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A MULTI-ROBOT EDUCATIONAL AND RESEARCH FRAMEWORK

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ABSTRACT

Robots have greatly transformed human's life. Multi-disciplinary research in robotics essentially demands having sophisticated frameworks with diverse range of capabilities ranging from simple tasks like testing of control algorithms to handling complex scenarios like multiple robot coordination. The present research addresses this demand by proposing a reliable, versatile and cheap platform enriched with enormous features. The framework has been conceptualized with three robots having different drive mechanisms, sensing and communication capabilities. The proposed 'Wanderbot' family consists of ForkerBot, MasterBot and HexaBot. The ForkerBot is a four-wheeled robot equipped with ultra sonic range finder, wheel encoder, bump sensor, temperature sensor, GSM, GPS and RF communication modules. The robot, having a payload capacity of 8 pounds, supports both Differential and Ackerman drive mechanisms and can be used to validate advanced obstacle avoidance algorithms. The MasterBot is also a wheeled robot with an on-board camera and is skid-steered. The robot finds potential in research on image processing and computer vision and in analysis and validation of algorithms requiring high-level computations like complex path traversal. The third member in the Wander family, HexaBot, is a six-legged robot, which is able to exhibit the movement of tripod gait and can be used for investigating walking and climbing algorithms. The three members of Wander family can communicate with one another, thus making it a good candidate for research on coordinated multi-robots. Additionally, such a prototyped platform with vast attractive features finds potential in an academic and vocational environment.

Key words: robotic research platform, swarm robotics, coordinated robots, mobile robots

1. INTRODUCTION

Progress in the field of science and technology has emerged new, innovative and interesting fields. The domain of robotics is an example of one of such fields. Revolution in this area has significantly widened the radius of robot applications. In addition to industrial (1,2), defense and entertainment sectors, the robots are being used for rehabilitation (3-6), assistance (7,8), Virtual Reality (VR) (9), nuclear power plants (10) and so on. Robotics is a combination of various disciplines such as electrical and electronics, computer science and engineering, mechatronics and mechanical design, control and automation systems, programming and so on, thus acting as a bridge among different fields. This naturally demands highly capable and flexible platforms that serve the purpose of educating and training individuals in an academic and educational environment. Such platforms greatly facilitates researchers and academicians by saving time in terms of design implementation and troubleshooting the robot structure, electronics, sensors and resolving integration issues. Research productivity can be accelerated if ready-made platforms are available at an affordable cost.

The remaining paper is organized as follows: Section 2 reviews the state-of-the-art of robotic systems specifically realized for academic and research purpose. Section 3 presents a brief theoretical overview of relevant terminologies. The proposed framework is introduced in Section 4. The capabilities of robots in Wanderbot family and their prototypes are presented. Finally, Section 5 comments on conclusion and elaborates the potential applications of the proposed framework.

2. STATE-OF-THE-ART OF ROBOTIC EDUCATIONAL FRAMEWORKS

Scientific literature reports various robotic platforms for teaching and training purposes. These include articulated based multi-Degree Of Freedom (DOF) frameworks (11-14) and virtual simulators for mobile robots (15-17). The virtual robotic systems, exploiting the integration of engineering software (usually MATLAB/Simulink) and a graphical tool (usually Virtual Reality Modeling Language (VRML)), provide cost-effective solution and give very fascinating pictures of a robot. However, these systems being totally 'soft' in nature essentially have their limitations. They may not completely and correctly specify in-depth performance corresponding to the real robot.

Practical limitations on actuators and force/torque transmission mechanisms can severely affect the specifications and stability of the virtual model controller. Moreover, virtual models do not usually address the non-linearities associated with the physical systems e.g. backlash, friction, non-collocation etc. Also, the accuracy and credibility of the results obtained in a simulated environment in many cases are not comparable with the results of experiments performed using the real physical systems owing to the fact that the virtual models may not completely imply a true practical approach. Because of these concrete reasons, researchers have realized many platforms employing a real mobile robot. Iqbal et al. proposed a novel track-driven mobile platform (18,19) for conducting experiments of control systems and robotics. Other examples of mobile robotic platforms that find potential in educational and academic sector includes Thymio II (20), Micromouse kit (21), Cube System (22), Hanover framework (23) etc.

