IEICE Proceeding Series

Harnessing control of sheepdog agents by on-line clustering

Yuichiro SUEOKA, Takuto KITA, Masato ISHIKAWA, Koichi OSUKA

Vol. 2 pp. 49-52
Publication Date: 2014/03/18
Online ISSN: 2188-5079

Harnessing control of sheepdog agents by on-line clustering

Yuichiro SUEOKA†‡, Takuto KITA†, Masato ISHIKAWA† and Koichi OSUKA†

†Department of Mechanical Engineering, Osaka University
2-1, Yamada-oka, Suita, Osaka, 565-0871 Japan
‡Research Fellow of Japan Society for the Promotion of Science
5-3-1, Koji-machi, Chiyoda-ku, Tokyo, 102-0083 Japan
Email: s.yuichiro@dsc.mech.eng.osaka-u.ac.jp

Abstract—In this paper, we discuss a multi-robots (flock of sheep) control by a robot sheepdog from spatial discretization (e.g. cellular automata) approach. This work was motivated by Sheepdog Project, in which a mobile robot is developed to gather a flock of ducks and maneuver them to a specified goal position. Then, we construct a discrete model of sheepdog system and compare the discrete model to continuous model. Moreover, we proposed a control method to maneuver two groups of sheep to goal by on-line clustering.

1. Introduction

A robot sheepdog project has demonstrated a robot system that a small number of sheepdogs gathers a flock of ducks and maneuver them to a specified goal position [1]. In previous studies, a fundamental flock control method was designed and tested using a simulation model, and successfully adopted to the real world. But, proposed control method is only adopted under the condition of that flock of sheep never separates.

In this paper, we analyze the sheepdog system from a spatial discretization (cellular automata) approach. The cellular automata approach, which was first proposed by Stephen Wolfram [2], leads to understand the many complex systems generated by agents [3]. First, we construct a discrete version of the sheepdog system, and compare the discretized model to continuous model. Moreover, we propose a control method to maneuver sheep that is composed of small attraction force or two groups of sheep.

This paper is organized as follows. Section 2 prepares basic properties hold on hexagonal cellular space, and introduces local rules of sheep agent and sheep dog agent. Section 3 discretizes a sheep model. Section 4 discretizes the proposed control method in previous study, and compares the discretized model to continuous model. Section 5 estimates the flock of sheep using confidence ellipse. Section 6 proposes a control method to maneuver two groups of sheep.

2. Rules of the discrete world

In this section, we define fundamental event rules in this cellular world, and introduce two types of agents: sheep and sheepdog (robot).

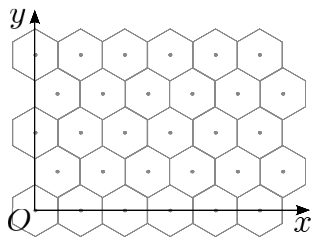


Figure 1: Coordinate setting in the hexagonal cellular space

2.1. Spatial discretization

Suppose a tessellation of the 2-dimensional Euclidean space $\mathbb{R}^2$ with *unit equilateral hexagons*, as shown in Figure 1. Let O be the origin, which coincides with the center of a hexagon. The x-axis is set as a line passing through O and is perpendicular to an edge, while y-axis passes through on of its vertex. Of course this is not the only choice, however, here we prefer hexagonal tiling to other possibilities such as square or triangular tiling, mainly thanks to the fact that all the distance between two adjacent cells are equal.

In ordinary continuous settings, configuration of an oriented object on the plane (such as mobile robot) is expressed by an element of the special Euclidean group $\mathbb{SE}(2) = \mathbb{R}^2 \times \mathbb{S}$ where $\mathbb{S}$ denotes the unit sphere. Now, in contrast, we suppose that every object is placed at the center of a hexagonal cell, thus its location is expressed by a pair of integers which belongs to $\mathbb{Z}^2$. Moreover, its *orientation angle* is supposed to take discrete value too; it should be confined to $0, \pm 1\gamma, \pm 2\gamma, \pm 3\gamma, \cdots \in \mathbb{S}$, where 3γ and -3γ are identified to each other. We will omit γ just for simplicity, so $i \in \mathbb{Z}$ actually implies $\gamma i \in \mathbb{S}$. In summary, the space of angles is identified with the set of integers modulo 6:

$$\mathbb{Z}_6 = \{0, \pm 1, \pm 2, 3\}$$

and the configuration space is $\mathbb{Z}^2 \times \mathbb{Z}_6$ instead of $\mathbb{SE}(2)$.

2.2. Fundamental rules of sheep and sheepdog

The world in concern consists of the hexagonal cellular space, sheep and sheepdogs. A robot sheepdog (robot) oc-

(a) A robot sheepdog (b) A sheep

Figure 2: Objects in the hexagonal cellular space

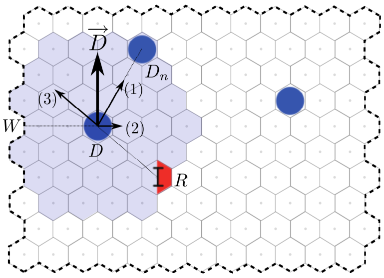


Figure 3: Sheep model. Sheep position D; other sheep position D_n; robot position R; nearest point on wall W.

cupies a cell (Figure 2(a)), and has its own state in $\mathbb{Z}^2 \times \mathbb{Z}_6$. On the other hand, a sheep does not have its orientation in order to treat a sheep model as simple as possible, so its state is in $\mathbb{Z}^2$. Multiple agents can never occupy a single cell; i.e., each cell is empty, or contains either a sheep or a robot. State of the world is collection of states of the robot and sheep.

State of the world changes stepwise. Every robot changes its state every step. On the other hand, every sheep changes its state every N steps. Thus, the robot is N times as fast as the sheep.

3. Discrete model of sheep

First, we define a vision area S_C of a sheep D. The purple color cells in Figure 3 show an example of the vision area $S_C = 3$. In this paper, we set the parameter of the vision area at $S_C = 15$. Then we consider a following setting; every sheep D is influenced by the effect of other sheep, robots, or walls within its vision area. The sheep's movement vector $\overrightarrow{D}$ is determined by the equation (1), where N_{S_C} denotes the number of sheep in its vision area. The flock of sheep is (1) attracted to each other ($\overrightarrow{V_{D_n}}$); (2) repelled from the wall ($\overrightarrow{V_W}$), preventing collisions; (3) also repelled from the robot ($\overrightarrow{V_R}$) (see Figure 3), and affected by disturbance L:

$$\overrightarrow{D} = \frac{1}{N_{S_C}} \sum_{n \in S_c} \overrightarrow{V_{D_n}} - \overrightarrow{V_W} - \overrightarrow{V_R} + L \qquad (1)$$

where $\overrightarrow{V_{D_n}} = K_{S_1}\overrightarrow{DD_n}$, $\overrightarrow{V_W} = K_{S_2}\overrightarrow{DW}$, $\overrightarrow{V_R} = K_{S_3}\overrightarrow{DR}$, and $L = K_{S_4}\overrightarrow{R_a}$, where $\overrightarrow{R_a}$ denotes the vector whose magnitude is lower than $R_a = 1$. $K_{S_1} - K_{S_4}$ are parameter gains.

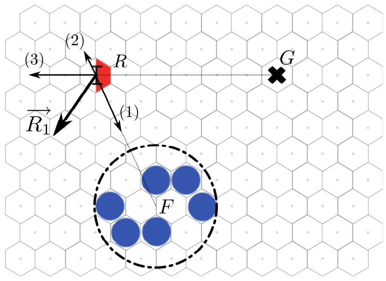


Figure 4: Center-tracking control. Sheep center F; Robot position R; Goal position G.

4. Center-tracking control

This section introduces a discrete version of proposed algorithm in the previous study [1].

4.1. Algorithm

The robot's movement vector R_1 is determined by the equation (2). (1) $\overrightarrow{V_F}$ causes the robot to move toward the sheep center F, (2) $\overrightarrow{V'_F}$ causes the robot not to collide with the sheep, and (3) $\overrightarrow{V_G}$ causes the robot to get away from the goal G (see Figure 4).

$$\overrightarrow{R_1} = \overrightarrow{V_F} - \overrightarrow{V'_F} - \overrightarrow{V_G} \qquad (2)$$

where $\overrightarrow{V_F} = K_{R_1}\min(|FG|, K)\overrightarrow{RF}/K$, $\overrightarrow{V'_F} = K_{R_2}\overrightarrow{RF}/|RF|^3$, $\overrightarrow{V_G} = K_{R_3}\overrightarrow{RG}/|RG|$. And, $\min(|FG|, K)/K$ is a coefficient, where K is a gain parameter. $K_{R_1}, K_{R_2}, K_{R_3}$ are also gain parameters. It has been already known that the proposed control method in the previous study is effective only if sheep attraction force is large; i.e., gain parameter K_{S_1} is large.

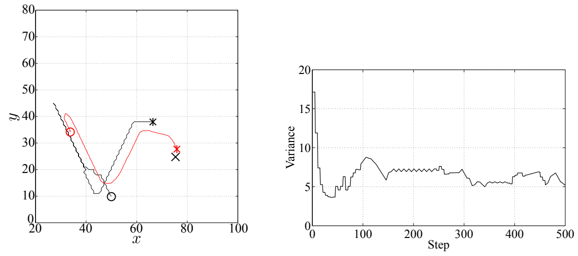
4.2. Simulation results

Now, 20 sheep are randomly distributed in an area (x, y), where (x, y) is set from $(30, 30)$ to $(40, 40)$. The initial position of the robot is set to $(x, y) = (50, 10)$, and the goal position is also set to $(x, y) = (75, 25)$

4.2.1. Simulation with large sheep attraction

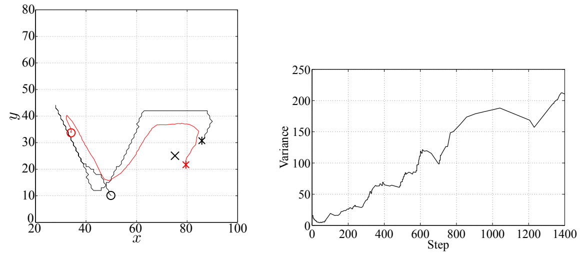
Let us begin to discuss the sheep control when sheep attraction gain K_{S_1} is large. The gain parameters of sheep are set to $K_{S_1} = 20, K_{S_2} = 5, K_{S_3} = 16, K_{S_4} = 40$, and those of robots are also set to $K_{R_1} = 0.11, K_{R_2} = 0.155, K_{R_3} = 1.0, K = 5.0$. Figure 5(a) shows a plot of the robot and flock center paths. Figure 5(b) also shows the variance of flock. The variance is calculated from the following equation:

$$\sigma = \frac{1}{20} \sum_{n=1}^{20} |FD_n|^2$$



(a) flock and robot path. (b) Variance of flock of sheep.

Figure 5: Simulation result ($K_1 = 20$). (a) Black plot: robot path; red plot: flock center path; black dot: initial position; $*$: final position; $\times$: goal position.



(a) Flock and robot path (b) Variance of flock

Figure 6: Simulation result ($K_1 = 10$). (a) Black plot: robot path; red plot: flock center path; black dot: initial position; $*$: final position; $\times$: goal position.

It seems that the flock of sheep is brought to the goal position. In addition, it can be seen that the variance converges at constant ranges.

4.2.2. Simulation with small sheep attraction

Let us turn to discuss the sheep control when the sheep attraction gain K_{S_1} is small. The different parameter is $K_{S_1} = 10$, other parameters are set to the same values in subsection 4.2.1.

Figure 6(a) shows a plot of the robot and flock center paths. Figure 6(b) also shows the variance of flock. It seems that the flock of sheep is brought near the goal, but the variance diverges. The reason is considered that flock will be separated because of the small attraction.

5. Tangent-tracking control

In this section, we propose to treat the flock of sheep as the area of the 95% confidence ellipse of the estimated location.

5.1. Algorithm

Suppose the flock of sheep is distributed in an area of the 95% confidence ellipse of the estimated location [4]. When, we write a tangent line to the ellipse, far tangent point from the goal position G is treated as a position Z (see Figure 7). The robot's movement vector R_2 is determined by the equation (3). (1) $\overrightarrow{V_Z}$ causes the robot to move toward the position Z, (2) $\overrightarrow{V'_Z}$ causes the robot to get away from the position Z, and (3) $\overrightarrow{V_G}$ causes the robot to get away from the goal G (see Figure 7).

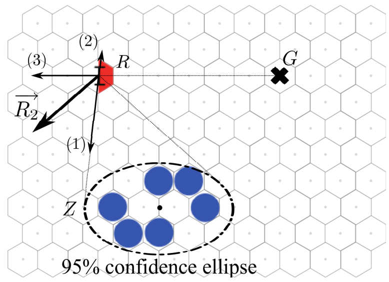
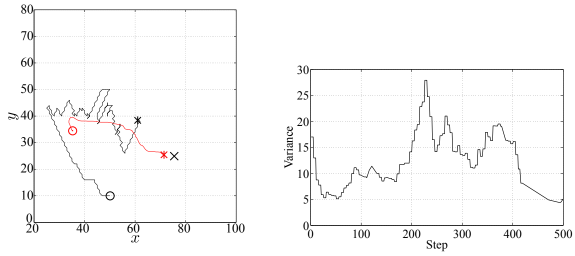


Figure 7: Tangent-tracking control



(a) Flock and robot path (b) Variance of flock

Figure 8: Simulation result. (a) Black plot: robot path; red plot: flock center path; black dot: initial position; $*$: final position; $\times$: goal position.

$$\overrightarrow{R_2} = \overrightarrow{V_Z} - \overrightarrow{V'_Z} - \overrightarrow{V_G} \tag{3}$$

where $\overrightarrow{V_Z} = K_{R_4}\min(|FG|, K)\overrightarrow{RZ}/K$, $\overrightarrow{V'_Z} = K_{R_5}\overrightarrow{RZ}/|RZ|^3$, $\overrightarrow{V_G} = K_{R_6}\overrightarrow{RG}/|RG|$. $K_{R_4}, K_{R_5}, K_{R_6}$ are gain parameters.

5.2. Simulation results

Now, 20 sheep are randomly distributed in an area (x, y), where (x, y) is set from $(30, 30)$ to $(40, 40)$. The initial position of the robot is set to $(x, y) = (50, 10)$, and the goal position is set to $(x, y) = (75, 25)$. Then, the gain parameters of the sheep are set to $K_{S_1} = 10, K_{S_2} = 5, K_{S_3} = 16, K_{S_4} = 40$, and the gain parameters of the robot are also set to $K_{R_4} = 0.11, K_{R_5} = 0.16, K_{R_6} = 1.0, K = 8.0$.

Figure 8(a) shows a plot of robot and flock center paths. Figure 8(b) also shows the variance of flock. It seems that the flock of sheep is brought near the goal, and it has no divergence.

6. Tangent-tracking based on bisectional clustering

From the proposed control methods in Section 4 and 5, the flock of sheep are maneuverd to the goal position only

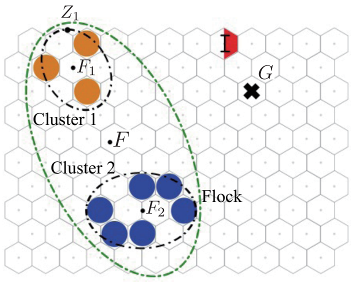


Figure 9: Tangent-tracking based on bisectional clustering.

if the flock is composed of one group. In this section, we propose a control method to maneuver two group of sheep.

6.1. Algorithm

Suppose the flock is divided into two groups like Figure 9. First, we divide the flock group into two groups by cluster analysis that grouping objects of similar kind into respective categories [5]. Then, small group is treated as cluster 1, and large group is also treated as cluster 2.

In this paper, we propose a two-phase control in order to maneuver the flock to the goal position.

Phase 1 Suppose cluster 1 is a target flock and cluster 2 center F_2 is a goal position. In this case, we use the proposed control method in Section 5. When we write a tangent line from the robot position R to the ellipse, far tangent point from the position F_2 is treated as a position Z_1 (see Figure 9). The robot's movement vector is determined by the equation (4):

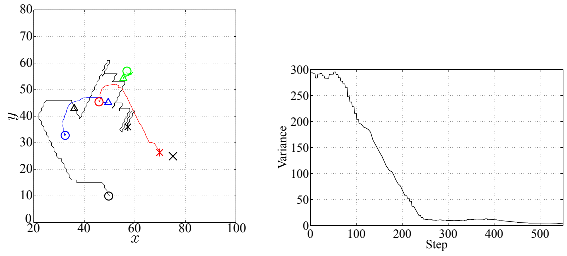
$$\overrightarrow{R_3} = \overrightarrow{V_{Z_1}} - \overrightarrow{V'_{Z_1}} - \overrightarrow{V_{F_2}} \tag{4}$$

where $\overrightarrow{V_{Z_1}} = K_{R_4}\overrightarrow{RZ_1}\min(|F_1F_2|, K)/K$, $\overrightarrow{V'_{Z_1}} = K_{R_5}\overrightarrow{RZ_1}/|RZ_1|^3$, $\overrightarrow{V_{F_2}} = K_{R_6}\overrightarrow{RF_2}|RF_2|$. $K_{R_4}, K_{R_5}, K_{R_6}$ are gain parameters.

Phase 2 After the variance of flock of all sheep is lower than a pre-determined threshold σ_t, the robot maneuvers the flock of all sheep to the goal position. The robot's movement vector is determined by the equation (3) in Section 5.

6.2. Simulation results

20 sheep are randomly distributed in an area (x, y), where (x, y) is set from $(30, 30)$ to $(35, 35)$, and (x, y) from $(55, 55)$ to $(60, 60)$. The initial position of the robot is set to $(x, y) = (50, 10)$, the goal is set to $(x, y) = (75, 25)$. Gain parameters of the sheep are set to $K_{S_1} = 10, K_{S_2} = 5, K_{S_3} = 16, K_{S_4} = 40$, and gain parameters for the robot is set to $K_{R_4} = 0.11, K_{R_5} = 0.15, K_{R_6} = 1.0, K = 8.0$. Then, we carried out some simulations, where the threshold from Phase 1 to Phase 2 is set as $\sigma_t = 40$.



(a) Flocks and robot path (b) Variance of flock

Figure 10: Simulation result. (a) Black plot: robot path; red plot: flock center path; blue plot: flock1 center path; green plot: flock2 center path; black dot: initial position; △: the flock center when phase 1 finished; ∗: final position; ×: goal position.

Figure 10(a) shows a plot of robot, flock, cluster 1, and cluster 2 center paths. Figure 10(b) also shows the variance of flock. It seems that flock of all sheep is maneuvered to the goal position after the cluster 1 is brought to the cluster 2.

7. Conclusion

In this paper, we constructed a discrete-space version of the sheepdog system, and compared the discrete model to continuous model. Moreover, we proposed a control method to maneuver two groups of sheep to a goal position. We examined effectiveness of proposed method by several simulations. In the future, we will concentrate on a multi-sheepdog system.

Acknowledgments

This research is partially supported by Grant-in-Aid for JSPS Fellows Grant Number 257750, and the Aihara Innovative Mathematical Modelling Project, the Japan Society for the Promotion of Science (JSPS) through the "Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program)," initiated by the Council for Science and Technology Policy (CSTP).

References

[1] R. Vaughan, N. Sumpter, J. Henderson, A. Frost, and S. Cameron, "Robot control of animal flocks," *Proceedings of the 1998 IEEE ISIC/CIRA/ISAS Joint Conference*, 1998.

[2] S. Wolfram, *Cellular Automata and Complexity : collected papers*. Westview, 1994.

[3] J. Schiff, *Cellular Automata : A Discrete View of the World*. John Wiley & Sons, 2008.

[4] N. R. Draper and H. Smith, *Applied Regression Analysis*. Wiley-Interscience, 1998.

[5] J. B. MacQueen, "Some methods for classification and analysis of multivariate observations," in *Proc. of 5-th Berkeley Symposium on Mathematical Statistics and Probability*, 1967, pp. 281–297.