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Fuzzy Logic-based Control System for Dissolved Oxygen Control on Indoor Shrimp Cultivation
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Deep Features Representation for Automatic Targeting System of Gun Turret

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***Abstract*—Visual sensory has attracted much researches in many applications. This specifically for a pointing target tracking platform such as gun turret. Existing works, which use only visual information, mostly still rely on quite a number of handcrafted features that can cause parameters are not optimal and usually require complex kinematic and dynamic. An attempt has been made using deep learning that shows quite well for auto-targeting gun turret by fine-tuning the last layer. However, target localization can be further improved by involving not only last layer features but also first and second convolution layer features. In this paper, an auto-targeting gun turret system using deep network is developed. The first, second, and last layer features are indigenously combined to produced a response map. Auxiliary layers are developed to extract the first and second layer features. First and second convolutional layers help for precise localization while the last layer features help to capture semantic target. From the response map, bounding box is formed using a common non-maximal suppression which then actuates pan-tilt motors using PID algorithm. Experiments show encouraging result, accuracy is 80.35%, for the improved auto-targeting system of gun turret.**

***Keywords*—Deep features, gun turret, visual sensory, deep learning, auxiliary layer, convolutional neural network**

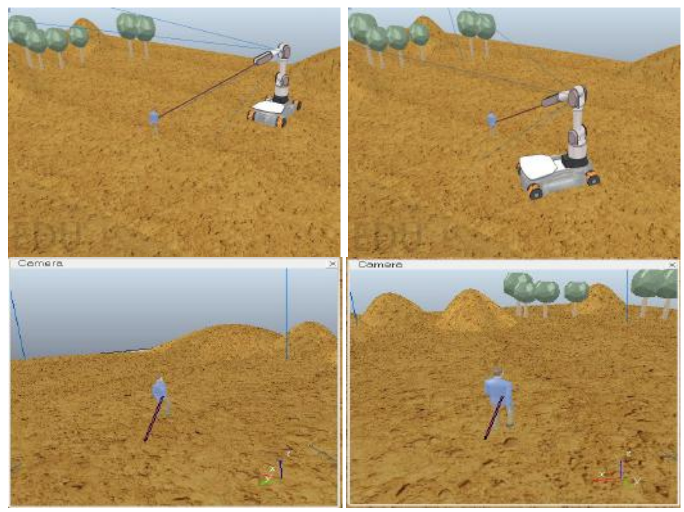

Fig. 1. Gun turret mounted on a mobile robot performs a target tracking in a quite complex background and changes appearance of the target. Performing tracking using only semantic information might not enough as the primary objective is locating the target.

I. Introduction

Visual sensory has becomed the main research focus for many applications. This mainly for a pointing target tracking platform such as gun turret. Gun turret is designed for directing the weapon and firing to the desired target. Such application is expected to have innovation to be automatic device pointing and following to the desired target for effectiveness, accurate, fast, and easy for operation. Employing only visual sensory has several benefits in practice such as less number of attached sensors and lightweight, but require a more sophisticated algorithm to perform tracking and actuating.

Several works [1]–[9] have performed an automatic targeting system gun turret which mostly employs many sensors. In practice, utilizing many sensors is not a cheap solution, heavy-weight, difficult for maintenance. The works [1]–[3], [7], [8] employed visual targetting using a monocular camera. Those works involve quite many manual designs such as handcrafted feature. Separate classification algorithm is then employed using the handcrafted features. Those features can decrease the accuracy due to not optimal parameters and usually non-trivial in practice and mostly depend on engineering's knowledge and experience. Moreover, the works require highly complex kinematic and dynamic.

Various visual detection and recognition tasks have been successfully improved by deep learning method [10]. Such application for example image classification [11], [12], image segmentation [13]–[15], and object detection [16]–[20]. Deeper network has a main advantage of the ability to learn effective feature representation automatically, which make appealing for practitioners.

