A method for work space optimization of a Hybrid robot using Genetic Algorithm

B.Hanish Reddy [1],Chandrashekhar.A [2]

B.Tech Final Year Student, Mechanical Engineering Department, Faculty of Science & Technology, ICFAI Foundation for Higher Education, Hyderabad, India[1].

Asst. Prof., Faculty of Science & Technology, ICFAI Foundation for Higher Education, Hyderabad, India[2].

Abstract:

This paper proposes a method to optimize the workspace of the hybrid robot using Genetic Algorithm (GA). One of the crucial factors to consider in the operation of a robot is its workspace, it plays an important role to plan a trajectory. For a robot the main objective is to complete a task accurately, by consuming less energy, at a minimal operational time, by avoiding the collision with the obstacles. Finding an optimal workspace where the robot has the shortest trajectory length can achieve the above factors effectively. As an instance, a 2 DOF Hybrid robot is used and considered a leg of that robot to do the analysis, the kinematics of this leg are evaluated, which will be used to evaluate the objective function. The objective function is developed in such way that it minimizes the workstation of the manipulator. Genetic algorithms are in general the most robust type of evolutionary algorithms, so it is used in this work to fulfill the requirement. The average eigen value obtained from the Analytical Hierarchy Process (AHP) is used as weighing factor in the objective function to regulate the deviation, if any, occurs due to the genetic algorithm from the realistic values. AHP is solved by giving the priorities to the control attributes that effect the robot motion. In this work it is concluded that the use of this optimization algorithms in the kinematics of the hybrid robot will achieve the required task most effectively and efficiently.

Keywords: Hybrid robots, Kinematics of the robot, Genetic Algorithm, AHP, Optimization methods.

1. Introduction:

Over the last decades, walking machines have posed an interesting field of research, due to their great potential features. Mobile robots have a wide range of applications such as: inspection, service, defense, manufacturing, cleaning, remote exploration, rescue and entertainment. In general, they can be grouped into two main types, legged and wheeled robots, with important differences in features, as regarding to mechanical design and control systems.

There is rapid development of robot technology and thus more and more applications for robots are designed with different configuration. This paper is concerned of hybrid robot, applications of which have been increasing at a rapid rate. In the near future, robots will interact with human beings in the same environment, which means that the robot design should be suitable for moving in an environment whit stair, obstacles, and so on, where humans live. However, it is difficult to generate humanlike walking motion automatically. Humans can walk not only on flat surface but also on rough terrain, such as steps, obstacles, or slopes. One of the most important advantages of legged robots is the ability to move over rough terrain, even if with a reduced speed. While legged locomotion is more adaptable in a wide range of ground, wheeled locomotion is faster, but only on smooth surfaces.

Recently, random sampling has emerged as a powerful technique for planning in large configuration spaces. Random-sampling planners are classified into two categories: PRM (Probabilistic RoadMap) and RRT (Rapidly-Exploring Random Tree). Another approach uses genetic algorithms which are Meta-heuristic search algorithms. Genetic algorithms (GA's) are search strategies based on models of evolution. They have been shown to be able to solve hard problems in tractable time. Here, we need a solution space composed of a set of nodes randomly generated in C_{free} (free Configuration space).

To achieve a hybrid robot with such good workspace properties, the design parameters with regards to the geometric parameters must be optimized. Based on the design goal, the optimal design of general robots' kinematic parameters is classified into two categories. The first type of optimal design is where a set of parameters of a parallel robot whose workspace is a maximized one, is found. The second type of optimal design is concerned with the dimensional synthesis of hybrid robots and tries to fit a prescribed working region as closely as possible. Merlet [1] in his work focused on the optimal problem of design parameters of the Gough-type PR, when prescribed workspace has been specified via the data that considers three types of workspace definition: via a set of points, via a trajectory and via a volume.

The purpose of this paper is to first, describe the kinematics and workspace of the leg structure of a hybrid robot under the design considerations and to demonstrate the benefits of applying genetic algorithms in the workspace maximization. This paper goes as follows, the pervious work done by the other researches are presented in the next section. Then the hybrid robots are described and kinematic model of 2-DOF hybrid robot is presented in the third section. After that the description of the genetic algorithm and objective function id developed in the fourth section and in fifth the results are presented.

