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Cooperative Mobile Robotics

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Abstract— "Cooperative control" is a term which is used to capture those problem areas in which some type of repetition of identical or non-identical subsystems, which are interconnected together, occurs. Such systems are often found in nature, i.e. in the motion of clusters of birds, fish, insects, etc. moving together, in the cell structure of mammals and life-forms, and also in the man-made systems such as in transportation systems. In such systems, a decentralized control configuration is often applied to control the overall system, so that some common objective is achieved. In this paper two non-linear models in multi-agent systems are proposed. These models operate on the principles of distributed control and cascade control.

Index Terms—About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

There has been much recent activity toward achieving systems of multiple mobile robots engaged in collective behavior. Such systems are of interest for several reasons:

- Tasks may be inherently too complex for a single robot to accomplish, or performance benefits can be gained from using multiple robots;
- Building and using several simple robots can be easier, cheaper, more flexible and more fault-tolerant than having a single powerful robot for each separate task.

In large systems which are made of identical or near-identical sub-systems called "agents", cooperation plays a critical role. Two different types of control are considered in this paper. First is the Distributed control and second is the cascade control.

In distributed control, instead of using one centralized controller, spatially separated controllers are introduced. The control object is composed of multiple subsystems where each subsystem has a local controller. To exchange the information and for subsystems to communicate with each other some interconnection exists between these controllers. Thus, distributed control laws are generated according to not only the local feedback, but also the messages from other controllers. There are different methods for achieving distributed control. This paper uses the technique where the output of a single subsystem is given as the input for all the other subsystems.

In cascade control, each agent has a local controller which tracks a reference signal for the velocity and heading angle. In leader-follower model, there is one leader and many followers. The output of the leader provides the input for the first follower. The output of the first follower in turn provides the input for the second follower and the same process continues till the last follower. In this type of control method, there is one main drawback as failure of any single agent will result in failure of all agents after that.

This paper considers two models: Modeling of fishes and Modeling of 4-wheel differential driven robots. The first model is an example of a system occurring in nature and the second model is an example of mobile robots. Both distributed and cascade control will be applied to these two models. The reference trajectory will be provided to the model as a step input and the output will be observed as the tracking of this reference trajectory with the help of MATLAB SIMULINK.

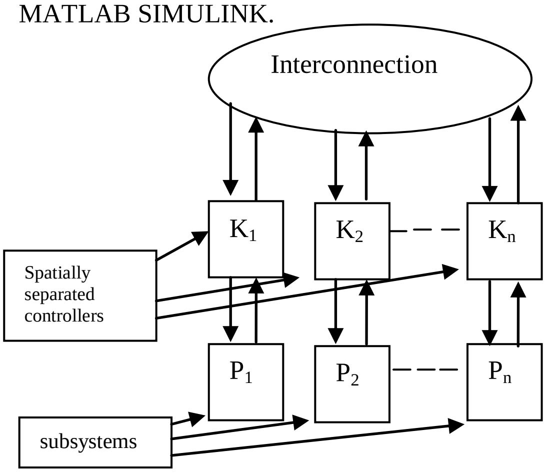

Fig 1(a) Distributed control of agents

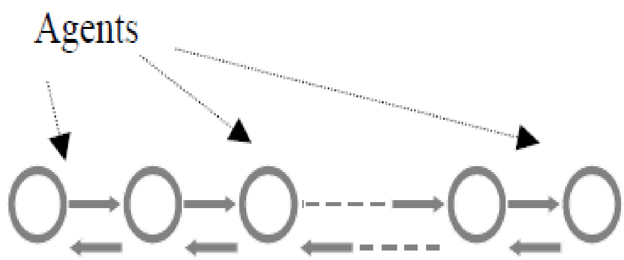

Fig 1(b) Cascade control of agents

SIMULINK software models, simulates and analyzes dynamic systems. It gives us an opportunity to pose a question about a system, model the system and see the results of the simulation.