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The work [21] has shown the performance of deep learning for gun turret target tracking which is tested on simulated environment. While it shows quite well for gun turret robotic platform, the target which is located in a complex background and target appearance still has not been tested yet. In practice, a desired target is highly likely located on a complex background. Complex background such as soil, grass, ruined building, etc that could potentially make any tracking methods fail to distinguish the desired target or not, as shown in Fig. 1. While fine-tuning on the last layer is commonly used in the work [20], [21], it seems not effective enough for precise localization which is the primary goal of gun turret. This could be attributed as the last layer features are highly related on semantics and invariant to intra-class variation for precise localization, which is suggested by the work [22].

In this paper, to address those issues, an improved automatic targeting system of a gun turret using only a camera is developed. A new convolutional neural network (CNN) is developed which is tested on a gun turret simulation system. More specifically, the first and second layers features are combined with the last layer features in an indigenous way to get a richer features representation. Response map is then produced followed by bounding box formation using a common non-maximal suppression. First and second convolutional layers are used in this work as these layers capture more spatial information for better localization, while the latter layers capture more abstract or semantic information. Auxiliary layers are developed to extract the first and second layer features. Training the weights of auxiliary layers are developed by a minimizing problem using the target center. From the response map, bounding box is formed using a common non-maximal suppression which then actuates pan-tilt motors using PID algorithm.

II. Related Work

The work by [23], [24] improved the performance of gun turret with remote control and camera. Remote control is utilized to drive the turret in a distance within a range of wireless communication system. An operator is in a safe place from enemies. In order to explore the surrounding environment, the turret is equipped with a vision sensor such as camera. A camera mounted on the turret body still operated manually by the operator.

Automatic target tracking of gun turret works has been conducted by [1]–[3], [7], [8]. Several features have been carefully designed to improve accuracy to detect and follow the target. Those works [25]–[27] involve manual feature design connected to a classifier. Then it is followed by a classification method. To actuate the motors, analysis of highly complex kinematics and dynamics is employed.

Manual design of features is mostly used from the above methods. Moreover, complex kinematics and dynamic is also used which is non-trivial in practice. Too many manual designs can degrade the accuracy of the tracking due to not optimal parameters obtained. Thus it is solely designed based on the knowledge and experience of engineers. Global optimization [28] could be used to optimize the parameters.

The work [21] performed deep learning for gun turret target tracking tested on simulated environment. While it shows quite well for gun turret robotic platform, the target which is located in a complex background and target appearance still has not been tested yet. While fine-tuning on the last layer is commonly used in the work [20], [21], it seems not effective enough for precise localization which is the primary goal of gun turret.

Various visual detection and recognition tasks have been successfully improved by deep learning method [10]. Such application for example image classification [11], [12], image segmentation [13]–[15], and object detection [16]–[20]. Deeper network has a main advantage of the ability to learn effective feature representation automatically, which make appealing for practitioners.

III. Auto Targeting System

Overall system is shown in Fig. 2. We assume the target is randomly moved of each frame, which is considered true in real scenario where the target tends to move smoothly. With this, the system must be able to follow the target with a great change of appearance and complex background.

A. Convolutional Neural Network

The Convolutional Neural Networks (CNN) as a deep learning method has shown the performance as a notably approach, which is applied in diverse computer vision applications, to learn effective feature automatically from training data and train in an end-to-end [29].

Basically, a CNN comprises of several layers which are staged together. A layer usually consist of convolutional, pooling, and fully connected layers that have different roles. During training forward and backward stages are performed. For an input patch, forward stage is performed on each layer. During training, once the forward stage is performed the output is compared with the ground truth and the loss is used to perform backward stage by updating the weight and bias parameters using a common gradient descent. After several iterations the process can be stopped when the desired accuracy is achieved. All layers parameters are updated simultaneously based on training data.

