# Control of Flocking Behavior Using Informed Agents

## An Experimental study


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***Abstract*— This work investigates the controlling effects of a small group of agents on a large flock. The flock consists of a small fraction of informed agents, who are aware of the final goal, and a large fraction of naïve agents, who are not aware of the final goal but tend to stay with the group. The interesting point of this work is that although the informed agents can not transmit information such as their moving direction or their headings, they, just as naïve agents, tend to stay with the group – but because of having the extra tendency (of goal attraction), they use any occasion to approach the goal . It is shown that the flocking target can be controlled using a small fraction of these informed agents. The evaluation experiments are executed on E-Puck miniature robots and the effect of some parameters, such as the fraction of informed agents, information about target, and randomness of movements, are investigated.**



***Flocking; Swarm robotics; Informed agents; Potential fields.***


## I. INTRODUCTION

Flocking is a form of collective behavior of a large number of interacting agents with a common group objective using limited environmental knowledge and simple rules. For many years, scientists from rather different areas such as animal behavior, physics, biophysics, social and computer sciences have been enchanted by the magic of flocking, schooling and swarming in groups of social animals [1].

Study of flocking behavior was first initiated by scientists in biology who had been fascinated by collective decision making of animals such as ants and bees, which, often need to make collective decisions to move together to a specific resource like a food source or nest site. Although the individual agents' intelligence is believed to be insignificant, the ability to fulfill complex tasks in the group and the mechanism behind their collective behavior has always been an important issue for scientists, specifically robotic researchers.

Formation control techniques of multi-robot systems are currently applied in search and rescue operations, land mine removal, remote space exploration and mapping, as well as the control of satellites. This is mainly due to the advantages of such systems over single robotic systems, especially in fulfilling complex tasks; e.g. overall system robustness, enhanced performance, and flexibility [2]. By applying behaviors inspired from group-living animals such as ants, bees, birds and fish to multi-robot systems, complicated tasks can be performed by a group of simple and cost effective robots.

Couzin et al. [3] showed many behaviors of group-living animals that can be artificially recreated by simple rules. They showed that in a group of animals, although only a small fraction of agents have relevant information about the location of a food source or of a migration route, these informed agents are able to guide the whole group through simple social interactions.

It is important to note that the informed agents live among the society and do not give orders to the whole population. The actual control takes place, not in a leader-follower manner, but in a decentralized manner. The social interactions that happen in microscopic levels among individuals spread little by little to the whole group until they reach a desired target. For example, a group of older birds or fish having the partial experience of previous immigration routes leads the flock to the destination. Robots with sophisticated navigation devices, manned vehicles among a group of unmanned vehicles, and experienced agents among inexperienced agents are some applications of informed agents in robotics, to name a few.

Halloy et al [5] showed that informed robots in a mixed-group of animals (cockroaches) and robots can control the aggregation behavior of the mixed-society through microscopic interaction. They showed in their study that a group of robots are able to convince a group of cockroaches to aggregate under any desired shelter, albeit with different individual preferences in the cockroach group.

Like aggregation (gathering in one place), flocking (moving in a group) is among the simplest collective behaviors in a society. Studying this behavior leads to better understanding of animal migrations and can help in distributed path planning and control in robotics.

The aim of this experimental work is to investigate whether it is possible to control a flock of robots using informed agents without direct communication (unlike the works like e.g. Celikkanat et al. [6], where the flock is guided by transmission of heading direction) and then to observe parameters that may affect the flocking control using this method.

We think the dynamics of a group of pure robots is different from the dynamics of groups of animals [3], simulated robots [4] or mixed animal-robots [5]. Animal societies might have some sorts of preferences or microscopic interactions that


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might be unknown to us. On the other hand, the behavior of a simulated robot is programmable, predictable (to some extent) and almost completely understood. This study fills the gap between simulated robots and real animals by running the experiments on situated robots. We think our study helps us enhance our understanding about the actual process that happens behind flocking. The results of this experimental study can be used in flock control on unmanned vehicles.

The rest of the paper is organized as follows: first the robots and experimental setup are explained. Then, the experiments and the results are explained. The paper is finalized by a conclusion and possible future continuations.

