Quadruped Robot for Landmine Detection and Network based Location Sharing

[1] Anaanya Kattali, [2] Prof. Vijay Bhosale

[1] Student, K J Somaiya College of Engineering, SVU, College address
[2]Professor, K J Somaiya College of Engineering, SVU, College address

Email: [1]anaanya.k@somaiya.edu, [2]vijaybhosale@somaiya.edu
Contact: [1]7506383925, [2]9930253341

Abstract:. Landmine detonations have severe impact on society and nature. In war stricken areas it has led to loss of innocent lives of locals as well as army personnel. Even now detection is done with heavy machinery and human expertise on the field which proves to be dangerous and expensive in terms of cost of life and equipment. Hence there is a need to implement autonomous systems in the field that can help save lives more effectively. Extensive literature survey has been done on the topics of development of robots for disaster management and for landmine detection, improvements in sensors to find the tricky or deep buried mines and future scope of demining the system itself to make the path safe to travel. This paper gives an overview of the methodology undertaken to develop a Quadruped Robot (instead of the wheeled robot that usually used for most projects), understanding of different gaits that can be used in the field, use low cost and suitable materials, development of a system for metal mine detection and obstacle handling and ways to relay the mine and robot location to home base in cases when there is and isn't any network conditions.

Index terms: Quadruped Robot, Landmine Detection, Positioning, Detection Sensors, GPS, IoT, RFID tag, MATLAB, SimScape

I. INTRODUCTION

Over the years, war has evolved from human combat and simple weapons to now involving advanced technology and remote targeting. Drone strikes, man made high intensity bombs, bio-warfare are all examples of methods of starting wars without need of being on the field. Mentioned before are highly sophisticated methods of warfare, however a more localized, easy and highly destructive method that is implemented vastly by the attacking groups is use of landmines.

These landmines are usually installed in remote places or smaller countries where the effect is much more pronounced. The UN- Mine action services describe that since 1960s more than 100 million mines have been spread across the globe and posing a threat in more than 78 countries.(j52 ppr) A brutal effect of landmines are once they are detonated they can still be active for days making them highly dangerous. What makes landmine detection difficult is basically a variety of factors – the type of landmine (AT, AP, Blast Fragmentation), the type of triggering for the same (weight, trip wire, contactless, chemical) and their placement on field in a zigzag or unpredictable buried manner.

Till now human expertise is used with heavy mine detection equipments which can endanger their lives and cost of replacing the equipment is high. This is where the need of remote controlled or autonomous objects like robots can prove to be useful in such high risk settings.

Demining Robots will change the approach to detecting landmines in post-war zones, avoiding direct human-to-mine contact until the threat removal stage, and ultimately introducing a safer demining procedure.
Specialized sensors are used to detect land mines, UXOs and IEDs namely:

- Ground Penetrating Radar,
- Optoelectronic,
- Metal Detector,
- Holographic Radar

For low cost development, we can utilize IR, chemical, inductive proximity sensors. These also detect in methods that do not trip or affect the detonation of landmine.

II. RESEARCH OBJECTIVES

The following points focus on how the project is different from exiting industry mine detection robots

1. Need for legged robots over wheeled robots : based on factors of

- Stability
- Energy Consumption
- Ground Terrain
- Maneuverability and Controllability
- Obstacle clearance

- This is because wheeled robots are much easier to assemble, code and maintain. The heavy topics of Robot Kinematics and Dynamics aren't used to a great extent.

2. Using simple concepts of RFID for location when communication and internet or radio based communication is lost

- In the field it is not possible for radio or internet services to work at all times so alternatives need to be made so that the robot can switch to either modes depending on the situation

3. Use of simple easily available sensors and exoskeleton materials to remake the robot in dire situations

- For most places ridden with mines, the economy isn't enough to invest in 3D printed or strong parts hence one place for cost saving and being sustainable is using available resources like tiny motors or aluminium, fibre or used wood/plastic sheets

4. Introducing switching between legged and wheeled mode based on terrain (Future Scope)

III. ROBOT DEVELOPMENT METHODOLOGY

Most companies would rely on wheeled robots as they are easy to develop and control. However in unsuitable terrains they would not be useful. Hence its imperative that legged robots be incorporated. A drawback of said robot is the concept of dynamics and tuning makes the development more complex. Many Quadruped robots have been used in the field for variety of tasks – Spot being the most famous – for carry weights, equipment, path planning and so on. COMET-I maybe the first legged robot purposefully developed for rescue missions. It is a six-legged robot developed at Chiba University, Japan, and incorporates different sensors and location systems. (hexapod paper).

i. Robot Selection

Quadruped robots are easier to build, control and implement. It is also inferred that:

• Bipedal Robots have high DoF hence they are used as a leg structure for the Quadruped robot.

