# Literature Review

## Robotics

### Robot

International Organization for Standardization (ISO) defines robots and robotic devices in [ISO 8373](https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-2:v1:en). ISO 8373 defines robot as: “actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks.”

The standard is also classified robots into an industrial robot or service robot.

While the industrial robot is manipulators with more than 3 DOF which can be either fixed in place or mobile, and service robot as robot that performs useful tasks for humans or equipment excluding industrial automation applications.

Robots are widely used, most of the robots today are industrial robots used in automotive factories, medical field, construction, space, agriculture, research and more. Other types of robots that are widely used are domestics robots, type of service robots, such as robotic vacuum cleaners, for kitchen, lawnmower and more.

### Robotics in Agriculture

Robotics in agriculture is today mainly used in seed mapping, weed mapping, and micro spraying[1], but also includes transplanting, irrigation, harvesting and plant protection in the field, greenhouse and aquaculture as well.

The main issue for agricultural robots is the ability to operate in unstructured agricultural environments with the same quality of work achieved by current methods and means[2].

The unstructured environments expressed in variation among crops(tomato, cucumber, pepper), the variety of objects in a crop(crop vary in position, size, shape, etc) and variation in the environment(orchard, field, greenhouse)[3].

Another major issue is the costs of robotic systems must be sufficiently low to economically justify their use since the agricultural produce being dealt with is of relatively low value. However, the recent cost reductions in electronics, computers, and robotics should enable such systems to penetrate more widely into agriculture[2].

The robot tasks and operations in agricultural are[4]:

* Weed control and disease monitoring: A major challenge in agriculture is the inability to detect stresses and risks early enough preventing the uncontrolled spreading of stresses causing irreparable damage, which causes to waste of pesticides and fertilizers.
* Navigation and guidance: Navigation and guidance are the basic parts of automation fo agriculture. They include three levels of autonomy: conventional steering, an operator-assisted or automatic system (supervised by a human operator), and a fully autonomous system.
* Transplanting and seedling: Automating transplantation is feasible in several situations, mainly when the operations are repeated every few weeks in the same plot, as is the case with leafy vegetables or herbs.
* Pruning and thinning: Pruning is a labor-intensive task used to control tree shape, increase exposure to sunlight and remove protruding branches.
* Harvesting: Harvesting/fruit-picking is one of the most common tasks in agriculture and also one of the most demanding and challenging areas for agricultural robotics.

### Robotics Manipulators

#### Serial Manipulator Kinematics

A serial manipulator consists of a fixed base, a series of links connected by joints, and ending at a free end carrying the tool or the end-effector[5].

The study of Kinematics is essential to Robotics. A robot, to perform most applications needs to process positional data and transform data from one frame of reference to another[6]. In the thesis, the kinematics format used is Unified Robot Description Format (URDF). URDF is an XML(extensible Markup Language) format for representing a robot model. It represents the appearance of the robot and its intended action[7].

Degrees Of Freedom(DOF) is defined by Chebychev–Grübler–Kutzbach criterion[5] for motion in 3D

( ‎1.1 )

Where N- number of links, J number of joints that connect 2 links, joint's freedom of the ith joint.

In serials manipulators

( ‎1.2 )

Therefore

( ‎1.3 )

#### Robotics performance indices

One way to classified performance indices is based on their scope( local \ global).

Local indices are performance metrics that are dependent on the posture of the manipulator and are also known as posture-dependent indices[8].

Global indices are posture independent indices. They represent a global characteristic of the manipulator’s workspace. Global indices are needed to compare the structure and behavior of two manipulators that perform the same task[8].

Manipulability index is a local index, which based on the Jacobian matrix is a kinematic performance index[9]. The manipulability index can be calculated in two forms:

The first form is

( ‎1.4 )

The second form is

( ‎1.5

The value of the Jacobian can be between [0-1] when 0 means the manipulator in singularity and 1 that the manipulator is far from the singularity.

Condition Number is also a local and kinematic performance index based on the Jacobian matrix[10]. Condition number measures the independencies of the columns of the Jacobian[8]. As the manipulability index, calculated as follow:

( ‎1.6 )

Where is the norm of the Jacobian matrix.

Condition number doesn’t have an upper bound so to avoid computational problems Local Condition Index is used.

Local Condition Index (LCI), which is more commonly used, is calculated as follow:

( ‎1.7)

Where k is the condition number.

where 1 the manipulator is in isotropic points: the Jacobian matrix columns are orthogonal and its column vectors are of equal magnitude.

Joint Mid-Range Proximity Index defined for the avoidance of joint limits and to maintain the joint displacement as close to mid-range as possible[8]. Baron[11] defined it as follows:

( ‎1.8 )

Where W is a positive-definite weighing matrix, is the current joints position and

( ‎1.9 )

Degree of Redundancy The degree of redundancy (r) is equal to the number of degrees

of manipulator freedom (n) less the rank of the workspace (m), given as[12]:

( ‎1.10 )

Redundancy is the ability of a manipulator to reconfigure itself with the end-effector remaining in a fixed position[8].