Some of these platforms suffer from limitation either in terms of flexibility, scalability or modularity while others lack financial affordability or have limited features. Also, most of these platforms are limited to a single robot, while research on robot coordination certainly requires multiple heterogeneous robots having a diverse range of capabilities.

3. THEORETICAL BACKGROUND

The steering mechanisms highlighted in the present research are briefly discussed below.

3.1. Ackerman Steering

Rudolf Ackerman discovered and defined the relationship between the front inside tire and front outside tire in a corner or curve. While turning around a point, the inner wheel of the robot is nearer to the point thus following sharper track as compared with the outer wheel. Practically the exact Ackerman steering wheel angles cannot be achieved due to precision errors in instruments, approximations in calculations and human errors. The Ackerman angle can be approximated by drawing the straight lines from the kingpins of the steering wheel to the center of rear axle length as shown in Fig. 1. The rotation arms can be kept and implemented parallel to these lines.

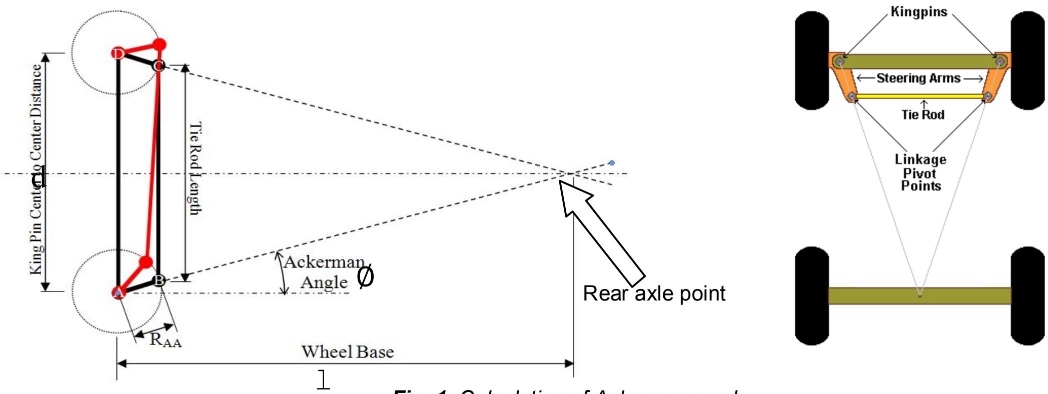


Fig. 1. *Calculation of Ackerman angle*

Mathematically, the Ackerman angle (Ø) can be given by.

$$\theta = tan^{-1}(\mathrm{l/d})$$
$$\emptyset = 90^{o} - \theta$$

where '*l*' is the distance between the front wheel kingpin and rear axle and 'd' is the kingpin center to center distance. R_{AA} is directly proportional to the torque because

$$\tau = R_{AA} \times F$$

Hence, R_{AA} can be designed by considering the servo's torque and the structure limitations. Another relation of the wheel turning angles and the structure parameters can be written as

$$\cot\theta_{\mathrm{i}} + \cot\theta_{\mathrm{o}} = \frac{d}{\mathrm{l}}$$

where θ_i and θ_o are inner and outer wheel turn angles respectively. The outer wheel's turn can be computed according to Ackerman's principle by putting the inner wheel turn angle and other parameters as given by

$$\theta_{o} = cot^{-1}\{\cot\theta_{\mathrm{i}} - \left(\frac{d}{\mathrm{l}}\right)\}$$

3.2. Differential Steering

In Differential steering or Skid steering, the wheel mostly skids on the road to stay on its path while turning around a curve. In addition to robots, this type of steering is used in tanks and wheel chairs. In this drive mechanism, the opposite wheels exhibit different speeds of rotation while turning. The mechanism can be realized with two different sources for drive torque or a complex gear mechanism. An equal but opposite directional movement of both wheels results in robot spin around its centre. The robot can rotate around its own pivot in either direction i.e. clockwise or anticlockwise. To attain differential movement, the required mechanical structure must contain two rotor wheels at rear side and one caster wheel on front to balance the weight. This steering is easy to design and implement and offers a light weight, inexpensive as well as agile structure. The robot always tends to turn around a point. Fig. 2 shows the nomenclature for calculation of the turn angle.

