A systematic Review on Humanoid Biped Robot: History, Design, Gait Analysis and Path Planning in Various Terrains

Abhishek Kumar Kashyap
Department of Mechatronics, Manipal Institute of Technology, Manipal Academy of Higher Education

Dayal R. Parhi
Department of Mechanical Engineering, NIT

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A systematic Review on Humanoid Biped Robot: History, Design, Gait Analysis and Path Planning in Various Terrains

Abhishek Kumar Kashyap[1,*], Dayal R. Parhi[2]

[1]Department of Mechatronics, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal 576104, Karnataka, India

[2]Department of Mechanical Engineering, NIT, Sector 1, Rourkela, Odisha 769008, India

*Author to whom correspondence should be addressed:
E-mail: abhishek.kashyap@manipal.edu

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Abstract: Because of its capacity to replicate human behavior and maneuver through challenging circumstances, humanoid robots have drawn a lot of interest. An overview of the literature that refers to history, kinematic analysis, dynamic analysis, gait stabilization and trajectory plan approaches for humanoid robots on even, uneven are presented in this paper. The study emphasizes on conventional techniques like fuzzy logic and artificial potential fields as well as methods inspired by nature, such as teaching-learning-based optimization, dynamic window approach, and ant colony optimization. It has been demonstrated that hybrid approaches, which combine classical and nature-based algorithms, improve flexibility and dependability in both static and dynamic contexts. The results show that when it comes to developing effective and reliable path planning, hybrid techniques perform better than traditional tactics. A roadmap for upcoming developments in model innovation and guidance tactics is provided by identifying key research needs in humanoid robotics.

Keywords: Humanoid robot; Kinematic analysis; Dynamic Analysis; Gait Design

1. Introduction

While modeling an approach for motion control of balanced humanoid robots, specific requirements such as obstacle avoidance, shortest path length, energy efficiency, etc., and their complexity should be considered. All of these are necessary to guarantee that humanoid robots sustain their stability during standing positions and when navigating unorganized terrain. The upgradation of technologies, automation, and the requirement for maximum and efficient outputs create a high demand for robots. Because they successfully imitate human behavior, human-like robots are favored. They are appropriate for use in employment since they can adapt to different situations and do jobs more quickly. Humanoid robots have attracted most users in contrast to their wheeled counterparts because they create more natural feelings for humans in the workspace. The human body is the most sophisticated and dynamic system in the world ever framed, and the structure of humanoid robots is similar to them, creating many difficulties. This can also be seen as the most demanding activity in robotics research, including the conception, design, manufacture, and trajectory planning study of a humanoid robot. Thus, numerous scientists have attempted to construct and evaluate different models of trajectory planning of humanoid robots in various difficult environments to provide maximum stability. The literature gaps and research problems are obtained by exploring the creation and maintenance, kinematic analysis, dynamic analysis and navigational strategies for different robots in various complex environments. This paper also discusses about the implementation of Nature-based algorithms to solve path planning problems in various robots. The term "nature-based techniques" describes optimization strategies that draw inspiration from natural phenomena, such as particle swarm optimization (PSO) and ant colony optimization (ACO), which study the motion behaviors of birds and ants, respectively. These methods are frequently employed to tackle challenging issues, such as trajectory optimization and robot guidance. The objective of this research paper is to obtain the literature gaps in the design of gaits and navigation humanoid robots in various environments. This will give future work ideas to researchers working in this field.

While modelling an approach for motion control of balanced humanoid robots, specific requirements such as obstacle avoidance, shortest path length, energy efficiency, etc., and their complexity should be considered. The humanoid robot navigation consists of various components, such as kinematics, dynamics, gait design, mapping and motion planning. These components are inter-connected with each other, which is portrayed in Fig. 1.

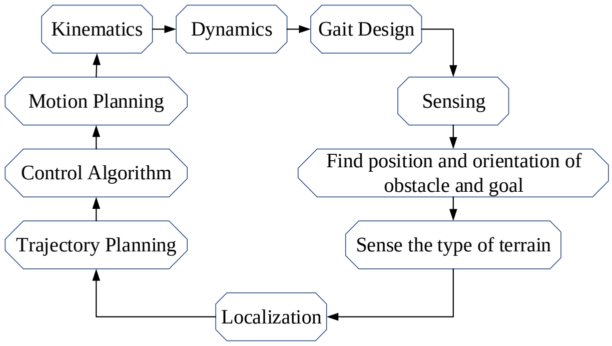

Fig. 1: Flowchart of navigation of humanoid robot.

1.1 History of Humanoid Robots

In the late 18th, numerous structures that can automatically intimate human activities have been designed. Leonardo de Vinci has developed the first human-like structure[1)] and further, in the earlier 20th century, a human-like structure named Elektro Humanoid has been developed by the Westinghouse Society[2)]. Researches on bipedal robot's walking behavior have been performed in the 20th century by japan Waseda University. They have created various robots like Wabot-1[3)], WL-10[4)] and WABIAN-2R[5)].

Table 1. Details of humanoid robots developed in late 18th, 19th and 20th century, showcasing the ways in which they have advanced humanoid robots.

Robots	Year	Citation	Developed by
Leonardo's robot	18th Century	1)	Leonardo de Vinci
Elektro Humanoid	20th century	2)	Westinghouse Society
Wabot-1	20th century	3)	
WL-10	20th century	4)	Waseda University, Japan
WABIAN-2R	20th century	5)	
BIPER	1980	6)	Japan
MELTRAN-II	1990	7)	Kajita and Tani

Japanese researchers created BIPER, a humanoid robot with passively ankle movements and dynamic walking abilities, in the 1980s to improve steadiness with broad feet[6)]. MELTRAN-II[7)] shows the humanoid robot designed by Kajita and Tani in 1990 with the idea of the movement of the inverted pendulum. The details of robots developed in the late 18th, 19th and 20th centuries is presented in Table 1. As covered in the section that follows, further discoveries have expanded the possibilities for humanoid robot functioning and architecture, building on these fundamental accomplishments.

1.2 Latest Progress of Development on Humanoid Robots

The advancement of humanoid robots has been characterized by major achievements, resulting in state-of-the-art systems that can perform adaptive and sophisticated actions. Modern humanoids have been upgraded and can show emotions and update their skills while walking because they learn by autonomous communication with the workspace. It also provides an effective strategy for the examination of human functioning and intellectual behaviors. Korea and Japan are the leading countries in the research operation of service robots. Research on various humanoid robots in several countries is presented here.

1.2.1 INDIA

In recent years, humanoid robots are establishing attention in India. Though the lack of evolution of artificial intelligence and robotics in comparison to other countries, both Indian start-ups, and the government are moving rapidly to implement new-aging technology. India is developing very fast in this field, and the sales of robots have improved in recent years, as per the Institute for Field Research report. A 21 degrees of freedom (DOFs) robot named Manav[8)] is the first humanoid robot made in India. It has been developed in late 2014 in A-SET Training and Research Institute. The robot includes various onboard processing like sound and visual to interact with users. Kempa[9)], a humanoid robot that has been developed by Sirena Technologies, which can interact and guide humans in English and Kannada language. A humanoid robot developed for functioning in space looks like a female named Vyommitra[10)]. It has been developed by ISRO (India Space Research Organization) in early 2020. It has been designed for a deeper knowledge of microgravity and emission in space for a long period. The details of robots developed by INDIA are presented in Table 2.

Table 2. Details of robots developed by INDIA in different decades.

Robots	Year	Citation	Developed by
Manav	2014	8)	A-SET Training and Research Institute
Kempa	2018	9)	Sirena Technologies
Vyommitra	2020	10)	ISRO

1.2.2 France

France has developed many humanoid robots, and their advancements are also in progress to enable them to perform various tasks autonomously. ROBIAN robot[11)] has been developed by the University of Versailles LIRIS lab with multiple degrees of freedom and flexible feet.. A humanoid robot with a weight of around 100 kg and a height of 1.82 m named BIP2000[12)] has been designed by INRIA Rhone-Alpes and LMS Potiers. An advanced small-sized robot named NAO[13)] has been developed by Aldebaran in the year 2006. It has a height of only 58 cm, and a weight of about 5 kg. The details of robots developed by France are presented in Table 3.

Table 3. Details of robots developed by france in different decades.

Robots	Year	Citation	Developed by
ROBIN robot	2018	11)	University of Versailles LIRIS lab
BIP2000	1998	12)	INRIA Rhone-Alpes and LMS Potiers
NAO	2006	13)	Aldebaran

1.2.3 Japan

Humanoid robots have been developed in japan quite early, which are guided by manufacturing firms. The Japan Minister of Finance, Trade and Industry (METI) has been funding the Humanoid Robotics Project (HRP). Since the 1990s, Honda has constructed a series of bipedal robots. Honda has started to develop P1 to P3 and later moved on to develop ASIMO[14)]. It has a height of 1.4 m and 25 degrees of freedom. A small humanoid robot of around 2 feet and 7.3 kg named QRIO[15)] has been created by Sony. Toyota has developed a humanoid robot for the purpose of entrainment. The robot[16)] can perform trumpet and violin to entertain humans. The details of robots developed by Japan are presented in Table 4.

