Occlusion-Based Cooperative Transport for Concave Objects with a Swarm of Miniature Mobile Robots

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***Abstract*—An occlusion based strategy for collective transport of a concave object using a swarm of mobile robots has been proposed in this paper. We aim to overcome the challenges of transporting concave objects using decentralized approach. The interesting aspect of this task is that the agents have no prior knowledge about the object and do not explicitly communicate with each other. The concept is to eliminate the concavity of the object by filling a number of robots in its cavity and then carry out an occlusion based transport strategy on the newly formed convex object or "pseudo object".**

***Index Terms*—decentralized approach, collective transport, occlusion based transport, concave object, convex object.**

I. Introduction and Background

Swarm Intelligence is the collective behavior of decentralized, self-organized systems which could be either natural or man-made. Swarm Intelligence exists in nature such as the behavior of ants, bees, birds which can be used as an inspiration for finding its applications in the field of robotics. Once such application is the transportation of objects using a number of mobile robots. Such tasks may seem trivial at first, but can be incredibly complicated depending on various aspects such as shape and size of the object, visibility and perception. Also, the process is decentralized i.e. every agent behaves independently instead of following a fixed leader. There are various techniques to transport an object using a decentralized approach. General structure of a robot's behavior while performing collective transport consists of searching of object, preparation of the object for transportation and then final transportation of the object [4].

Collective transport methods can be categorized into three: Pulling, Pushing and Caging. Pulling constitute of complex mechanism like grasping and lifting of the objects, whereas caging requires robots to maintain their shape during dynamic movements, which are moved only by few robots in the swarm therefore decreasing the efficiency of transportation. During pushing, robot's pushing positions and speed are the constraints to be addressed. Increasing the number of pushing robots increases the stability of the object as pushing force is distributed over multiple points. Also, due to hardware requirements for pulling and caging strategies, we will prefer pushing strategy for our analysis.

In the paper [4] a simple odometry-based team co-ordination strategy in combination with omini-directional camera has been used. There is no communication between robots while performing collective transport task. The transportation strategy in this paper consists of four stages, namely prey discovery, team co-ordination, recruitment and transportation. In [2] a collective transport approach has been proposed by the authors using kilobots and r-ones. The agents have no prior knowledge about the object's shape or size, location of its neighbors or the object. They only know the location of the goal. The agents perceive the direction of the goal by using their light sensor(s) and apply forces on the object in the direction of perceived light. By doing so, they optimally transport objects of complex shapes to the desired location. The r-ones also execute flocking behavior in case some agents are occluded from the light source. In such a case, the robots observe the direction of their neighbors to modify their own directions. The authors proved experimentally the scalability, robustness and optimality of their approach by testing their agents under different circumstances. In [3] the authors have proposed a 5 step approach to successfully transport an object of any shape be it, concave or convex. The tasks assigned to the robots are in the following order. First the robots have to explore the environment and locate the object. Once the robots find the object, they will align themselves with the object and grasp it. The third step is object characterization. i.e., finding the centroid of the object,width,diameter, orientation etc. They do so by determining their own positions and centroid. The objects diameter determines the minimum distance from an obstacle where it is safe to rotate the object. Once the object information has been extracted, the robots then perform a path planning function. During this phase, some of the robots stay attached to the object while others explore a suitable path. The object is then navigated through a chosen path. The paper talks about various algorithms for each of it's steps, hence giving an idea about collective transport of complex objects.

Our paper uses an occlusion based collective transport strategy.The concept behind the occlusion based strategy is that each agent searches the object, moves towards it and then looks for the goal. All the robots push the object by moving in a direction perpendicular to the objects surface at their points of contact, the motion of the object will be approximately toward the goal. The robots work in a decentralized manner and conduct co-operative transport without explicitly communicating with each other. The task sequence starts with the robot searches for an object, and performs a random walk. Once the object is seen, robot approaches the object. When the robot reaches the object, it checks if the goal is visible from its position, it moves around the object and looks for the goal again. If the goal is not visible (or occluded), the robot starts pushing the object. Otherwise the robots moves around object, executing a left-hand-wall-following behavior. This is repeated by every agent collectively, till the object is transported to the goal. While this approach has been successfully tested on convex objects [1], concave objects pose much harder challenges. The agents can easily lose the sense of direction towards the goal and might never transport the object.