## II. METHODOLOGY

Figure 1. Experimental setup, 9 E-Pucks were used in this work, Informed agents were capped in red and naïve agents were capped in black labels.

The task that the robots were to accomplish was flocking in a group until reaching an unknown target. The target was only revealed to a fraction of the group, whom we call informed agents. So, the robots were of two types: informed and naïve. The group members were neither allowed to communicate any information about the target, nor aware of the existence of informed agents.

The naïve robots were not aware of the goal but had the tendency to remain in the group and act so that they do not become separated from the group. The informed robots had the tendency to remain in the group as well but whenever possible they were allowed to move a little bit toward the target point hoping they could bring the whole group closer and closer to the target. To make it as simple as possible we used a light source to specify the target.

### A. Experimental Setup

Experiments were performed on the setup, shown in Fig.2, which consisted of a 240×150 cm rectangular arena, 9 robots, a light beacon as the flocking target and an overhead camera to track flock movements.

Robots used in these experiments were E-Puck[1] miniature robots, a 7.0 cm diameter mobile robot, designed at EPFL University, Switzerland (Fig.1). Each robot is equipped with a differential wheel locomotion system and several sensors including a ring of 8 IR proximity sensors.

[1] http://www.epuck.org.


Figure 2. Experimental setup, the arena consisting of informed robots (indicated by red circles) and naïve robots (indicated by black circles), and the target at the top right side of arena

### B. Potential Field

The behavior of robots used in these experiments was governed by some simple flocking rules, inspired from the work of Reynolds [4] that was applied to animated characters. The ultimate behavior of the robots consisted of a weighted sum of the following basic behaviors: attraction toward the group, repulsion from obstacles (including robots in very close vicinity), and attraction toward the target point. Each basic behavior created a potential field, based on which a force vector was generated:

- If a robot was closer than a threshold (5 cm in our study) to another robot, a repulsive force vector was generated by both robots in order to take them apart. The magnitude of the force was inversely proportional to their distance (Fig.3 (a)).
- If the distance was more than another threshold (15 cm in our study), an attractive force vector was generated to get the robots closer. The magnitude was proportional to their distance (Fig.3 (b)).
- For informed robots, an attractive force vector toward the target point was generated (Fig.3 (d)), the heavy red arrow).
- In order to test the sensitivity of the methods to noise, a uniformly random vector with a rather small magnitude was generated in some experiments. (Fig.3 (d)).

Note that the attraction and separation thresholds were chosen based on the specification of IR sensors. The maximum distance that is detectable by these sensors is 25cm.

Multiple force vectors were combined by weighted sum. Then, the resultant vector was calculated by normalizing the weighted sum. Normalization was done by dividing the vector to the number of participating behaviors. The resultant vectors, specified how fast and in which direction the robots should move. Then, the resultant vector was mapped to the velocity of the left and right wheels.

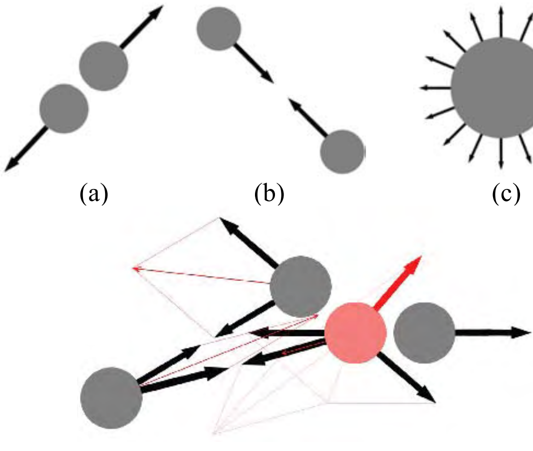


Figure 3. Potential field vectors for flock formation, (a) Separation vector, (b) Cohesion vector, (c) A random vector representing movement of the robots in a random direction, (d) Calculation of resultant vector, shown by light red vectors. The heavy red vector depicts the direction of target used by informed robots (specified by a red circle).

