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A Mobile Sensor Network Tracking Moving Targets in a Dynamic Environment

Anh Duc Dang and Joachim Horn

***Abstract*—This paper presents a novel approach to control a mobile sensor network to track moving targets in a dynamic environment. In this approach, we solve two main issues: the sensor splitting and merging control when the number of the targets is changed. The subgroup merging into the main group is controlled by the invariable attractive force field of the virtual leader in the main swarm. In other words, under the effect of this attractive force field, free-sensors can easily reach the main group and become new members in formation of this group. In contrast, subgroups will be split from the existing group to track new targets that appear. The splitting algorithm is built based on the geometry between targets and group position. The members in a split subgroup will connect with their neighbors in order to generate a robust formation without collision while tracking their target. In addition, when a target disappears, the sensors that are tracking this target will automatically distribute into the nearest existing subgroup. The effectiveness of this proposed approach has been verified in simulations.**

***Keywords*—Formation control, swarm intelligence, obstacle avoidance, vector fields, mobile sensor network**

I. INTRODUCTION

In recent years, the mobile sensor network has been an interesting research topic in the control community all over the world [1]-[10]. Its potential applications in many areas, such as search and rescue missions, and forest fire detection and surveillance, is the motivation for this attraction.

One of the important issues in the mobile sensor network to reach the target position is formation control or flocking control [8]-[14]. The sensors in the network have to link with each other in order to avoid collision and maintain their velocity during tracking. Obstacle avoidance [5]-[7] is also an interesting topic in path planning for autonomous mobile sensors to reach the target. The artificial potential field is known as a positive method in order to solve these problems. In recent years, the artificial potential field method has been widely studied and powerfully applied to formation control of a swarm of multi-agents to reach a target in a dynamic environment, see [1]-[6].

Furthermore, the control of a mobile sensor network is important and presents two main issues: sensor splitting and sensor merging. Sensor splitting arises when new targets appear, automatically splitting from the main group of the moving sensors into the subgroups in order to track the new targets. In contrast, sensor merging can occur when targets disappear, forcing those subgroups to redistribute to the remaining sensor groups still tracking their targets. Additionally, sensor merging is required at operation start time due to initial sensor placements. Although this topic is very interesting, and has potential applications in military and civilian areas, the research results in this field are still very limited. The published literature has mainly focused on the control for the mobile sensor network to reach a single target. Using the artificial attractive potential field, which is generated from the target and has decreasing amplitude to the target's position, the free sensors will automatically meet during tracking [13]-[17]. However, in practice, it is very difficult to execute this method, as the velocity of a free sensor is very high when it is far from the target.

In this paper, we propose a novel approach to control the sensor merging/spitting in a mobile sensor network while tracking the moving targets in a dynamic environment. This approach is developed based on the traditional potential field method [1]-[4] combined with the geometry method and the energy level partitioning method. In this approach, the invariable global attractive force field around the target is used to drive all sensors in a group towards their target. Simultaneously, a constant global attractive force field is also generated from the virtual leader of a group in order to control the free-sensors to combine into their group. In a group, a member-sensor, which has the shortest distance to the target of this group, is chosen as the virtual leader. Under the effect of the total force field, which contents the attractive force field of the target and the virtual leader, the free-sensors will usually move towards their group during tracking because the attractive force of the virtual leader is always designed larger than the global attractive force of the target. In contrast, sensor splitting, wherein a sensor group is broken into subgroups in order to track the new targets, is performed by the geometry method. In this method, when a new target appears, a boundary line through the target position and the center of the main group is generated as the basis for the sensor splitting. The sensors that lie together on one side of this boundary line will form to a new subgroup with a new virtual leader.

The rest of this paper is organized as follows: The sensor merging control algorithm is given in the next section. Section III presents the sensor splitting control algorithm. In section IV, the general controller for each sensor in a mobile sensor network is given. The results of the simulations are presented

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in section V. Finally, section VI concludes this paper and proposes research directions for the future.

II. MERGING CONTROL ALGORITHM

In this section we consider a network of N mobile sensors ($N \geq 2$) that track a moving target in a two-dimensional Euclidean space $\{R^2\}$ with M obstacles in the environment. The free-sensors have to merge into the formation of a group and become new members. The member-sensors in a swarm will connect with their neighboring sensors in order to generate a stable formation without collisions. Each sensor, which is assumed as a moving point in the space, is described by the dynamic model as:

$$\begin{cases} \dot{p}_i = v_i \\ m_i \dot{v}_i = u_i \end{cases} \quad i = 1, \dots N. \tag{1}$$

Here $(p_i, v_i, u_i) \in \{R^2\}$ and m_i are the position vector, the velocity vector, the control input and the mass of the sensor i, respectively.