Our motivation for this project comes from the paper [1]. In which one of the major limitation was its inability to transport concave objects. We propose a method to overcome this draw-back of the occlusion based strategy. The object's concavity can be eliminated by filling a number of agents in it's concave contour, thus making it more 'convex' like. Another swarm of agents which will be referred to as the 'pushing agents' can then perform an occlusion based approach mentioned above by treating the object as any other convex polygon. Therefore, a concave object can be transported to the goal.

II. Proposed Work

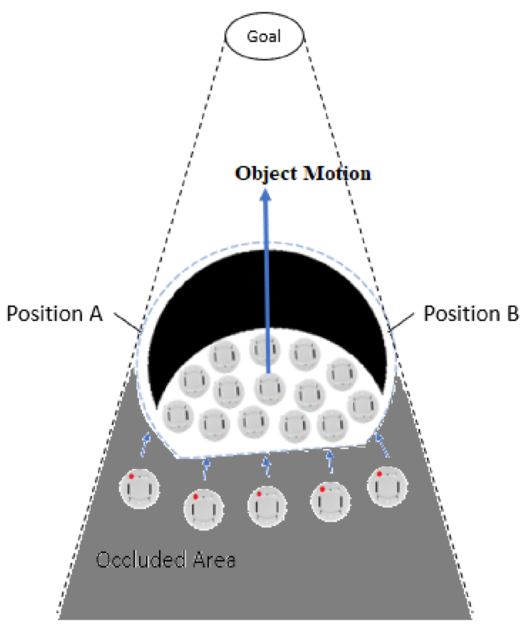

Fig. 1. Occlusion-Based Collective Transport for Concave Object

As described above the occlusion based collective transport strategy only works when the object is in convex shape. If the object is concave the strategy doesn't work. Based on the strategy we are proposing initially the robot searches for an object, and performs a random walk. Once the object is seen, robot approaches the object. When the robot reaches the object, it performs a left-hand-wall-following behavior around the object to checks if the object is concave or convex. If the range of the angles where the object is detected relative to each robot is greater than pi, the object is identified to be a concave object, else it is a convex object. It can be seen in the figure 2 that the robot is on the convex side of the object. Hence, the angle is less than pi and the object will be identified as convex object. Whereas in figure 3 it can be seen that the robot senses the object at an angle more than pi ,therefore identifying it as an concave object.