• Bipedal Robots also use symmetric gaits for walking hence in turn high degree of freedom can be achieved in Quadruped Robot in lieu.

• With four legs, they can be more stable on rough or unprecedented terrain during autonomous operation

• Dynamic balancing, maneuverability aspects, and control algorithms much easier to solve compared to others.

Hence Quadruped robot with biped leg structure was used to develop the project.

ii. Software Simulation

- SimScape

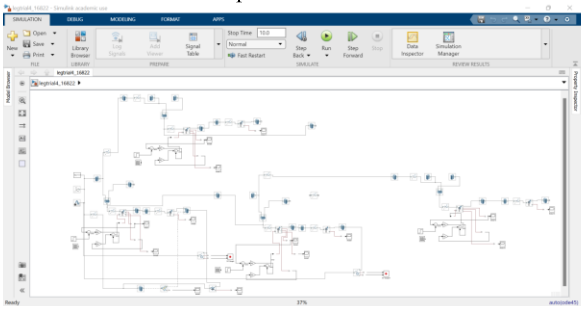

Figure 1: SimScape Robot development

iii. Hardware Components

- Aluminium and fibre pieces
- Arduino Uno/Mega and Esp8266
- PCA9658 PWM Servo Driver
- MG995 motor
- Ultrasonic Sensor
- GPS Neo
- SD card module
- ESP32 CAM
- Identifier(RFID) placer

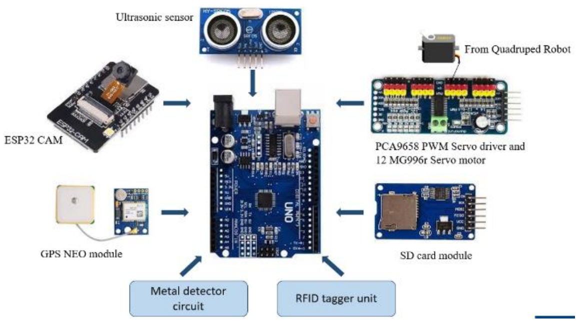

Figure 2: Basic circuit components

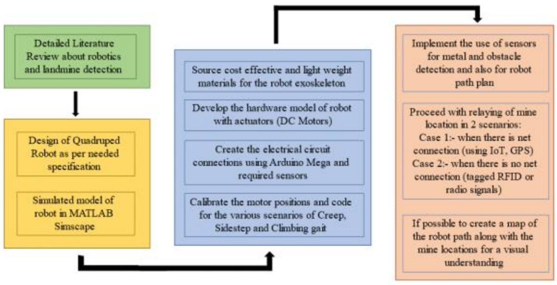

Figure 3: Flow of project development

IV. IMPLEMENTING KINETICS FOR ROBOT LEG PLACEMENT

The joint space is represented by joint angles. The conversion of the position and orientation of a manipulator end- effector from Cartesian space to joint space is called as inverse kinematics problem. There are two solutions approaches namely -

geometric and algebraic used for deriving the inverse kinematics solution, analytically.

Geometric solution (used in this scenario) for 2DoF is given as below –

$$\theta_2 = A\tan 2\left(\pm\sqrt{1-\left(\frac{p_x^2+p_y^2-l_1^2-l_2^2}{2l_1l_2}\right)^2}, \frac{p_x^2+p_y^2-l_1^2-l_2^2}{2l_1l_2} \right) \tag{5}$$

$$\theta_1 = A\tan 2\left(\pm\sqrt{1-\left(\frac{p_x(l_1+l_2c\theta_2)+p_yl_2s\theta_2}{p_x^2+p_y^2}\right)^2}, \frac{p_x(l_1+l_2c\theta_2)+p_yl_2s\theta_2}{p_x^2+p_y^2} \right) \tag{6}$$

A quadruped robot legs are also 2DoF (only inverted) and we use equation (1) and (2) to control the actuator angles to place the leg at desired location.

