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Deep Learning based collision detection system for construction sites: System Architecture and working of viAct's Smart Module

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ABSTRACT
Accidents related to machine collision is in fact, a matter of great concern in the construction industry. Accidents in the construction sites generally occur due to three scenarios viz. human-machine collision, machine object collision, and machine-machine collision which not only is the a reason for workforce injuries but also a cause for defaults in machine leading to delayed work timelines. In lieu to this issue viAct has developed its scenario based collision detection system through viAct's tailor-made, self developed AIoT product viz. Danger Zone Alert Sensoring System (DZASS). The module uses the convolution neural network for image recognition and processing and creation of danger zones for detection any collision in the jobsite. The mean average precision of the model was evaluated to be 76.5 in working environment demarcating the effectiveness of the model in construction job-site. Additionally, after detection of potential collision scenarios, viAct powerful cloud sends audio-visual alerts to machine operators for urgently taking appropriate action to prevent collision. On the same time real time alerts are also sent to jobsite managers as well as remote stakeholders for transparent functioning of construction sites. Moreover, viAct's smart dashboard keeps a track of all such non-compliances for effective planning of collision risk mitigation efforts.
KEYWORDS: *viAct, Artificial Intelligence, ConTech, Machine Anti-collision*

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I. INTRODUCTION

Heavy machineries are common elements in the construction sites. The construction vehicles/machineries reduces the time to complete a particular task, which otherwise would require much time if done manually and as such increases the productivity. As for example, the cranes perform the lifting functions that were once performed by the pulleys and backbreaking human labour. However, with the great number of advantages of using massive and powerful machineries in the construction sites, comes great number of inherent risks. Accidents related to machine collision is in fact, a matter of great concern in the construction industry. Accidents in the construction sites generally occur due to three scenarios viz. human-machine collision, machine object collision, and machine-machine collision which not only is the a reason for workforce injuries but also a cause for defaults in machine leading to delayed work timelines. Thus, the huge property and labour loss bought by the machine related collisions every year in the construction industry have generated the need for some advanced monitoring options to be employed in the construction sites, which is way more efficient and reliable than manual monitoring.

In this connection, viAct which is one of the leading Ai based ConTech startup from Hong Kong, has developed its scenario based collision detection system through viAct's tailor-made, self developed AIoT product viz. Danger Zone Alert Sensoring System (DZASS). This collision detection system is a smart AI & computer vision enabled solution that allows the machine operators, on-site as well as the remote managers to effectively monitor and avoid any scenario of machine collision. This smart plug & play system has been developed in such a way that it works effectively with any kind of CCTV cameras with the resolution of 2 MP by installing it around the machinery. In case of any close proximity of human/object/machine towards the machinery, the edge processing unit automatically detects it and sends instant and automatic audio-visual alerts to machine operator to stop and prevent any such collision. Further, viAct's integrated dashboard records these smart insights, which can be later used for training the workers to avoid the occurrence of any such mishappening in the future.

Therefore, this paper presents the structural architecture behind viAct's smart collision detection system with its working mechanism. The paper also brings forward a comprehensive understanding on how AIoT offers a smart solution which is error free with low human interference, sophisticated yet effective for monitoring deadly machine collisions in construction jobsites.

II. EXPERIMENTAL FRAMEWORK

2.1 System Architecture of viAct's collision detection system

viAct leverages the benefits of a Artificial Intelligence of Things (AIoT) architecture to provide for maximum scalability. AIoT is the amalgamation of artificial intelligence (AI) and Internet of Things (IoT) which has been utilized for achieving enhanced IoT operations, enhancing human-machine interactions for an effective data management and analytics. viAct has made use of AIoT for advanced detection of collision scenarios difficult to be monitored via human inspection. The technology is based on equipping IP cameras with a standard computer vision, later the cameras are customized in accordance with specific use cases by training it with deep learning algorithms.

viAct has developed the collision system to detect three collision scenarios which are human-machine collision, machine object collision, and machine-machine collision. All the three developed modules follow architectural similarity and thus to understand the system architecture of the entire smart collision system, viAct's human-machine collision detection module has been chosen as a reference and described in a step-by-step fashion below.