Table 4. Details of robots developed by Japan in different decades.

Robots	Year	Citation	Developed by
ASIMO	1990	14)	Honda
QRIO	2003	15)	Sony
Toyota Robot	2007	16)	Toyoto

1.2.4 Korea

HUBO-2 Plus[17)], an enhanced version of the 2006 Albert HUBO robot, was created in 2011 by the Korea Advanced Institute of Science and Technology. This humanoid robot is better than their previous robots in mimicking the movement and appearance of humans. They have previously created KHR-1[18)] and KHR-2[19)] with 21 DOFs and 41 DOFs, respectively. The KHR-1 has no head and hands, and KHR-2 has a head and hands and imitates human movement. The details of robots developed by Korea are presented in Table 5.

Table 5. Details of robots developed by Korea in different decades

Robots	Year	Citation	Developed by
HUBO-2 plus	2009	17)	Korea Advanced Institute of Science and Technology
Albert Hubo	2005	20)	
KHR-1	2003	18)	
KHR-2	2004	19)	

1.2.5 Other European Country

Vrije Universiteit Brussel has developed the humanoid robot LUCY[21)] with 18 degrees of freedom. Germany has created a TORO robot[22)], which has a weight of 75 kg and 160 cm tall. It was initially developed in 2010-2012, and various modifications result in a strong and efficient humanoid robot. The University of Genova Italy has developed a humanoid robot that looks like a two-year child and names it iCub[23)]. The details of robots developed by other European country are presented in Table 6.

Table 6. Details of robots developed by other european country in different decades.

Robots	Year	Citation	Developed by
LUCY	2021	21)	Vrije Universiteit Brussel
TORO	2009	22)	Germany
iCub	2004	23)	University of Genova Italy

2. Kinematic Analysis of Humanoid Robots

Li et al.[24)] have described a humanoid body that is being utilized as a trunk of humanoid robots. It can efficiently imitate human body movements with high liberty and has strong rigidity and simple operation. Simulations are performed with the objective to verify that method of analysis of inverse kinematics (IK) is right and effective. Wu et al.[25)] have established the system, which consists of a conventional three-degree delta robot and a sequential system of two degrees of liberty. The mathematical approach is then employed for the forward kinematics, and Denavit-Hartenberg (D-H) matrix approach is used to create inverse kinematics. And then, simulation and experimentation test the effectiveness and benefit of the established robot. Authors[26)] have provided a unique design for a biped robot with seven DOFs and one DOF at each leg and toe, respectively. They also separated the walking steps into sagittal and frontal planes to discuss the forward and inverse kinematics. The article includes many simulations in order to provide proof of the findings, and the results obtained are checked by SimMechanics of the MATLAB and SolidWorks tools. Virgala et al.[27)] have addressed the kinematic analysis of the hand of a humanoid robot of 23 DOFs. The discussed setup should be capable of performing activities such as grasp, hold or pinch. An effective mapping procedure in MATLAB makes it possible to get the working space of a specific finger. Kofinas et al.[28] have examined the kinematics of the humanoid robot NAO and introduced a detailed, precise, numerical model for the forward and inverse kinematics, along with the application in a real-time system. They constructed it by splitting the whole body of a humanoid robot into five individual problems, including a head, two legs, and two arms. It has been done using the D-H approach by studying the non-linear set of problems and using the structure and joint geometries. Figure 2 represents the calculation of all four parameters (a, α, d, θ) of D-H parameters.

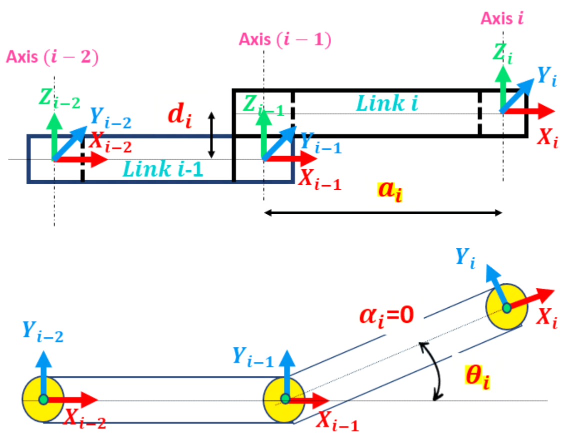

Fig. 2: Representation of D-H Parameters (a-link length, d-Link Offset, α- Link Twist, θ- Joint Angle).

Fadli et al.[29] have proposed a system that uses Kinect to identify the human body and collect data on its 3D skeleton design that helps the robot quickly mimic the behavior of humans. This 3D design is handled by inverse kinematics and transformed into angle details to mimic the gesture of a human. Authors[30] have attempted at the architecture of the system for entertaining purposes, the kinematic study of a recent humanoid robot on a mathematical and scientific basis. They have explored the design processes, theory and function of the robot with ten DOFs in two prosthetic arms. Atmeh and Subbarao[31] have introduced a walking mechanism for humanoid robots that utilized inverse kinematic solver, dynamic neural network and feedforward network. Humanoid robot Atlas has been utilized as the testbed to show the produce standard ZMP robot gaits. Pandey et al.[32] have proposed a human imitation machine based on inverse kinematics to smoothly and safely project the movement of humans in top limbs to the joints on the robot. Real-time findings have demonstrated that the machine is stable enough to mimic different human gestures. A basic framework to design a control system of a robot has been demonstrated in which the inverse kinematics is measured in advance is proposed instead of a traditional control method that can resolve the inverse kinematics at the time when robot walks[33]. It significantly minimizes computational complexity by optimizing the inverse kinematic system with a genetic algorithm (GA). A study of kinematics and proposal of a sketch of humanoid robotic eye similar to the characteristic of human eye and powered with pneumatic prosthetic limps has been proposed[34]. This framework has been developed as a parallel system and computational mechanism has been utilized to resolve the inverse kinematics of versatile ligaments. Authors have shown results based of simulation in regards of saccadic activities in various situations to confirm the preferred theory. Sancaktar et al.[35] have utilized an adapted PSO (Particle Swarm Optimization) for solving inverse kinematics of a robot to minimize failure via an exterior fixer. An improved result is obtained when the approach is examined on a three linear and three rotational axis robot compared to conventional PSO. Kim et al.[36] introduced a 12 DOFs low humanoid component called CHP-1 in order to acquire mutual movements for elevating or moving an object and carried out its kinematic analysis in compliance with the form of application for adequate motor choice. They have evaluated and ratified torques for every humanoid joint using simulation from MATLAB. In[37], authors have established forward and inverse kinematics strategies using DH parameter frameworks to maintain acceptable and collision-free movements in challenging situations for the humanoid robot Darwin. They have utilized MATLAB and Webots software to simulate the designed methodology.

3. Dynamic Analysis of Humanoid Robots

Deng et al.[38] have created a system porotype of a humanoid robot and concluded the dynamic and kinematic formula established on D-H formulation. The proposed controller can simulate the dynamics of the robot and evaluate the function approaches that are the simulated equivalent of the real-time humanoid robot. It can manage a dynamic stability function, movement and path mapping, etc. The test on a real humanoid robot has shown the effectiveness and viability of the proposed approach. In view of joint projections, joint motions have been derived from the D-H approach and Newton-Euler methods, and inverse dynamics have been established for both single and double subsidies[39]. The result obtained from simulations shows the use of an approach to prepare the path planning of a biped robot. Bharadwaj and Prateek[40] have introduced ten DOFs of the manipulator as mathematical modeling and D-H parameters to obtain the environment for each leg. The torque of dynamics achieved by using the concepts of the Lagrangian dynamic. To stop machine oscillation, a measured control torque method has been utilized. Experiments have been carried out in MATLAB in order to evaluate the outcomes of analytical and simulation. A proactive method for measuring velocity and acceleration has been suggested by Zand and Song[41]. They computed the dynamic governing formulas, torque, and inertia using the Newton-Euler technique. Geyer and Herr[42] have built a human locomotive design that is regulated by muscular reflexes, encoding legged dynamics concepts. This design has been fitted with this reflex mechanism to stabilize into a moving disruption from its complex interaction with the surface; mimic human movement and limb dynamics; accommodate disruptions of the surface, and adjust to slopes with no interference parameters. Moreover, they have found this design to estimate such specific structures of muscular strength identified by walking experiments. A method has been defined for a 3D inverse dynamic examination of a human arm while free mobility through a multibody methodology[43]. It is discussed specifically as a case study in which arm kinematics is achieved via a video-based human movement test device.