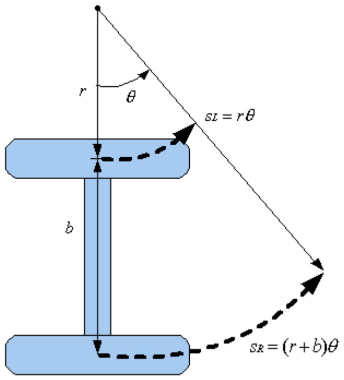


Fig. 2. *Calculation of the distance covered in differential drive*

If both wheels have relative motion, the turning point is away from the inner wheel. This point can be under the inner wheel in case if the inner wheel has zero torque. The angle (θ) can be computed as

$$\theta = \frac{S_0}{r + b/2}$$

where S_0 is the distance travelled by the outer wheels of the robot and r is the distance between the inner wheel center point and the pivot point.

3.3. Hexapod Gait

The main motivation behind using leg locomotion is to enhance stability. Each leg is broken down into step cycles, where a cycle is considered as complete only if the current leg position is at the same location as in the beginning of cycle. By repeating this pattern of foot position, a walking gate is formed that helps the robot to move forward or backward. There are many different gaits that are used by animals and insects to move from one place to other. The two most popular gaits with six legs are the alternating tripod gait and the wave gait. Minimum three legs are required to touch the ground forming a tripod for stable movement when dealing with a six leg robot. Most walking robots are designed to balance statically because it is almost impossible to attain dynamic balance. The easy way is to move only three legs at a time while supporting the robot on the remaining three legs.

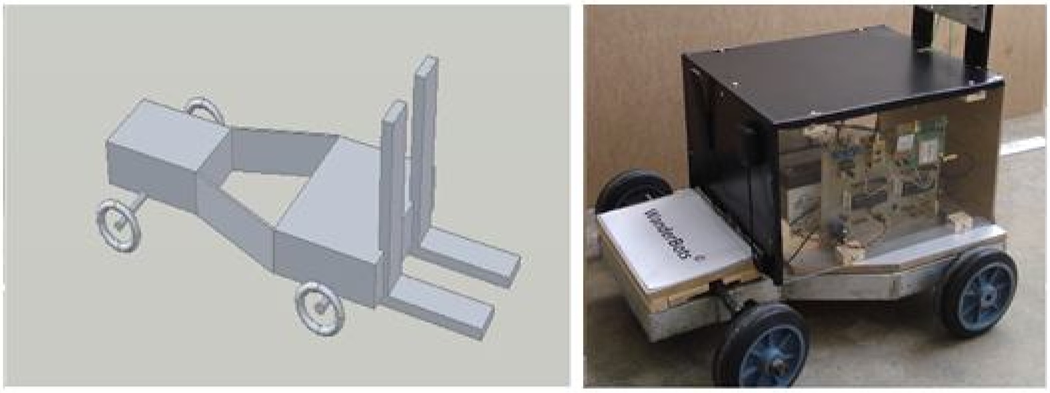
4. PROPOSED FRAMEWORK

In order to address the need to have a sophisticated and a highly capable framework, three robots named as Wander Forkerbot, Wander Masterbot and Wander Hexabot have been designed and fabricated.

4.1. Wander ForkerBot

Forkerbot is a wheeled robot equipped with Ultrasonic Range Finder (URF), wheel encoder, bump sensor and temperature sensor. URF circuit is centered on PIC 16F819 microcontroller to calculate the distance by generating 40 KHz pulses and receiving them after being bounced back from an obstacle. It then communicates with the master controller to respond accordingly. The wheel encoders, designed using "Encoder Design Program ver. 1.2", have resolution of 60 and diameter of 3 inches. These encoders together with IR sensors determine the speed and distance covered by the robot. Six micro switches are attached to the ForkerBot for the touch sensing so that it can perform obstacles avoidance. These switches give a high signal when it is touched by anything. Temperature sensor is installed to detect any environmental temperature variations that may occur due to any reason.The set of communication modules that are attached to Wander Forkerbot include Global System Mobiles (GSM), Global Positioning System (GPS) and Radio Frequency (RF) modules. The attached SIM300 GSM module operates on AT commands. The master microcontroller reads the message when the corresponding interrupt is activated and informs the operator about the requested information via text reply. The operator can also find the exact location of the robot. The GPS communication is implemented on ForkerBot for robot localization while RF communication is used for intra-communication among the robots and also to permit remote control the robot. Custom-designed H-bridge having high power rating has been used to drive the DC motors and to control the movement of the robot. The design of H-Bridge is based on simulation results of “Proteus”. The designed H-Bridge PCB is successfully tested to withdraw current of 2A.