A convolutional layer consist of N linear filters which is followed by a non-linear activation function h. This work used an activation h on layer m such as the Rectified Linear Unit (ReLU) $h_m(f) = \max\{0, f\}$. In this convolutional layer, a CNN utilizes various kernels to convolve the whole image as well as the intermediate feature maps, generating various feature maps $f_m(x, y)$, where $(x, y) \in \mathcal{S}_m$ are spatial coordinates on layer m. The feature map $f_m \in \mathbb{R}^{A\times B\times C}$ contains A width, B height, C channels to indicate size of feature map. A new feature map f_{m+1} is produced after each convolutional layer such that,

$$f_{m+1} = h_m(g_m), \quad \text{where } g_m = W_m * f_m + b_m \qquad (1)$$

g_m,W_m, and b_m indicate net input, filter kernel, and bias on layer m, respectively.

To reduce the dimensions of feature maps, pooling layer is usually used which is then followed by convolutional layer. Pooling layers are invariant to translation since it takes the

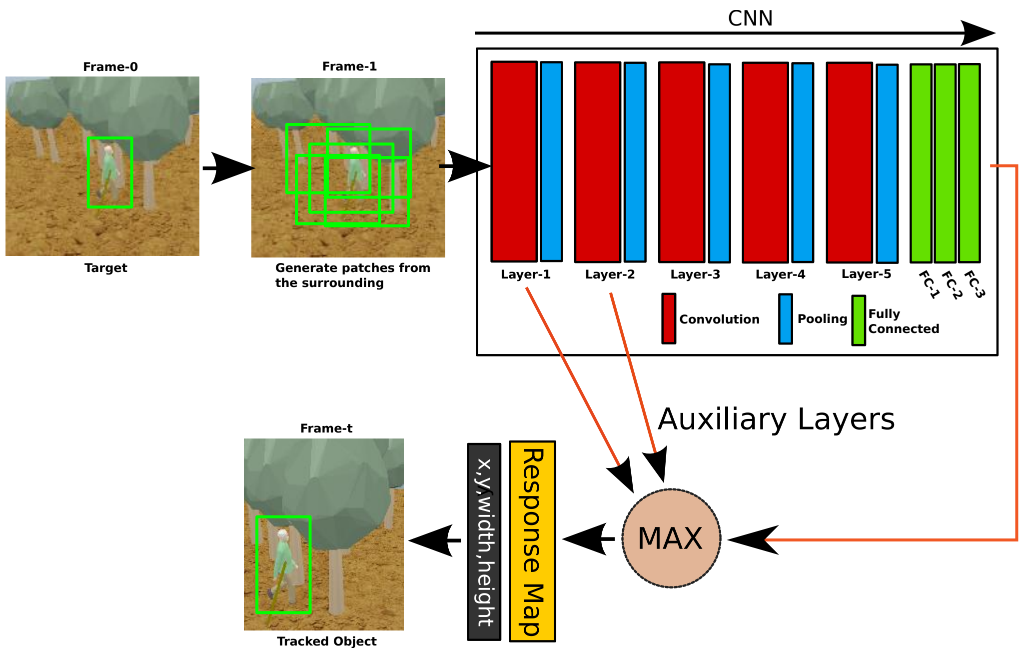

Fig. 2. Overview of overall system of our method. At first frame the desired object is located manually. Then the surrounding nearby patches of the object are extracted and one-by-one becomes an input to the CNN. A response map is then produced by indigenously combining first, second, and last layer features. Bounding box is formed using NMS. The center position of the tracked object is then sent to turret's actuators (pan-tilt) using PID. Best viewed in color.

neighboring pixels of feature maps. Max pooling is the most commonly used in many applications. Max pooling is simply taking the maximum value from a predetermined window.

Fully-connected layers perform similar as feed forward neural network. It provides us to convert previous multidimensional feature maps into a pre-defined length. It acts as a classification and it could be used as a feature vector for the next processing.

CNN is usually employed to learn a richer features representation for many applications. All layers are learned simultaneously without much tedious jobs of trial and error tuning features and classifier. This is differ from the previous manual features design.