Noot et al.[44] have designed a torque-based system, which is bio-inspired to enable the rise of a modern generation of durable walking that is energy efficient. The developed system employs simulated muscles powered by reflections and a central pattern generator and, therefore does not involve reverse movie or dynamics modeling with mathematical intension. This operator can generate powerful and human-sensitive spots, in a 3D world, for a wide variety of forwarding speeds. Corral et al.[45] have emphasized the support foot slip of the PASIBOT biped robot and creates its forward and inverse dynamics to encourage single and double support phases. They have recognized additional free assistance on foot and also differentiate among static and kinetic friction conditions to deal with the slippage concept. Ramos et al.[46] have demonstrated the HRP-2 robot for entrainment purposes using inverse dynamic for dynamically stable movement and follow the instruction of the human. The objective of the authors to provide an outline of how dance movement is produced using the successful inverse dynamics process. Asif et al.[47] have introduced a motion design system that incorporates entire body movements and steps under a quasi-static flat terrain plane hypothesis for humanoid Robots. They have addressed gesture management as a graphic solution space in view of the robotic starting position and the expected terminal efficiency of the robotic system by implementing Multi-heuristic A* approach. In[48], authors have emphasized the inverse kinematic framework along with the dynamic modeling of the NAO robot, considering its lower body part. Along with it, confirmation by experimental evidence of the positions of the joints is also focused. They have addressed a novel method to develop the inverse dynamics on the lower body of NAO. Dynamic modeling is described, and joint angles of directions are modeled and graphically demonstrated in two separate planes, minimal situations and path calculations. Bajrami et al.[49] have emphasized the development of advanced locomotion of biped robots in the single support phase (SSP) and double support phase (DSP) using ZMP approach. Authors have considered the environment along with the robot’s design for designing the control system and checked the dynamic modeling by evaluating the achieved results with the simulation data. Hashemi and Jadidi[50] have concentrated on the dynamic modeling and evaluation of stability for NAO to achieve reliable walk. Indrajit and Muis[51] have discussed the approach in which a humanoid robot mimics the entire character of a human. Joint Space Management monitors robot movement via common biological movement recorded in Microsoft Kinect. The results of the approach have been demonstrated by the experimentation through the use of a humanoid robot to mimic the dance step of traditional Indonesia’s dance having 18 DOFs. Authors[52] have discussed a variety of human body movements, both pre-programmed and learning from human observation, which are required to be performed by the robots. They have introduced a technique to mimic a humanoid robot's dynamic walking by describing the task as a method of optimization. The technique is tested using the NAO robot, and the results demonstrate the efficiency of the suggested dynamic walking approach. Sentis and Khatib[53] have produced whole-body actions for a humanoid robot incorporating several primitives such as actions of the leg, hand and hands, body postures, center of gravity, joints and contacts. To allow the fullest use of the entire variety of potential movements, Saab et al.[54] have proposed an approach to deal with the complete dynamics of the robot multibody, including any constraints described as equal or unequal system and response variables.

4. Gait Design and Stability of Humanoid Robots

Graf and Rofer[55] have proposed a closed-loop step utilized during the Robocup contest and illustrated the utilization of IPM (Inverted Pendulum Model). They have proposed it to build trajectories for CoM of an omnidirectional step and removed the DSP requirement by continuously changing the period when the foot alternates. They have also explained the target route com CoM is converted into locations for foot positions. LIPM (Linear Inverted Pendulum Model) is utilized for achieving stabilized gait movement of the humanoid robot[56]. They have utilized IMU (Inertial Measurement Unit) for calculating ZMP as well as the direction of the robot’s torso. The dynamics of 3D-LIPM has been analyzed by Kajita et al.[57], wherein movement is restricted to move along a random plane. Simulation is carried out on a biped robot of 12 DOFs in regards to its motion control. For the purpose of COM training, Mayub et al.[58] have intended to develop an autonomous bipedal robot with COP feedback modeling, explain its viability for learning, explain students' desire for learning, and explain students' knowledge of science following use. The LIPM is further utilized for the dynamic control of push recovery of the humanoid robot[59]. They have utilized condition feedback of the linear system to sequentially monitor all ZMP (Zero Moment Point), CoM and CP (Capture Point). Authors have implemented LIPPFM (Linear inverted pendulum model plus flywheel model)[60] to create standard movement pathways, fade the complications, and enhance versatility and functionality. This design has been modified to eliminate the CoM height restriction and create more natural movement and provide a larger step. Authors in[61] have extended and approximated the total dynamics of a humanoid robot using LIPPFM for push recovery. Kasaei et al.[62] have presented a framework that includes a CPG-based omnidirectional movement with a closed-loop architecture. It uses two human-inspired push recovery plans into consideration for designing a dynamic structure for quick and stable movement. Furthermore, this design is completely parametric and enables the optimal step variables to be identified using a rule-based method. A series of experiments on a virtual NAO robot has been performed to demonstrate the efficiency of the implemented framework. Feng and Sun[63] have presented a novel simplified model with three links representing two legs and trunks for the dynamic walking of a humanoid robot. If the biped robot goes on a level field, the mass of 3-point altitudes is held continuously, and there is a null supportive ankle torque. Garofalo et al.[64] have recognized the Spring Loaded Inverted Pendulum (SLIP) model that displays an open-loop balanced response. They have enforced two methods on the lower-level body. Firstly, they have attempted to precisely replicate similar acceleration that a SLIP would have if placed in a similar position. Secondly, they have emphasized a simplified regulation rule without precisely repeating the acceleration described. This method has been taken to one stage by preferring a 3D actuated Dual-SLIP model for obtaining the self-stable gaits[65]. The LQR operator calculates the status of the leg midstance system on the basis of its return graph dynamics. Xia et al.[66] have developed a repository of multi-walking design baes of the outcomes of experiments on a self-designed individual movement that collect data from the joint kinematics and the ground-response forces. There have been reviews focused on this repository, part of which has been carried out in design concept and biped robots gait design. Zhou et al.[67] have concentrates on the inventions of generic guide technology to improve locomotive flexibility for varying objectives and also stores information and gives modes of information between the various components. The efficacy and effective applicability of the presented gait technology on a humanoid COMAN has been demonstrated. To provide dynamic stability to the humanoid robot, Erbatur and Kurt[68] have maintained the ZMP reference in a walking motion in the center of the supportive foot sole. They have presented a LIPM and ZMP reference for moving support foot centered benchmark generation methodology. To create an external orthotic model to help people with knee joint injury and an analytical system of stabilized human movement, Pal et al.[69] have presented a system that reduces the knee joint torque during movement. They have calculated the locus of ZMP and DBM (Dynamic Balance Margin) to keep the human body steady when performing tasks. In the analysis[70], a neuron consisting of a coupled neural resonator is powered on every joint of the humanoid, and the subsequent joint and neuron are linked by intensity weight. A multi-target optimization method is employed to address the weight optimism problem in order to accomplish normal and efficient gait patterns. Shaari et al.[71] have created walking gaits to use at a frame of reference during walking using points situated at both ankles and hip of NAO. Dzeladini et al.[72] have discussed the movement of the humanoid robot based on CPG control strategy. Mandava and Vundavilli[73] have presented a new deterministic optimization method induced by weed colonization conduct in biped robotics research. The IWO configured PID approach has also been checked by a genuine 18 DOFs humanoid robot and has effectively accomplished a flat pitch with a dynamically controlled gait. An evolutionary dynamic equilibrium system has been developed and evaluated on a humanoid robot[74]. The Robot can start and finish on command and move at a rhythm of up to 100 moves per minute, with constant movement on smooth terrains. Authors have described the regulation of "unified bipedal gait" that automatically chooses the energy-minimized posture from moving and running with any possible walking speed[75]. In lieu of energy optimization and adaptation, humans tend to walk/run at low/high speed. The unified bipedal gauge utilizes the operator that integrates a damping and spring-loaded inverted pendulum (D-SLIP) system with passive dynamic autonomous control (PDAC). The unified bipedal gear subdivides for automated movement to travel and run to reduce energy costs at possible speeds. Alba et al.[76] have developed a new approach for the generation of gait to improve the structural model and energy utilization of humanoid robot. A PD adaptive system for gait development is designed to achieve efficiency. Behera et al.[77] have illustrated the push recovery mechanism and the equilibrium of a small, biped robot with a 20 DOFs. They have created a method to stabilize the biped robot's stance while in stationary pose and to stabilize it on a gradually increasing inclination in an inclined plane. The stabilization regulators are included in the moving mechanism to retain the equilibrium of the biped robot. Kim et al.[78] have introduced a procedure for the capture evaluation to prevent arbitrary disruptions in bipedal robots. Simulations test the efficiency of the integrated fall prevention system. Tlalolini et al.[79] have designed a stochastic optimization techniques to solve optimum cyclic gaits within the space for a 13-link 3D bipedal robot. The methodology is evaluated for a bipedal robot with statistical results. As part of an Airbus use-case demonstration maker, Authors have considered complex escalation with the humanoid HRP-4 robot[80]. They have incorporated experimental expertise to carry out this mission, a task that has never been addressed by HRP-4.

