Tracking the motion of multiple Robots on the ground using a single overhead Camera

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Abstract

The applications involving multiple robots moving in and around an arena to perform a specific task(s) are widely growing day by day. With the advent of new technologies and increasing areas of applications leading to solving intrinsic and computationally expensive and complex tasks in the arena, tracking applications come in very handy, wherein the position, direction and movement of robots can be observed by users who take measures accordingly. The most commonly used methodology to track robots are placing markers on them, where the markers act as an identity to the robot(s). The paper presents a QR code based tracking and detection of robots in a centralized environment involving a single overhead camera. The benefits of using a QR based approach is discussed contrasting it's differences and improvements over other methodologies. Extensive experiments have been performed on multiple robots using cameras of different resolutions and the results document clearly show the benefit(s) of the approach

1 Introduction

QR codes serve as excellent means to store information of varying length which can be used as means of storing and/or conveying information. We have used QR codes as a marker that acts as an identity to robots which are Lego NXJ(description). The aim of the project was to determine how smoothly and to what extent the robots can be placed in the arena such that they can be tracked with minimum delay and loss using a central camera. The QR codes used by us were of version 2 since we primarily focused on the identity of robots which can be implemented with small amount of information embedded. For rich information, one may go till version 25. We have used just one camera as of now that overlooks the arena as using multiple cameras, where each camera is embarked upon a robot presented further difficulties in identifying robots and placing markers on appropriate positions.

Previous work done in this field was primarily on the usage of colors as markers for robots. The solution is handy when dealing with a small number of robots(upto 3) in the arena, as the color ranges were large and significant overlap was observed beyond 3, the result of which causes the values to be garbled and significant loss in detection is observed. The new approach overcomes this limited capability and also seeks to minimize errors in detection due to height by using the method exponential averaging that will be discussed in the upcoming sections.

Our work is presented in the following sections, starting with a formal description of our work, followed by the algorithm and then the detailed description of experiments and results. Status of the present scenario and further improvement opportunities are presented in the last section.

2 Problem Statement

The problem given to us were tracking and detection of multiple robots on the ground using a single overhead camera. A color based solution to this problem were provided to us and we had to work on it's shortcomings and come up with a deliverable solution. A formal description and behavior of both systems are presented with their advantages and solutions to the shortcomings.

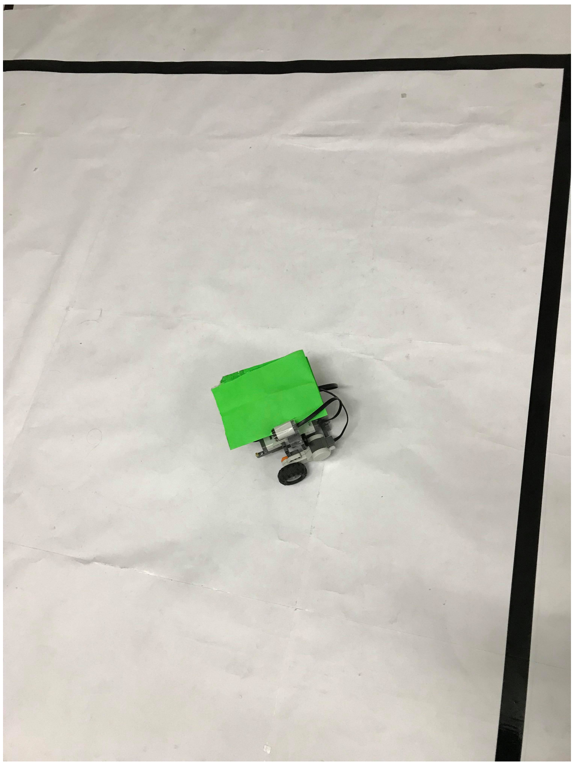

Figure 1: Color based marker on Lejos NXJ.

2.1 Color based markers on Robots

The robots were assigned a specific color by physically pasting a section of chart paper on top of the brick of Lejos NXJ robot. There were no other sensors required except for the magnetic compass to move around. The number of sensors would depend on the application one wants to incorporate. The robots were hence lightweight.

2.1.1 Behavior

The robots were tracked efficiently up to three in number by a central overhead camera at a good height, which shows that distance between the robot, precisely the marker and the camera isn't a significant issue hence no extra measures were to be accounted for in there.