For viAct's human-machine collision detection module, in the first step the IP cameras installed over the machineries is linked to viAct's cloud platform via the Real Time Streaming Protocol (RTSP) link which captures the images of objects which is then retrieved and decoded from the stream for AI processing in the second step (Fig. 1)

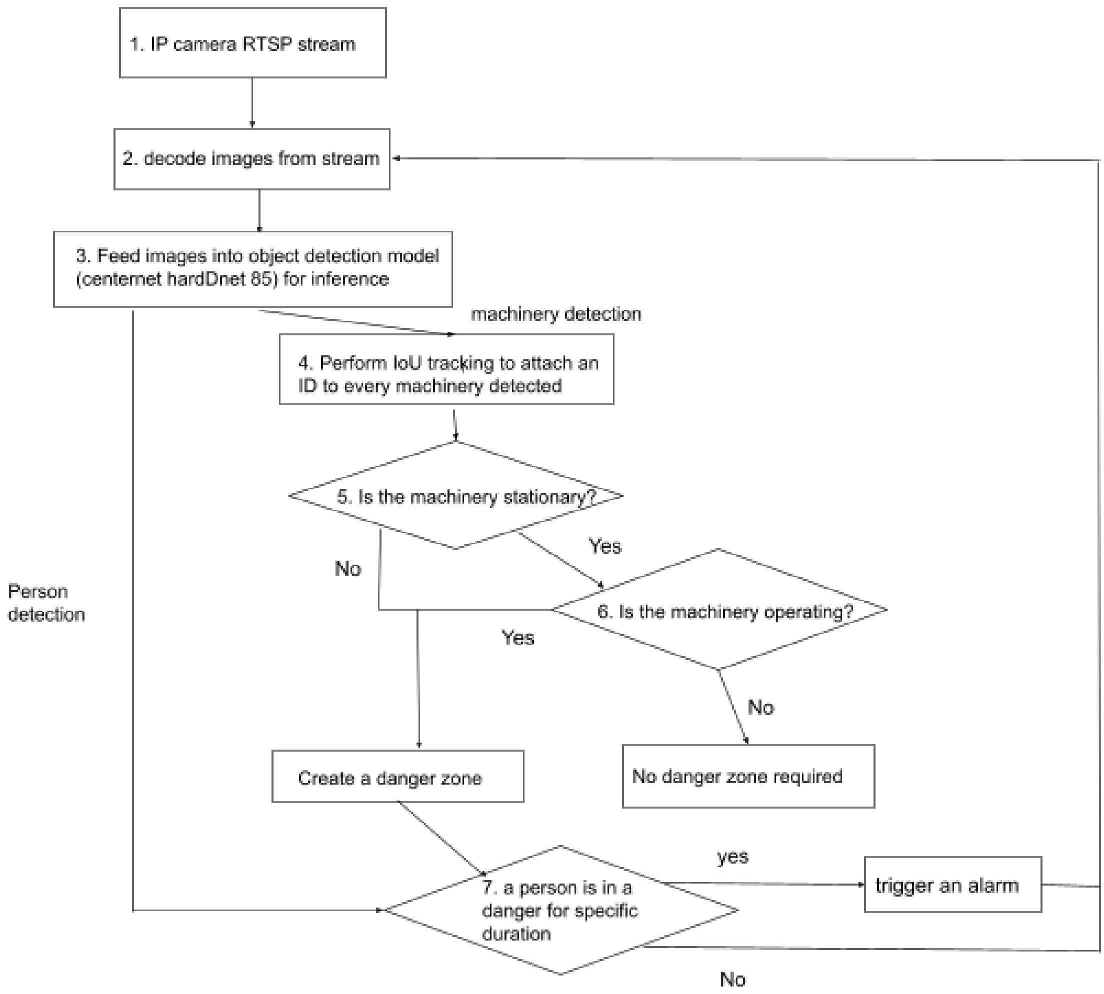

Fig 1: System Architecture of viAct's human-machine collision detection system for construction jobsites

The third step comprises of feeding images into object detection model. For the current module, Centernet harDnet85 is selected as the CNN architecture of the object detection model which gives "person" and "machinery" as the predicted classes. As opposed to anchor-based architecture such as Yolo and SSD, Centernet does not require pre-configured anchor selection which sometimes needs to be adjusted based on dataset (Zhou et al., 2019). Using HarDnet85 as the backbone, it reduces the Dynamic Random Access Memory (DRAM) traffic and hence increases the inference speed (Chao et al., 2019).

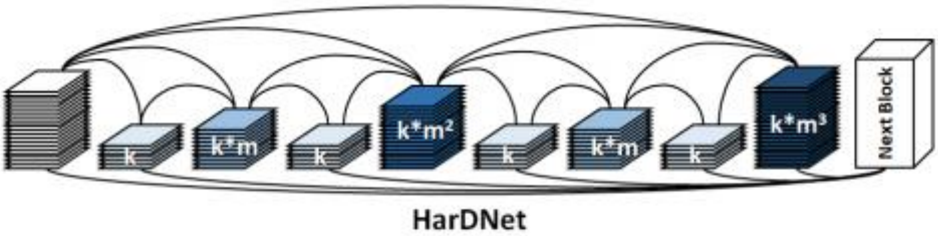

Fig 2: HarDNet Block Overview

In the forth step, every machinery detected is attached with an ID by performing IoU (intersection over union). IoU calculates the percentage of overlap between two bounding boxes. Pairwise IoU is computed between the bounding boxes i.e. results of the current time frame and the previous time frame. Bounding boxes are assigned to achieve the maximum total sum of IoU.