5. Analysis of Navigational Techniques for Route Planning of Robots

In the past several years, intense research has focused on navigational techniques for the smooth and trouble-free operation of robots. The following sections emphasize numerous navigational techniques that have been designed and adopted for various robots.

5.1 Artificial Potential Field

Weerakoon et al.[81] have presented a stalemate-free APF centered route design method for mobile robot navigation in order to solve the problem of local minima. In unspecified 2D settings, the Implemented (P-APF) method aims for the objective point. This approach is capable of overcoming mobile robot navigation's stalemate and non-reachability issues. Authors have suggested an intelligent framework in static terrains to local as well as global route design of the robot[82]. The route design is built on the APF approach to provide efficiency, and the sensitivity to local minima is decreased by employing certain heuristic techniques to improve robustness. Kowdiki et al.[83] have introduced a novel training management approach for a unit of differentially controlled mobile wheeled robots using APF based guidance and the control system for leader-follower creation. A membrane evolutionary APF technique is introduced in[84] to solve the issue of mobile robot route design that integrates membrane computation with a GA and the approach of APF to find the variables to produce a viable and stable route. McFetridge and Ibrahim[85] have provided a review of the analysis to establish a new efficient robot guidance and barrier avoiding technique. This new technique is focused on the APF system that is commonly employed for the avoidance of obstacles. In an unfamiliar complex terrain focused on the APF system, Mohanta et al.[86] have concentrated on autonomous trajectory tracking of multi mobile robots. The robot control guidance method, utilizing a new APF, relies on the ranges between barrier locations in relation to robots, goals and bearing angle between them. In contrast, classical methods enable the application of the distances between barrier locations in relation to robots and goals. Only the spacing range between the robot and the nearby barriers is based on the traditional APF. The new system incorporates a factor that is required to decide how important each barrier is to the future path of the robot[87]. In order to minimize oscillations and prevent complications when the goal is near to a barrier, a new type of repelling potential is introduced. A rotational force is also added, creating a smoother path through the barriers. An enhanced attractive potential mechanism and an enhanced repulsive potential mechanism are included in the new process[88]. The minimal gap between the robot and the barrier is taken into consideration by the attractive potential mechanism. In contrast, the repulsive potential mechanism takes into consideration the relative location between the robot and the goal. The impact issue is also well resolved by dynamically changing potential fields in the area[89]. Shi and Zhao[90] emphasize designing a specific model that enables a robot to be managed to achieve its target while overcoming unidentified barriers on its path. The attraction towards the goal and repulsion towards the obstacle has been illustrated by Fig. 3.

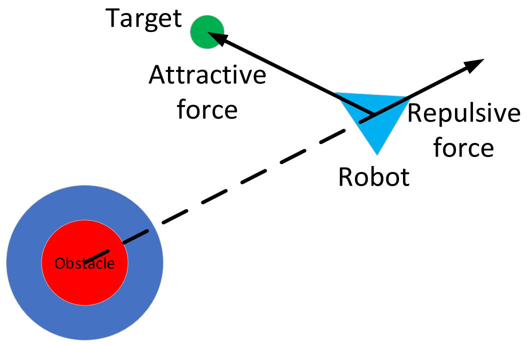

Fig. 3: Representation of attraction towards the target and repulsion force from obstacle exerted by robot.

In order to demonstrate the feasibility of the suggested model, the simulation outcomes of the deferential mobile robot are provided[91]. Li et al.[92] have reframed possible features to remove challenges with non-reachable and local minima, and use robot interactive local goal to avoid oscillations. They have designed a regression search (RS) approach to optimize the expected route because the planned path by enhanced APF is not the fastest path. The enhanced potential field functionality approach could not address all local minimum issues by simulating research[93]. The findings of the simulation indicate that the updated APF in an unknown setting has higher outcome than the traditional APF[94]. An additional controlling force technique is introduced to be implemented, additional control force is introduced to mobile robot focusing on the barrier, which can allow it out of local minimum, and the simulation outcome demonstrates the efficiency of this process. Centered on the fuzzy system for the concept of avoiding obstacles using APF, Wu et al.[95] have suggested an intelligent proactive route planning strategy. Outcomes from simulation demonstrate that the proposed technique is efficient. The MATLAB simulation study evaluates the impacts of various design variables on the barrier prevention efficiency of a multi-joint snake-like robot. And the optimal variables appropriate for a robot's barrier avoidance are needed to enhance the speed and reliability of the whole system[96]. To enable the underwater snake robot adopt the specific pattern, a single direction route following the control system is suggested[97]. Simulation outcomes are described, demonstrating the efficiency of both lateral curvature and eel-like movement of the suggested direction control scheme. The approach of the traditional APF is not adequate and inefficient as it has the challenge of local minima. A novel approach model is a conjunction of a modified APF method with fuzzy logic is developed to achieve the efficiency of the traditional

APF method and to generate more effective and reliable route mapping for mobile robots[98].

5.2 Fuzzy Logic

Mohanta and Keshari[99] have suggested a unique knowledge-based fuzzy command scheme with the Probabilistic Roadmap (PRM) approach for route planning and goal-reaching characteristics of mobile robots in the presence of barriers. The suggested approach operates in two layers; the first layer produces the shortest path in a priori established cluttered terrain between the initial locations to the goal location. The PRM has been employed by attaching the intermediary nodes to create straight-lined paths. A fuzzy PID-based path monitoring of the robot manipulator for various arrangements is suggested by Krishna and Vasu[100] that allows the use of minimal error for various functions, and these scenarios are examined using a dynamic robot design. In[101], the autonomous mobile robot (AMR) model is designed for specific actions, one for avoiding obstacles and the other for targeting different environments. Fuzzy logic, neural network and adaptive neuro-fuzzy inference system (ANFIS) controllers with a secure constraint framework are used to traverse the AMR. An optimization approach for the balance, direction and yaw steering performance of a mobile inverted pendulum robot is described in[102]. Focused on the Newtonian framework, the dynamic framework is constructed. Each robot is configured with a range of onboard ultrasonic detectors to measure the ranges of barriers and other robots around it, and a set of infrared detectors to determine the focus of the goal in order to obtain the necessary detail between robots, goals and barriers[103]. Omrane et al.[104] have illustrated the development and application of a path monitoring framework for mobile robot navigation in indoor spaces employing fuzzy logic[105]. Utilizing MATLAB software and the SIMIAM guidance framework, various trajectories are utilized and simulated to test the efficiency of smart guidance methodologies. The laws provide statistical information as well as heuristic and fuzzy information gathered from a mathematical examination of the controller design, taking into account the kinetic and dynamic limitations of the robot[106]. To optimize and modify the input/output membership mechanism variables of the fuzzy controller, the WDO (wind driven optimization) methodology has been employed[107]. In order to minimize processing time for real-time implementations, the strategy employed by Abubaker[108] uses a hybrid neuro-fuzzy strategy where the neural network appropriately selects the optimal values of amplification laws. Utilizing the Fuzzy-PI control system, initial simulation and experimental findings revealed drawbacks as the robot conducted a more comprehensive route as the required end angle improved[109].

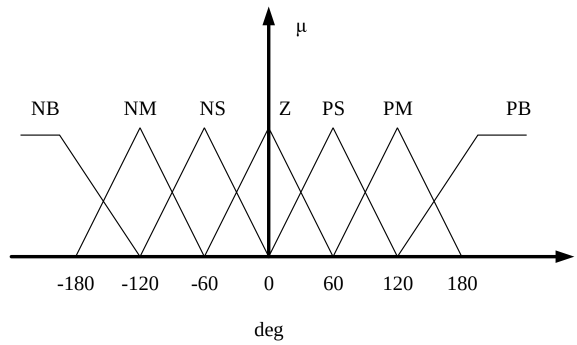

Fig. 4: Representation of input of distances and angles to fuzzy.