### C. Sensor Processing

In order to implement the mentioned behaviors, the robots needed to detect the other robots in their vicinity and find their relative position. Also, informed robots needed to find the relative position of the target. To benefit the most out of the existing equipment on the robots, the IR sensors were used for three purposes:

- **Proximity sensing** for obstacle avoidance and group attraction on all robots. This is the most usual use of proximity sensors.
- **Ambient light detection** to find the target point on informed robots. The proximity sensors have the ability to measure the ambient light. So a light source could be used as a target point for the flock.
- **Broadcasting a hello signal** used for robot detection on all robots (explained in the next section).

### D. Detection of Neighbors

Local interactions that led the flock to target took place between neighboring robots. A robot adjusted its velocity and direction by detecting the relative position of its neighbors. Detection of robots was done through broadcasting a FSK modulated signal containing a simple one-byte data via the 8 IR proximity sensors that were available in different directions around the robot.

The received information from different directions by the IR sensors was then gathered in a table, called The Table of Neighbors, consisting of:

- **Neighbor's ID:** Each robot has a unique identification number. The hello signal emits this ID repeatedly.
- **Neighbor's distance** to the robot (cm)
- **Neighbor's relative position angle** (radians): an approximated value specified from the pointing angle of the sensor that receives the most intensive *hello* signal among all 8 IR sensors.
- **A time-stamp** (seconds) recording the arrival time of the *hello* message.

The Table of Neighbors gave a simple map of the relative position of the neighboring robots. The map was updated when a new hello message arrived. Upon reception of a message from an already existing ID, the time-stamp, distance and relative angle were modified. Upon reception of a message from a new ID, a new row in the table was created. When a robot moved or rotated, the entries of table (distance and relative position of neighbors) were modified based on dead reckoning.

When a robot used the table to compute the force vectors, the time-stamp of the table entries was looked up in order to see whether the information is up to date or not. In case the time stamp showed the information was very old (older than 5s in this study) that entry was discarded.

### E. Tracking

For analysis purposes, the position of informed and naïve robots as well as the center of flock were recorded once a second during the experiments. This information came from a visual flock tracker system that used an overhead camera[2]. The images were taken in 658×492 pixels resolution and frame rate was 49.61 fps. The image processing program was developed in MATLAB. In order to visually tag the robots, different color labels were used for the informed (red) and the naïve (black) robots (Fig.1).

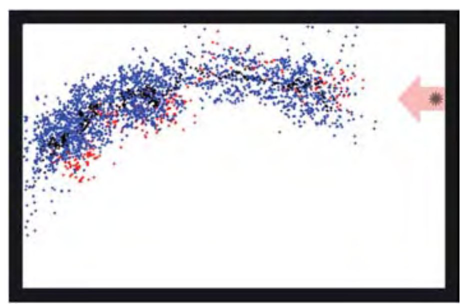

Figure 4. One informed robot (red dots) vs. 8 naïve robots (blue dots). Black dots represent flock center (IF=1 without noise).

## III. Experiments and Results

The initial positions of robots were like Fig.2. An experiment finished when the center of flock reached the right-most quarter of the arena on the horizontal axis.

The thresholds for attraction and repulsion were empirically specified so that the robots could move along with each other while avoiding collisions. For our case, the virtual attraction vector generation started from the longest distance that the sensors could cover (around 25cm) until 15 cm and virtual vector repulsion generation started from 5cm and its magnitude got bigger for closer distances.

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[2] BASLER A311F RGB camera developed by Basler Vision Technologies: http://www.baslerweb.com.

As mentioned before, multiple force vectors were combined by weighted sum and normalization into a resultant vector. Different weights could create different behaviors. We simply set the weights of obstacle avoidance, robot attraction, and random movements to one and the weights were the same for all informed and naïve robots.

By giving different weights to the target attraction vector, we could create two different categories of behaviors:

- **Reaching rapidly to the target**; therefore, having *selfish robots* who seek more to reach their target.
- **Staying with the group of robots**; therefore, having *social robots* who pay attention to their society as well.

We call the weight assigned to the target attraction vector, the Information Factor (IF), since it specifies how much the magnitude of the vector that points toward the target, effects on the ultimate behavior. Based on this factor we say the informed robot is selfish if IF=1, and we say it is social if IF=0.5 (that means the target is not as important as society).

Experiments in each category were done with and without noise. The noise was defined as a uniformly random vector that was added to the resultant vector of all robots in the population. Its length was 10% of the length of the resultant vector and its direction was a uniformly selected direction between 0 and 360 degrees. This vector represents free movement of social animals and has positive and negative effects on the group movements that will be described later.

