the H-Bridges, and the H-bridges then control the motion speed and direction of the DC motors. The L298N driver is shown in Figure 4.
f. Ultrasonic Sensor: is an electronic module that is used to detect the obstacles based on sending and receiving of ultrasonic waves [40], [41]. This module is used to detect obstacles near the robot by sending and receiving ultrasonic waves at high frequencies. Based on the received wave, the microcontroller determines the distance between the robot and the obstructing object and issues commands to avoid the obstacle. The ultrasonic sensor module is illustrated as shown in Figure 5.

Figure 6 shows the electrical parts of the proposed grouting robot composed at which the aforementioned parts are assembled: 1: Battery, 2: On-off Switch, 3: Regulator, 4: Keypad, 5: LCD, 6: Ultrasound Sensor, 7: Arduino microcontroller, 8: Motor driver, 9: The Encoder, 10: DC motor for cleaning brush 11: Two DC motor for moving the robot wheels, 12: Servomotor for moving dustpan up and down, 13: DC motor to move the screw conveyor.

Figure 4. The L298N driver

Figure 5. Ultrasonic sensor

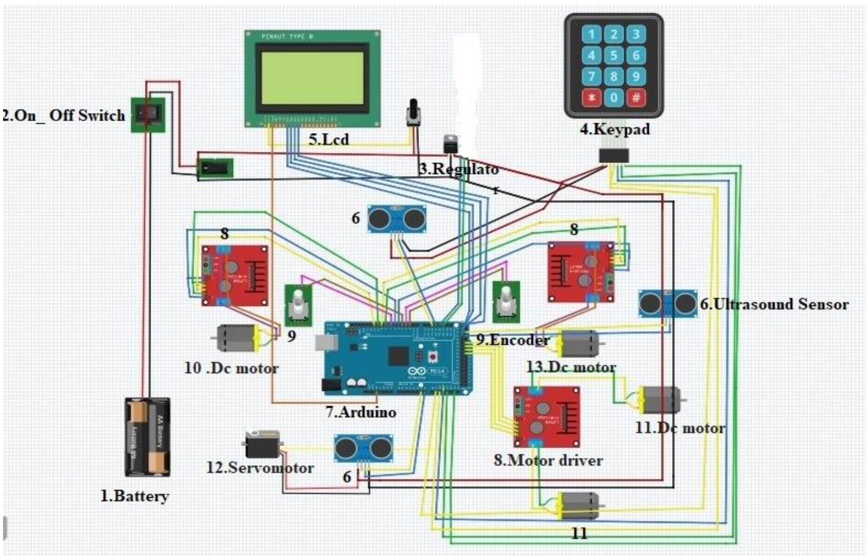

Figure 6. The overall electric circuit

2.2. Mechanical system

The mechanical system is as follows.

a. The wheel: This is the main component required to move the robot. The wheels are fixed to rotate on the axle bearing. The wheels work together with the axle to facilitate movement or transportation. The wheel used in the robot model is 10 cm in diameter and 5 cm in width.
b. The belt: In the proposed design, two motors were used to move the robot, and the tensioners were placed on the back side. The belt acts as a tool used to connect the front wheels and the rear wheels. The width of the belt used is 4.5 cm as shown in Figure 7.

Figure 7. The belt

c. Base structure: The internal frame structure of the proposed grouting robot base is made of solid iron metal, which is used to install and assemble most of the electronic and mechanical parts on it. The internal base structure of the proposed system is shown in Figure 8.
d. The grout tank: In order for the robot to inject the grout, there must be enough grout for a longitudinal or transverse work cycle of the place. Therefore, a grout tank made of stainless steel in the form of a conical container was used, inside which the grout filler for the tiles is placed as shown in Figure 9.

Figure 8. Robot base structure

Figure 9. Grouting tank

e. The screw conveyor: It is placed at the bottom of the grouting tank and moves the grout material out of the tank as a mechanical pump in order to push the grout into the tile joints as shown in Figure 10.
f. The Dustpan: It is a tool installed at the bottom of the robot to compress the tile grout and insert it into the space between the tile joints. The dustpan is shown as in Figure 11.

Figure 10. Screw conveyor

Figure 11. Dustpan

g. Cleaning brush: It is a cleaning tool installed at the bottom of the robot’s front. It cleans the work area before starting the grouting process, and also after the grout material dries in the tile joints, the brush is shown in Figure 12.

Figure 12. Cleaning brush

All of the electrical and mechanical components of the mobile grouting robot that was developed are shown in Figure 13, which depicts the final complete construction of the robot.