An image patch u as an input to the CNN, then begin forward stage layer-by-layer, and ends by fully-connected layers producing certain labels with its probability. All the parameters are learned from the training data using the common stochastic gradient descent (SGD) by minimizing the loss over ground truth training labels.

B. Auxiliary Layer

An auxiliary layer is formed to get richer feature representation. First and second convolutional layers are used in this work as these layers capture more spatial information for better localization, while the latter layers capture more abstract or semantic information. During learning process, the weight W_m^* of auxiliary layers are trained by minimizing the following problem,

$$W_m^{**} = \arg\min_{W_m^*} \sum_{x,y} ||W_m^* \cdot f_m(x,y) - z(x,y)|| + \lambda ||W_m^*||_2^2 \quad (2)$$

where dot product is defined as $W_m^* \cdot f_m(x,y) = \sum_c^C W_m^{*c\top} f_m(x,y,c)$ and regularization parameter $\lambda \geq 0$. Eq. 2 is considered to estimate as close as possible to the target center. We opt not to use hard threshold by employing Gaussian function for the target center $z(x,y)$ which is defined as,

$$z(x,y) \triangleq \exp^{-\frac{(x-A/2)^2+(y-B/2)^2}{2\sigma^2}} \quad (3)$$

where σ is kernel width. It is noted that the target center is obtained from the ground truth. The target center should have a value 1 in Eq. 3 while it gradually decreases when away from the target center.

Once the weights of auxiliary layers are obtained by learning process, the response of this auxiliary layer is computed using the following formula,

$$V_m(f_m) = \sum_c^C W_m^{*c} \cdot f_m(c) \quad (4)$$

where V_m has size $V_m \in \mathbb{R}^{A\times B}$. The estimated target center should be,

$$(x^*, y^*, \mathcal{R}) = \arg\max_{x,y,\mathcal{R}} \sum_m \frac{\alpha_m V_m(f_m(x,y))}{\max(V_m)} \quad (5)$$

where $\mathcal{R} \in \mathbb{R}^{A\times B}$ is response map from all layers, $\alpha_1 = 0.0625$, $\alpha_2 = 0.125$, and $\alpha_{\text{last layer}} = 1$, otherwise $\alpha = 0$ which are found experimentally.