The robots were marked with a circular boundary which showed that it has successfully been tracked by the camera with the help of the underlying algorithm. It works excellently for colors red, blue and green. However, on bringing in a fourth robot of different color or even a single robot in the arena of a different color other than red, green or blue hampered the detection, affected the smoothness by a significant factor which lead us to conclude that the method isn't efficient when you need more than three robots. The speed of the robots could be supported up to maximum with no such effect on delay. However, we cannot formally prove this as three robots are too less to show an effect on delay versus speed graph.

To overcome the shortcomings encountered by this approach, we moved on to the next approach as a solution to the problem statement

2.2 QR code based markers on Robots

The robots were assigned a specific QR code by physically pasting an A4 printed QR code pasted on a cardboard and mounted on two pillars designed on the Lejos NXJ robot. There were no other sensors required except for the magnetic compass to move around. The number of sensors would depend on the application one wants to incorporate. The robots were hence lightweight, other than the QR code which occupied a significant portion and acted as a camouflage to the robots.

Figure 2: QR code based marker on Lejos NXJ.

Item	Quantity
Widgets	42
Gadgets	13

Table 1: An example table.

2.2.1 Behavior

The QR codes served as an unique identity to the robots which eliminated the overlapping ranges that destroyed the uniqueness. Hence, robots up to any number could be tracked.

The rectangular track boundary helped in identifying the successful tracking of robots. By the method exponential averaging, the tracking became smoother as the height was increased between the camera and QR code, but it still caused problems as the heights were increased further. The details are further discussed in the experiments and results section.

The problem is solved in three stages. Firstly the QR code version 2 is generated and it is populated with information that acts as a marker. Secondly, the camera is connected with the system and the script is run. Thirdly, the QR configured robots are started and their movements are observed and recorded.

3 Algorithm

Initially in our QR Code tracking system we found that when you keep on increasing the distance between camera and QR code, then after certain threshold there was a fluctuation in detection. So, to overcome this issue we came up with this concept ‘exponential averaging’ to smooth the detection. There are other algorithms available to remove this issue like multi-hypothesis tracking (MHT) and GM-PHD but these algorithm have much higher execution time than exponential averaging.

Exponential averaging has been used in operating system to predict the CPU burst of next job in shortest job first scheduling algorithm. It has also been used in Computer Network to predict the round trip time in TCP connections and has been used in machine learning for learning gradient using Adam optimizer.

The data sequence is often represented by x_t and prediction at time t using exponential averaging is denoted as s_t. The exponential averaging is governed by two equation as given below:

$$s_0 = x_0$$
$$s_t = \alpha x_t + (1 - \alpha)s_{t-1}; t > 0$$
where α is smoothing factor and $0 < \alpha < 1$.

In our tracking system we used exponential averaging to predict the four coordinates of QR code for each corner and when there is no measurement at particular time instant then we set output of exponential averaging as the detection.

4 Results and Experiments

Experiments were preformed in multiple stages. At first, we built a basic application consisting of two robots, a police and a thief and tested our system by running them on the arena at different speeds. The components used in the experiment are :

Overhead Camera
Logitech C310 with 5 mega pixel resolution
Height :
Robots
Lejos NXT series:
Maximum Speed of motor : 720
Wheels : 2
Motors : 2
Magnetic Compass : 1
QR Code
Version 2 QR codes generated online

4.1 Police and Thief

We ran the experiment on two robots namely the "police" and the "thief" which were embedded in the QR codes to act as an identity for the robots. The steps of the algorithm mentioned were followed and we ended up with smooth tracking of both robots at varying speed. Our results showed no glitch even at maximum speed. Hence for two robots, the system worked perfectly fine in terms of *tracking* and *detection* . However, due to the placement of the QR code above the magnetic compass, the compass wasn't mounted at a good height, hence it encountered interference with the wheels, as a result of which there were a few glitches observed while changing direction. These were minor issues, and with improvised design they can be removed.

4.2 Large Scale Test

The application built by us was small scale as it involved only two robots, so we were not able to draw a general conclusion on how efficient this approach is, i.e. when we involve surplus robots, up to what extent can they be supported on the arena and the effect of speed and delay on the system. For this we generated a set of twenty QR codes and labeled them from numeric one to twenty and put them on the arena one by one, keeping the growth rate as one, five, ten, fifteen and twenty codes in the arena to determine the speed and delay. We also moved the QR codes to and fro to determine whether increasing speed has a significant impact on delay. The results observed are presented in the graph.

As observed in the graph, the delay shows a linear growth till eight, then increases exponentially till twelve then saturates for a while and again follows the linear nature. From this, we conclude that the delay significantly increases with increase in robots in the arena and might have a negative impact on the performance if the arena is very large, i.e. it is able to accommodate thousands of robots. This however is not feasible as our system is centralized and with the given constraints on height and camera, the arena will be able to accommodate small number of robots only(say around thirty), which is a good number for a centralized approach.