Four groups of experiments were done. Each experiment was repeated almost 30 times and the averaged results are reported here.

A 2D view of the position of robots recorded by the tracking software is seen in Fig.4. It is seen that the informed agent was located most of the time in the right side of the flock center, meaning the informed robot had the tendency to approach the target (which was at right side) but it did not leave the group behind. Also, by taking a look at the density of blue dots, it becomes evident that at the beginning, due to the inertia of the group, a big effort had been made by the informed robot to push the group toward the target. Once the group started moving in a proper direction, the whole group moved faster.

Time-to-reach the target line (the right-most quarter) for all four categories of experiments are shown in Fig.5. The population remained 9 and naïve robots were replaced by informed robots one by one. The x axis shows the percentage of informed robots out of nine total robots on the arena.

### A. Selfish robots

In Fig.5, the blue and green lines show the results when informed robots are selfish (IF=1). Even with one informed robot, we could control the whole population and bring them to the target line in a rather short time.

In the absence of noise, the time to reach the target was around 6 minutes. The time reduced by one minute when we added another informed robot, and reduced by another minute when we had three informed robots. Adding more informed robots also reduced the time but not by as much as before (only by around half a minute). Finally, when informed robots were in majority, the time reached to around 2.5 minutes.

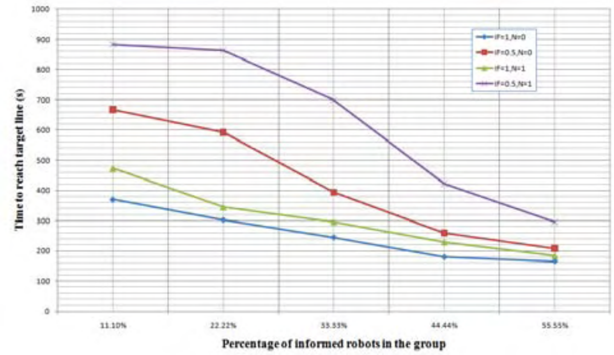



Figure 5. Time taken for the flock center to reach the right-most quarter of the arena's length vs.different proportions of informed robots.

In the presence of noise, the time to reach the target line was 10 minutes (4 minutes longer than without-noise case). Adding the next robots reduced the required time by around three minutes and then by two minutes. Then, the effect of additional robots got smaller until there was a majority of informed robots, in which, the time reached to almost the same level as the without-noise case.

Comparing the results of the two cases of selfish robots (both with and without noise), showed that the negative effect of noise on the time to accomplish the mission disappeared when the number of informed robots increased. Even with three informed robots (33% of the whole population) the noise was almost ineffectual.

Adding informed robots was more important when the number of informed robots was small compared to the whole population. But when the number of existing informed robots was high enough, addition of informed robots was less effective. It seems the effectiveness of adding more informed robots is inversely proportional to the number of existing informed robots.

### B. Social robots

In Fig.5, the red and purple lines show the results when informed robots are social (IF=0.5). Again, even with one informed robot, we could control the whole population and bring them to the target line in a short time.

In the absence of noise the time to reach the target was around 11 minutes (5 minutes longer than with selfish robots). The time reduced by two minutes when we added another informed robot, and by around 5 minutes when we had three informed robots. Then, adding more informed robots shortened the time but not as much as before. When informed robots were in majority the time reached to 4 minutes (around one minute longer than with selfish robots). The time to reach the target is longer than with selfish robots because the target vector has 50% less effect on the movements of the informed robots.

In the presence of noise, the time to reach the target line was rather long (we stopped the experiment after around 15 minutes). Adding even two robots did not reduce the time by much. When the number of informed robots reached 4, the time reduced by 5 minutes; and finally with 5 informed robots, the time reached to almost the same level as in case without noise.

Comparing the results of the two cases of social robots (with and without noise) showed that the effect of noise on the time to accomplish the mission was worse than in the selfish robot cases. So in selfish robots, the target vectors compensated a bit for the latency created by the noise vectors.

