Errata of the Thesis as per the suggestions of the examiners

Q. No. 1: Page 47

What is difference in the working of these different sensors?

Answer: The Magnetic Compass is used as sensor for giving directions.

The basic fluxgate compass is a simple electromagnetic device that employs two or more small coils of wire around a core of highly permeable magnetic material, to directly sense the direction of the horizontal component of the earth's magnetic field. The advantages of this mechanism over a magnetic compass are that the reading is in electronic form and can be digitised and transmitted easily, displayed remotely, and used by an electronic autopilot for course correction.

The Hall effect refers to the potential difference (Hall voltage) on the opposite sides of an electrical conductor through which an electric current is flowing, created by a magnetic field applied perpendicular to the current. Edwin Hall discovered this effect in 1879.

Magnetoresistance is the property of a material to change the value of its electrical resistance when an external magnetic field is applied to it. The effect was first discovered by William Thomson (more commonly known as Lord Kelvin) in 1856, but he was unable to lower the electrical resistance of anything by more than 5%. This effect was later called ordinary magnetoresistance (OMR). More recent researchers discovered materials showing giant magnetoresistance (GMR), colossal magnetoresistance (CMR) and magnetic tunnel effect.

Magneto-Elastic is the change of Young's modulus of ferromagnetic materials.

Q. No. 2 : Page 54

The chapter seems to end without explaining the results obtained.

Answer: This chapter is discussed about the Kinematic analysis of mobile robot. Form the analysis we found steering angle in terms of right wheel and left wheel velocity, which are subsequently used in all the remaining chapters.

Q. No. 3 : Page 91

a. Why sigmoid function chosen? What is its significances? Where its fail? Explain.

Answer: Sigmoid function gives the faster learning process for achieving the desired output.

b. α = Momentum chosen as 0.25 } and η = learning rate chosen as 0.3 } what is justification of choosing then value? What is physical significance of these parameters?

Answer: Momentum is chosen for forward progress, learning rate is chosen for backward learning and to achieve desired output.

Q. No. 4 : Page 106

The path lengths and search time are taken statistically from one thousand simulation results what is value of minimum, maximum and standard deviation of these parameters. Are these arithmetic means?

Answer: The results given for the path length are arithmetic means.

(Maximum Value-Minimum Value)/(Maximum Value)= 0.023

Standard deviation/Maximum Value = 0.0124.

Q. No. 5 : Page 112

A comparison has been tried between the two situations, which are different. In one case it is a point object moving where as in 2nd case it is the object with

finite dimensions that is moving. In the second case the angular momentum is present and thus two cases are not similar.

Answer: First case represents the navigation path in simulation mode. With the same environment as of Janglova D., [99], I have navigate Khepera II mobile robot which is not a point mass and found that my path length is less than the path length of Janglova D.

Q. No. 6 : Page 124

Logic of arriving at these specific values is not explained.

Answer: One thousand seven hundred situations, which may be encountered by the robots while searching targets, are fed to See5 (Clementine data mining software package). From this software I have got the rules.

Q. No. 7 : Page 151

"The rule base technique has a set of rules obtained from rule induction and enhanced with manually derived heuristics" explain the statement? How do you set rules?

Answer: The rule base technique is composed of several hundred rules, which are derived on the basis of simulation, real data by various trial runs in simulation and experimental mode. Again the numbers of rules are squeezed using SEE-5 algorithm.

Q. No. 8 : Page 153

$$U_{att}(q) = \frac{1}{2}\delta\rho^{m}\left(q, q_{Target}\right)$$ **............................(7.1) also (7.3) Khatib (162).**

It is the basis of your hypothesis now explain this equation- (can you derive it) (Why m = 2)

Answer: If m < 2 then it is not possible to get global minima. If, m> 2 more computational time is required due to higher order.

Potential energy is defined as the capacity for doing work that arises from position or configuration. In our case, a charge will exert a force from the robot on any other charge (target) and potential energy arises from collection of all the charges. If a positive charge is fixed at some point in space, any other positive charge, which is brought close to it, will experience a repulsive force and will therefore have repulsive potential energy. If a negative charge is fixed at some point in space, any other positive charge, which is brought close to it, will experience an attractive force and will therefore have attractive potential energy.

The potential energy of a test charge 'q' in the vicinity of the source charge 'Q' will be:

$$U = \frac{kQq}{r} \qquad \text{Coulomb's Law}$$

where k = Coulomb's Constant.

r = distance between the two charges.

The attractive potential function used [162] is,

$$U_{att}(q) = \frac{1}{2}\,\delta\rho^{m}\left(q, q_{Target}\right) \tag{7.1}$$

Where δ is a positive scaling factor

$\rho\left(q, q_{Target}\right) = \| q_{Target} - q \|$ is the distance between the robot q and the target q_{Target} .