With SIMULINK, one can easily build models from scratch or modify already existing models to meet their requirement. SIMULINK supports linear and non-linear systems modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, that is, having different parts that are sampled or updated at different rates.

There is a neighborhood control strategy in control system which is also a part of cooperative control.

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In the neighborhood control, there is coordination among all the agents of the system. Thus, if any subsystem fails, it would not affect the operation of the entire system thereby removing the drawback of the cascade control.
This paper strictly deals with distributed and cascade controls and does not account for this advanced neighborhood control strategy. It will provide a basis for this strategy.

II. MODELING OF FISHES

The fish model as shown in fig.2, is non-linear system described by the following first order equations:

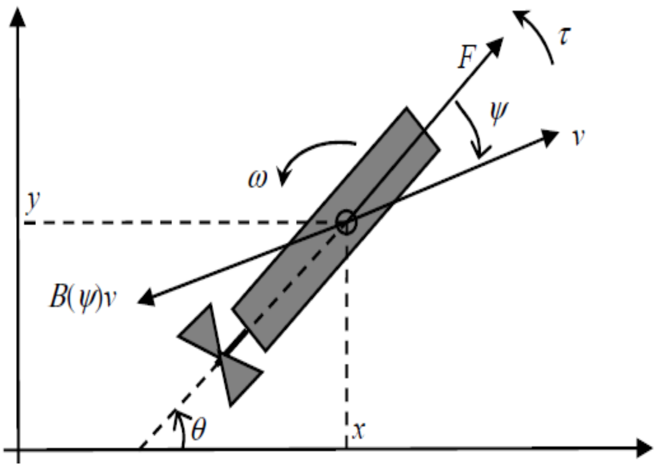

Fig 2 Model of a fish

$\dot{\psi} = -\omega + \frac{F}{mv}\sin\psi$ (1)

$\dot{v} = -B(\psi)\frac{v}{m} + \frac{F}{m}\cos\psi$ (2)

$\dot{\omega} = -\frac{b}{J}\omega + \frac{1}{J}\tau$ (3)

$\dot{x} = v\cos(\theta + \psi)$ (4)

$\dot{y} = v\sin(\theta + \psi)$ (5)

$\dot{\theta} = \omega$ (6)

These six equations are described for a single fish (agent) where ψ, v, ω are the three dynamical states and x, y, θ are the three kinematical states. The terms involved are explained as follows:

x and $y \rightarrow$ position of fish in x and y direction,
$\theta \rightarrow$ Orientation, $v \rightarrow$ Linear velocity,
$\omega \rightarrow$ Angular velocity, $m \rightarrow$ Mass of fish,
$\psi \rightarrow$ Skidding angle, $F \rightarrow$ Applied force,
$\tau \rightarrow$ Rotary torque, $J \rightarrow$ Moment of inertia,
$b \rightarrow$ coefficient of rotary damping of the fish,
$B(\psi) \rightarrow$ viscous friction coefficient which depends highly on the shape of the object. It is approximated as follows:
$B(\psi) = B_1|\cos\psi| + B_2|\sin\psi|$

There are two control inputs in this model for each fish, F and τ. Each fish exists in a two dimensional plane and has a local controller(a PID controller is considered in this model) which tracks a reference signal for the velocity and heading angle. Thus, each fish (agent) has two PID controllers. These PID controllers must be able to track constant velocity and constant heading angle references without any steady state error. The velocity v of each fish is controlled by the traction force F and the heading angle θ is controlled by the rotary torque τ.

This entire model of a fish (from equations 1 to 6) is considered as a subsystem. In this paper on multi-agent systems, one can consider many such identical or non-identical subsystems and apply distributed control and cascade control to the entire system. This system consists of five such subsystems (fishes) and outputs (tracking of velocity υ and heading angle θ) are obtained for each individual subsystem in MATLAB SIMULINK.

In distributed control, there are 5 agents with 2 PID controllers each simultaneously connected with each other. Thus, there are 10 controllers and 5 subsystems in this SIMULINK model. Agent 1 is connected to agents 2, 3, 4 and 5 at the same time. The output of agent 1 becomes the input for the remaining subsystems.

