Design and Implementation of Autonomous Lawn-Mower Robot Controller

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Abstract— **The objective of this paper is to design and implement a Behavior-Based Lawn Mower Robot controller that can be used to mow grass from lawns and play grounds autonomously. The controller uses "sense-act" approach to work in dynamic, unstructured and unknown environment without having any reliance on surrounding world information. The controller is implemented using Motor Schema architecture, which uses continuous response encoding and cooperative coordination method for behavior coordination. A set of concurrently running behaviors are defined to perform mowing operation. Sonar ranging is used to detect and avoid obstacles. Shaft and visual odometry in coordinated form are exploited for local positioning, while Global Positioning System (GPS) is used for global positioning. Camera is used to detect grass field and optocouple sensors are utilized to differentiate between mown and un-mown grass.**

Keywords- behavior-based; camera; controller; cooperative coordination; global positioning; lawn mower; local positioning; motor schema; odometry; robot; sonar.

I. INTRODUCTION

Behavior-Based approach is employed for robot controllers in order to perform the desired task in outdoor environment, which is normally dynamic and unstructured. The conventional approach for mobile robot, i.e. Hierarchal approach is reliant on uncertain symbolic information about the world model. This approach stipulates that the world should not be dynamic and unstructured, which is only probable in fixed indoor environments with static objects. The controller designed using this approach works in sequential fashion to process the information acquired from the environment and to decide the appropriate actions. To develop the environment map it also requires a lot of processing power and Long Term Memory (LTM). Behavior based controller overcomes all of these deficiencies by using sense-act methodology in parallel fashion, while throwing away all dependencies on global world information.

The field of lawn mower robot is still immature and necessitates a lot of investigation for mowing patterns autonomously. In [1] authors suggested the design of mobile robot but didn't discuss propositions for mowing operation. Moreover local positioning, static and dynamic obstacle detection and avoidance are overlooked. Autonomy is also disregarded by having remote monitoring and human control, which indicates lack of intelligence. In [2], authors proposed optimal route planning of a mobile robot, but autonomy to find and steer in the grass field didn't confer. Initially robot requires boundary traversing to execute navigation function. Moreover obstacle avoidance algorithm would work for static obstacles not for dynamic ones. In [3], the fundamental idea of a mobile robot was discusses, devoid of simulation and implementation results. In [4], hierarchal design of mower was practiced i.e. requiring boundary information of mowing field with large memory and lack of concurrency. Without global and local positioning the robot's localization is problematic.

II. DESIGN METHODOLOGY

The intended controller consists of five behaviors running concurrently. These behaviors, on getting stimuli from environment will appropriately react to modify the motor actions of robot. The robot initially starts wandering in the workspace, which is the basic behavior of robot. Robot keeps moving without any change in its direction until it perceives an obstacle or finds the goal. The robot uses sonar ranger to detect the presence of obstacles and executes obstacle avoidance behavior. It continues searching for goal, which is grass field and as it finds it, starts moving towards that. The detection of goal is done with camera, to find green color field using Blob finder algorithm. Once it reaches at goal, it starts executing mowing behavior along with other appropriate behaviors. To differentiate between mown and un-mown grass, the designed controller check for the change in grass height using optocouple sensors incorporating with global coordinates. The robot also keeps track of its local positioning using shaft and visual Odometry, and that of global positioning it uses GPS. This positioning information is used to traverse the grass field.

III. CONTROLLER DESIGN

Motor Schema architecture is used for the design of lawn mower controller. The behaviors of robot are designed and described using situated-activity based approach. This technique allows defining a complete set of robot behaviors, that are required by analyzing the situation in which robot has

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to work. To perform mowing task autonomously, the robot should be able to navigate through the work field without collision, while looking for grass field and should move towards it after finding it. In outdoor environment, since robot has no information about dynamic and unstructured world, it should be able to react in real-time. After completing the task, robot should come back to home position. It is quite obvious that by just analyzing the problem, behaviors of robot can be easily defined. Fig. 1 shows the stimulus response diagram of lawn mower robot controller. Five basic behaviors are required, to perform mowing autonomously.