### *C. Dispersion of the group*

If all the robots knew about the target point, we could expect to see them go straight toward the target. However, naïve robots had no information about it, so they sometimes wandered around the flock perimeter (and sometimes got lost).

A 3D view of the experiment is shown in Fig.6, plus, three other settings are seen in Fig.6 (one informed robot and 8 naïves, with different types for the informed robot, with or without noise). In this 3D view, the vertical axis represents time.

In the absence of noise and when the informed robot was selfish (IF=1, Fig.6 (a)), the society moved almost in a straight line toward the target and had small deviation from the flock center. However, in the presence of noise, the deviation increased (Fig.6 (b)). This is clear from the dispersion of points around the flock center. The same thing happened when the informed robot was social (IF=0.5, Fig.6 (c))). The dispersion was at its maximum when the informed robot was social and noise was present (Fig.6 (d)). Fig.7 shows the 3D view for the experiments with 3 informed and 6 naïve robots. The same conclusion as Fig.6 can be made here. Moreover, by comparing the two figures, we can say the density of points in the latter is far less than in the former. That is because three informed robots could guide the whole group to the target in a shorter time than one informed robot, and therefore a fewer number of points were required to be drawn.

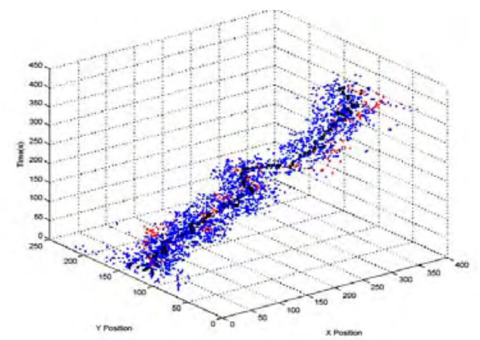
## *IV.* CONCLUSION

In this experimental work, a distributed approach for the control of flocking using informed agents was investigated. The flocks consisted of informed robots (who were aware of the target) and naïves (who only had the tendency to stay with the group), programmed with very simple rules. Our method can be used in robotic flocks when a simple algorithm is needed and the equipment on each agent is limited.

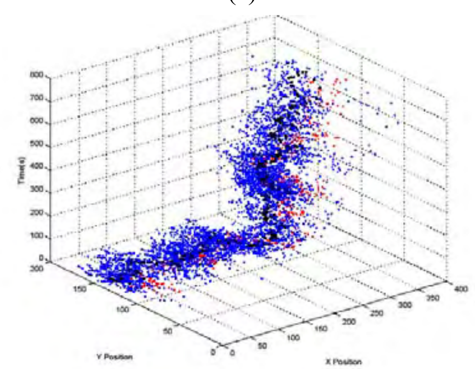
Here, neither did the robots have the capability to differentiate informed robots from naïve ones, nor were they allowed to transmit any information about the target or the heading direction of informed robots.

The controllability of the flock in order to reach a target using informed agents was evaluated under different circumstances i.e. existence of noise or ignorance of the target point.

It was seen that, as the fraction of informed robots approached 50%, neither the ignorance of the target nor noise could create a serious obstacle against the guidance of the flock. It was perceived that if informed agents constituted around 33% of the whole population, the flock could reach the




(a)

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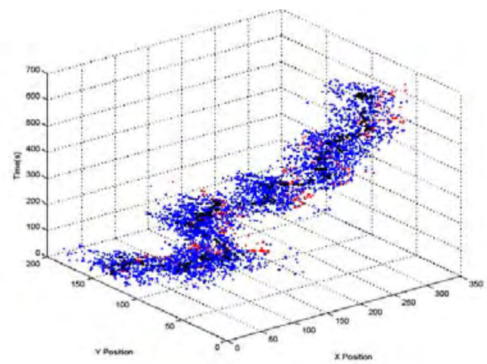