2. Literature review:

Parallel manipulators, such as the Stewart Platform [2], are robotic mechanisms which are composed of a set of parallel limbs, connecting the base plate to the moving plate, and they are able to achieve high stiffness and high forceto-weight ratio. This property makes parallel mechanisms an excellent option for high loads applications. The most important disadvantage of parallel manipulators is their restricted workspace. Parallel manipulators have limited workspace with respect to their serial counterparts. However, they have inherent advantages in terms of rigidity, high payload capacity, high velocity and high precision.

To balance the positioning accuracy and workspace, a hybrid robot is used. Some researchers have designed manipulators that present a compromise between the high rigidity of parallel manipulators and the extended workspace of serial manipulators. Many different types of hybrid robots have been investigated [3, 4, 5].

P. L. Yen [6] presented Cartesian parallel mechanism as the key module of the constructed knee surgical robot. In the constructed robot, the limited workspace and high rigidity of Cartesian parallel manipulator provide the surgical robot with enhanced safety and high cutting accuracy. S. Bruni [7] presented the design of a portable robot that can be easy handled in the surgical room, the robot presents an hybrid structure that permits to realize in a simple way the different milling bone cut planes to implant the prosthesis into the knee patient. T. Wang [8] presented a hybrid robot for lung cancer cryosurgery. Can Tang [9] presented kinematics study on the 7-DOF (degree of freedom) hybrid robot in minimally invasive surgery. R. Ye [10] presented 6 DOF robot for femur fracture reduction surgery. During such surgery, both patient and surgeon are exposed to a great amount of radiation, which is harmful to their health. Computer assisted orthopedic surgery is a less invasive approach for its ability to reduce the usage of image intensifier. W. Wei [11] in his Ph.D. Work designed high-precision hybrid robotic systems with application for ophthalmic micro-surgery. D. Liu [12] presented 9 degrees of freedom hybrid robot for CT-Guided Surgery. Simulative clinical experiment showed that the locating precision of the hybrid robot reaches 1.08mm which can meet the requirement of CT-Guided Surgery. Z. Fan [13] presented study on recently developed 9-DOF hybrid robot for thoracoabdominal percutaneous cryosurgery.

T. Tanev [14] presented an algorithm for the determination of the workspace of a new type of hybrid manipulation system is proposed in the paper. This algorithm is based on the obtained closed form solution of the inverse kinematic problem for the hybrid manipulator. The determined reachable and dexterous workspaces are graphically presented. The knowledge of the workspace is important for the design, trajectory planning and application of the manipulators.

3. Hybrid Robots:

Serial manipulators are made of a series of links and joints that connect the base to the end-effectors, and are capable of achieving large workspace. Serial robots have the advantages of large workspace, high dexterity and maneuverability, but their disadvantages are obvious. The enormous workspace leads to safety problems such as collision between the robot and the surrounding environment and a large area is consumed at the work table. Low payload to weight ratio and low stiffness leads to the high moving mass makes the robot's movement uneasy. The accumulated errors of the links lead to the low position accuracy. Moreover, the large size and high-power consumption of the robot results in its high costs. Thus, serial robot is inappropriate for tasks requiring either the manipulation of heavy loads or a good positioning accuracy.

Hybrid type manipulation system is a combination of closed-chain and open-chain mechanisms or it is a sequence of parallel mechanisms. Hybrid robots have drawn continuous interest in both industry and academia in the machine tool/robot sectors since the 1990s because of their potentially desirable fast dynamic performance, rigidity, and acceptable accuracy.

Fig 1: Hybrid Robot

Hybrid robot has also taken its place in Medical robot technology which is on one of the most thriving and the fastest developing research fields. Robot-assisted surgery has the advantage of reducing surgeons' hand tremor, decreasing post-operative complications, reducing patients' pains, and increasing operation dexterity inside the patients' body.

3.1 Motion Planning:

One of the most important issues in the process of design of the robots is to determine their workspace. For hybrid robots, this issue may be even more critical since they will sometimes have a rather limited workspace. The approaches where optimization methods are used for the workspace boundary determination can be also found in the literature. Various numerical methods for determination of the workspace of the hybrid robots have been developed in the recent years. Stan [15] presented a genetic algorithm approach for multi-criteria optimization of PKM (Parallel Kinematics Machines).