Given:

• Link lengths : l1, l2 (a1 , a2)

• Desired height of robot from the ground : h (where h < l1 + l2)

• Desired step size : x

To find:

• θ1 and θ2 to control actuator (motor)

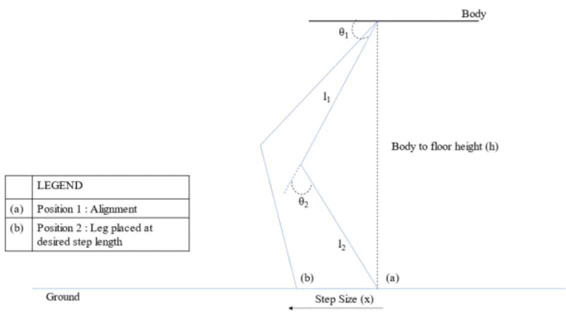

Figure 4: Leg Placement

V. ANALYZE GAIT AND SIDESTEP FOR ROBOT

The servo motors are used for this robot for its 2 gaits:

i. Forward Creep Gait:

So, our plan of action is:

• for each leg in a set order, shift the body away from that leg

• raise the leg

• move the leg forward

• set the leg on the ground

• shift the body ahead for behind leg and repeat the process.

Below figure gives a representation of the gait movement with one important concept to be followed – ensuring the Centre of Gravity (CG) of the body is always within the triangle made by the three legs in ground contact during leg movement pr within the quadrangle when all four legs are in ground contact at time of body shift.

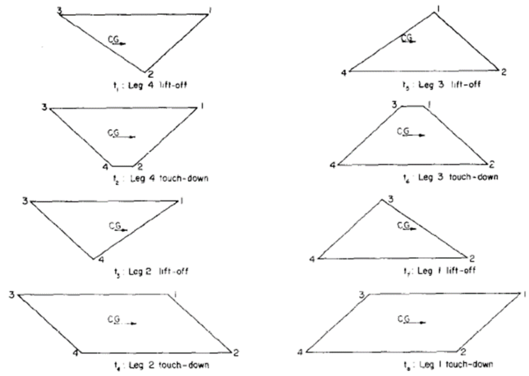

Figure 5: CG at all time of Robot Locomotion

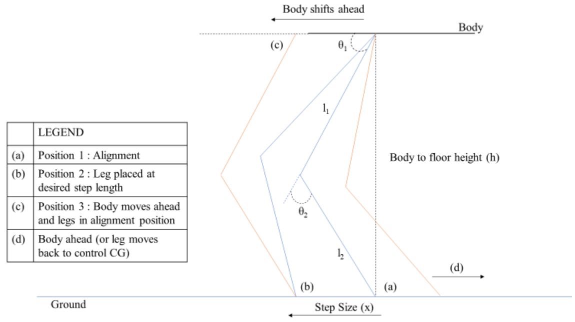

Figure 6: Robot Creep gait movement

ii. Sidestep Gait

To avoid obstacles we use the same concept of creep or trot along with above DK and IK principles but utilize the third motor attached to the robot body for lateral movement.

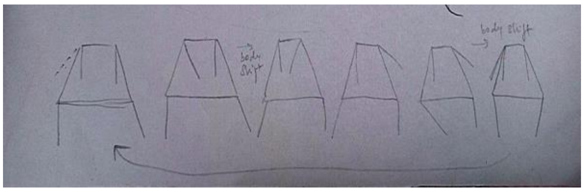

Figure 7: Robot Side Step gait movement

VI. SIMULATIONS AND EXPERIMENTAL RESULTS

The simulation in SimScape gives us an understanding of the basic structure and movement of the robot.

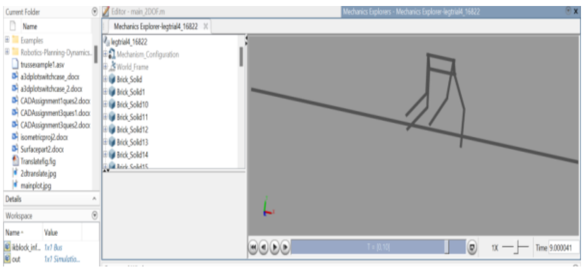

Figure 7: Simulation of SimScape project

Through Inverse Kinematics and trial programming the motor angles are calculated and validated for error and leg movements.