Figure 4 portrays the input (turning angle) to fuzzy. A detailed analysis has thus established that the Fuzzy-PI method is unable to regulate linear and angular velocities at a relatively similar time. The behavior-based system technique has been implemented by Li et al.[110] to evaluate and accumulate a challenging process based on stimulus-response behavior and to experimentally develop each type of behavior through fuzzy sets and fuzzy rules with a simple function. In addition, to organizes disputes and interaction through fuzzy reasoning between numerous types of behavior. Fuzzy logic operator and artificial neuronal fuzzy logic has been combined by Bajrami[111]. In the simulation system and on the actual mobile robot, the implemented methods are evaluated with satisfactory findings with respect of routes and process time. The results show that in the existence of state limitations of the standalone strap-down inertial navigation system through signal obstruction of global guidance satellite framework. The introduced integration methodology enhanced navigation precision, efficiency and reliability[112]. The hybrid program utilizes a takagi-sugano-kang style fuzzy concept framework that incorporates type 2 fuzzy sets in the previous sections and the outcomes in the subsequent sections from the computational connection artificial neural network[113]. Utilizing a simulated mobile robot and a 3D route focused on graph concept, experiments are performed by computer simulation. Finally, Iwasa et al.[114] have concerned regarding the outcome of the simulation. The goals of the control scheme has been mapped to obtain expected route and to prevent moving barriers from colliding[115]. To conduct the tests, a Nomadic 200 mobile robot has been equipped to demonstrate the outcomes of the simulation. Simulation experiments show the efficacy and reliability of the suggested solution[116].

5.3 Dynamic Window Approach

The DWA Distributed Control system has been designed by Seder and Petrovic[117] to traverse dynamic barriers in partly unidentified environment. DWA[118] or automated mobile robots influenced them. By virtue of the configuration tool, it recognizes the application interface and provides the most acceptable and kinodinamically viable route that ensures collision avoidance[119]. Schroter et al.[120] have introduced an anticipatory local navigation method for an automated mobile robot. The aim of local guidance is to drive the robot as per a stated goal, such as a proposed route to a destination, and prevent barrier collisions while training. It is suggested to provide a two mapping framework for independent indoor exploration[121]. As doors are pervasive and descriptive for movement in indoor terrains, the high-level module applies a stereo vision-based technique to find doors to create a number of target points. A new, dual-mode model predictive control system is presented by Droge[122], which integrates the DWA to navigation with relative monitoring control systems. This introduces a consultative dimension to the assurance of barrier avoidance available in the DWA and enables dynamic robot designs to be used. Due to the inability to recognize the scale limitation of a mobile robot, the dynamic window approach (DWA) has the disadvantage of leading in local minima and non-optimal movement determination to avoid obstacles. An enhanced DWA that reflects the relationship between the scale of the mobile robot and the available space between barriers is, therefore, introduced[123]. A Follow the Gap Method (FGM) aided DWA is suggested by Ozdemir and Sezer[124] that incorporates the toughest factors of FGM and DWA approaches to accomplish secure, seamless and quick navigation. Teso-Fz-Betono et al.[125] have emphasized enhancing DWA for mobile robots by introducing a predictor window using a fuzzy inference method to adjust to design variables, focusing on the constraints around it. Hong et al.[126] have presented an updated DWA coupled with fuzzy logic, which can be achieved by evaluating the target and barrier data and using fuzzy logic to calculate acceptable weights in real-time. In order to integrate a cost function dependent on energy usage, Henkel et al.[127] have extended DWA. It is using a regression model, which is trained on the move, the projected energy demand while scheduling is expected. Molinos et al.[128] have suggested two extensions of the classical DWA to cope with dynamic barriers, such as dynamic-window for dynamic obstacles and dynamic-window for dynamic obstacles tree. Xie et al.[129] have enhanced the DWA by introducing a specific energy-related parameter for reducing the energy demand of automated mobile robots in order to increase the efficiency of the Mecanum wheel. The Mecanum robot's energy demand is first modeled by contemplating major variables. Then, in the enhanced DWA-based local path operator, the model is used to further test the robot's omnidirectional velocities. A fresh concept focused on the merging of the improved A* method and DWA is introduced by Cheng et al.[130] to fulfil the criteria of global optimal and real-time barrier detection in mobile robot route scheduling. In ensuring the global optimality of route planning, the proposed approach outperforms conventional DWA, and the route distance decreases. Based on a simple, comparatively small pixel shader local graph, Zeng and Si[131] have introduced a new realistic approach for automated mobile robot that incorporates Rapidly-exploring Random Tree and DWA techniques. Horn and janschek[132] have introduced a new technique to mobile robot globalization based on established theoretical approaches. Realistic studies in simulation demonstrate the feasibility of the method introduced. The suggested model enhances the methodology of the probabilistic DWA and can be regarded as a generalised navigation planning approach capable of including the highly complicated frameworks needed to explain the dynamics of outdoor automobiles on difficult ground[133].

5.4 Ant Colony Optimization

To resolve the mobile robot route scheduling issue, the ACO method is implemented[134]. The assessment uses many plots of varying difficulty developed by an earlier author to illustrate the feasibility of ACO in resolving the mobile robot route scheduling issue. Garcia et al.[135] have introduced a new concept to handle the route optimization issue for mobile robots focused on Meta Heuristic ACO. Firstly, APF is strengthened in three respects depending on the grid system: the attraction region, the trajectory of the resulting power, and the continuous loop leaping out[136]. The hybrid approach, coupled with global upgrading and local upgrading, is then established to model the ACO pheromone's update process. Initially, the mobile robot free space design is generated utilizing the observable chart process. The ACO[137] method is used to look for a global collision-free route that is the shortest route across established static barriers[138]. Secondly, the APF technique is used to create a real-time local route in order to prevent a collision when unidentified barriers are observed. An ACO based technique is introduced by Blondin and Sicard[139] for global off-line optimization of proportional-integral-derivative (PID) operators with anti-windup. The variables of the methodology has been examined and optimized for various work areas by Uriol and Moran[140] with barriers in various proportions, sizes and shapes. The efficiency of the ACO method has also been checked for various working region identification decisions. Wu et al.[141] have introduced improvements using furthest point optimization and a multi-objective approach to overcome the shortcomings of the existing ACO method for mobile robot route planning, such as early blind search, sluggish integration, and decreased path smoothing. Baghli et al.[142] have included the ACO in this research as an optimization method since it is proven to be reliable for concerns with selection and optimization. The behaviour of ant in obscure environment has been presented in Fig. 5.

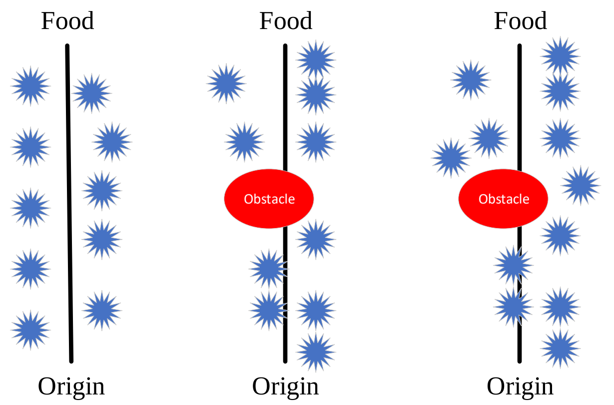

Fig. 5: Illustration of behaviour of ants with and without obstacle and finding the shortest possible path.

In order to determine the optimal route in an unknown setting, a global route mapping methodology based on improved ACO is introduced[143]. The Grid approach is utilized to describe the modeling of the robot world. The findings demonstrate that the approach proposed by Yang et al.[144] can effectively and reliably produce better collision-free paths that shows the efficacy of the implemented method. In addition, its efficiency is confirmed in indoor and outdoor conditions by experiments. By implementing ACO with the probabilistic roadmap planner, a novel method for robot trajectory tracking is suggested[145]. (PRM). Initial test findings indicate that in an appropriate runtime, the proposed technique is able to reduce the intermediary complexity between the source and target configuration. Xiao et al.[146] have introduced a new approach to direct multi-robot research. The simulation findings have shown that the preferred approach fixes the issue of optimal goal allocation efficiently and that the performance of research is much higher. Hsu and Juang[147] have introduced a multi-objective, rule-coded, sophisticated, continuous-ACO fuzzy controller model and its implementation to a mobile robot's multi-objective, wall-following function. This research also involves experiments that show an actual mobile robot following the wall. A novel method to addressing mobile robot movement in complex terrains is suggested by Purian and Sedeghian[148], focused on the heuristic function of an optimized ACO. Utilizing this method, mobile robots can work in various terrains, particularly in dynamic and uncertain terrains, through the optimal route to the goal focused on the optimal fuzzy control systems.

5.5 Teaching-Learning Based Optimization

In recent times, the Teaching-Learning-Based Optimization (TLBO) method has been developed. It is a novel method for optimizing the swarm-based system that simulates a classroom's teaching-learning behavior. A new global route planning approach for mobile robots focused on an enhanced TLBO technique, the Nonlinear Inertia Weighted TLBO (NIWTLBO) method, is discussed by Wu et al.[149]. In an unusual terrain focused on TLBO, research presented by Aouf et al.[150] examines the possibility of employing a new evolutionary-based approach as a response to the navigation task of a mobile robot. TLBO is used to practice the ANFIS design variables for optimum path and minimal travel time to achieve the objective. To optimize the robot path for a 3R robotic arm, the TLBO method, an optimized control method, and the artificial bee colony (ABC) optimization algorithms are adopted by Savsani et al.[151]. The issue recognized introduces multi-objective modeling with the goal of designing a path that can concurrently minimize mutual travel time, mutual travel length and total joint Cartesian distances. An effective algorithm to optimized off-line path preparation for welding robots is provided[152]. The welding route is known as a continuous compromise route for a number of polynomial sections. The end effector is diverted from the workpiece route during the robotic welding method due to jerk development. For the optimal development of a robot manipulator, the efficacy of the TLBO and ETLBO methods is tested by evaluating different scenarios. And by applying various criteria to illustrate the efficacy of the development process[153]. Rao et al.[154] have examined the efficiency of the TLBO method in order to acquire a robot gripper's optimal structural proportions. The development of robot grippers is a significant element of the overall efficiency of the robot and the most complex phase in any robot process to fulfill the development requirements. The TLBO-PD (Proportional-derivative) method has complied with the issue of the complexity of combined kinematic and dynamic monitoring. The efficiency of the optimized TLBO-PD method is compared with the optimized PSO-PD control algorithm to demonstrate the efficacy of the proposed system[155]. By combining the actual TLBO with variable neighborhood scope, the Improved TLBO method has a greater potential to overcome the local optimum[156]. In the context of disturbances, the control system can manage the challenge of embedded kinematic and dynamic monitoring[157]. The simulation findings showed the supremacy of the control system suggested. A hybridized variant of TLBO with a shuffled frog leaping algorithm (SFLA) has been suggested by Singh et al.[158] to increase optimization performance and resolve the weak convergence speed. Simulation findings and statistical evaluations confirm the efficiency of the designed STLBO. A new simulated-annealing and TLBO technique for global route mapping for mobile robots is discussed by Zhongsheng et al.[159]. The findings of the numerical simulation revealed that the classification approach has a quick convergence rate and higher scan precision with better global search capabilities. In addition, it can address the global optimization problem for global mobile robot navigation efficiently. For demonstration purposes, a four-DOFs SCARA robot manipulator has been recognized in order to evaluate the effects of IK results calculated by implementing the methodologies[160]. A Teaching-Learning-Interactive Learning-Based Optimization is investigated to obtain a collision-free route in a defined static setting for a mobile robot[161]. In this research, various relevant barrier charts obtained from the various study has been confirmed. Findings of the simulation showed that the approach proposed was successful for route mapping.

5.6 Other Miscellaneous Techniques

Ali et al.[162] have introduced a novel method, termed the shortest distance method, for multi-robot navigation in complex terrains. To measure the collision free path, this method requires both the present location and direction of other robots. In a 3-D environment, the research proposed by Kundu and Parhi[163] has used a population focussed innovative navigational technique to map the collision-free optimal solution direction for the underwater robot. The evolutionary-based harmony search algorithm has been progressively modified and utilized to search for the nearest best global underwater robot posture, while the barrier is found near the present pose of the robot. Optimum routes for a mobile robot in terrains with static and dynamic barriers are determined utilizing a new route planning system[164]. A practical, efficient and secure route is assured by the planned model called Bacterial Potential Field. The issue of how to dynamically conduct simultaneous localization and mapping using sonar has been discussed by Feder et al.[165]. The creation of a multilayered or deep neural network for the Spartan-6 FPGA target fields controlled gate matrix hardware is the centre of the research[166]. Stochastic navigation is a CML feature-based method that generalizes the expanded Kalman filter to integrate mapping of vehicles and localization of the area. The fuzzy logic operator is configured by Algabri et al.[167] by combining fuzzy logic with certain computational intelligence methods such as genetic algorithm, neural networks and PSO. Computational intelligence methods are employed to configure the membership function variables of the fuzzy logic control system to enhance the efficiency of navigation. There are two superiorities in the suggested series of new concepts and improved genetic operators of a genetic algorithm: rapid development towards the global optimal and the viability of all development approaches[168]. The goal of route mapping is to establish an ideal route from a starting position to a goal position, avoiding collisions or avoiding obstacles. Gueaieb and Mianh[169] have used Radio Frequency IDentification (RFID) processing to introduce a groundbreaking mobile robot guidance strategy. In order to address the issue of mobile robot navigation, Freire et al.[170] have suggested an alternative solution, which is called control signal fusion. Whenever the robot has to perform comparatively complicated tasks, the suggested model clearly indicates positive results. Wahab[171] has explained a methodology of fixing the issues of motion planning, including artificial neural networks in mobile robot operation. The method creates a collision-free route focused on multiple neural networks for moving robots between barriers. The strategy proposed by Teimoori and Savkin[172] is of collision prevention features an integrated sensor solution that supports the requisite data about objects in the proximity of the robot. Khriji et al.[173] have demonstrated how the Q-learning method can be applied to solve the issue of mobile robot guidance in a suitable way. In real-world scenarios where a significant number of barriers are included due to obscenely large search space, a typical Q-learning method would face difficulties. In different contexts, the method provides adaptive control systems, thereby developing collections of' ecosystems' that can be used in common conditions[174]. The usage of genetic algorithms for an adaptive system model as an unmonitored learning approach significantly eliminates the expense needed for a guidance system to be configured. Loukianov and Sugisaka[175] have illustrated the design of adaptive learning for an intelligent mobile robot with an analytical control system. A method of learning the ability to monitor colored instructions is discussed on the basis of controlling behavior. Ali et al.[176] have presented updated PID controller variables using ABC and GA for autonomous mobile robot route monitoring. The findings have specifically demonstrated the efficiency and great efficiency of PID controllers calibrated to GA through the ABC method. For mobile robots utilizing ultrasonic sensors, a neural network induced guidance approach is utilized. In order to achieve some user-defined goal, the neural network has a robust control framework that can not only optimize the parameters, as well as the input sensory accessibility[177]. The successful efficiency of the method is demonstrated through both simulated world and actual experiments. Adaptive fuzzy logic is used to restrict the power of 'unrestricted' so as to facilitate the push towards the target[178]. A few simulations, including some initial experimental findings, are provided to display the potential of the techniques. Using life-strength restrictions, Authors[179] models the post-disaster evacuation strategy issue as a variation of the traveling salesman problem (TSP).

5.7 Hybrid Techniques

Robot navigation has seen the emergence of hybrid approaches, which combine the advantages of many methods of optimization to get around the drawbacks of each one. When Ant Colony Optimization (ACO)[180] and Particle Swarm Optimization (PSO)[181] are combined, for example, a hybrid system is created that combines the flexibility and speed of PSO with the pathfinding effectiveness of ACO. Robots may now more precisely and effectively explore dynamic, complicated surroundings because to this hybridization. Trinh et al.[182] have introduced a new route design method in the presence of various activities for multiple robots operating in an unregulated terrain. A three-layer framework, SSS, for robot command, is defined by Connell[183]. In a manner that facilitates the benefits of each approach to be utilized entirely, it incorporates a servo-control framework, a subsumption framework, and a symbolic framework. The interaction between the various frameworks is the core of this synergy. To build an efficient navigational control system, the GA method has been applied to the Petri-Net framework[184]. The implemented method is based on an incremental non-linear analysis that uses matches between the environmental configuration encountered and the position diagram a priori, to approximate an effective steering angle, thus adjusting the location and direction of the robots to achieve goals. Frameworks and free variables of dynamic harmony memory are tailored for these fuzzy control systems so that they can assure the necessary stabilization and at the same time include adequate tracking efficiency for mobile robots' vision-based route planning[185]. In[186], in the existence of traveling barriers, a genetic-fuzzy method is presented to overcome the motion scheduling problems of a mobile robot. A new configuration approach for improving the precise robot position of industrial manipulators is proposed by Le and Kang[187]. The structural errors and mutual diversion errors can be interpreted along by integrating the joint deflection concept with the traditional kinematic model of a manipulator to improve its spatial precision. Chen[188] has developed a non-deterministic polynomial-hard concept as a multiple traveling salesman problem along with a single dock or multiple docks. A hybrid controller incorporating beneficial glowworm optimization characteristics and evolutionary programming has been developed by Zhang et al.[189]. They have attempted to resolve the constraints of the synergistic system of gradient-based techniques. The results produced from the hybrid algorithm has been tested against the independent techniques, and with improved convergence speed, a substantial-high efficiency has been identified. Gigras et al.[190] have formulated a hybrid ACO-PSO-based method for navigational evaluation of mobile robots in complicated environments. They have designed it to enhance the precision of metaheuristic techniques and improve adaptability data analysis capacity. The findings of the hybrid control system simulation analysis have been contrasted against the findings of individual methods, and significant improvements in performance have been identified. Saraswathi et al.[191] have hybridized cuckoo search with the bat method to optimize the effectiveness of a mobile robot path optimization model. They have evaluated the mentioned control system on a MATLAB simulation system and collected improved comparable outcomes to the standalone methods. The complicated system of an autonomous underwater mapping scheme includes extremely effective navigational control systems to regulate the movement of an underwater robotic operator. To acquire short precision and a GPS for long-term precision, an underwater robotic agent requires an inertial guidance module. A linear and an improved Kalman filter have been developed by Loebis et al.[192] to incorporate the two components earlier in this thread. To adjust the variables of a fuzzy system to find a seamless navigational route, they have utilized a multi-objective GA method. The established strategy has been recognized via the simulations. A hybrid navigational control system for mobile robots has been established by Ju et al.[193], incorporating a GA to PSO. The conceptual tree encoding has also been incorporated into the hybrid model and evaluated on a simulation model with efficient navigational route creation. Wang et al.[194] have presented a hybrid path planning method that combines the Fuzzy DWA and an improved A* method. The A* method is first modified to create global routes in greenhouses by taking environmental challenges rates into consideration and adjusting the approach to search according to challenges density. The pursuit neighborhood is then optimized to a five-neighborhood settings to improve node search effectiveness. Selecting the sampling strategy for the RRT* path-planning algorithms requires striking a balance between exploiting and investigation. The study[195] suggests Hybrid-RRT*, a path design technique that uses hybrid sampling, to address this.