Ackerman steering mechanism has been implemented on the rear wheels to turn the Forkerbot to either right or left. The rear wheels turning mechanism has been actuated by Hitec servo. The robot mechanics has been designed such that the inner wheel attains more turning angle than the outer wheel. The maximum achievable turning angle is 30^{o}. The forward and backward movement is entailed by the front wheels attached with two DC geared motors. With a focus on stability and control, the robot body has been designed using “AutoCAD”. 3D CAD model of the robot is illustrated in Fig. 3a while fabricated prototype with all the necessary hardware equipped with sensors and motors can be seen in Fig. 3b.

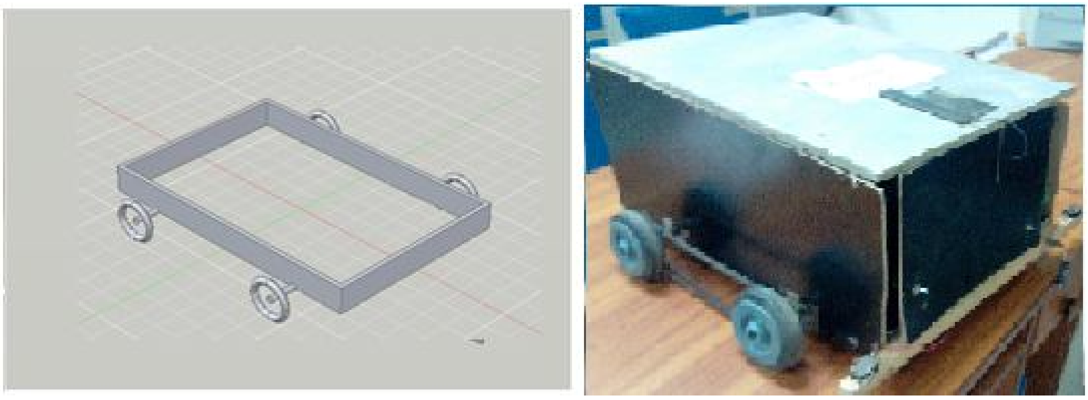


(a) (b)

Fig. 3. *Wander Forkerbot(a) CAD model (b) Fabricated prototype*

4.2 Wander MasterBot

Another wheeled platform, MasterBot, equipped with an on-board camera has capabilities of capturing and processing of images in addition to having variety of sensing and communication interfaces. The robot is a Unmanned Ground Vehicle (UGV) and is specifically designed for high level computations. A laptop computer can be mounted on it for complex calculations of image processing and testing sophisticated path traversing algorithms. The skid steering mechanism has been implemented on four wheels to turn the robot to either right or left. The corresponding right and left wheels on front/rear are coupled to each other to achieve the four wheel drive. Like Fokerbot, URF, GPS, wheel encoders, bump sensors and temperature sensors have been mounted on the robot along with GSM and RF communication modules. The robot body has been designed using “AutoCAD” tool (Fig. 4a) to achieve stability and control. The fabricated prototype is shown in Fig. 4b.