The output from each behavior is provided to coordination block, which generates appropriate overall motor response for the robot, at any instance of time, for given values of environment stimuli. The stimulus to each behavior from environment is mapped onto motor response using very basic definition of stimulus to response mapping**.**

$$\beta(\mathrm{s}) \rightarrow \mathrm{r} \qquad (1)$$

Where β is the behavior, which on receiving stimulus s, initiates motor response r. More precisely, a response should be produced when the value of stimulus exceeds a specific threshold value τ.

$$\beta : (\mathrm{s}, \lambda) \rightarrow \{\text{for all } \lambda < \tau \text{ then } \mathrm{r} = 0,\ \text{else } \mathrm{r} = \mathrm{f(s)}\} \quad (2)$$

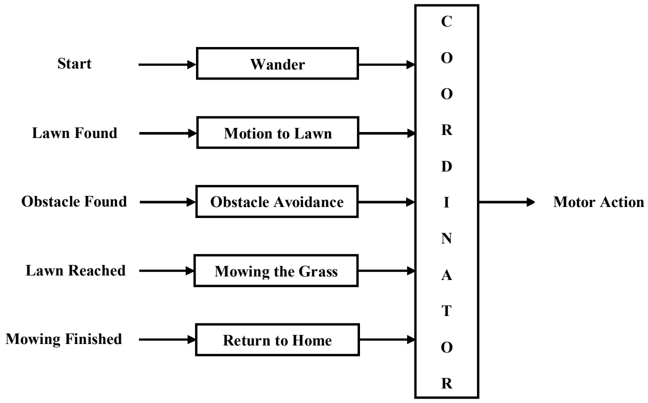

Fig.1 Stimulus response diagram of lawn mower robot controller

For example, the obstacle avoidance behavior uses following stimulus to response mapping function, on having stimulus from sonar sensors.

$$\begin{aligned} &\mathrm{F} = 0 \qquad \text{for sonar[s]} < 5, \text{and} \\ &\mathrm{F} = \sum \mathrm{G/sonar[s]}^2 \qquad \text{elsewhere} \end{aligned} \quad (3)$$

The robot uses continuous functional encoding of stimulus to produce motor response. This allows the robot to have infinite space of actions in its world. Robot, at every instance of time, uses stimuli to calculate motor response.

Some behaviors of robot runs concurrently and some of them make transition between them, which can be easily viewed from Finite State Acceptor (FSA) diagram of lawn mower robot controller, shown in Fig. 2. As robot starts wandering obstacle avoidance behavior runs concurrently with it. After locating goal, motion to lawn behavior starts running in parallel with obstacle avoidance behavior. Similarly, both mowing and motion to home behaviors will run in parallel with obstacle avoidance.

The designed controller uses cooperative method for behavioral coordination, which is simply the vector addition of behavioral responses produced by each behavior. The sagacity of intelligence comes from environmental stimulus and behavioral response fusion in cooperative coordinator.

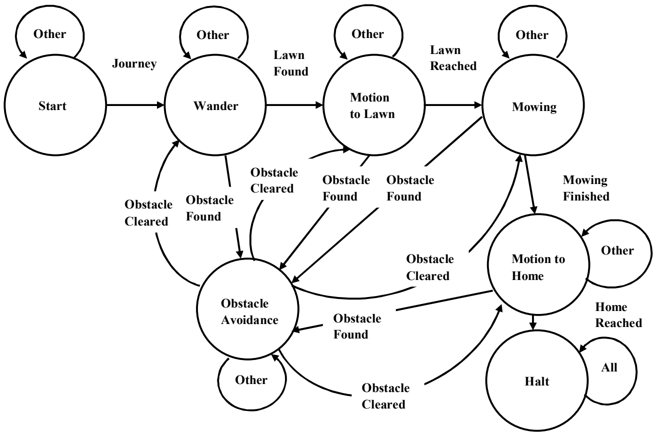

Fig.2 Finite state acceptor diagram of controller

IV. EXPERIMENTAL DEVELOPMENT AND EVALUATION

The designed lawn mower robot controller is simulated using Player/Stage[1] mobile robot simulator. For simulation in Stage, a model of Pioneer 3DX[2] mobile robot platform is used, being equipped with necessary sensors such as sonar sensor arrays, camera, GPS etc. Each behavior is programmed and simulated in simulation environment to test the control algorithms. Initially, robot starts exhibiting its rudimentary behavior i.e. wandering, which only turns on the robot motors. Robot continues to exhibit this behavior until it encounters an obstacle or grassy field. The simulation result of wandering behavior is shown in Fig. 3.

In obstacle avoidance and motion to goal behaviors, robot uses Artificial Potential (AP) theory for transforming sensory information into behavioral reaction, obtained from sonar sensors. This approach produces a field representing the navigational space, based on an arbitrary potential function. In AP field theory, obstacles are treated as having repulsive potential field and goal as having attractive potential field. Separate potential fields are constructed for both goal and obstacles. These two fields are then super-positioned to construct a global field.

$$TF[d] = APF[d] + RPF[d] \qquad (4)$$

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[1] http://playerstage.sourceforge.net/