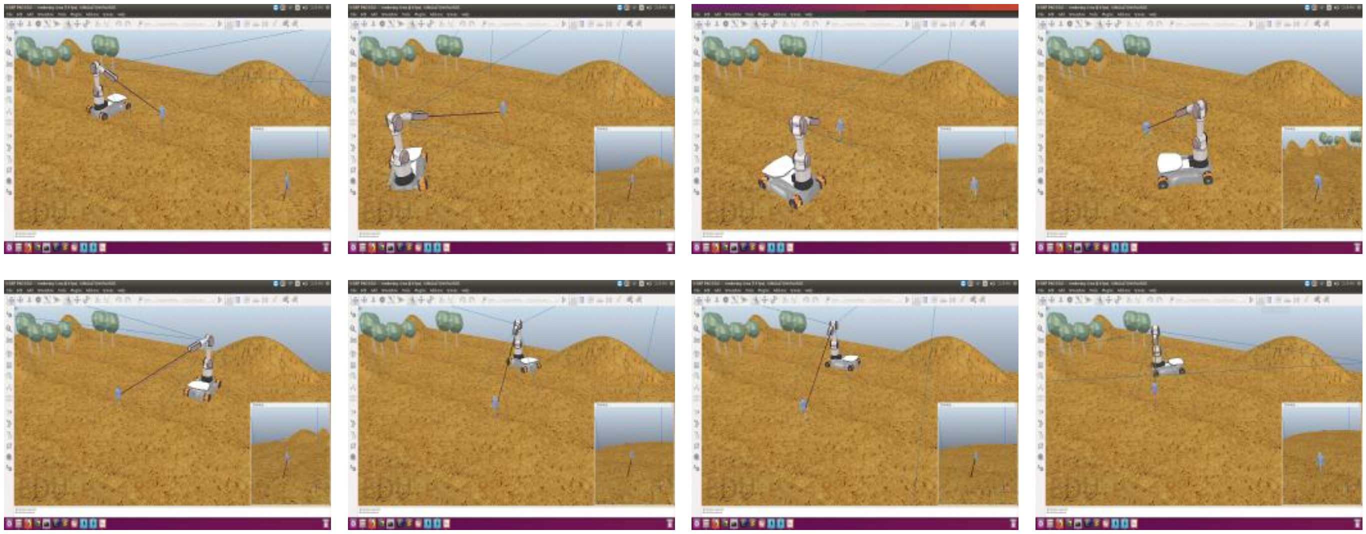

Fig. 3. Our system tested in a simulated environtment to track and follow an object which is a person. The person moves in a circular. A camera view of mobile robot is shown at the bottom-right image.

TABLE I. DEEP NETWORK ARCHITECTURE

Layer	Type	Input Size	Kernel Size	Feature Map
1	Convolution	224x224x3	11x11x3x96	96
	Relu	55x55x96	-	96
	Pooling	55x55x96	3x3	96
	Normalization	55x55x96	5x5	96
1*	Weight aux layer	55x55x96	55x55x96	96
2	Convolution	55x55x96	5x5x96x256	256
	Relu	27x27x256	-	256
	Pooling	27x27x256	3x3	256
	Normalization	27x27x256	5x5	256
2*	Weight aux layer	27x27x256	27x27x256	256
3	Convolution	27x27x256	3x3x256x384	384
	Relu	13x13x384	-	384
4	Convolution	13x13x384	3x3x384x384	384
	Relu	13x13x384	-	384
5	Convolution	13x13x384	3x3x384x256	256
	Relu	13x13x256	-	256
	Pooling	13x13x256	3x3	256
6	Fully Connected	13x13x256	-	4096
7	Fully Connected	4096	-	4096
8	Fully Connected	4096	-	4096
9	Fully Connected	4096	-	2

C. Structure of Network

The network architecture is shown in Table I. A patch $u \in \mathbb{R}^{224\times224\times3}$ from RGB input image frame becomes an input to the CNN. Pre-trained convolutional layers from first to five layers of CaffeNet [30] are used in this system. We remove all the fully connected layers at the end of convolutional layers and add new three fully connected layers with 4096 nodes. Finally, the last new fully connected layer connects to an output layer that contains 2 nodes which represent the desired target or not. With this, we save several hours from training a complete network. We found that this step is important to achieve quite well the accuracy for generic target tracking as those layers are pre-trained on ImageNet datasheet.

Interestingly, our system can be viewed as a kind of previous framework [31], which consist of several stages. Feature extraction from the previous framework is viewed as the beginning layers of CNN, while the classification stage can be viewed as non-linear transformation of CNN. The difference is that CNN performs this process in an end-to-end manner, without requiring manual feature design. In addition, at last layer could be easily connected with a new layer for a more discriminative system.

D. Training

The first to five convolutional layers are pre-trained on ImageNet datasheet while performing fine-tuning on the new fully-connected layers. The last fully-connected layer has output of two labels, desired target, and non-target. During fine-tuning, first to five layers are set fix to prevent overfitting. Learning rate of $1e-5$ is used, and default hyperparameters of CaffeNet [30] are taken. Auxiliary layers on convolutional layer 1 and 2 are trained by minimizing eq. 2 to get the weights. Label in eq. 3 is obtained from the target center of the ground truth.