The repulsive potential function used [162] is,

$$U_{rep}\,(obs_i) = \begin{cases} \frac{1}{2}\,\alpha_i \left(\frac{1}{\rho\,\left(q, q_{obs_i}\right)} - \frac{1}{\rho_0} \right)^2 & \text{if } \rho\left(q, q_{obs_i}\right) \leq \rho_0 \\ 0 & \text{if } \rho\left(q, q_{obs_i}\right) > \rho_0 \end{cases} \tag{7.3}$$

Where i = 1 to n, n is number of obstacles, 'α_i'is the positive scaling factor,

ρ_0 = Positive constant denoting influences of the obstacle on the robot and $\rho\left(q, q_{obs_i}\right)$ is the minimum distance from the robot 'q' to the obstacle.

$\rho\left(q, q_{Target}\right)$ = gives the distance between the robot and the target, which gives the measure of the force between the robot and the target. δ is given to encounter the Δ operator. m is given to alleviate the problem when $\rho\left(q, q_{Target}\right)<1$.

If m < 2, then it is not possible to get global minima. If, m> 2 more computational time is required due to higher order.

Q. No. 9 : Page 156

Check 7.6 equation.

Answer: Equation 7.4 of page 154 should be read as follows

For obstacle 1, $F_{rep}\ (obs_1)$ =

$$\begin{cases} \alpha_1 \left(\dfrac{1}{\rho\left(q_x, q_{obs_{1x}}\right)} - \dfrac{1}{\rho_0} \right) \dfrac{1}{\rho^2\left(q_x, q_{obs_{1x}}\right)} \dfrac{\partial}{\partial x}\rho\left(q_x, q_{obs_{1x}}\right)\hat{i} \\ + \alpha_1 \left(\dfrac{1}{\rho\left(q_y, q_{obs_{1y}}\right)} - \dfrac{1}{\rho_0} \right) \dfrac{1}{\rho^2\left(q_y, q_{obs_{1y}}\right)} \dfrac{\partial}{\partial y}\rho\left(q_y, q_{obs_{1y}}\right)\hat{j} \\ + \alpha_1 \left(\dfrac{1}{\rho\left(q_z, q_{obs_{1z}}\right)} - \dfrac{1}{\rho_0} \right) \dfrac{1}{\rho^2\left(q_z, q_{obs_{1z}}\right)} \dfrac{\partial}{\partial z}\rho\left(q_z, q_{obs_{1z}}\right)\hat{k} & \text{if } \rho\left(q, q_{obs_1}\right) \le \rho_0 \\ 0 & \text{if } \rho\left(q, q_{obs_1}\right) > \rho_0 \end{cases} \quad (7.4)$$

and Equation 7.6 of page 156 should be read as follows

For obstacle 3, $F_{rep}\ (obs_3) =$

$$\begin{cases} \alpha_3 \left(\dfrac{1}{\rho\ \left(q_x\ ,\ q_{obs_{3x}}\right)} - \dfrac{1}{\rho_0} \right) \dfrac{1}{\rho^2\ \left(q_x\ ,\ q_{obs_{3x}}\right)}\ \dfrac{\partial}{\partial x} \rho\left(q_x\ ,\ q_{obs_{3x}}\right) \hat{i} \\ + \alpha_3 \left(\dfrac{1}{\rho\ \left(q_y\ ,\ q_{obs_{3y}}\right)} - \dfrac{1}{\rho_0} \right) \dfrac{1}{\rho^2\ \left(q_y\ ,\ q_{obs_{3y}}\right)}\ \dfrac{\partial}{\partial y} \rho\left(q_y\ ,\ q_{obs_{3y}}\right) \hat{j} \\ + \alpha_3 \left(\dfrac{1}{\rho\ \left(q_x\ ,\ q_{obs_{3z}}\right)} - \dfrac{1}{\rho_0} \right) \dfrac{1}{\rho^2\ \left(q_z\ ,\ q_{obs_{3z}}\right)}\ \dfrac{\partial}{\partial z} \rho\left(q_z\ ,\ q_{obs_{3z}}\right) \hat{k} & \text{if } \rho\ \left(q\ ,\ q_{obs_3}\right)\ \leq\ \rho_0 \\ 0 & \text{if } \rho\left(q\ ,\ q_{obs_3}\right)\ > \rho_0 \end{cases} \tag{7.6}$$

Q. No. 10 : Page 182

Explain reasons of difference in values in Table 7.3

Answer:

Number of robots	Total time taken during simulation in seconds		Total time taken during experiment in seconds	
	Potential field navigation technique	Potential field neuro-fuzzy technique	Potential field navigation technique	Potential field neuro-fuzzy technique
1	10.86	7.01	11.75	8.10
2	11.07	7.21	12.51	8.16
4	11.71	7.43	12.93	8.96

The differences in values are due to the mode of observation taken i.e., in simulation and experimental techniques and different controllers used.