III. MODELING OF MOBILE ROBOTS

The following model is the non-linear model for differential driven mobile robots and is comparatively simpler than the model of fish. Following are the equations for this model:

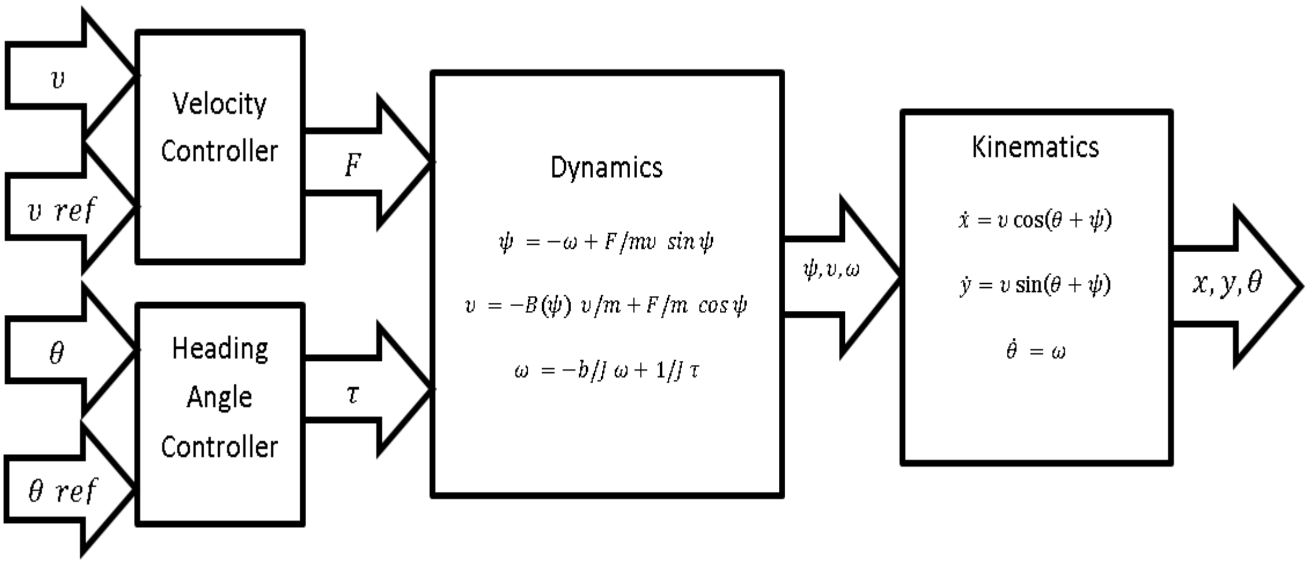

Fig 3 The local tracking controller for each fish (agent)

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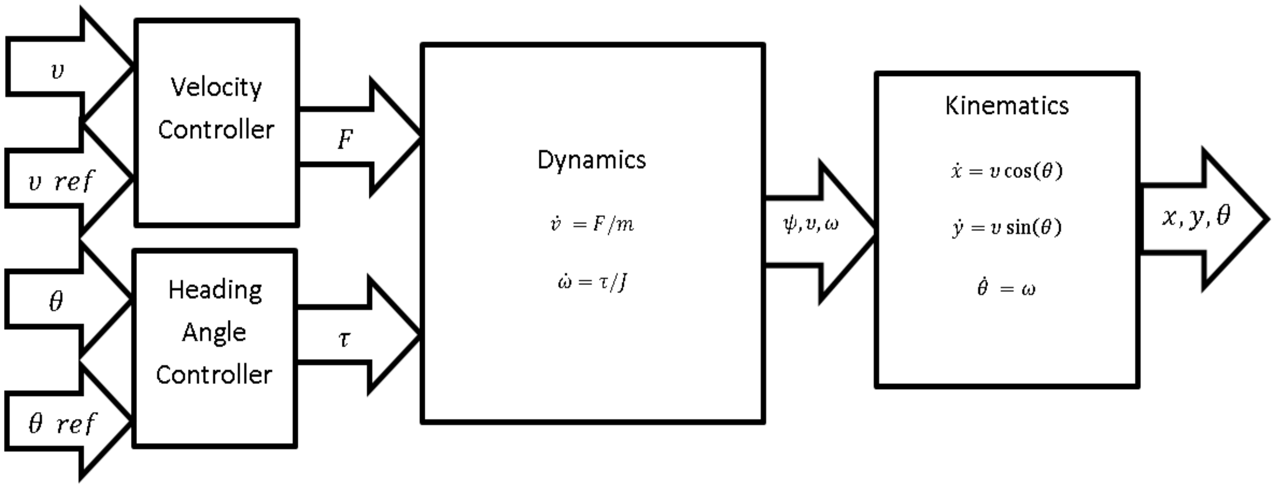