## Optimization

### Evolutionary Algorithm

Genetic Algorithms (GAs) and Evolution Strategies (ESs) are both Evolutionary Algorithms [EA], an optimization search algorithm and based on the principles of the survival of the fittest and natural selection, which are the laws of natural evolution argued by Darwin[13].

EA relies upon the collective learning paradigm gleaned from natural evolution and implement the principles population, mutation, crossover, and selection. Besides, ESs try to use a collective self-learning mechanism to adapt its strategy parameters during the optimum search (adaptive search)[14].

Basic EAs are characterized by the genetic operations of selection, crossover, and mutation [15].

The first step in the algorithm, after initializing the population, is fitness. During each generation, the population is evaluated for fitness according to the ability to attain a satisfactory result[15].

The next step is the stop condition if the EA fulfills one of the criteria to stop, for example, how many generations to run, running time, etc.

If the EA didn’t stop in the stop condition, it will get into the selection step. In this step, the best population, according to fitness, has the most likely to continue to the next step. There are many types of selection methods, presented here two basics selection methods:

* Tournament selection: involves running several tournaments among a few randomly selected individuals from the population, and the individuals with the best fitness continue
* Roulette Wheel Selection(RWS): The fitness function assigns fitness to possible solutions. This level of fitness is used to link a probability of choice to everyone.

The next step is genetic operators to create the next generation of the population. The genetic operators are crossover and mutation.

The role of crossover is to generate better solutions by exchanging information contained in the current good solution.

Because of the low disruptiveness of the crossover, disruptive mutation operators are needed for the EA to continue to search without premature loss of genetic diversity[16].

While in GA the crossover is the main genetic operator in ES the mutation is the main operator and crossover needs to be used in cases where each child has multiple parents.

ES usually include elitism. Elitism guarantees that the solution in the next generation won’t decrease from the previous generation.

GA more likely to find the global maximum and usually slower and used when an optimal solution is needed and more common for solving computational problems.

ES is usually faster but find a local maximum, so it good when a good enough solution acceptable. ES more common to solve engineering problems.



Figure -Basic EA

### Window Of Interest

The Window Of Interest (WOI) indicates what is considered as an acceptable performance vector. Rather than being interested in finding concepts' fronts, here the designers are interested in finding which of the considered concepts have at least one solution with a performance vector within a pre-defined WOI. Concepts that meet this requirement are considered satisficing[17].

In decision making, satisficing refers to the use of aspiration levels when choosing from different paths of action. By this account, decision-makers select the first option that meets a given need or select the option that seems to address most needs rather than the "optimal" solution.

The two main advantages of WOI compared to concept based Pareto method are first, in the WOI, there is no need to find any front. Second, the WOI, within which solutions are sought, is pre-defined[17].

### set-based concept

The set-based concept approach has been suggested as a means to simultaneously explore different design concepts, which are meaningful sub-sets of the entire set of solutions[17].

It involves a comparison of subsets of the solution set, where each such sub-set represents a conceptual design solution. The use of a set to represent a concept reflects the fact that a design concept is not a final solution[18].

set-based concept search approach is not optimization but gaining general knowledge of the design space. The approach to design space exploration includes predefined design concepts that are used to explore the design space at both the level of concepts and the particular designs that accompany it. This is achieved by the set-based concept approach[19].

## Manipulators Optimization

In the past, the mechanical design of robotic manipulators has been based on some simple criteria, such as the number of joints, link sizes and weights, and payload capacity. The design process includes deciding upon a robot configuration largely by intuition or experience[20]. Those days research efforts have been divided between those concerning performance measures (indices) and those that deal with optimization approaches and techniques(Ami draft paper).

Some of the optimizations studies focused to optimize the kinematic design such as geometric parameters, joint travel ranges, and tolerances, links lengths, manipulator workspace[20].

Other studies focused to optimize the dynamic design such as the link masses, torques, inertias, and material properties and some studies tried to optimize by kinematics and dynamics.

Most studies on optimizing manipulators employ numerical methods. Early attempts to numerically optimize manipulators employed gradient-based methods. Nevertheless, using gradient-based methods for optimizing manipulators is very difficult[21]. GA have become popular since the nineteens for solving such optimization problems.

[1] N. V. Reddy, A. V. V. V. Reddy, S. Pranavadithya, and J. J. Kumar, “A critical review on agricultural robots,” *Int. J. Mech. Eng. Technol.*, vol. 7, no. 4, pp. 183–188, 2016.

[2] A. Bechar and C. Vigneault, “Agricultural robots for field operations: Concepts and components,” *Biosystems Engineering*, vol. 149. pp. 94–111, 2016, doi: 10.1016/j.biosystemseng.2016.06.014.