In practice, an object tends to move smoothly for each frame. Thus, only the surrounding previous target center is located. At first, the desired object on initial frame is located manually $[x, y, w, h]$ where (x, y) target bounding box center and (w, h) is width and height respectively. Then image patches c are randomly cropped and generated. For each image patch, we add padding by increasing the surrounding certain pixels to allow some contextual information about the target background. The desired target was not occluded in this work and not moving too fast. Basically, for fast moving object, the surrounding region could be increased but sacrificing the performance of the network and require more computation.

E. Generating bounding boxes

The CNN produces response map and target bounding box is estimated from the response map using common non-maximum suppression (NMS). Bounding box is represented by target center and width, height $[x, y, \text{width}, \text{height}]$. PID control is then employed to rotate pan-tilt turret to the target center.

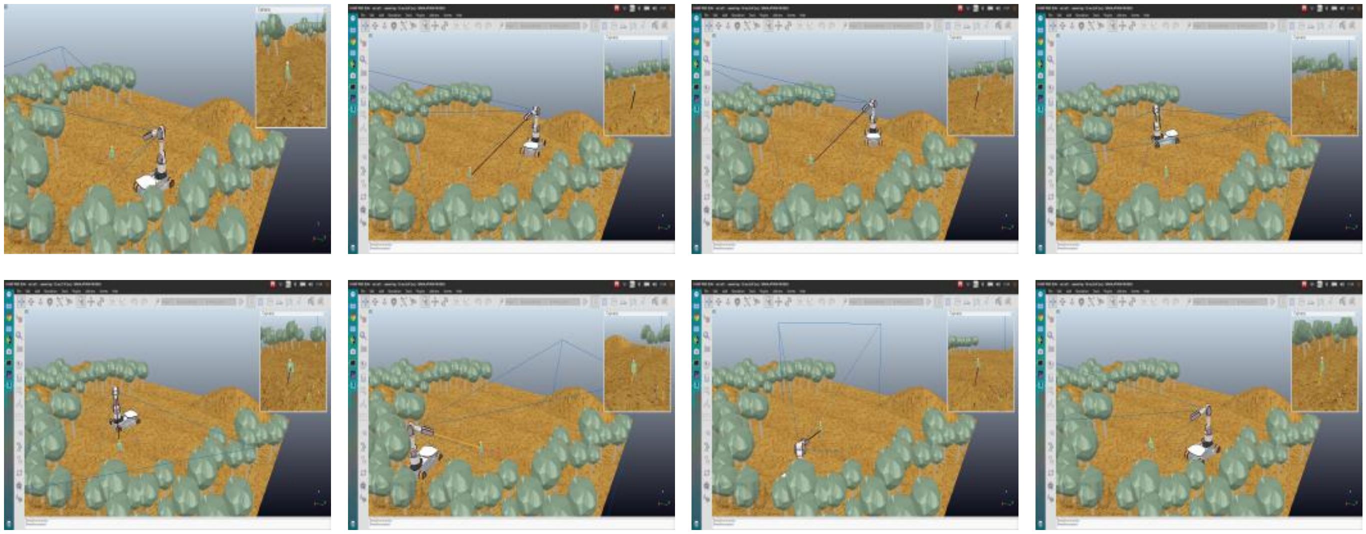

Fig. 4. Results of our system for tracking people while the mobile robot moves in circular. A turret's camera view is shown at the bottom-right of each image with the pointing laser.