Fig 4 The local tracking controller for each robot

$\dot{v} = \frac{F}{m}$ (1)

$\dot{\omega} = \frac{\tau}{J}$ (2)

$\dot{x} = v\cos\theta$ (3)

$\dot{y} = v\sin\theta$ (4)

$\dot{\theta} = \omega$ (5)

These five equations are described for a single robot where v, ω the two dynamical states are and x, y, θ are the three kinematical states. The terms involved are same as the terms explained in the previous model. The working is also similar to the previous model.

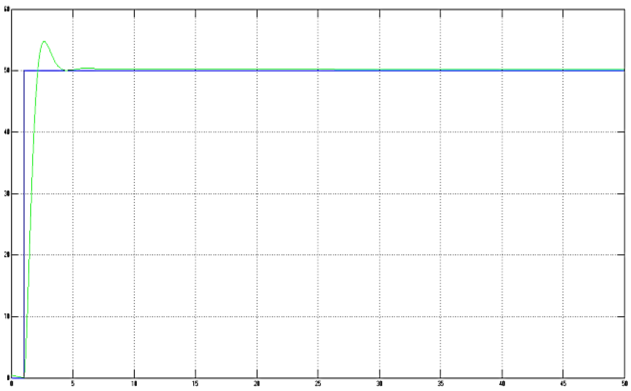

Fig 5(a) Heading angle tracking of single agent

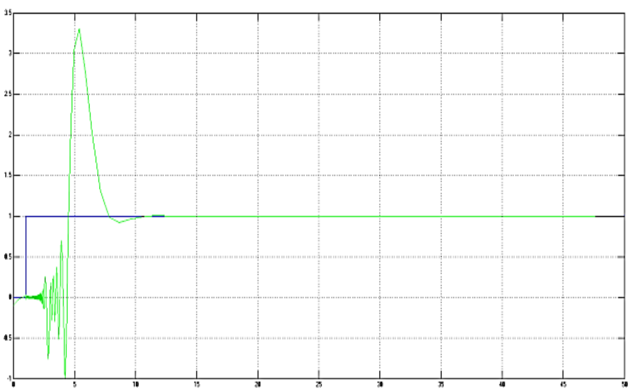

Fig 5(b) Velocity tracking of single robot

The results are obtained using the above model in SIMULINK. Here four mobile robots (subsystems) are considered. The output for the heading angle tracking and velocity tracking of a single agent is plotted. The simulation time has been mentioned with the figures. The outputs of all the subsystems obtained here for mobile in distributed control are the same which means that all of the subsystems here are identical. If one wants to consider the non-identical subsystems, then it can be achieved by changing the PID controller values. Due to the change in controller values the outputs observed will be different for different subsystems. In cascade control, there is an additional trajectory for the output of every successive robot.