[2] http://www.mobilerobots.com/Mobile_Robots.aspx

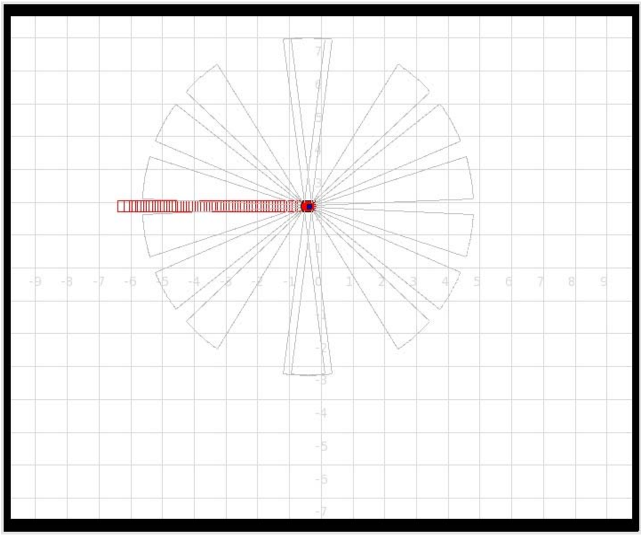

Fig.3 Simulation of wander behavior

The basic mathematical relationship between force and distance that grows quadratically with d_{goal} distance to goal is:

$$RPF[d] = \begin{cases} \frac{1}{2}\eta(\frac{1}{D[d]} - \frac{1}{Q^*}), D[d] \le Q^*, \\ 0, D[d] > Q^* \end{cases} \quad (5)$$

Whose gradient is:

$$\nabla RPF[d] = \begin{cases} \eta(\frac{1}{Q^*} - \frac{1}{D[d]})\frac{1}{D^2[d]}\nabla D[d], D[d] \le Q^*, \\ 0, D[d] > Q^* \end{cases} \quad (6)$$

Where $Q^* \in \Re$ factor permits the robot to overlook obstacles amply far away from it and the η can be viewed as a gain on the repulsive gradient. The distance values obtained from every sonar sensor are used to calculate artificial potential field for every sensor using the Repulsive Potential Field (RPF) function given above. These filed values are then used to navigate the robot in workspace without hitting any obstacle. The algorithm compares the sum of RPF values of front four sensors i.e. 2, 3, 4 and 5 with rear end sensors 10, 11, 12 and 13, to check whether or not the forward or rear sensors are in effect of stronger repulsive field. If the sum of RPF values of front four sensors is greater than sum of rear four sensors, then there would be some obstacles near the robot. After making decision, that there is an obstacle in front or backside of robot, the next step is to decide, whether robot should turn clockwise or anticlockwise to avoid that obstacle. The robot then checks, whether it's right or left side is in influence of higher repulsive potential field, by comparing values of sonar sensors on each side i.e. if right side has got higher then turn left and vice versa. If RPF values of both sides are same then robot does not turn at all and moves straight. Same thing happens if the rear end sensors are in influence of larger potential filed. The simulation results of this behavior are shown in Fig.4.

In motion to lawn behavior, robot uses a camera to get stimulus from environment as it comes across a grass field, otherwise it continues to wander and avoid obstacles if obstacles encounter. Robot uses blob finding algorithm to sense green color of ground, as it senses green color, this algorithm starts calculating slope and distance between robot current position and lawn. These distance values are used to calculate Attractive Potential Field (APF) instantaneously. The function, used to calculate APF is quite similar to RPF function, however the value of gain of APF is much larger than gain of RPF, is as under.

Fig.4 Simulation results of obstacle avoidance behavior

$$APF[d] = \frac{1}{2}\zeta d^2(d, d_{goal}) \quad (7)$$

With the gradient

$$\nabla APF[d] = \nabla(\frac{1}{2}\zeta D^2(d, d_{goal})) \quad (8)$$

The values of APF and RPF are coordinated, to create a global field, in such a way that the robot is directed towards lawn without hitting obstacles, as in case of the RPF, robot tries to steer away from obstacles, but in case of APF it tries to turn towards goal. The values of turning angles, obtained from obstacle avoidance and motion to goal behaviors, are used to choose the resultant steering angle of robot. For simulation in player/stage, robot uses Blobfinder proxy that can process images obtained by robot. Using blobfinder proxy, the robot can detect green color and can also detect the perimeter of lawn or grass field. The simulation results of this behavior are shown in Fig.5.

After reaching at goal, which is grass field, the robot initiates the mowing behavior. This behavior involves three micro behaviors; starting of cutting blade for mowing, traversing through the field and detection of mown and un-mown grass. Robot integrates optocouple sensors, GPS and shaft odometry, to avoid repetitive traversing of mown area.