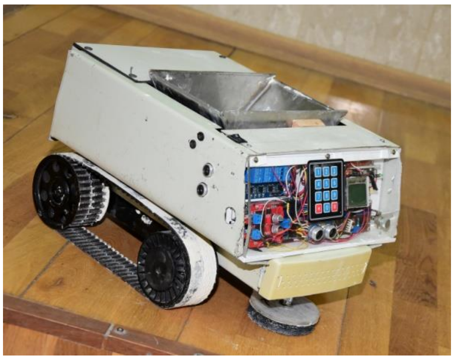

Figure 13. The final grouting robot prototype

3. METHOD

In this section, clarification is offered regarding the particulars of the procedure that is implemented in order for the robot to function. An illustration is provided of the procedures that are carried out in order to initiate and run the system that is being presented.

First, the microcontroller is defined with the dimensions of the tile in the room that needs to be grouted by entering them through the keypad and displaying them on the robot's LCD screen. The tank is filled with the appropriate amount of the required grouting material. Then the robot is placed at the beginning of the work area and then turned on to start. While the robot is performing cleaning or injection tasks, the ultrasonic sensor prevents the robot from hitting the wall to complete the required task. The robot moves and starts pumping the grouting material into the spaces between the tiles, by the bottom valve, then the dustpan presses the grout filler.

The Arduino controller is programmed so that the robot starts its task (cleaning or grouting) by walking longitudinally at the work site, and after finishing that, it moves to walk in the transverse direction. When the robot is placed at the beginning of the longitudinal track, it continues to walk in the forward direction until it reaches the end of the work area. The ultrasonic sensor located at the front of the robot detects the approach to the end of the path, and as a result, the robot stops the grouting pump or lifts the dustpan. The longitudinal injection path of the robot is shown in Figure 14.

Then the robot turns left into the work area at a 90-degree angle, walks a distance equal to the length of one tile, turns left again, and then completes the walking process and pumping the grout until the end of the longitudinal path again. It continues in the same way to finish all the longitudinal joints within the workspace to be filled with grout.

After completing the longitudinal joints, the robot turns to the right at a 90-degree angle and then continues to inject the grout into the transverse joints in the same manner as described in the previous longitudinal direction until the end of all transverse lines. The transverse path of the robot's movement and grout injection is shown in Figure 15.

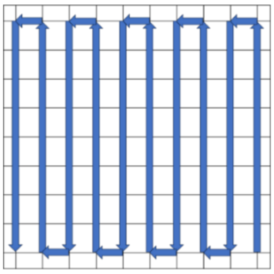

Figure 14. Longitudinal track of the grouting robot

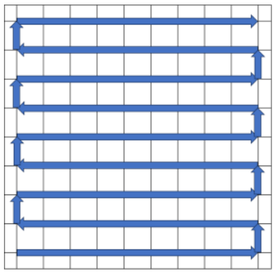

Figure 15. Transverse track of the grouting robot

After the end of the grouting operation, the robot returned to the same starting point to start cleaning the remnants of the grout material. A cleaning brush is installed on the DC motor to move the brush at high speed to ensure cleaning the working area effectively. The flowchart in Figure 16 explains the flow of the grouting robot's grout and clean operations.