3.2 Kinematics of Leg:

Each of the two equal legs is composed by Chebyshev and Hart mechanisms, as it is shown in Fig.2 The Chebyshev mechanism is used to generate an approximately straight-line trajectory. The lengths of the links are chosen in such a way that the shape of the leg end-point trajectory is similar to the shape of a man's ankle. Moreover, the straight part of the trajectory is relatively accurate, which is important to limit the body raising during the walk. The Hart mechanism inverts and amplifies the trajectory. The amplification factor, from point B to point A, is of 2. Thus, the body can move horizontally by moving the legs. Several walking robots have a design containing mechanisms, a class of slider-cranks can be also used for the purpose. The values of transmission angles, velocity and acceleration of significant points, and design leg parameters (for example CM=z1) have been determined through a parametric study of the kinematic performance of the system.

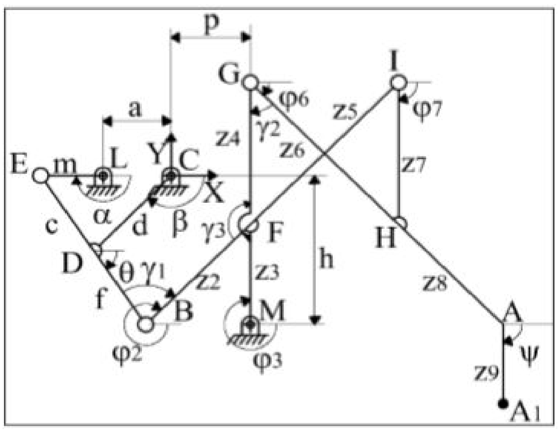

Fig 2: Kinematic Scheme of leg

A kinematic analysis has been developed in order to evaluate and simulate performances and operations of the leg system. A fixed reference system CXY has been considered attached at body in point C, as shown in Fig.1. The position of point B with respect to CXY frame can be evaluated as a function of the input crank angle α and kinematic parameters of the Chebyshev mechanism.

$X_b = -a + m \cos \alpha + (c + f) \cos\theta$

$Y_b = -m \sin \alpha - (c + f) \sin\theta$

The position of the point A with respect to the fixed frame can be written as:

$X_A = X_M - (z_3 + z_4) \cos\varphi_3 + (z_6 + z_8) \cos\varphi_6$

$Y_A = Y_M + (z_3 + z_4) \sin\varphi_3 - (z_6 + z_8) \sin\varphi_6$

Now, the position of the point A_1 with respect to the fixed frame can be written as:

$X_{A1} = X_A + z_9 \cos \psi$

$Y_{A1} = Y_A - z_9 \sin \psi$

The transmission angle can be evaluated as:

$\gamma_1 = -\theta + \varphi_2 - \pi$,

$\gamma_2 = \varphi_3 - \varphi_6 - \pi$,

$\gamma_2 = \varphi_3 - \varphi_2 + \pi$

The velocity of points B, A and A_1 can be evaluated by using time derivatives from the above equations. Angels θ, φ_2, φ_3 and φ_6 can be evaluated and can be written as:

$$\theta = 2\tan^{-1}\left\{sin\alpha - \frac{\sqrt{((sin\alpha)^2 + B^2 - D^2}}{B + D}\right\}$$

$$\varphi_2 = 2\tan^{-1}\left\{-K_2 + \frac{\sqrt{K_2{}^2 - 4K_1 K_3}}{2K_1}\right\}$$

$$\varphi_3 = 2\tan^{-1}\left\{-L_2 + \frac{\sqrt{L_2{}^2 - 4L_1 L_3}}{2L_1}\right\}$$

$$\varphi_6 = 2\tan^{-1}\left\{-M_2 + \frac{\sqrt{M_2{}^2 - 4M_1 M_3}}{2M_1}\right\}$$