6. Control of Humanoid Robot Navigation Using Various Approaches

6.1 Even Terrain

The emphasis of biped locomotion analysis has turned towards activities in real environments, such as stepping on uneven ground, going through doors, ascending stairs and ladders. One such human-inspired technique for route scheduling and realization of biped walk suitable for movement in a complicated unknown setting is presented by Rakovic et al.[196]. Route optimization leads to clothoid curves being determined that reflect the human-like movement route effectively. In[197], by employing fuzzy logic as a smart method to escape barriers in the terrain and comfortably enter the required goal location, a navigational control system for a humanoid has been designed. Thus, by means of fuzzy rules, the control system has been constructed with proper analysis of navigational variables. The predictive PID control system, which imitates the measured time and simplifies the optimization technique, is proposed by Bouhajar et al.[198]. The objective of the designed biped robot control planning is to maximize walking smoothness and more effectiveness. For the acquired motion pattern, Elhosseini et al.[199] have conducted a ZMP evaluation to test the walking stabilization. Due to the lower set of regulation variables and the fast convergence of the code, the Whale Optimization Algorithm has acquired more popularity. Park[200] has described a trajectory model for fuzzy-logic ZMP, which would gradually substantially decrease the swing movement of the torso. The leg approach is casually constructed solely to escape barriers. The model of the fuzzy-logic ZMP route utilizes the leg trajectory as a source. Delfin et al.[201] have introduced a comprehensive humanoid navigation system centered on a visual memory geometrical mapping consisting of a collection of the key image obtained off-line through a controlled teaching process (human-guided). The humanoid position in the visual memory, a visual route guide, and a route observer with barrier avoidance are built into the autonomous navigation system. In humanoid robots, posture model accuracy is a major priority, and many scientists are now involved in such research. The calibration phases of the variables or postures, though, are rather time-consuming and boring. An ABC predictive method for a central pattern generator (CPG) posture development mechanism is suggested to address this issue[202)]. Utilizing a policy gradient approach, Endo et al.[203)] introduced a learning system for a CPG-based biped motion control system. Evaluating walking speed and reliability with computer modeling and hardware tests, they have observed that the trained model is effective of adapting to variations in the situation. Abi-Farraj et al.[204)] have introduced a whole-body balancing system focused on complacency to ensure a humanoid robot's stability when executing various interaction activities where it is challenging to predict the task forces operating on the robot. A variety of suitable testing experiments verify the efficiency of the method. Fakoor et al.[205)] have introduced a database schema and a method for a humanoid robot's real-time route strategy. Because of the many degrees of freedom, the design of the robots and the possible behavior are estimated in order to explore solutions effectively. For quick and hassle-free trajectory tracking of humanoids, a hybrid navigational concept developed incorporating regression analysis with the fuzzy logic system has been suggested by Kumar et al.[206)]. A Petri-Net design has been incorporated with the established hybrid control system to escape potential inter-collision hazards for the mobility of numerous humanoids on a single base. The humanoid bipedal posture stability analysis and the related posture performance are discussed by Hooi and Mahyuddin[207)]. In order to research the newly established walking posture control scheme, the task involves the application of an operating system humanoid robot, PLEN 2. For the movement of humanoid robots[208)], Lee et al.[209)] have introduced a new online multi-objective innovative perspective. The humanoid robot movement task is broken down into a set of small multi-objective optimization tasks with associated local knowledge in the suggested solution. Parhi et al.[210)] have intended to use a hybridized strategy composed of adaptive PSO and adaptive ACO to develop a guidance method for humanoid robots. In both virtual and real-time conditions, humanoid navigation is carried out, and a distinction is made between them. After that, the implemented control scheme is contrasted by other authors with the methodology described shows effective improvements. For humanoid robot trajectory tracking, Furlan et al.[211)] have introduced a regulatory control scheme. The preferred scheme is a managerial framework created by a discrete event mechanism at two hierarchical stages. A Petri net is defined by the high-level method. For secure dynamic walking, Galdeano et al.[212)] have operated with an efficient ZMP centered pattern designer. The framework developed is focused on the Three-Mass Linear Inverted Pendulum System employed as a generalized biped robot dynamical system. As a three-point mass and two-linking device, the preferred model simplifies the biped robot. Juang and Yeh[213)] have introduced generalized multi continuous ACO to optimize a fully linked recurrent neural network for the multi-objective posture training of a NAO. Simulations are carried out via correlations with various multi-objective automation methods to validate the posture generation results of the proposed controller. Michel et al.[214)] have proposed a method that integrates vision-based perception with a footstep designer to automated humanoid movement, enabling the robot to move towards a specific target location while avoiding barriers. In real-time, the ASIMO humanoid robot has enabled the combination of real-time vision and design reuse to independently navigate in complex terrains comprising unexpectedly dynamic barriers. The A-star method has been employed to determine the shortest route in the analysis, depending on the latest robot and intended object locations[215)]. In this method, the A-star method can be implemented effectively. The robot has been able to locate a new path with the inclusion of a redirecting function if the robot unexpectedly shifted by the operator or if the robot mistakenly walked beyond the coordinates. For the QRIO robot, Sabe et al.[216)] have introduced a technique for route planning and collision avoidance, enabling the robot to move through independently in a real situation. Experimental findings conclude the proposed system's definition. Samant et al.[217)] have developed a simple technique for coordination between humanoid robots centered on fuzzy logic in challenging terrain and its application on an experimental framework that has been evaluated using soccer games. Two online route optimization approaches for the SURENA III robot are introduced by Mirjalili et al.[218)] utilizing the model predictive control system. As it is the position with the maximum torque absorbed, the distinction is made with the emphasis on the knee joint. The findings demonstrate that, relative to the GA off-line route planning process, the predictive control strategy decreases the knee joint torque by 13 %.

6.2 Uneven Terrain

A critical role in biped navigation is the implementation of the gaits created with the aid of a gait designer. In order to maintain the smooth walking of the biped robot, this activity is to be performed with the aid of an appropriate torque-based control system. It is essential to recognize that the performance of the established PID control system focuses on the specified gains of the control system. With the support of various non-traditional evolutionary methods, including modified chaotic invasive weed optimization and PSO techniques, an effort is introduced to modify the gains of the PID control system for the biped robot moving up and going down the staircase and sloping terrain[219]. An online adaptation technique is suggested by Khadiv et al.[220] for bipedal movement on uneven terrain with level variability.

The walking of the humanoid robot over obstacles can be observed in Fig. 6. The projections in the activity space are designed to meet the complex stability and slippage protection limitations. And also to ensure the safe landing of the swing leg in order to produce walking behaviors on a flat surface. The prearranged projections in the task space should be modified to maintain a stable landing of the swing leg in environments with level variability. An updated PSO algorithm is suggested to improve the weights of the neural network and fuzzy logic control system to resolve the limitations resulting from explicitly regulating the robot by the control system[221]. A guidance method with a surface approximation is introduced for humanoid robot navigation on completely undiscovered environments.

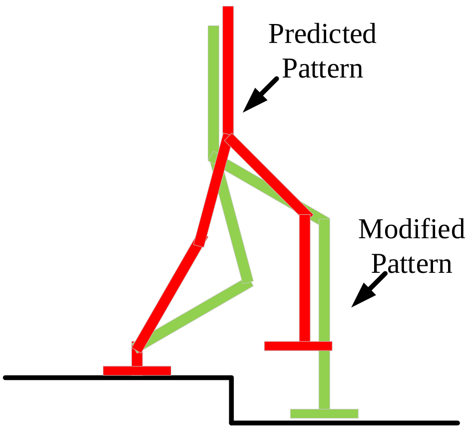

Fig. 6: Illustration of walking of humanoid robot over obstacle.