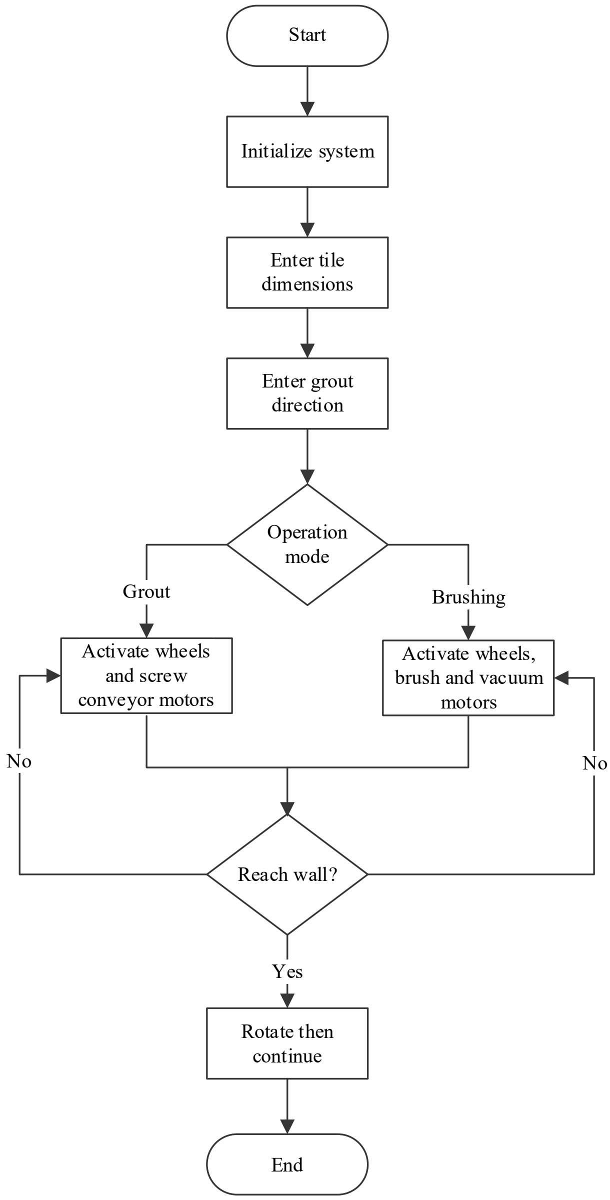

Figure 16. Grouting robot workflow

4. RESULTS AND DISCUSSION

Grouting tiles is considered one of the most tiring processes for workers. These jobs cause many workers to suffer from chronic diseases such as herniated discs, back discs, and knee osteoarthritis, due to the worker sitting on their knees for long periods of time. Therefore, the idea of this proposed model of the grouting and cleaning robot was to find a way to support and assist construction workers in grouting tiles to complete their work as easily as possible using modern technology.

The functioning mechanism of the proposed model is depicted in Figure 17, along with the outcomes of employing this electromechanical system for the grouting process of tile joints. These outcomes are shown both before and after the robot has successfully finished all three stages of the process (initial cleaning, grouting, and after grout cleaning).

This robot basically completes the three stages of the tile grouting process, which involves. The first step is to clean the spaces between the tiles and vacuum the dust and dirt. The next step is to inject the tiles with the appropriate grout to fill the spaces between the tiles. After completing the injection process, the third step begins with cleaning the remaining grout using the brush located at the bottom of the robot after the grout dries. The proposed model of the tile grout robot was tested to complete the three stages of the grout process. The results showed that the grout robot performed the required task satisfactorily and, in less time, than the time required to make the grout using the traditional manual method.

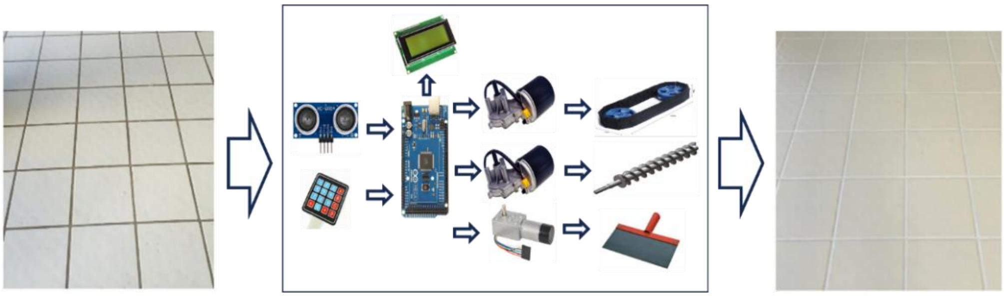

Figure 17. Grouting system

For example, when grouting a room with dimensions of 4m*4m, the time required for the grouting process in its three stages of cleaning, grouting, and cleaning after grouting by hand ranges from two and a half to three hours. While this time was reduced to less than half when this work was completed with the help of the proposed robot. Moreover, performing the grout work manually requires the presence of at least three workers, where the main worker injects the grout, the second worker prepares the grout, and the third worker cleans.

When comparing the quality of work done by the proposed model to the manual method, the quality of work done by using the robot was comparable to the quality of work done by hand. In addition, completing the process using the robot requires only one worker to prepare the materials and supervise the work of the robot. Get good results for the grouting and cleaning process. The worker's effort is reduced by approximately 80%. Thus, enabling the worker to complete more than one task at the same time. As well as reduce consumption of grout material and provide more clean and efficient work.

5. CONCLUSION

The construction process requires high effort and time from workers to accomplish it. Tiles grouting is found among these duties that suffer from inefficiency, in addition to the high labor effort required. This paper describes the design and development of a mobile robot model that is designed to complete the grouting process to ensure that the grout is injected uniformly and effectively in the tiled areas. Furthermore, the proposed robot is capable of cleansing tiles in a rapid and precise manner. The robot fills based on user-defined workspace coordinates. Set the robot at the start location to begin grouting. The robot then follows the user-defined code and coordinates to fill the requirement. After grout filling, the robot returned to the starting position to clean. When compared to manual approaches, this model produced results that demonstrated an increase in both the speed and accuracy of the grouting process, as well as a reduction in the amount of time necessary to finish the injection process. Overall, the findings were positive in terms that the tile grouting was satisfactorily done.

ACKNOWLEDGEMENTS

The authors are grateful to Palestine Technical University - Kadoorie for their financial support to conduct this research and for providing the needed laboratory facilities to conduct this project. The authors also thank the technicians and undergraduate students who provided technical assistance and supported the work in the laboratory.

FUNDING INFORMATION

The authors are grateful to Palestine Technical University - Kadoorie for their financial support to conduct this research under PTUK-research 2025.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Wael A. Salah	✓	✓		✓	✓	✓		✓	✓	✓		✓	✓	
Mohamed Elnaggar	✓		✓	✓			✓			✓				
Mai Abuhelwa	✓		✓	✓			✓			✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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