Where,

$B = \cos\alpha - \frac{a}{m}$,

$D = \frac{a}{c}\, cos\alpha - \frac{a^2 + m^2 + c^2 - d^2}{2md}$

$K_1 = -2 X_B z_2 + 2 X_M z_2 + X_B{}^2 + X_M{}^2 + z_2{}^2 + Y_B{}^2 + Y_M{}^2 + z_3{}^2 - 2 X_B X_M - 2 Y_B Y_M$

$K_2 = 4 Y_B z_2 - 4 Y_M z_2$

$K_3 = 2 X_B z_2 - 2 X_M z_2 + X_B{}^2 + X_M{}^2 + z_2{}^2 + Y_B{}^2 + Y_M{}^2 + z_3{}^2 - 2 X_B X_M - 2 Y_B Y_M$

$L_1 = 2 X_M z_3 - 2 X_B z_3 + X_B{}^2 + X_M{}^2 + z_3{}^2 + Y_B{}^2 + Y_M{}^2 - z_2{}^2 - 2 X_B X_M - 2 Y_B Y_M$

$L_2 = - 4 Y_B z_3 + 4 Y_M z_3$

$L_3 = - 2 X_M z_3 + 2 X_B z_3 + X_B{}^2 + X_M{}^2 + z_3{}^2 + Y_B{}^2 + Y_M{}^2 - z_2{}^2 - 2 X_B X_M - 2 Y_B Y_M$

$M_1 = -2 X_G z_6 + 2 X_I z_6 + X_G{}^2 + X_I{}^2 + z_6{}^2 + Y_G{}^2 + Y_I{}^2 - z_7{}^2 - 2 X_G X_I - 2 Y_G Y_I$

$M_2 = - 4 Y_G z_6 + 4 Y_I z_6$

$M_3 = 2 X_G z_6 - 2 X_I z_6 + X_G{}^2 + X_I{}^2 + z_6{}^2 + Y_G{}^2 - Y_I{}^2 - z_7{}^2 - 2 X_G X_I - 2 Y_G Y_I$

4. Optimizing method Strategy:

4.1 Genetic Algorithm:

The growing interest for more flexible and autonomous robots leads to the need for automatic path planning and robust obstacle avoidance algorithms. Numerous implementations of GAs in the field of robot path and trajectory planning have been carried out in the last decade. The main difficulties with finding an optimum path arise from the fact that the complexity of the system means that analytical methods may be intractable, while enumerative search methods are overwhelmed by the size of the search space. GAs was first introduced by Holland 1975 based search and optimization techniques have recently found increasing use in machine learning, robot motion planning, scheduling, pattern recognition, image sensing and many other engineering applications.

In a broader usage of the term, a genetic algorithm is any population-based model that uses the selection and recombination operators to generate new sample points in a search space. Many genetic algorithm models have been introduced by researchers largely working from an experimental perspective. Many of these researchers are application oriented and are typically interested in genetic algorithms as optimization tools.
Some of the advantages of a GAs are their abilities to:

- deal with a large number of variables,
- be well suited for parallel computers,
- optimize with continuous or discrete variables,
- do not require derivative information,
- optimize variables with extremely complex cost surfaces and
- provide a list of optimum variables, not just a single solution

These advantages are intriguing and produce stunning results when traditional optimization approaches fail, which makes it a suitable option for optimization work.

4.2 System Development:

GA planning scheme renders an optimized trajectory having minimum space, minimum time, while not exceeding a maximum pre-defined torque, without colliding with any obstacle in the workspace. The motion planning adopts direct kinematics to avoid singularity problems. The trajectory parameters are encoded directly, using real codification, as strings (chromosomes) to be used by GA.
The initial population of strings is generated at random and the search is then carried out among this population. The evolution of the population elements is nongenerational, meaning that the new replace the worst elements. The main different operators adopted in the GA are reproduction, crossover, and mutation.
The flow chart of the above steps of GA is presented in the figure 3 below.