At this number with medium speed(say 200), the system works well, though definite impacts on delay are observed as more and more robots are introduced. From our experiments, we can conclude that the system can run very well up to ten robots, beyond which the exponential growth

Figure 3: Successful detection of twenty markers in the arena.

gets scaled up to an extent that although it works, but it is no longer smooth and doesn't support maximum speed at all.

5 Limitations

The QR code based approach for detection and tracking of multiple robots on ground suffers from limitations of speed and delay with increasing number of robots in the arena. It also shows roughness in detection if the camera is increased beyond height ten foot and completely fails when it is at height thirteen foot.

We thus require a camera of sharper resolution to position it at a greater height for smooth working of the system. This would lead to increase in cost when compared to the color based solution. Hence a major limitation is the height at which the camera is situated. The lesser the height is, smaller the arena coverage is, and as a result the number of robots supported will also decrease as it depends on the bounds of the arena which in turn depends on the height, positioning and resolution of the camera.

The rise in delay and limitations in speed have been discussed in the previous section which again puts a limit on the number of robots supported on ground. This trade off is however balanced by the previous limitation imposed by the camera and the fact that the system is centralized. Still, 10 robots is less in number and we feel more work needs to be done

6 Conclusions and Future Work

QR code based tracking and detection is a robust method which shows no glitches in detecting any number of robots, and hence is a significant improvement over the color based solution which can detect up to three robots only. The solution proposed by us can track efficiently up to ten robots and is convenient for a centralized application involving a small arena.

There are ample scope of improvements. The limitations discussed can be overcome by introducing multiple cameras and subdividing the arena into smaller arenas, by treating them as local maps and the whole arena as a global maps. This might eliminate the need of buying a camera with

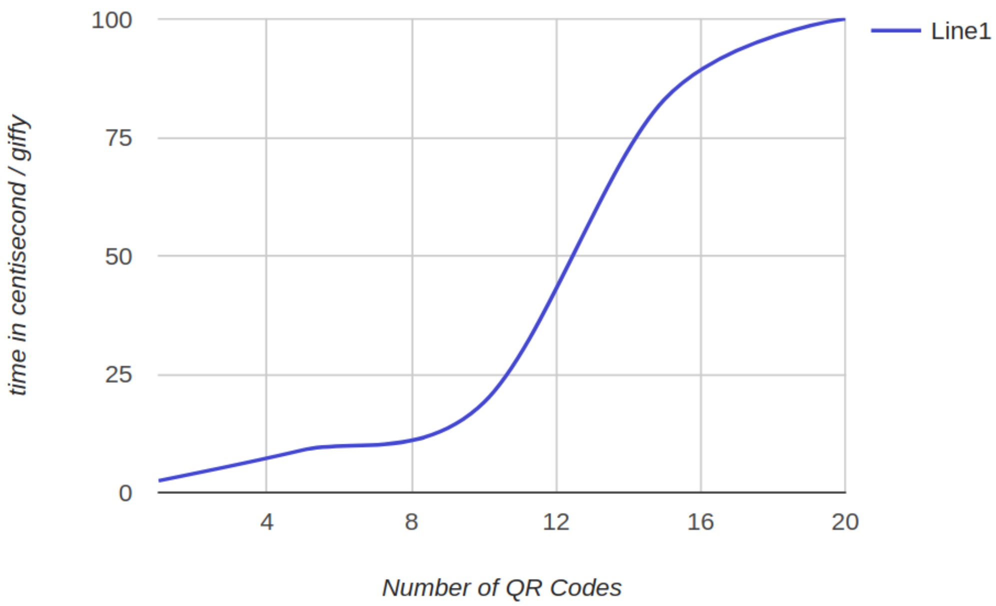

Figure 4: Time delay observed as number of robots are increased in the arena.

higher resolution but the cost of introducing other camera(s) are encountered. Also, with smaller areas, the efficient support for up to ten robots can be plugged in, with each arena supporting a maximum of ten robots and together implementing a large community of robots performing a specific application.

Thus the extension of this work can be done by integrating further hardware which can prove to be effective and efficient in solving a large scale of applications.

References

1. https://en.wikipedia.org/wiki/Exponential_smoothing
2. P. Cano and J. Ruiz-del-Solar, "Robust Tracking of Soccer Robots Using Random Finite Sets," in IEEE Intelligent Systems, vol. 32, no. 6, pp. 22-29, November/December 2017.