Table 1. Motor Angles at each position of creep gait

	Leg 1			Leg 2			Leg 3			Leg 4		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
Position 0	65	110	30	120	105	145	50	115	32	30	90	45
Position 1	65	76	94	120	139	81	50	81	96	30	124	-19
Position 2	65	55	130	120	160	45	50	60	132	30	145	-55
Position 3	65	67	90	120	148	85	50	72	92	30	133	-15
Position 4	65	88	92	120	97	83	50	93	94	30	112	-17

The metal detector gives an sense of any mine placed in the soil with the LED blinking as indication

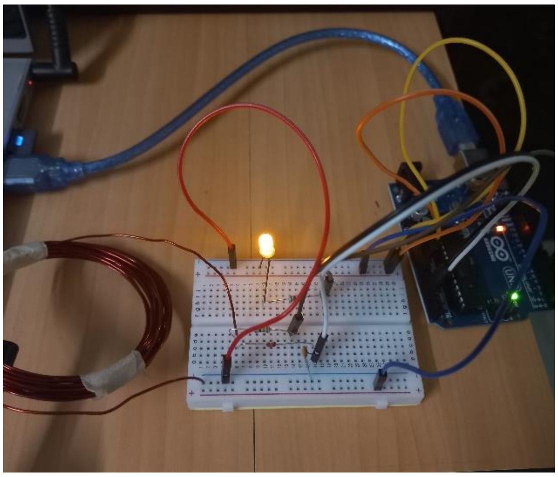

Figure 8: LED on when metal is detected

The distance from an object impeding the path is recorded by the ultrasonic sensor.

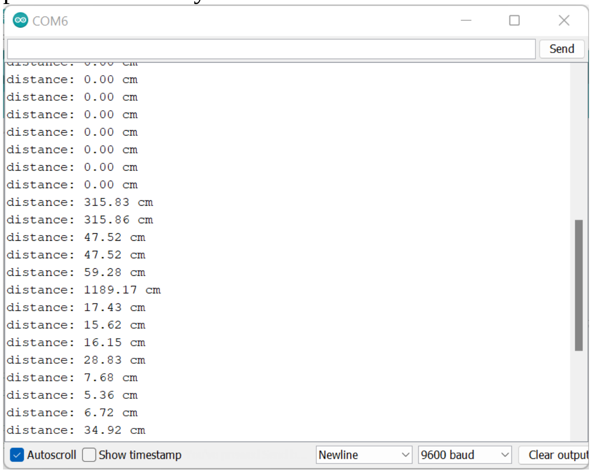

Figure 9: Distance of various objects from Ultrasonic sensor

The ESP32 CAM gives a live stream video footage of the path ahead of the robot.

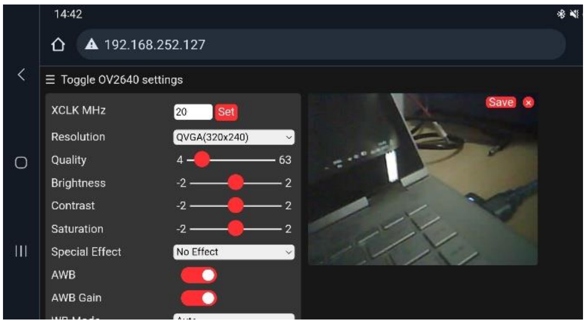

Figure 10: Live video stream from robot pov

In the case where there is network connectivity, GPS NEO gives the robot and mine location to the main base. Also as backup the coordinates are recorded in a sim card too.

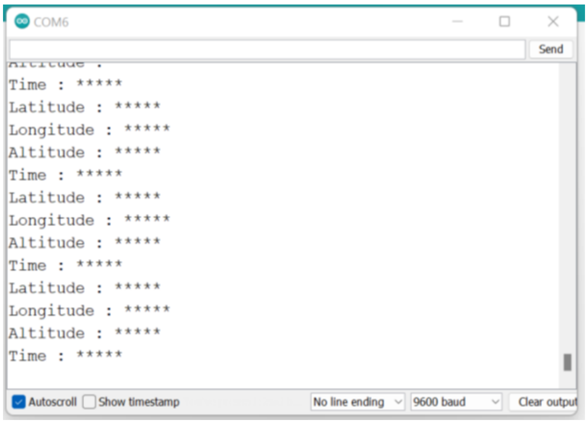

Figure 11: GPS location of mine and robot

In case of no or loss of network, the RFID tag is placed for the later stages of robot movement.

VII. FUTURE SCOPE

The robot setup can be made more smarter and robust by few future additions :

- Introduce dynamics to robot development to calculate the force on each link and maintain the robot for its movement.
- Integrate SLAM or a trajectory software to get a pictorial path followed by the robot in real time.
- Use IoT to gather data and visualize/predict the next probable mine location
- Add gyroscope to control the motor angles and attain self-balance of robot

CONCLUSION

Considering the low cost and technology used in the robot, this setup can be used extensively in countries that cannot afford to spend on high technology and machinery for their safety. The concepts are simple to understand and develop hence if the robot triggers a mine it can be remade easily. This will help to atleast locate mines in a localized manner without much human damage and loss. These types of small projects can help war stricken countries at fraction of the cost and by implementing some new technologies the robot can be more effective and robust to survive various conditions.