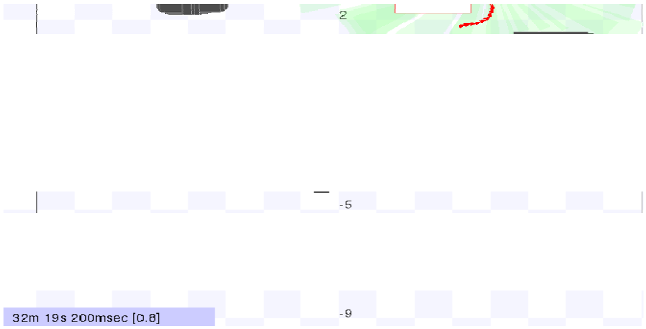

Fig.5 Simulation results of motion to lawn behavior

Blob finder and GPS fusion is used to detect dimensions and perimeter of grass field. It also provides the area information of the field, using which coordinate values of all four corners can be found. After identifying corners, robot calculates the line equation between two corner coordinates and follows that line to reach other end. The slope intercept form of line equation is given below:

$$y = mx + b$$

$$m = \frac{\Delta y}{\Delta x} = \frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} \qquad (9)$$

As robot reaches at second corner, it steers at 90º and again calculates line equation between second and third corner and then moves to that. This process will continue until robot traverses sides of whole field. After this robot reduces its coordinate values of corners by some Δx and Δy, depending upon the physical dimensions of cutting blade, and continues to execute same algorithm as described above. The idea, behind this technique, is shown in Fig.6 along with simulation results in fig. 7 of this behavior.

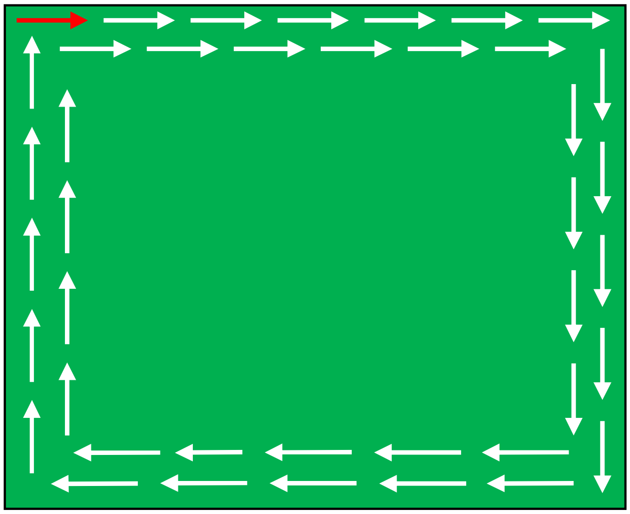

Fig.6 Grass field traversing strategy

Fig.7 Mowing behavior simulation results

After completing mowing task, robot turns back for home location, and this is done by motion to home behavior. This behavior uses the registered coordinate values of home location and that of final robot position. Robot uses these points to calculate slope of line between these points. Then it starts following that slope by comparing it with the new slope calculated at each instantaneous value of robot position, while avoiding obstacles. This method ensures that robot will reach at home location, which may not be possible if it uses same kind of behavior as that of motion to lawn. The simulation results of this behavior are shown in Fig.7.

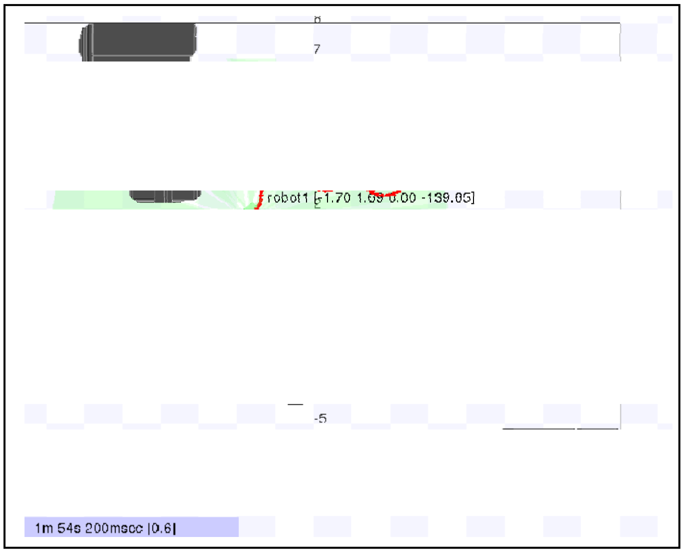

Fig.7 Simulation result of motion home behavior

V. CONCLUSION AND FUTURE WORK

The designed controller works well and endows with comprehensive information and work plan for hardware implementation of actual robot. With some enhancements, the performance of the robot controller can be excelled. Camera can be used for obstacle detection, and also for visual odometry with some modifications, to overcome the difficulties of moving obstacles and the error occurs in local coordinates due to wheels slip. Improved and more intelligent techniques can be adopted for motion to lawn behavior and also for identifying boundaries of lawn. More importantly, there is still lot of room available to improve the mowing task with different patterns of grass. By improving grass field traversing strategies using machine vision techniques, various mowing patterns can be developed in grass fields, as being commonly developed in play grounds.

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