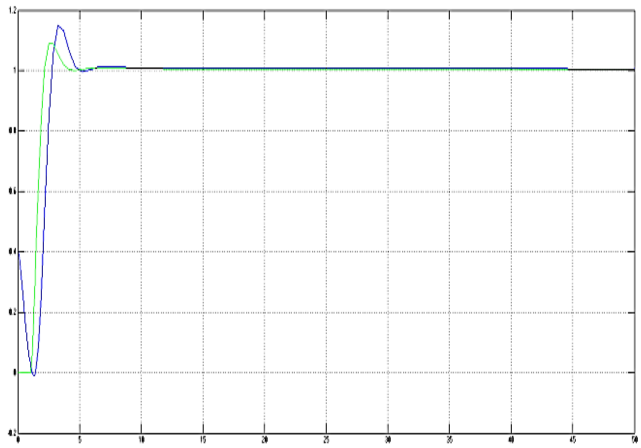

Fig 6(a) Heading angle tracking for follower robot 2 in distributed control.

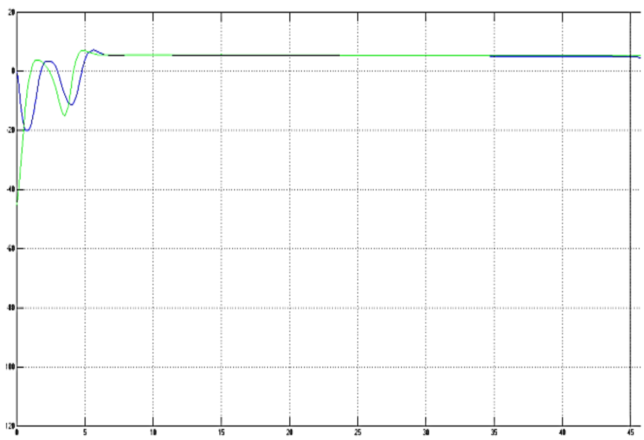

Fig 6(b) Velocity tracking for follower robot 2 in distributed control.

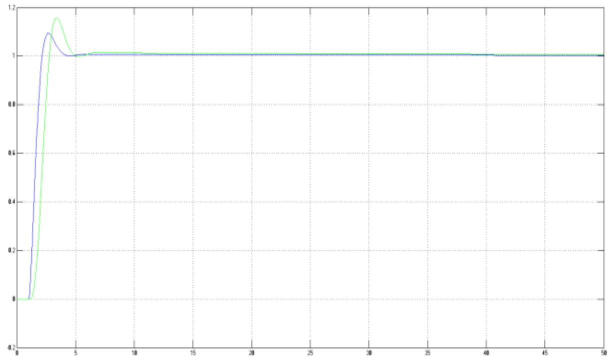

Fig 7(a) Heading angle tracking for follower 4 in cascade control

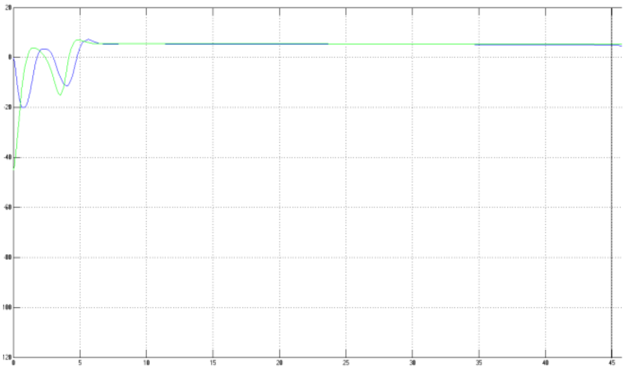

Fig 7(b) Velocity tracking for follower 4 in cascade controller

IV. CONCLUSION

In this paper, two different forms of control strategies, distributed control and cascade control for multi-agent systems are considered. There are two models proposed, one for fishes and the other for the 4-wheel mobile robots. Both the models are constructed and simulated in MATLAB SIMULINK software. The results for them were also obtained, which is tracking of a reference trajectory for the velocity and the heading angle of all the subsystems. This paper provides a starting approach for the neighborhood control strategy where coordination takes place among all the agents of the subsystems.

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