The proposed guidance method only includes a minimal modification to the actual walking posture[222]. The swing step path is revamped to guarantee that the feet land at the ideal horizontal locations below different terrain heights. Sun[223] has suggested an energy-efficient posture for humanoid robots traveling on even rough surfaces. For a robot movement on rough surfaces with barriers, Deits and Tedrake[224] have proposed a novel technique for managing footstep positions utilizing a mixed-integer quadratically-constrained quadratic program. The method is special in that it deals with barrier avoidance, kinematic accessibility, and footstep positioning rotation that usually have non-convex limitations needed, in a unified enhancement of mixed-integer that can be effectively achieved to its optimum solution. Sun and Roos et al.[225] have corresponded to the research on energy-efficient postures for humanoid robots on uncertain surfaces, whose motion control mechanism has humanoid features. First of all, they have presented an energy effective posture for humanoid robots in this research. The lack of a region of assistance is the main characteristic of the current gait.

7. Discussion

A rigorous literature survey has been carried out. Various papers from different journals have been collected over different years.

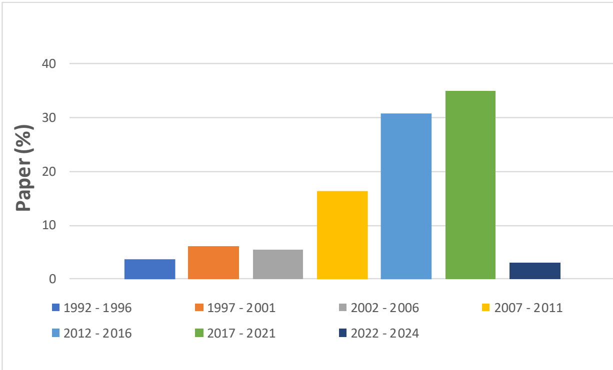

Fig. 7: Comparative analysis of paper published based on years.

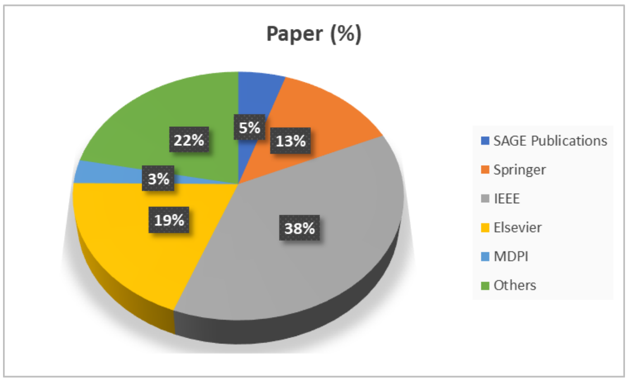

Fig. 8: Comparative analysis of paper published based on publishers.

Almost 450 papers have been downloaded in the first screening. After the completion of first screen, some papers were found duplicate and out of the scope. After this, around 380 papers were found useful. After multiple screening, few papers were found that have presented similar work and result. The authors selected 225 papers that are related with history of humanoid robot, its kinematics, dynamics and gait analysis. Further, a few papers were selected that discuss the navigation and obstacle avoidance of various robots using different nature-based algorithms. Then, specific papers are presented that portrays the navigation of humanoid robots in static and dynamic environments.

After detailed review of different research papers based on years, it has been observed that most of the related research papers were obtained from 2017-2021, as shown in Fig. 7. From Fig. 8 to Fig. 10, a comparative analysis has been carried out based on publisher, different categories, algorithms in both static and dynamic environment. It has been observed from Fig. 8, that research papers have been mainly downloaded from well known publishers. From the comparative analysis of shown in Fig. 9, it can be concluded that, most of the paper presented in this article is based on the navigation and decent number of papers have been reviewed for Gait analysis, which is one of the most important term to understand the navigation of humanoid robots. Figure 10 shows the number of papers reviewed based on various algorithms in static and dynamic environments. From the analysis, it has been observed that papers related to DWA has more numbers in static and dynamic environment. Various papers are present and reviewed on different algorithms. Papers related to static environment has a decent number but the paper related to dynamic environment is still had less numbers. Lastly, the comparison has been carried out for research papers based on humanoid robot navigation in even and uneven environments and presented in Fig. 11. From the comparison; it is observed that research related to the humanoid robots in uneven environments is lesser than in even environments.

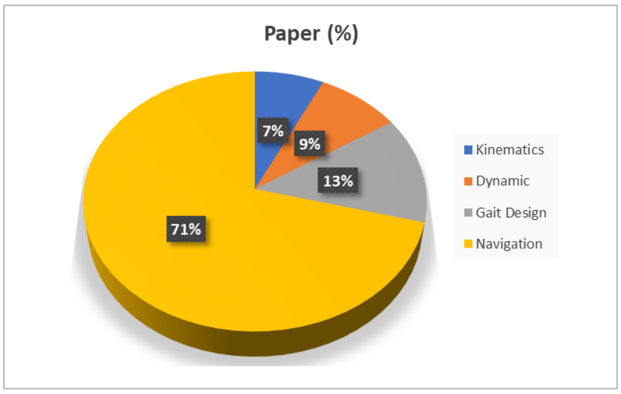

Fig. 9: Comparative analysis of paper published based on various categories

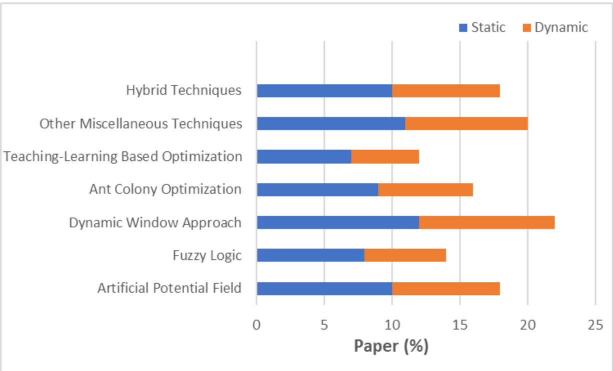

Fig. 10: Comparative analysis of paper published based on navigation of various robot using different algorithms.

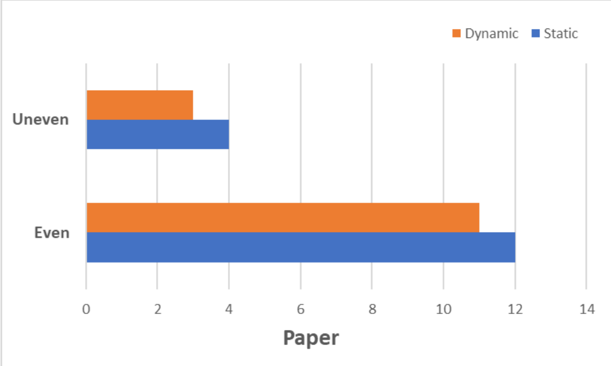

Fig. 11: Comparative analysis of paper published based on the navigation of humanoid robots in even and uneven environments.

8. Summary

This paper comprises research on a broad range of literature on different elements relevant to the balancing and trajectory planning of humanoid robots. The emphasis here is on previous design and advancement of humanoid robots, kinematic analysis, dynamic analysis, gait design and stability of humanoid robots, and implementation of various techniques in seamless trajectory planning in various complicated terrains. The following important and relevant points from the thorough research study of the literature can be illustrated.

- The architecture of biped and humanoid prototypes has been created in the earliest periods of civilization, although the design, structural characteristics, and humanoid features have been regularly improved over time.
- As kinematics of biped and humanoid robots require multiple sophisticated motions with complex joint mechanisms, it can be perceived to be more difficult than other counterpart robots. The DH parameter method has been commonly employed to address the issue of kinematics.
- The dynamics of biped and humanoid models are very complex due to the presence of multiple degrees of freedom. The dynamic study is the most crucial element to be considered in order to completely balance the humanoid robot during walking and obstacle avoidance.
- The design of the simplified model for the biped and humanoid robot is essential for the gait design. It is important to balance and increase energy efficiency while walking over uneven surfaces and climbing on slopes.
- Plenty of methods have been proposed for navigation are mainly employed to the humanoid robot's wheeled counterpart. The application of intelligent humanoid navigation methods is inferior. However, many scientists have studied the implementation of various methods for humanoid robots. The vast majority of their research focused on structure perception, stabilization and posture regulation on flat surfaces.

- The hybridization of individual approaches for humanoid navigation is very specific. Several significant studies on the utilization of hybrid methods have been noticed to be mainly adapted to mobile robotics.
- Usage of intelligent approaches for multiple robot navigation on a single platform is limited. A few of the notable works on the relevant topic are mainly performed for mobile robotics.
- The research based on navigation of humanoid robot in uneven terrains is very limited and can be incorporated in the future.
- Humanoid robot navigation in dynamic environments needs a significant focus to increase its analysis to make robots better in unstructured terrains.

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