List of Figures

1.1	Taxonomy proposed by Iocchi et al. to represent different types of collective robots [1]
2.1	Techniques for indoor localization
2.2	Technologies for indoor localization
2.3	MRTA Taxonomy proposed by Gerkey and Matarić
2.4	iTax MRTA Taxonomy
2.5	Optimization based Approaches
3.1	Uncertainties and delays in wireless timestamping
3.2	CC2500 packet and payload format
3.3	Overview of Robot Hardware Architecure Overview
3.4	a) 'tsync' messages and associated timestamps during time offset compensation. b) GD01, GD02 signals captured on logic analyzer during tsync message transmissions (GD02_N1) and receptions (GD01_N2, GD02_N2)
3.5	Reference node (COM2) and slave node (COM1) timestamps recorded at base station after time offset compensation
3.6	Time offset of slave nodes $N_2 - N_5$ with respect to reference node N_1 , after initial
	time offset compensation
3.7	Relative skew measured for nodes $N_2 - N_5$ with respect to reference node N_1 6
3.8	Analysis of relative skew with temperature. For t≤600 and t≥5400, temperature is
	maintained at $23^{\circ}C$
3.9	Analysis of relative skew with temperature. Poller node is kept in insulated case. For
	$t \le 600$ and $t \ge 5400$, temperature is maintained at 23°C 6
	Distribution of relative skew with temperature
	Distribution of average relative skew with temperature 6
3.12	Overall Swarm-Sync Framework. (Dotted lines indicate control frames, solid lines
	indicate the data frames, Bulleted line ends indicate the timestamping instants)
	Synchronization error (time offset) for different values of 'n'
3.14	Time offset between reference and slave nodes post synchronization, α'_{avg} calcu-
	lated prior to deployment using wired relative skew fingerprinting
3.15	Time offset between reference and slave nodes post synchronization, α'_{avg} calcu-
	lated using wireless relative skew fingerprinting post the deployment
	Deployment of nodes in multi-hop scenario
3.17	Time offset between reference and slave nodes for 4-hop deployment, α'_{avg} calcu-
	lated using wireless relative skew fingerprinting as in Option 3

List of Figures xiv

3.18	Time offset (Prediction error) for LR based reference clock prediction for different T_{resync} periods a) Initial offset between between N_1 and N_2 was 60ms b) Initial	
2 10	offset between N_1 and N_5 was $10\mu s$	83
3.19		85
3 20		85
3.21	a) Prediction error (Measured time offset- Predicted time offset) for LP based prediction, $T_{resync} = 1second$. b) Prediction error for LP based prediction,	
2.22	resyne	86
3.22		86
3.23		
		89
3.24		90
4.1	Overall architecture of the beacon based localization system	96
4.2	Attenuation of ultrasound signal with frequency	97
4.3	Beam angle of 400EP18A ultrasonic transducer [93]	97
4.4	Ultrasonic transmitter circuit	98
4.5	Ultrasonic receiver Circuit	98
4.6	Signal at top- Ultrasonic signal output received at receiver (Y-axis-1 square= 1V), Signal at the bottom -Transmission frequency 40kHz generated by central unit,	
	1	99
4.7		02
4.8		08
4.9		09
4.10	1 2	14
4.11		15 18
		18
		10 23
		23 24
		2 4 25
	*	25 25
	•	23 27
		27
5.1	Flow chart depicting the steps involved in two-dimensional localization 1	41
5.2	Raw accelerometer readings along 3-axes under static conditions of robot 1	42
5.3		43
5.4		45
5.5		50
5.6		50
5.7	Test scenario-1 for validation of Self-localization	54

List of Figures xv

5.8	Path estimated by the self-localization scheme and the Path traced by robot for Test	
	scenario-1	155
5.9	Activity detection for Test Scenario-1	156
5.10	Measured x-axis and y-axis displacement of robot- Test scenario 1	157
5.11	Measured velocity and angular turns of the robot for Test Scenario-1	157
5.12	Actual and Estimated path of robot for Test Scenario 2	158
5.13	Measured x-axis and y-axis displacement of robot for Test scenario 2	159
5.14	Velocity and angular turns of the robot measured for Test Scenario-2	159
6.1	DTTA- State Flow diagram	166
6.2	The Architecture of ARGoS Simulator [2]	171
6.3	Application scenario 1- Foot-bots performing object pick-up task	177
6.4	No of tasks serviced by robots/round for Application scenario 1	179
6.5	Total number of task assignment messages/robot for 8 rounds for Application	
	scenario 1	179
6.6	Foot-bot clusters at their target location-Application Scenario 2	181
A. 1	Software Architecture of the Robot.	194
B.1	Hardware developed for Beacon based indoor localization system	196
C.1	Hardware Set-up for testing Self-Localization	198