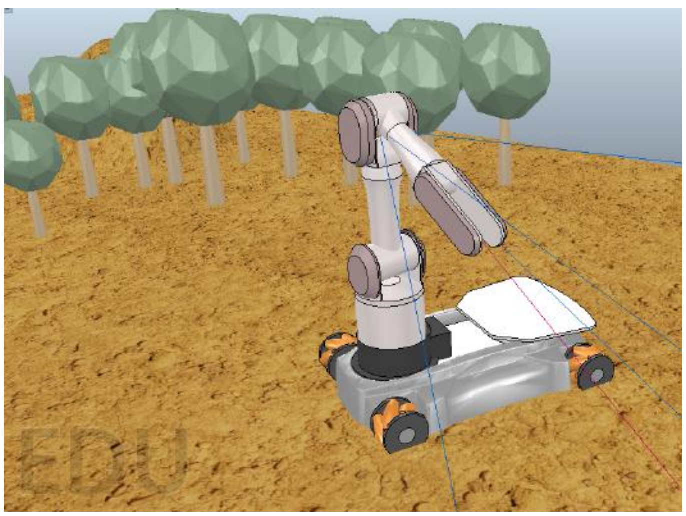

Fig. 5. Simulation setup in our experiment. A camera mounted on the end effector of the turret, with the laser pointing for better visualization and measuring tracking accuracy.

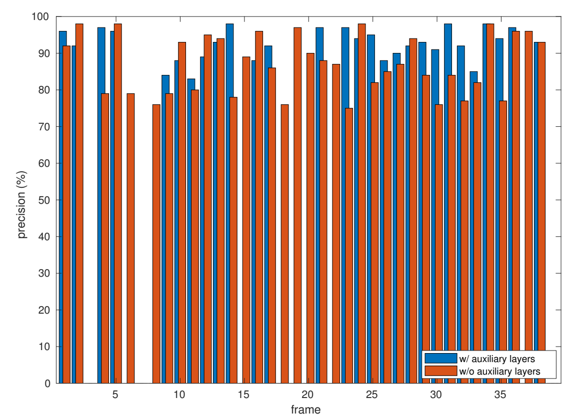

Fig. 6. Precision of our system with and without auxiliary layers. Frames with complex background and changing object appearance from video as in Fig. 4 are used.

IV. Experimental Results

In the experiment, a standard desktop PC with core i7 16Gb RAM running GPU 8Gb memory. Gun turret robotic platform is simulated in free version of V-REP [1]. The turret is equipped with laser as a pointing target. V-REP is connected with MATLAB for the CNN. A mobile platform of KUKA-Youbot robot with a turret is mounted on top it, as shown in Fig. 5. The robot's wheels are non-holonomic and the turret has two degree of freedom and a pointing gun. A camera is mounted at the end of turret effector.

The performance of our system is studied for tracking a person moving randomly—the person position does not jump quickly around the image. In the experiment, we found a delay in millisecond when MATLAB transfer certain robot data to VREP simulation system, which cause late detection. While it can slightly affect the accuracy of detection due to slight movement of a person. Despite of the delay, our system shows fairly well to track the desired target especially when the background is full of soil, a person changes the appearance as the person moves different angles, and uneven terrain. Bigger object (when the person is close to the camera) and smaller object (when the person is far to the camera) is shown still robustly been detected, as shown in Fig. 3. A more challenging object with the background is also tested as shown in Fig. 4. The desired object, which is a person, has quite similar appearance with the trees, but our still able to track the object relatively well.

Accuracy of our system is measured using the precision, which is shown in Fig. 6. Using the same configuration, the accuracy of the method is 80.35%. The effect of auxiliary

[1]http://www.coppeliarobotics.com/

layers can also be seen clearly in the figure as the precision leading compared to without auxiliary layers. This could be attributed to the richer feature representation that can solve complex background and changing appearance of object relatively well. For certain position where the object is occluded with the tree, our method fails to track due to missing object and could be attributed to the slow motor and PID parameters not optimally set. Despite of those, our method still manage to track relatively well.

V. Conclusion

An automatic targeting system of gun turret is developed in this paper. The system is designed to be able to work on complex background and changing appearance of generic object. Differing from the previous manually design features works, our system is learned in an end-to-end manner. Parameters are solely learned from training data. While fine tuning only on the last layer can capture semantic information of the target, however the main purpose for object tracking is localize the target. Therefore, we have developed a network to perform target tracking with auxiliary layers to get a richer feature representation. First and second layers are used to capture spatial information with the addition of semantic from the last layer. The experiments have shown fairly well for visual targeting system of gun turret.

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