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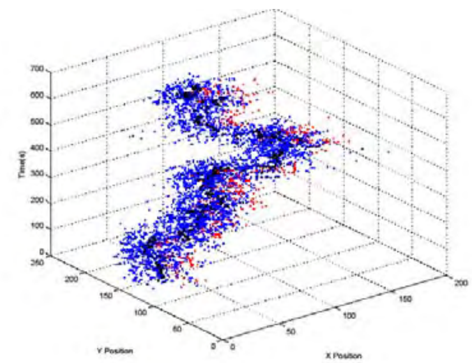
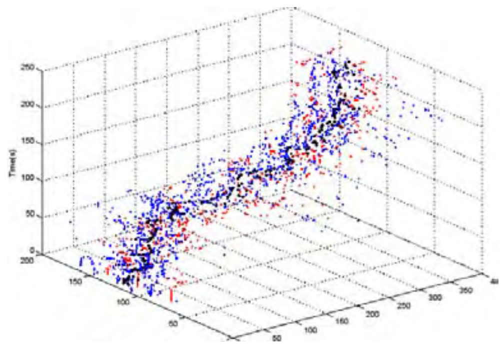
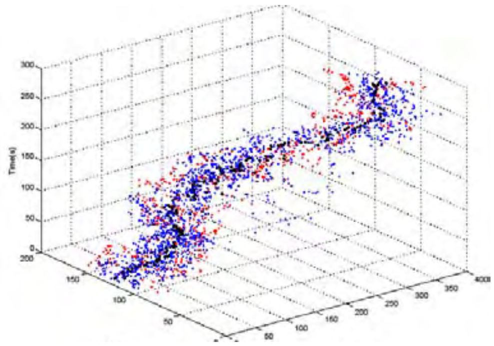



(d)

Figure 6. Evolution of flocking in time (vertical axis), one informed and 8 naïve robots (a) IF=1,without noise (b) IF = 1, with noise (c) IF = 0.5, without noise (d) IF = 0.5, without noise



(a)



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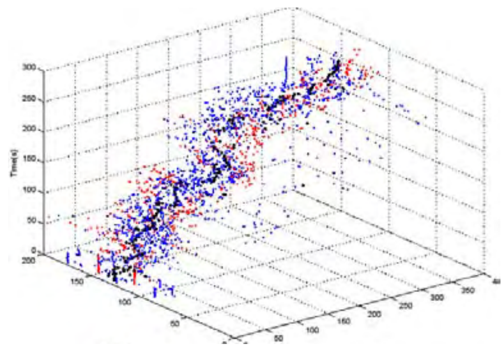

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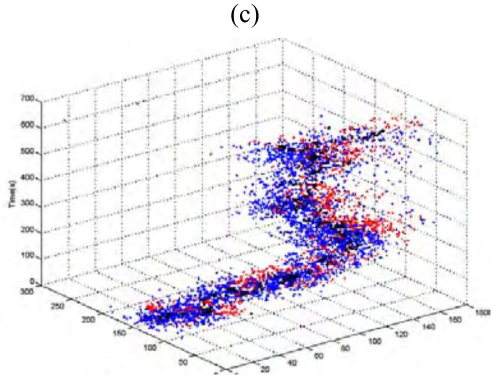

(d)

Figure 7. Evolution of flocking in time (vertical axis is time), 3 informed and 6 naïve robots (a) IF=1,without noise (b) IF = 1, with noise (c) IF = 0.5, without noise (d) IF = 0.5, without noise

target in a very short time, approximately the same time as an ideal situation (i.e. where noise is absent, informed robots are in majority and have IF = 1).

In the presence of noise or ignorance about the target (IF = 0.5), the robots wandered around more, therefore they explored the environment with bigger coverage. This is good for a flock in two ways: First, the chance to find something useful nearby increases. Second, the group members, especially the ones in the center, have more space to move and have more resources to use e.g. when grazing. However, the dispersion has its deficiencies: The time to travel to the target as well as the danger of being attacked by enemies increases.

These conclusions observed from robotic groups are almost the same as the Couzin et al. observation of biological systems about effective leadership and decision making of group-living animals [3]. Moreover, the group size in our experiments is one order of magnitude less than their simulations and the required fraction of informed agents in order to control the society is one order of magnitude more in our case. This result is also in accordance with their conclusion that when population increases, the fraction of required informed agent gets smaller.

We would like to run the experiments on a larger group of robots as well. We think the required fraction of informed robots for the control of flocking would decrease with the population size. In addition, since we used a light source as a target, in order to reduce the interference with the vision-based tracking system, we had to use a low intensity overhead light source. In order to be able to improve the tracking system, an infrared or another type of beacon is suggested.

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