Q. No. 11 : Page 199

Shows the actual experiment and compare with simulation results. Does it follow almost the same path?

Answer: The experiment path is not almost exactly same with the simulation result.

Q. No. 12 : General

a. The forward and inverse kinematics not discussed

Answer: Forward and Inverse Kinematics are not pertinent to the current research on "Navigation Techniques for Control of Multiple Mobile Robots". They are required in robot arm design.

Q. No. 13 : General

b. Local path planning tasks – not to be considered

Answer: If the local path planning tasks are not considered than, problem will occur in avoiding the local obstacles and random obstacles (such as one robot moving towards another robot).

Q. No. 14 : General

c. Explain simulated annealing technique.

Answer: Simulated Annealing (SA) is a variant of the stochastic search methods, and has been applied to a wide range of practical problems. SA was initially inspired by the laws of thermodynamics which state that at temperature, T, the probability of an increase in energy of magnitude, δE, is given by equation

$$P[\delta E] = \exp\left(\frac{-\delta E}{kT}\right)$$

Where k is the physical constant known as Boltzmann's constant and T can be considered to be a parameter of the process. In a simulated version this equation is used with in a system that is ‘cooling’ to wards a steady state. SA can find solutions in non-linear models. It is versatile since it does not rely on any restrictive properties of the model. In order to use SA a representation of possible solutions and an annealing schedule (an initial temperature and rules for lowering it) are required.

Q. No. 15 : General

d. Optimisations of path not considered.

Answer: This suggestion given by the examiners are mentioned in article 9.3 for further investigations

Q. No. 16 : General

e. By image processing & connecting it to installing system could direct its better.

Answer: This suggestion given by the examiners are mentioned in article 9.3 for further investigations.

Q. No. 1 : Page 1, Line 6

“Autonomous Robotics” not defined

Answer: “Autonomous robots” are robots, which can perform desired tasks in unstructured environments without continuous human guidance.

Q. No. 2 : Page 2, Line 8

“High-level map reading ability” not defined

Answer: "High-level map reading ability” refers to the higher level (user friendly) of abstraction from machine language. Rather than dealing with registers, memory addresses and call stacks, high-level map reading deal with variables, arrays and complex map recognition algorithms.

Q. No. 3 : Page 3, Line 22

To solve navigation problems of mobile robots

Answer: Line No. 22 of page 3 should be read as **“to solve navigation problems of mobile robots”** instead of to solve mobile robots navigation problems.

Q. No. 4 : Page 7, Line 10

c) Relates to avoiding obstacles and moving towards the target.

Answer: Line No. 10 of page 7 should be read as **“(c) relates to avoiding obstacles and moving towards the target.”** instead of (c) relate to avoid obstacles and move towards the target.

Q. No. 5 : Page 7, Line 12

“Must have the capability to………..”

Answer: Line No. 12 of page 5 should be read as **“must have the capability to perceive its environment”** instead of must have a way to perceive its environment.

Q. No. 6 : Page 11, Line (a)

Physical and mental tasks

(ii) Car, cleaning of house etc.

Answer: Line No. 9 of page 11 should be read as **"wide variety of physical and mental tasks without any explicit measurements or"** instead of wide variety of physical and mental task without any explicit measurements or

Q. No. 7 : Page 11, Line (a)

(ii) Car, cleaning of house etc.

Answer: Line No. 11 of page 11 should be read as **"car, and cleaning of house etc."** instead of car, and cleaning of house.

Q. No. 8 : Page 11, Line 17

Provides a means towards

Answer: Line No. 17 of page 11 should be read as **"logic provides a means towards accomplishing this goal"** instead of logic provides a mean towards accomplishing this goal.

Q. No. 9 : Page 15, Line 7

<u>Non-holonomoic</u> mobile robot (not defined anywhere)

Answer: The common characteristic of mobile robots is that they cannot autonomously produce a velocity, which is transversal to the axle of their wheels. A deferentially driven robot has one such constraint; the caster wheels are mounted on a swivel and hence give no constraint, except for friction. Bicycles and cars have two constraints: one on the front wheel axle and one on the rear wheel axle. These constraints are nonholonomic constraints on the velocity of the robots, i.e., they cannot be integrated to give a constraint on the robots' Cartesian pose. (The word "holonomic" is built from the Greek words holos ("integral") and nomos ("law"). The nonholonomic constraints reduce the mobile robot's instantaneous velocity degrees of freedom, and hence most robots have only two actuated joints: A constraint is said to be nonholonomic if it cannot be written as an algebraic constraint in the configuration space.

Q. No. 10: Page 15, Line 20

"highest priority" (It is not explicitly defined)

Answer: It is the highest priority among the thirteen possible directions.

