Tugboat Swarms for Distributed Manipulation

Joel Esposito, Matthew Feemster, Erik Smith

US Naval Academy

Swarm Manipulation

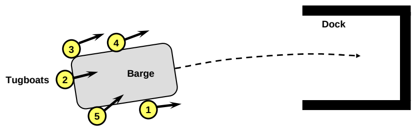
Army Ants: no communication, limited visual sense.

Humans: communicate only qualitative information during manipulation.

Can one design a distributed manipulation algorithm that requires no communication between swarm members?

To what extent does communication improve performance?

Tugboat Mission



- –Assume tugs "tie-up" to barge, actuator limits
- –Non-trivial hydro-dynamics
- –Distributed decision making
- –Can use wireless messages to coordinate

Related work

Swarms, Flock, Formations:

- Distributed control
- Kinematics objective

Desai, Kumar, Fierro Bishop, Tanner, Pappas, Jadbabaie Passiano,Olfati-Saber, Murray

Cooperative Manipulation:

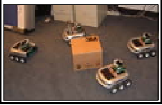
- Centralized /Static control
- Dynamic objective

Sugar, Brock, Khatib, Li, Lentz, Canny, etc

Closely Related Works:

- Caging

Zhidong, Kumar Ponce, et al.



Sub-Problems and Approach

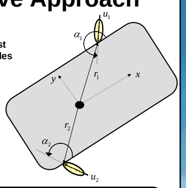
	Phase 1: Grasp Planning	Phase 2: Force control
Known	Own pose, barge pose, number of tugs, goal pose	
Uncertain	Exact attachment point of other tugs	
Find	Best attachment point	Best applied thrust
How?	Min-max grasp quality function	Adaptive control

Force Control: Adaptive Approach

Dynamics: $M(v)\dot{v} + Dv = BU$ ← Tug thrust magnitudes

Tug configuration matrix UNKNOWN!

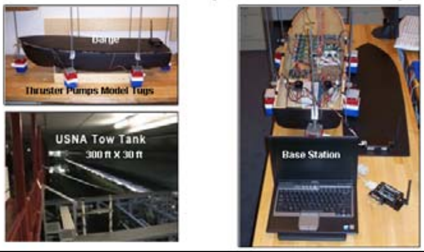
$$B = \begin{bmatrix} \cos(\alpha_1) & \cos(\alpha_2) & \cdots \\ \sin(\alpha_1) & \sin(\alpha_2) & \cdots \\ r_1 \sin(\alpha_1 - \theta_1) & r_2 \sin(\alpha_2 - \theta_2) & \cdots \end{bmatrix}$$



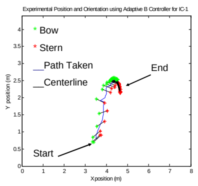
Control: $U = \left[R(\psi) M^{-1} \hat{B} \right]^{-1} \left[\ddot{P}_d + \alpha \dot{e} + K_r r + \dot{\psi} \times \dot{P} + R(\psi) M^{-1} D R^T \dot{P} \right]$

Adaptive update law estimates magnitudes of entries

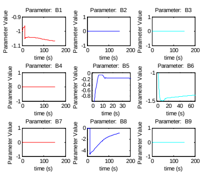
Force Control: Experimental Set-up



Force Control: Results



Converges to desired pose with small steady state error



Unknown tug locations in B matrix are adjusted online

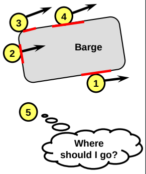
Force Control: Conclusions

- Adaptive control provides a method to infer information about other swarm members without communication.
- Only a priori information is number of tugs and signs of moment arms.
- Experimental verification on 6 boats, needs to be generalized.

Grasp Planning: Quality Function

Select ***new*** contact location to… ...apply largest wrench using smallest forces

$$Q^* = \max_{B_N} \min_{\substack{w \in W \\ B_{i \neq N} \in \hat{B}}} \max_{\substack{u \in U \mid \\ w = Bu}} \frac{\|w\|}{\|u\|}$$



Plan for worst case wrench direction

AND

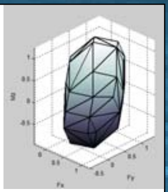
Worst case locations of other tugs!

Grasp Planning: Geometry

Set of possible wrenches under $L-\infty$ norm is a polyhedral in R3 (a Zonotope)

Want to max/ min distance from origin to closest facet (weakest direction)

$$\max_{B_N} \min_{B_1 \cdots B_{N-1}} \left(\min_{(j,k) \in [1,P']} dist(F_{jk}) \right)$$

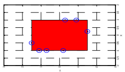


Concave? $dist(F_{jk}) = \left(\sum_{i=[1,N]} \max \left[0, \frac{(B_j \times B_k) \cdot B_i}{\|B_j \times B_k\|} \right] \right)$

No. Determine which wrenches are active. But may be done a priori in certain cases.

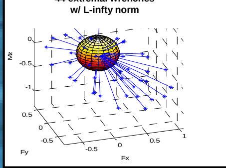
Yes. Second- order Cone. Easy to solve

Grasp Planning: Results

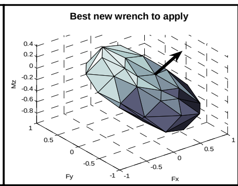


Example: 7 tugs

44 extremal wrenches w/ L-infty norm



Best new wrench to apply



Grasp Planning: Conclusions

- Optimize a grasp quality function, max-min framework for uncertainty, $L-\infty$ norm unique geometry.
- Concave in certain cases. Scales well with swarm size. Makes computation easy.
- More investigation of concavity needed for general case.

{esposito, feemster, m076276} @ usna.edu

Funded by the ONR Grant #N0001405WRY20391