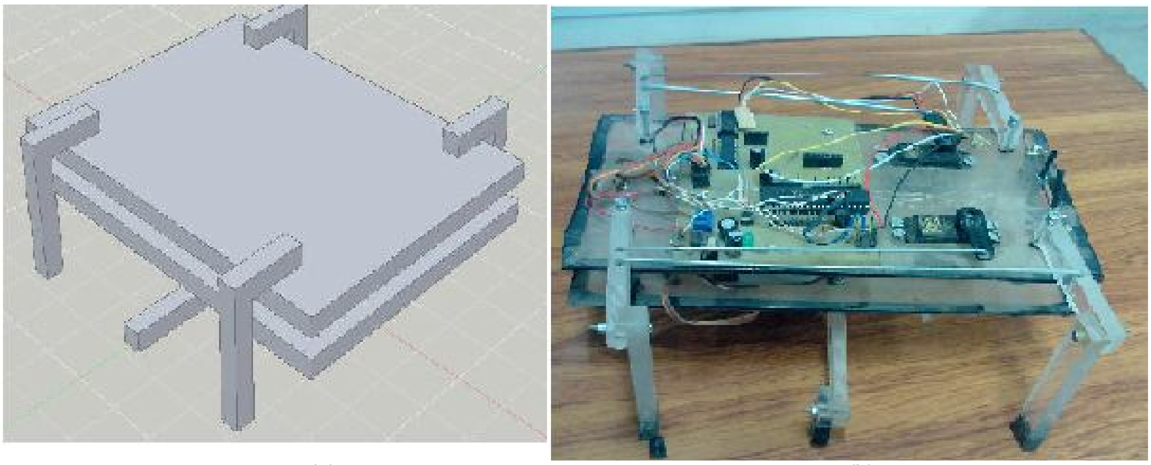


(a) (b)

Fig. 4. *Wander Masterbot (a) CAD model (b) Fabricated prototype*

4.3. Wander HexaBot

In contrast with Fokerbot and Masterbot, Hexabot is a six legged robot. The legs are actuated by four servos and exhibit the movement of Tripod gait. It is a very compact design with respect to shape, size and weight. The sensory and communication system of the robot is same as its siblings in Wanderbot family. To drive the servo motors for controlling the robot movement, a 5V voltage regulator has been used. Pulse Width Modulation (PWM) signal generated by the microcontroller varies the speed of the motors and controls the direction of rotation. Fig. 5 presents CAD view and fabricated prototype of Wander Hexabot.



(a) (b)

Fig. 5. *Wander Hexabot (a) CAD model (b) Fabricated prototype*

5. CONCLUSION

A framework consisting of three robots having diverse range of features has been presented in this research. Possibility to implement and validate coordinated multi-robots algorithms together with the platform's modular design, inherent flexibility, inexpensive and easily available Commercial Off The Shelf (COTS) components and open architecture makes it an excellent framework to be used in wide range of applications. All the parts-lists, schematics, source code and user interface are freely available on request. This certainly makes the platform attractive for academic and research community by skipping licensing costs and shortening the development time. The target application areas of the proposed platform include academics, training and research. Current work includes research and performance analysis of the control algorithms for mobile robots using the proposed platform. In near future, it is envisaged to implement brain control of Wanderbot robots using techniques mentioned in (24).

REFERENCES

1. R. ul Islam, J. Iqbal, S. Manzoor, A. Khalid and S. Khan. An autonomous image-guided robotic system simulating industrial applications. 7th IEEE International Conference on System of Systems Engineering (SoSE), Italy, 2012, pp. 344-349.
2. A. Meddahi, K. Baizid, A. Yousnadj and J. Iqbal. API based graphical simulation of robotized sites. 14th IASTED International Conference on Robotics and Applications (RA), Massachusetts US, 2009, pp. 485-492.
3. J. Iqbal, A.H. Khan, N.G. Tsagarakis and D.G. Caldwell. A novel exoskeleton robotic system for hand rehabilitation - Conceptualization to prototyping. Biocybern Biomed Eng, 2014, In Press, (doi:10.1016/j.bbe.2014.01.003)
4. J. Iqbal, N.G. Tsagarakis, A.E. Fiorilla and D.G. Caldwell. A portable rehabilitation device for the hand. 32nd annual IEEE international conference of Engineering in Medicine and Biology Society (EMBS), Buenos Aires, Argentina, 2010, pp. 3694-3697.
5. J. Iqbal, N.G. Tsagarakis and D.G. Caldwell. A human hand compatible optimised exoskeleton system. IEEE international conference on RObotics and BIOmimetics (ROBIO), China, 2010, pp. 685-690.
6. J. Iqbal, N.G. Tsagarakis and D.G. Caldwell. Design optimization of a hand exoskeleton rehabilitation device. proceedings of RSS workshop on understanding the human hand for advancing robotic manipulation, Seattle US, 2009, pp. 44-45.
7. J. Iqbal, N.G. Tsagarakis and D.G. Caldwell. A multi-DOF robotic exoskeleton interface for hand motion assistance. 33rd annual IEEE international conference of Engineering in Medicine and Biology Society (EMBS), Boston, US, 2011 pp. 1575-1678.
8. A.A. Khan, S. Riaz and J. Iqbal. Surface estimation of a pedestrian walk for outdoor use of power wheelchair based robot. Life Sci J - Acta Zhengzhou University Overseas Edition, ISSN 1097-8135, 2013; 10(3): 1697-1704.
9. J. Iqbal, N.G. Tsagarakis and D.G. Caldwell. Design of a wearable direct-driven optimized hand exoskeleton device. 4th International Conference on Advances in Computer-Human Interactions (ACHI), France, 2011, pp. 142-146.
10. J. Iqbal, A. Tahir, R.ul Islam and R.un Nabi. Robotics for nuclear power plants – Challenges and future perspectives. IEEE International Conference on Applied Robotics for the Power Industry (CARPI), Zurich, Switzerland, Sep. 2012, pp. 151-156.