Q. No. 11: Page 18, Line 6

Genetic fuzzy system – (neither explained nor used subsequently)

Answer: From genetic fuzzy system hybrid technique idea has been taken and implemented in neuro-fuzzy technique.

Q. No. 12 : Page 19, Line 17

Achieves "effectively" How do you explain the term here?

Answer: The technique has been tested and found effective for navigation of one mobile robot in simulation mode. Also from the result it is seen that the robots can effectively achieve the control on navigation using their technique.

Q. No. 13 : Page 23, Line (b)

Ramping fn. How do you explain 2nd value?

Answer:

For $v = -0.5$, $\varphi(v) = v + 0.5 = 0$,

For $v = 0.0$, $\varphi(v) = v + 0.5 = 0.5$,

For $v = 0.5$, $\varphi(v) = v + 0.5 = 1.0$

Q. No. 14: Page 27, Line 16

The robot is able to navigate

Answer: Line No. 16 of page 27 should be read as **"With their formulation the robot is able to navigate in an open environment and"** instead of With their formulation the robot able to navigates in an open environment and

Q.No 15: into account dynamic, page 37 line 21

Answer: The dynamic is taken for mobility of the robot.

Q. No. 16 : Page 55, Line 15

"For of" what do you want to use out of the two

Answer: Line No. 15 of page 55 should be read as **"Fuzzy Control Technique for Multiple Mobile Robots' Navigation"** instead of Fuzzy Control Technique for of Multiple Mobile Robots' Navigation

Q. No. 17 : Page 56, Line 22

.. Two not required

Answer: Line No. 22 of page 56 should be read as **"the robots are calculated. Left wheel velocity and right wheel velocity are"** instead of the robots are calculated. . Left wheel velocity and right wheel velocity are

Q. No. 18 : Page 58, Line A

Table – variables not written clearly

LOD

ROD

FOD

Answer: Line No. (a) of page 58 should be read as

(a) Parameters for Left, Right and Front Obstacle

Variables	Very Near (Meter)	Near (Meter)	Medium (Meter)	Far (Meter)	Very Far (Meter)
Left Obstacles Distances (LOD)	0.0	1.0	2.0	3.0	4.0
Right Obstacles Distances (ROD) and	1.0	2.0	3.0	4.0	5.0
Front Obstacles Distances (FOD)	2.0	3.0	4.0	5.0	6.0

Q. No. 19 : Page 58, Line C

LWV – three values given for two parameters

RWV

Answer: Line No. (c) of page 58 should be read as

(c) Parameters for Left and Right Velocity

Variables	Very Slow (Meter/sec)	Slow (Meter/sec)	Medium (Meter/sec)	Fast (Meter/sec)	Very Fast (Meter/sec)
Left Wheel Velocity (LWV) and Right Wheel Velocity (RWV)	0.0	0.5	1.0	1.5	2.0
	0.5	1.0	1.5	2.0	2.5
	1.0	1.5	2.0	2.5	3.0

Three values are given to represent the Gaussian membership function for Left Wheel Velocity (LWV) and Right Wheel Velocity (RWV).

Q. No. 20: Page 70, Line 6

It should be "Petri" rather than "prtri"

Answer: Line No. 6 of page 70 should be read as **"tasks. The details of the Petri Net technique are given in appendix –B. "** instead of tasks. The details of the Prtri Net technique are given in appendix –B.

Q. No. 21: Page 86, Line 7

It should be "capable of negotiating with"

Answer: Line No. 7 of page 86 should be read, as **"the robots are capable of negotiating with each other. It has been seen that, by"** instead of the robots are capable of negotiate with each other. It has been seen that, by

Q. No. 22: Page 95, Last para

Avoid colliding with the obstacles……

Answer: Line No. 9 of page 95 should be read, as **"avoid colliding the obstacle by changing its path and proceed towards target. The**" instead of avoid collide the obstacle by changing its path and proceed towards target. The

Q. No. 23: Page 98, End of second para

----robots <u>stay well</u> away from the other robots.

Answer: Line No. 13 of page 98 should be read, as **"the exercise has begun. It can be seen that the robots stay well away from the**" instead of the exercise has begun. It can be seen that the robots are stay well away from the

Q. No. 24: Page 154

Should be (mid page three obstacles surround the target)

Answer: Line No. 9 of page 154 should be read, as **"In the environment shown in Figure 7.1 three obstacles are surrounding the target**" instead of In the environment shown in Figure 7.1 three obstacles are surrounded the target

Q. No. 25: Page 184, Line 10

Should be "capable of negotiating with…."

Answer: Line No. 10 of page 184 should be read, as **"use of Petri net model the robots are capable of negotiating with each other. It has"** instead of use of Petri net model the robots are capable of negotiate with each other. It has