[3] C. Wouter Bac and Eldert J. van Henten, J. Hemming, and Y. Edan, “Bac\_et\_al-2014,” *Journal\_of\_Field\_Robotics*, vol. 71, no. 5, pp. 486–494, 2018, doi: 10.1002/rob.

[4] A. Bechar and C. Vigneault, “Agricultural robots for field operations. Part 2: Operations and systems,” *Biosyst. Eng.*, vol. 153, pp. 110–128, 2017, doi: 10.1016/j.biosystemseng.2016.11.004.

[5] A. Y. C. Nee, “Kinematics of Serial Manipulators,” *Handb. Manuf. Eng. Technol.*, no. September 2015, pp. 1–3487, 2015, doi: 10.1007/978-1-4471-4670-4.

[6] A. Yousuf, W. Lehman, M. A. Mustafa, and M. M. Hayder, “Introducing kinematics with robot operating system (ROS),” *ASEE Annu. Conf. Expo. Conf. Proc.*, vol. 122nd ASEE, no. 122nd ASEE Annual Conference and Exposition: Making Value for Society, 2015, doi: 10.18260/p.24361.

[7] Y. Kang, D. Kim, and K. Kim, “URDF Generator for Manipulator Robot,” *Proc. - 3rd IEEE Int. Conf. Robot. Comput. IRC 2019*, vol. 1, pp. 483–487, 2019, doi: 10.1109/IRC.2019.00101.

[8] S. Patel and T. Sobh, “Manipulator Performance Measures - A Comprehensive Literature Survey,” *J. Intell. Robot. Syst. Theory Appl.*, vol. 77, no. 3–4, pp. 547–570, 2014, doi: 10.1007/s10846-014-0024-y.

[9] T. Yoshikawa, “MANIPULABILITY OF ROBOTIC MECHANISMS.,” 1985, pp. 439–446.

[10] J. K. Salisbury and J. J. Craig, “Articulated Hands: Force Control and Kinematic Issues,” *Int. J. Rob. Res.*, vol. 1, no. 1, pp. 4–17, 1982, doi: 10.1177/027836498200100102.

[11] L. Baron, “A Joint-Limits Avoidance Strategy for Arc-Welding Robots,” *Int. Conf. Integr. Des. Manuf. Mech. Eng.*, 2000.

[12] P. H. Chang, “A Dexterity Measure for the Kinematic Control,” 1988, [Online]. Available: https://apps.dtic.mil/dtic/tr/fulltext/u2/a196223.pdf.

[13] S. Hwang, H. Kim, Y. Choi, K. Shin, and C. Han, “Design optimization method for 7 DOF robot manipulator using performance indices,” *Int. J. Precis. Eng. Manuf.*, 2017, doi: 10.1007/s12541-017-0037-0.

[14] F. Ho and T. Back, “Genetic Algorithms and Evolution Strategies : Similarities and Di erences,” no. February 1992, 1997.

[15] P. S. Shiakolas, D. Koladiya, and J. Kebrle, “Optimum robot design based on task specifications using evolutionary techniques and kinematic, dynamic, and structural constraints,” *Inverse Probl. Eng.*, 2002, doi: 10.1080/1068276021000004706.

[16] L. J. Park and C. H. Park, “Application of genetic algorithm to job shop scheduling problems with active schedule constructive crossover,” *Proc. IEEE Int. Conf. Syst. Man Cybern.*, vol. 1, pp. 530–535, 1995, doi: 10.1109/icsmc.1995.537816.

[17] E. Farhi and A. Moshaiov, “Window-of-interest based multi-objective evolutionary search for satisficing concepts,” *2017 IEEE Int. Conf. Syst. Man, Cybern. SMC 2017*, vol. 2017-Janua, pp. 3705–3710, 2017, doi: 10.1109/SMC.2017.8123209.

[18] B. Samina, “Evolutionary Many Concept Optimization under Multiple Objectives Evolutionary Many Concept Optimization under Multiple Objectives,” 2019.

[19] A. Moshaiov, A. Snir, and B. Samina, “Concept-based evolutionary exploration of design spaces by a resolution-relaxation-pareto approach,” *2015 IEEE Congr. Evol. Comput. CEC 2015 - Proc.*, pp. 1845–1852, 2015, doi: 10.1109/CEC.2015.7257111.

[20] S. S. Rao and P. K. Bhatti, “Optimization in the design and control of robotic manipulators: A survey,” 1989. [Online]. Available: http://mechanicaldesign.asmedigitalcollection.asme.org/pdfaccess.ashx?url=/data/journals/amread/25573/.

[21] A. R. Shirazi, M. M. S. Fakhrabadi, and A. Ghanbari, “Optimal design of a 6-DOF parallel manipulator using particle swarm optimization,” *Adv. Robot.*, vol. 26, no. 13, pp. 1419–1441, 2012, doi: 10.1080/01691864.2012.690187.