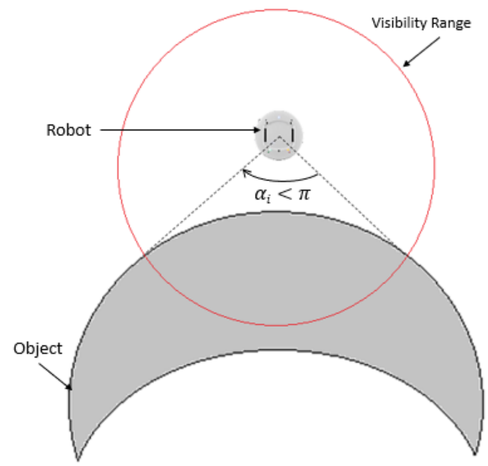

Fig. 2. When robot approaches from convex side

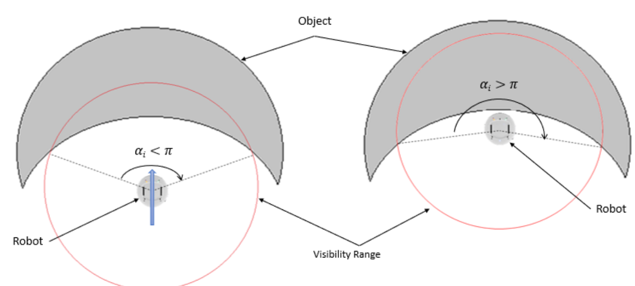

Fig. 3. When robot approaches from concave side

If the object is detected to be concave object, the robot will stay at the particular position and change its robot id to "**object robots**". Hence, filling the concavity of the object. When a next robot arrives behind this robot it will consider the first robot as an object and check if the concavity of the object still exists. This process will repeat until the concavity of the object is filled and collectively form a "**pseudo object**" which incorporates both the actual object and the object robots. Once the pseudo object changes its shape to convex the remaining robots will change their robot id to "**pushing robots**", and the "object robots" will keep intact with the object. Hence, the task of converting the concave object to convex object will be completed.

At this point, the occlusion based collective transport strategy continues. Now it checks for goal to see if the goal can be seen from its position. If it is not visible or if the robot is in occluded region the robot must start pushing the object. Otherwise the robots should move around object, executing a left-hand-wall-following behavior.

As shown in figure 1 the robots after filling the concavity of the object now start applying the occlusion based collective transport strategy for moving the object. The robots with red LED's are now the ”pushing robots” in the occluded area of the object. The position A and the position B are the positions of the observer robots from where the goal is visible.

III. Proposed Experiments

Our Experiments are broadly divided into two sub-experiments.We will implement these experiments in Buzz programming language [5] and simulate it in ARGoS Simulator [6].

A. Concave Filling

First experiment is to execute concave filling for different concave shapes as shown in the figure 4. Our desired experimental result for this sub-experiment will be as shown in figure 5.

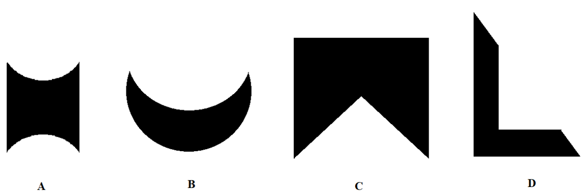

Fig. 4. Experimental Objects

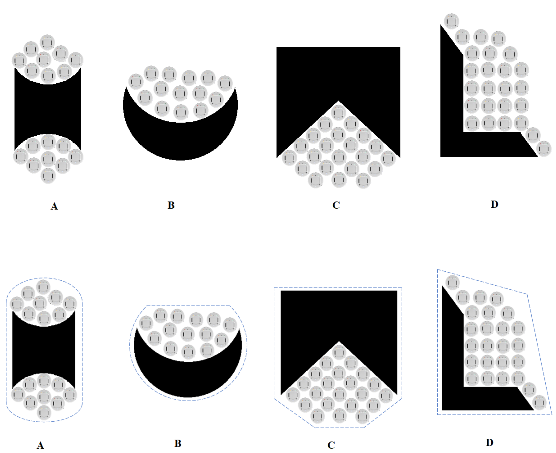

Fig. 5. Proposed Filling to form Convex Object

B. Collective Transport

In our second experiment we will replicate Occlusion-based convex object based experiments implemented in [1] for concave objects. We will carry out 15-trial runs and compare our completion time and path efficiency with the results obtained in [1].

IV. Weekly Schedule

TABLE I
SCHEDULE

Week	Task
Week 1	Argos simulation of occlusion based experiment
Week 2	Convert Concave object to convex by filling
Week 3	Integration of above experiments
Week 4	Demonstration and Final Paper drafting

Our project can be divided into three major parts as can be seen in the following table. The task is to implement the occlusion based collective transport in the ARGoS simulator [6]. Here we will be using the khepera robots to perform the simulation. The objects in this experiment will be convex objects. The next task is the major part of this project, wherein we would perform experiments in simulation of filling the cavity of concave objects by robots to make it convex. These experiments would be performed on four concave object mentioned above. These experiments would be done in week 2. Finally in order to perform collective transport of these objects, we would be integrating the above two experiments in week 3. Therefore, our final experiment would consists of occlusion based collective transport of the concave objects after filling their concavity and converting them to convex. The last week will be used to demonstrate and draft the final paper of the project.

References

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