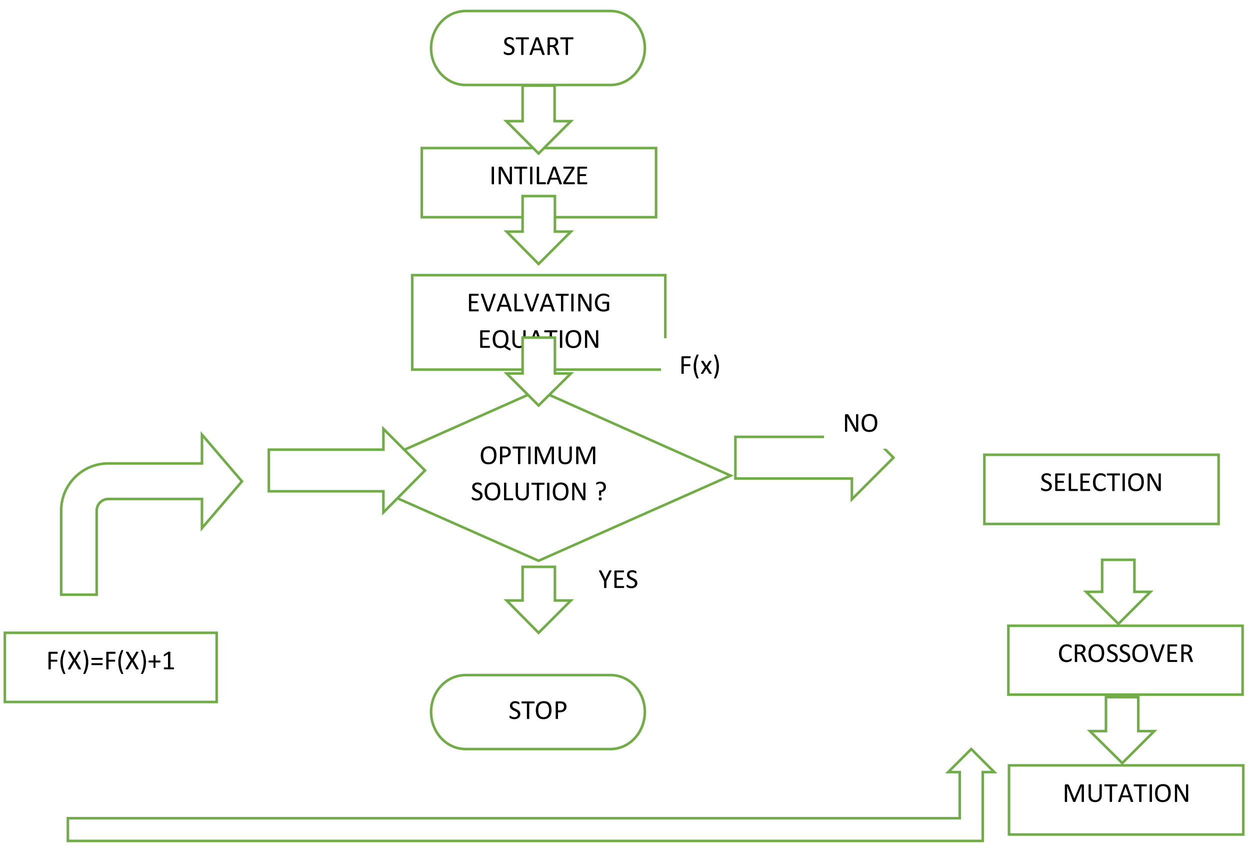

Fig 3: Process flow chart

The workspace of the robot is parameterized using several design parameters that span over a large range of values. In this work, three performance indices will be used to characterize a robotic system's workspace. The fitness function f(t) adopted to optimize the workspace is:

$$f(t) = \lambda * ma * Workspace$$

Where the "λ" here is the weighing factor sloved by the AHP, it is a pragmatic method of mathematically ranking the various available alternatives (which get evolves during the execution of GA in various test runs / iterations) along with approximate reasoning. In this paper we selected AHP, to find the value of weighing factor, in place of conventional techniques like Roulette Wheel, Rank Selection to reduce the ambiguity of the equations. However, there are innumerable optimization methods, the above factor driven us to use these techniques, which meet our requirement. AHP is solved by giving the priorities to the control attribute like trajectory length, driving force, total travelling time for the robot operation. The ranking is given on a scale of 9 and developed a 3 x 3 matrix.

The above objective function is iterated using the Genetic algorithm in the MATLAB toolbox. Where the parameters used to optimize the function are population: 100, generations: 100, cross over rate: 0.008 and mutation rate: 0.005. Using a population size of 100, the GA was run for 100 generations. A list of the best 50 individuals was continually maintained during the execution of the GA, allowing the final selection of solution to be made from the best structures found by the GA over all generations.

The objective here is to find the optimal workspace for the robot to perform an operation, so the use of this hybrid method, where the optimized value is incorporated in the Genetic algorithm gives the better results. The real-time operations values will always deviate the from the simulated values, so here the use of hybrid optimization method reduces this error.

5. Conclusion:

In this paper a method is proposed to optimize the workspace of a hybrid robot. In a walking machine a leg is considered and kinematics of that leg is studied. The previous work on hybrid robots done by other researchers is studied and presented in this work. GA is used to optimize the workspace; the objective function is developed by considering the geometrical parameters. A weighing factor is included in the objective function to make the values closer to the operating values. Trajectory length, driving force and travelling time of the robot are prioritized according to their importance by AHP to find the value weighing factor. The heuristic search algorithms, such as GA, do not guarantee to find a solution, but when they do, they do it so much faster than classic search algorithms and here in this. The stated method will be able to optimize the workspace of the more accurately and for this case the GA and AHP will help to achieve the results more effectively and efficiently.

6. Future Work:

As we got the method to simulate and operate the robot as per the need, the working prototype of this robot will be developed in the coming days. This work is only permitted to the analyze the kinematics of the leg, also there is a need to analyze the steering system of the robot and been left as the future scope.

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