REFERENCES

[1] Zubair, M., & Choudhry, M. A. (2011). Land mine detecting robot capable of path planning. *WSEAS Transactions on Systems and Control*, *6*(4), 105–114.

[2] Zeng, X., Zhang, S., Zhang, H., Li, X., Zhou, H., & Fu, Y. (2019). Leg trajectory planning for quadruped robots with high-speed trot gait. Applied Sciences (Switzerland), 9(7). https://do. *Applied Sciences (Switzerland)*, *9*(7).

[3] Widodo, A., Muzakki, A., & Baskoro, F. (2019). *A 2-DoF Robot Arm Simulation for Kinematics Learning*. *242*(Icovet 2018), 249–252. https://doi.org/10.2991/icovet-18.2019.60

[4] Wang, H. B., Li, Y., Ren, K., Yang, L. J., & Han, Z. H. (2021). The development status and trends of ground unmanned combat platforms. *Journal of Physics: Conference Series*, *1721*(1). https://doi.org/10.1088/1742-6596/1721/1/012065

[5] Thavai, R. R., & Kadam, S. N. (2016). *Dynamic Modelling of Biped Robot*. *4*(2), 252–262.

[6] Sun, W., Tian, X., Song, Y., Pang, B., Yuan, X., & Xu, Q. (2022). Balance Control of a Quadruped Robot Based on Foot Fall Adjustment. *Applied Sciences (Switzerland)*, *12*(5). https://doi.org/10.3390/app12052521

[7] Spröwitz, A. T., Ajallooeian, M., Tuleu, A., & Ijspeert, A. J. (2014). Kinematic primitives for walking and trotting gaits of a quadruped robot with compliant legs. *Frontiers in Computational Neuroscience*, *8*(MAR), 1–13. https://doi.org/10.3389/fncom.2014.00027

[8] Siravuru, A. (2020). Geometric Control and Learning for Dynamic Legged Robots. *ProQuest Dissertations and Theses*, *December*, 127.

[9] Raibert, M. H. (1986). *(Artificial Intelligence) Marc Raibert-Legged Robots That Balance-The MIT Press (1986).pdf* (p. 235).

[10] Rachkov, M. Y., Marques, L., & De Almeida, A. T. (2005). Multisensor demining robot. *Autonomous Robots*, *18*(3), 275–291. https://doi.org/10.1007/s10514-005-6840-y.

[11] Biswal, P., & Mohanty, P. K. (2021). Development of quadruped walking robots: A review. *Ain Shams Engineering Journal*, *12*(2), 2017–2031. https://doi.org/10.1016/j.asej.2020.11.005

[12] Bielecki, Z., Janucki, J., Kawalec, A., Mikolajczyk, J., Palka, N., Pasternak, M., Pustelny, T., Stacewicz, T., & Wojtas, J. (2012). Sensors and systems for the detection of explosive devices - An overview. *Metrology and Measurement Systems*, *19*(1), 3–28. https://doi.org/10.2478/v10178-012-0001-3

[13] Bhat, S., & Meenakshi, M. (2016). *The Role of Wireless Communication for Autonomous Military Robot*. *December*.

[14] Al-shuka, H. F. N. (2014). *Dynamic Modeling of Biped Robot using Lagrangian and Recursive Newton-Euler Formulations.* 101(3), 1–8.

[15] Ahmed, M., R., M., Billah, M., & Farh, S. (2010). Walking Hexapod Robot in Disaster Recovery: Developing Algorithm for Terrain Negotiation and Navigation. *New Advanced Technologies*, *March*. https://doi.org/10.5772/9437 [2] B. Ramkumar, H.M. Kittur, and P. M. Kannan, "ASIC implementation of modified faster carry save adder," *Eur. J. Sci. Res.*, vol. 42, no. 1, pp.53–58, 2010.

[16] Gouasmi, M., Ouali, M., Fernini, B., & Meghatria, M. (2012). Kinematic modelling and simulation of a 2-R robot using solidworks and verification by matlab/simulink. *International Journal of Advanced Robotic Systems*, *9*, 1–13. https://doi.org/10.5772/50203

[17] Ghaleb, N. M., & Aly, A. A. (2018). *Modeling and Control of 2-DOF Robot Arm*. *6*(11), 24–31. [3] T. Y. Ceiang and M. J. Hsiao, "Carry-select adder using single ripple carry adder," *Electron. Lett.*, vol. 34, no. 22, pp. 2101–2103, Oct. 1998.

★★★