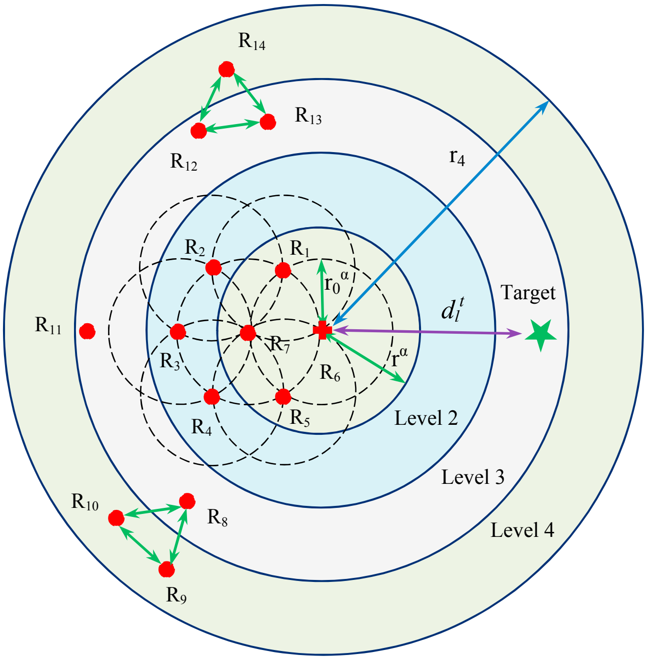

Fig.1. The description of a group of mobile sensors in the energy level partitioning around the leader while tracking a moving target.

Firstly, in order to build the sensor merging control algorithm, we have some definitions and remarks as follows:

Remark 1. In a mobile sensor network, each subgroup has the mission to track a respective moving target. In each subgroup, a sensor which has the shortest distance to the target will be selected as the leader of this group. This virtual leader has the mission to attract free-sensors towards the formation of this group. Under the attractive force of this leader, these free-sensors will quickly combine into the formation and become new members. Moreover, the formation of a group will be maintained by the connection between neighboring member-sensors in this formation during tracking without collisions, see [12]. A sensor is determined as a free-sensor or member-sensor in a group which depends on the relative position between this sensor and the leader through energy levels as describe on Fig.1.

Definition 1. A sensor j is the neighbor of the sensor i if it lies in the limited communication range r^α of the sensor i (radius of neighborhood circle, shown in Fig.1). During the motion of sensors the relative position between them can change, hence the neighbors of each sensor can also change. Therefore, in general we can define the set of the sensors in the neighborhood of sensor i at time t as follows:

$$N_i^\alpha(t) = \left\{ j : d_i^j \leq r^\alpha, j \in \{1, .., N\}, j \neq i \right\}, \tag{2}$$

where $d_i^j = \|p_i - p_j\|$ is the Euclidean distance between sensor i and sensor j in the space. For example, in Fig.1, the robot R_1 has three neighbors: R_2, R_6 and R_7.

Definition 2. A sensor i is the member of a group if it lies in the energy level 1 of the leader. In other words, it is the neighbor of the leader (the distance from this sensor to the leader is smaller than the radius of the neighboring circle r^α). For example, in Fig.1, sensor R_6 is selected as the leader, hence sensors R_1, R_5, R_6 and R_7 are member-sensors. In case, sensor i lies in the energy level n ($n=\{2,3,4 \dots\}$), it is a member-sensor if it has the least two neighbors which lie in the smaller energy level corresponding to *(n-1)*, or it has the least one neighbor that lies in the energy level (*n-1*) and the least two neighbors that have the same energy level n with sensor *i*. For example, in Fig.1, sensors R_2, R_3, R_4 and R_{14} are member-sensors. In other cases, sensor *i* is a free-sensor, for example sensors R_{11}, R_{12} and R_{13} in Fig.1. Furthermore, sensors R_8, R_9 and R_{10} also are free-sensors, although they are connected in a sub-formation.

Based on the above analyses, the sensor merging control algorithm is built by the following steps:

Step 1. Choose a sensor, which has the shortest distance to the target, as the virtual leader. The distance from the virtual leader to the target is computed as:

$$d_l^t = \min\left\{ d_i^t = \|p_i - p_t\|, i = 1, \dots N \right\}, \tag{3}$$

Step 2. Partition the energy levels from the virtual leader in order to determine if sensor i is a free-sensor or a member-sensor. Let r_n be the radius of the energy level n from the leader. Then the magnitude of the energy level *n,* ($n=\{1,2, \dots\}$), is described as (r_n-r_{n-1}). The magnitude of each energy level is designed the same and equal ($r_0^\alpha = r_n - r_{n-1}$), see Fig.1. The positive constant r_0^α is a minimum desired distance between the neighboring sensors at which the attractive/repulsive forces balance, see [12]. In general the radius of the energy level n is built as follows:

$$r_n = \lambda + n r_0^\alpha . \tag{4}$$

In equation (4), the positive constant λ is used to determine the radius of the neighborhood circle r^α ($r^\alpha = \lambda + r_0^\alpha$), see Fig.1. Now, we consider a sensor i that has the relative distance to the leader, $d_i^l = \|p_i - p_l\|$. In order to determine which of the leader's energy levels the sensor is lying in, we build an inequality as follows: