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# Soldiers' Group Behaviors Simulation Based on Improved MAPRM

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***Abstract***

*Soldiers' group behaviors are a class of flocking behaviors in which a squad of soldiers march forward according to a specified formation and try to keep it when encountering narrow corridors. It has a leading application in deterring the behavior and activities of a potentially hostile crowd and bringing a mob engaged in a riot under control in social stable maintenance. In this paper, we focus on investigating soldier's group behaviors based on an improved MAPRM algorithm. Firstly, we use MAPRM algorithm to sample configurations from the medial axis of the simulation space. Secondly, in the construction and query phase of MAPRM, clearance information of the space is introduced to local planner and used as heuristic information to A* algorithm which improves the MAPRM algorithm. Thirdly, when the soldiers pass through narrow corridors, their formation transitions are achieved by sampling the desired formation shape. The simulation results show that our approach is effective and feasible.*

***Keywords***: *Crowd simulation, flocking, soldiers' group behavior, MAPRM*



## 1. Introduction

Crowds, ubiquitous in the real world from groups of humans to flocks of insects, are vital features to model in a virtual environment. Various simulation models and architectures have been developed. Crowd management means all measures taken in the normal process of facilitating the movement and enjoyment of people, as well as all measures prepared to be taken in the emergent process of people evacuations. Crowd management can be successful only when viewed as a combination of management of all the crowds, environment and their relationship. This is especially necessary for the crowd incidents in urban circumstances.

Soldiers' group behaviors are a class of flocking behaviors in which a squad of soldiers march forward according to a specified formation. Its application area includes the means to influence the behavior and activities of a potentially hostile crowd, as well as, the capability to bring a mob engaged in a riot under control. Soldiers' group i.e. a squad of soldiers is a coherent group which never splits up into several sub-groups. In current applications, the quality of coherent group behavior is in general not very good, especially few researchers investigates the soldiers' group behaviors. The primary reasons are the needs to compute the paths in real-time and control the group's formation transitions when the soldiers' group passes through narrow corridors.

In respect of motion planning problem for groups of entity, the most common approach to simulating group movement is to use flocking. The concept of flocking was introduced by Reynolds. His boids model described the behavior of the entities in a group using only local rules for the individual entities [1]. Later, Reynolds extended the technique to include autonomous reactive behavior. But in Reynolds's work, little motion planning was considered. In the robotics community, one of the dominating techniques is the probabilistic roadmap approach (PRM). Efficient probabilistic (centralized) techniques for multiple entities have been developed. They treat the different entities together as one large robotic system. Unfortunately, each entity has two degrees of freedom (assuming it is defined by its position on a floor surface) so the total robotic system has 2*n* degrees of freedom when there are *n* entities. When *n* gets larger the running time becomes too large. To overcome this problem decentralized techniques, like path

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coordination, have been developed, enabling the planning of motion for a larger number of entities. Still though, these methods fail when the number of entities grows and the resulting motion is not coherent [1]. Recently, Bayazit, Lien and Amato have combined the PRM approach with flocking techniques. The entities use the roadmap created by PRM to guide their motion toward the goal while they use flocking to act as a group and avoid local collisions. But groups still split up easily. Li and Chou developed a new approach that allows dynamic structuring of the entities such that the centralized planning of the motions is greatly improved. However, this approach lacks the ability of guaranteeing coherence [1]. So it can't be used directly in soldiers' group behaviors simulation. A. Kamphuis, J.F. Helgers and M.H. Overmars introduced a new approach to motion planning for groups of entities in virtual environments. They modeled the group as a deformable shape of large enough area and planned the motion for this shape through the environment using an extension of the probabilistic roadmap method [1, 2]. But A. Kamphuis ignored the clearance information of the space when generating the group's traveling path. Although Steven A. Wilmarth developed MAPRM algorithm and used it to generate paths on the medial axis of the free space, he didn't use the clearance to improve the local planner and query phase of MAPRM [3].

In respect of formation control problem of groups, currently, the popular means of forming a target group formation is to specify the desired position of each agent at a particular moment and then generate realistic transitions between the current position and the target. So most existing work adopts the common process of first sampling the desired formation shape, followed by a path planning stage for each sample points. Subsequently, agents in the flock follow the corresponding sample points, while at the same time exhibiting flocking behaviors. Based on this ideology, Anderson et al. considered an iterative sampling method to generate group animations with predefined formation. More recently, Xu et al. proposed a shape constrained flock algorithm to handle complex 2D and 3D shape constrained flocks that move along predefined paths [4, 5, 6].

This paper focuses on the soldiers' group behaviors, which is used mainly for social stable maintenance and mob controls. Our approach is inspired most heavily by A. Kamphuis's innovational research in the domain of motion planning for groups of entities and Steven A. Wilmarth's momentous work on MAPRM (a probabilistic roadmap planner with sampling on the medial axis of the free space), Choon Sing Ho's work is also helpful to fulfill this paper [4, 7, 8, 9].

Our paper consists of three phases: preprocessing phase with MAPRM, query phase considering the clearance information of the space in A* algorithm, formation transitions phase. In the first phase, milestones are generated with MAPRM sampling strategy which can increase the samplings on the medial axis of the corridors in the space. The nodes lie on the medial axis of the free space which potentially provides the soldiers' group a maximum passage. The medial axis facilitates acquiring process of the clearance information which is used in local planner of MAPRM to improve the collision-free links. In the second phase, the MAPRM algorithm is improved by considering the clearance information of the space. The group's traveling path is generated by A* algorithm with an improved heuristic function. As the soldiers' group formation changes according to the current clearance information, formation transitions are achieved in the third phase using B-spline curve.

## 2. Improve MAPRM Algorithm

### 2.1. Using MAPRM Algorithm to Generate Milestones and Improve Local Planner with Clearance Information

MAPRM (A Probabilistic Roadmap Planner with Sampling on the Medial Axis of the Free Space) uses a sampling strategy of generating random milestones lie on the medial axis of the free space. It efficiently retracts any sampled configuration, free or not, onto the medial axis of the free space without having to compute the medial axis explicitly. Sampling and retracting in this way give excellent performance on problems of generating paths requiring traversal of narrow passages [3].

In our paper we regard the space as a 2D configuration space in which the free space and obstacles are polygonal. For simplicity, we consider only sets $P$ that are the disjoint union of a finite number of closed polygons (including the interior, possibly with holes). For $x \in P$, we define $B_P(x)$ to be the largest closed disc centered at $x$ that is a subset of $P$, i.e.,

$B_P(x) = \overline{B}\left(x, \rho_P(x)\right)$, where $\overline{B}\left(x, r\right)$ denotes the closed disc of radius $r \geq 0$ centered at $x$ and $\rho_P(x) = dis\tan ce\left(x, \mathbf{R}^2 \setminus P\right)$ is the distance to the boundary for points inside $P$ and 0 for points outside $P$ [3]. The medial axis $MA(P)$ of $P$ is defined as

$$MA(P) = \left\{x \in P \mid \nexists\ y \in P \text{ with } B_P(x) \varnothing B_P(y)\right\} \quad (1)$$

Formulation (1) means that $MA(P)$ are the set of all points $x$ of $P$ whose associated $B_P(x)$ is maximal. A point $x \in P$ is called a *simple point* if $x$ has a unique nearest point $x_0$ in $\partial P$. Otherwise, $x$ is called a *multiple point*. $P'$ is defined to be $P$ minus its non-convex vertex points.

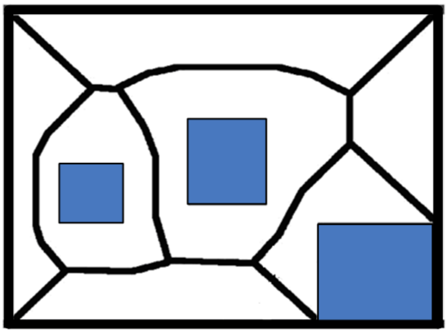


Figure 1. Medial axis of a closed polygon

The following facts hold according to reference [3]:

1. Let $x \in \partial P$, Then $x$ is in $MA(P)$ if and only if $x$ is a convex vertex of $P$.

2. Any multiple point of $P$ is contained in $MA(P)$. If $x \in MA(P)$, then $x$ is in the interior of $P$ if and only if $x$ is a *multiple point* of $P$ [5].

3. For each $x \in P'$, $B_P(x)$ is contained in a unique maximal disc $B_P(y)$, where $y \in MA(P)$. Furthermore if $x \in \left(P \setminus \partial P\right) \setminus MA(P)$, then $y$ is on the ray $\overrightarrow{x_0 x}$. If $x$ is a non-vertex point of the boundary, then $y$ is on the line through $x$ normal to the boundary at $x$.

4. The map $P \setminus MA(P) \to \partial P$ taking each point to its nearest boundary point is continuous and $MA(P)$ is a closed set. Especially important is the fact that $MA(P)$ is an deformation retract of $P'$ because $P'$ can be continuously deformed onto $MA(P)$ without moving any of the points of $MA(P)$.

Let $C$ denotes the configuration space in $\mathbf{R}^2$ and $B \subseteq C$ the $C-obstacle$ be a disjoint union of a finite number of polygons, then $F = \overline{C \setminus B}$ is the free space which consists of a finite number of connected polygonous components. According to aforementioned facts, **Proposition 1** is obtained [3].

**Proposition 1.** The canonical retraction map $F' \to MA(F)$ can be extended continuously to map $C \setminus MA(B) \to MA(F)$.

On the basis of **Proposition 1**, we can increase the samplings in medial axis of all the corridors which have various clearances in the space. In our preprocessing phase, the MAPRM algorithm for sampling the milestones on the medial axis is given in **Algorithm 1** [3].

**Algorithm 1** MAPRM sampling strategy

Input: $N$, the number of milestones to generate

Output: $N$ milestones on the medial axis of $F$

1: **repeat**

2: Generate a uniformly random point $p$ in $C$.

3: Find the nearest point $q$ on $\partial F$ to $p$.
4: **if** $p$ is free **then**
5: Take the retraction direction $\vec{v}$ to be $\overrightarrow{qp}$, and let the start point $s$ be $p$.
6: **else**
7: Take the retraction direction $\vec{v}$ to be $\overrightarrow{pq}$, and let the start point $s$ be $q$.
8: **end if**
9: Using bisection, move $s$ in the direction $\vec{v}$ until $q$ is not the unique nearest point of $\partial F$ to $s$. This moves $s$ onto the medial axis of $F$.
10: **until** $N$ milestones have been generated.

After the milestones which are used to construct a roadmap are generated by **Algorithm 1**, we can use the clearance information computed by medial axis to improve the local planner of MAPRM. The clearance of one point $x \in MA(F)$ is $clearance(x) = distance(x, x_0)$ which is illustrated in Figure 2. A corridor is defined as:

$$cor_z^w = \{x \in MA(F) \text{ and } x \in [z, w] \mid z, w \in MA(F), clearnce(z), clearnce(w) \in [0, \mu]\} \quad (2)$$

in which $\mu$ is a predefined value of width. The clearance information of $cor_z^w$ is $clearance(cor_z^w) = \min\{clearance(x) \mid x \in cor_z^w\}$ which is the minimums value of the clearances of all the points that are in the corridor (Figure 2).

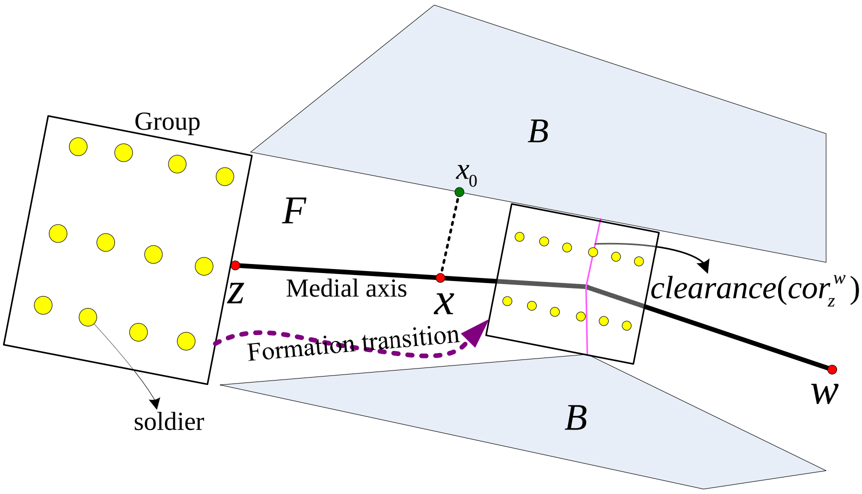



Figure 2. The clearance information of a corridor

After the milestones on medial axis are generated and the clearance information of the corridors is acquired, we can improve the existing local planner of MAPRM by adding the following rule to it.

**If** $clearance(cor_z^w) < \ell$ **Then** the milestones in $cor_z^w$ are deleted. At the same time, we supplement the number of milestones that are deleted using **Algorithm 1**.

In which, $\ell$ is an user defined value and aforementioned rule means that if the clearance of a corridor is smaller than $\ell$, then the corridor is forbidden to pass. At the same time, we should supplement the number of milestones to $N$. Up to present, the preprocessing phase is accomplished.

### 2.2. Improve Query Phase of MAPRM

In this phase, A* algorithm is used to find a path between the start and the goal configuration, using the roadmap constructed in the preprocessing phase. Simultaneously, we improve the MAPRM algorithm once again by renovating the heuristic function of A* algorithm in existing MAPRM.

We use $h(z)$ to denote the heuristic function in existing A* algorithm and $\bar{h}(z)$ to denote the improved heuristic function.

$$\bar{h}(z) = h(z) + \left| clearance(x) - \max\left(clearance(z), clearance(w)\right) \right| \quad (3)$$

where $\left| clearance(x) - \max\left(clearance(z), clearance(w)\right) \right|$ means that we should take into account the variation of the clearance information of the corridor in the estimated cost of the path from milestone $z$ to the goal configuration. In this way, the bigger is the variation of the clearance of a corridor, the larger the cost of passing this corridor to the goal. As the variation of the clearance reflects the changing degree of group's formation when passing the corridor, $\bar{h}(z)$ corresponds to the probability to select the path through the corridor. Obviously, $\bar{h}(z)$ never overestimates the cost to reach the goal. So far, using improved A* algorithm, the group's traveling path can be generated.

## 3. Formation Transition of the Soldiers' Group

In this section, we present a flexible formation handling by the process of first sampling the desired formation shape, followed by a path planning stage for each sample points on the basis of jiayixu's work [6]. Subsequently, soldiers in the group follow the path between the corresponding sample points, while at the same time avoiding collisions with each other.

In order to drive the motion of an entire group in a more coherent manner when it migrates from initial formation to desired one, we specify a global path $R(t)$ (B-spline curve) between the centers of the two formations [6].

Let $O_1$ and $O_2$ respectively represent the centers of the initial formation and the desired formation. We set $O_1$ as the start point, $O_2$ as the end point of the B-spline curve. Similarly, we assume $S_1$ and $S_2$ as the two corresponding sample points of one soldier in the group on the initial formation and the desired formation, as illustrated in Figure 3.

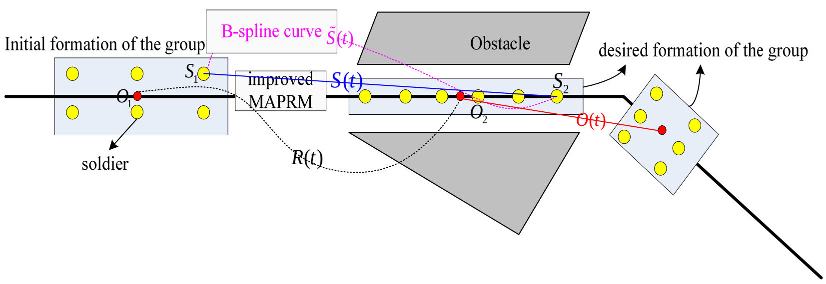



Figure 3. The formation transition of the group

Then the center of the group $O(t)$ between the initial and the desired formation can be computed by formulation (4).

$$O(t) = (1-t)O_1 + tO_2 \quad (4)$$

Similarly, $S(t) = (1-t)S_1 + tS_2$. Then the path between $S_1$ and $S_2$ can be constructed as:

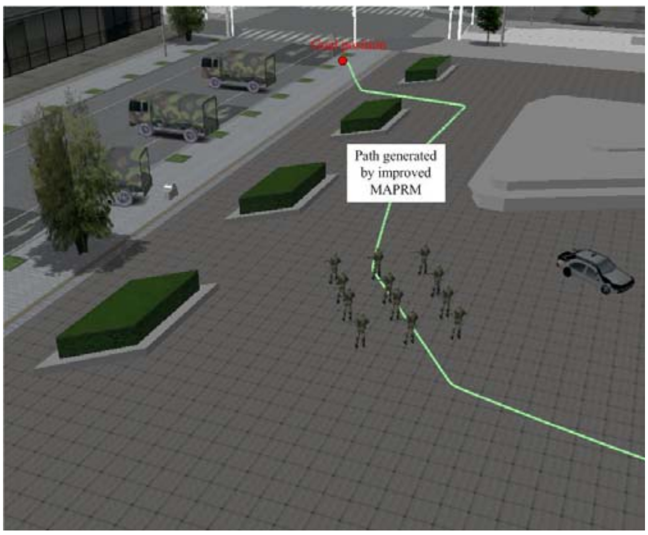
$$\tilde{S}(t) = \frac{\|S_1S_2\|}{\|O_1O_2\|}R(t) - \frac{\|S_1S_2\|}{\|O_1O_2\|}O(t) + S(t) \quad (5)$$

One major advantage of this path control scheme is that we only need to parameterize the path once for all sample points [6]. At the same time, Homing behavior which is used to drive the soldier and collision avoidance behavior which is used to avoid collisions between soldiers are utilized to steer the soldier. In this way, the formation transition phase of the group is accomplished.

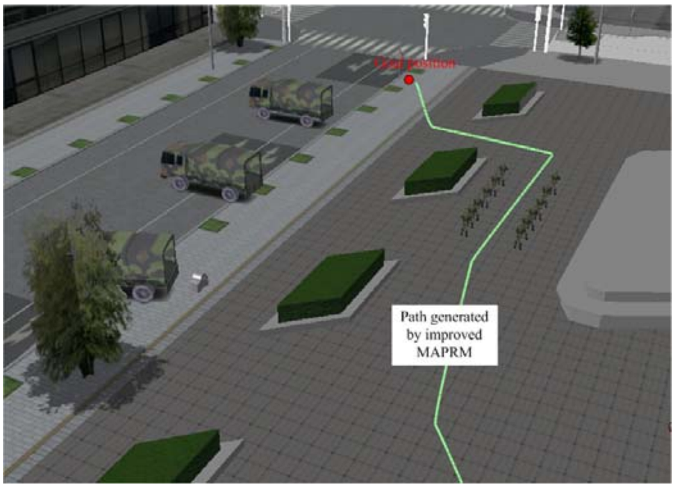
## 4. Experimental Results and Conclusions

In our simulation, we employ a human animation software package called DI-Guy, which is commercially available from Boston Dynamics Inc. we control the behaviors of the shepherd and the flock using SDK by C++ programs. We suppose the following scenario to prove our model: a squad of soldiers forms a coherent group, this group tactical target of marching from the initial position to the goal position to get on the army trucks. Figure 4(a) gives the initial configuration of environment. Fig. 4(b), (c), (d) give the snapshots of simulation results.

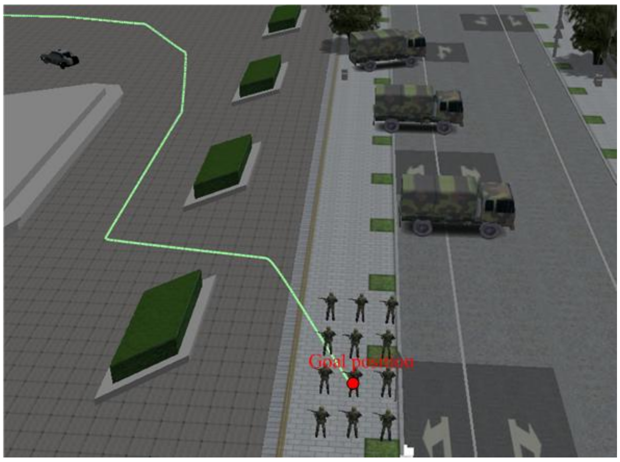
(a) initial simulation environment



(b) snapshot at t=20s




(c) snapshot at t=29s




(d) snapshot at t=35s

Figure 4. Simulation results of the soldiers' group

From Figure 4, we can see that improved MAPRM algorithm generate a more realistic path for soldiers' group by considering the clearance information of the space. And in narrow corridors, the group changes its formation automatically.

## 5. Summary

In this paper we have presented the soldiers' group behaviors by introduce an improved MAPRM algorithm. In our approach, we incorporated MAPRM algorithm with clearance information of the space by improve the local planner and A* algorithm in query phase of MAPRM. Simultaneously, the soldiers' group can adapt its formation according to the clearance information. But, this paper doesn't take the interaction between the mob and the soldier into consideration. Further researches will focus on this problem.

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