11. S. Manzoor, R.U. Islam, A. Khalid, A. Samad and J. Iqbal. An open-source multi-DOF articulated robotic educational platform for autonomous object manipulation. Robotics and Computer Integrated Manufacturing 2014; 30(3): 351-362 (doi:10.1016/j.rcim.2013.11.003)
12. U. Iqbal, A. Samad, Z. Nissa and J. Iqbal. Embedded control system for AUTAREP - A novel AUTonomous Articulated Robotic Educational Platform. Teh Vjesn, Print ISSN: 1330-3651, Online ISSN 1848-6339, 2014, 21(6), Paper # TV-20130914230038. (In Press)
13. Candelas FA, Puente ST, Torres F, Ortiz G, Gil P Pomares J. A virtual laboratory for teaching robotics. International Journal of Engineering Education 2003;19(3): 363-370.
14. J. Iqbal, R.U. Islam and A.H. Khan. Modeling and analysis of a 6 DOF robotic arm manipulator. Canadian Journal on Electrical and Electronics Engineering (CJEEE), ISSN: 1923-0540, 2012; 3(6):300-306.
15. Dunn TL, Wardhani A. A 3D robot simulation for education. 1st International Conference on Computer Graphics and Interactive Techniques in Australasia and South East Asia 2003, 277-278.
16. Levin I, Kolberg E, Reich Y. Robot control teaching with a state machine-based design method. International Journal of Engineering Education 2004;20(2):202-212.
17. M. Zohaib, S.M. Pasha, N. Javaid, A. Salaam and J. Iqbal. An improved algorithm for collision avoidance in environments having U and H shaped obstacles. Studies in Informatics and Control (SIC), ISSN: 1220-1766, 2014, 23(1):97-106.
18. J. Iqbal, S. Riaz, A. Khan and H. Khan. A novel track-drive mobile robotic framework for conducting projects on robotics and control systems. Life Sci J - Acta Zhengzhou University Overseas Edition, ISSN 1097-8135, 2013; 10(3):130-137.
19. J. Iqbal, S. Heikkila and A. Halme. Tether tracking and control of ROSA robotic rover. 10th IEEE International Conference on Control, Automation, Robotics and Vision (ICARCV), Vietnam, 2008, pp. 689-693.
20. Magnenat S, Riedo F, Bonani M, Mondada F. A programming workshop using the robot “Thymio II”: The effect on the understanding by children, IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO) 2012, 24-29.
21. Su J.H., Lee C.S., Huang H.H., Huang J.Y. A micromouse kit for teaching autonomous mobile robots. International Journal of Electrical Engineering Education 2011; 48(2):188-201.
22. Birk A. Fast robot prototyping with the Cubesystem. In: Proceedings of IEEE International Conference on Robotics and Automation (ICRA) 2004, vol. 5, 5177-5182.
23. Wagner B., Hohmann P., Gerecke U., Brenneke C. Technical Framework for robot platforms in education. In: Proceedings of International Conference on Engineering Education and Research 2004, 699-703.
24. K. Naveed, J. Iqbal and H. ur Rahman. Brain controlled human robot interface. IEEE International Conference on Robotics and Artificial Intelligence (ICRAI), Islamabad, Pakistan, 2012, pp. 55-60.