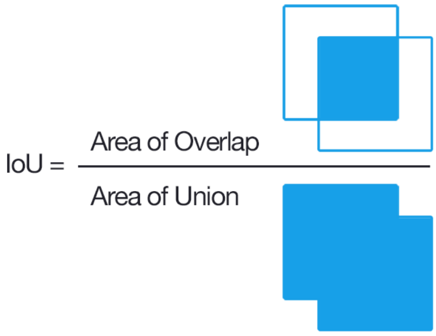

Fig 3: IoU equation with visual interpretation

Furthermore in the final step, machinery movements are analyzed for defining danger zones. Two criterions are employed. First of all, machinery needs to be in a moving state. Secondly, machinery is stationary but in operation, as indicated by action such as moving crane arm.
To identify the movement of stationary machinery, Lucas Kanade method (Lucas et al., 1981) is used to estimate its motion. The movement of pixels in x,y direction (u,v) is given by the following equation

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} \sum_i {f_{x_i}}^2 & \sum_i f_{x_i} f_{y_i} \\ \sum_i f_{x_i} f_{y_i} & \sum_i {f_{y_i}}^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i f_{x_i} f_{t_i} \\ -\sum_i f_{y_i} f_{t_i} \end{bmatrix}$$

Here fx and fy are the image gradients in x,y direction respectively
Therefore through a similar CNN architecture the system also detects machine-object collision and machine-machine collision (Fig 4).

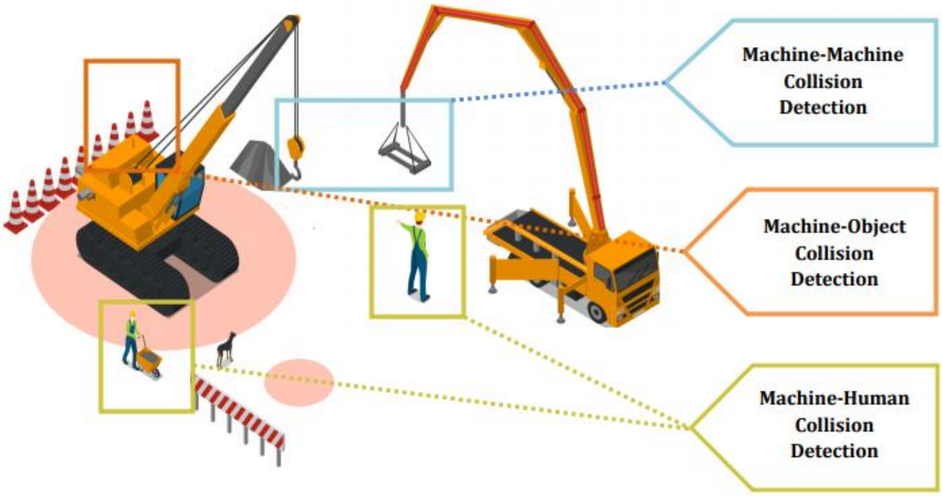

Fig 4: Overview of viAct's Scenario based Collision detection system for construction sites

2.2 Model Output

The model is tested on mean average precision (mAP) metric which is the product of precision and recall of the detected bounding boxes. The mAP value ranges from 0 to 100. Any detection is considered a true positive only if the mAP is above 0.5. The mAP is considered as a good measure of the sensitivity of the network while not raising many false alarms (Nath et al., 2020). The on testing the existing model in real work environment i.e. construction job-site, it has been observed that the model for object detection was evaluated to be 76.5 demarcating the effectiveness of the model in detection of collisions in construction job-site to create a anti-collision environment.

III. Working of viAct's collision detection system

Despite of the sophisticated system architecture, viAct's collision detection system is a simple plug and play facility. The four step working of the system makes it easy for any person even without technical expertise to deploy and use it on their construction sites.

a) Connecting cameras to the machinery

The preliminary step comprises of connecting 4 IP cameras around the machinery like excavator, crawler, crane, forth lift, loader or bull-dozer which will be connected to viAct's smart cloud platform. Any IP camera with a resolution of 2 MP or more can be connected to viAct's cloud platform via the RTSP link. These cameras will capture any instance of human-machine collision, machine-object collision, and machine-machine collision in the construction sites

Fig 5: Connecting cameras to the machinery

b) Drawing/defining different layers of danger zones

Once the cameras are connected the users are required to draw/define different layers of danger zones in viAct.ai platform either as an area or a line.

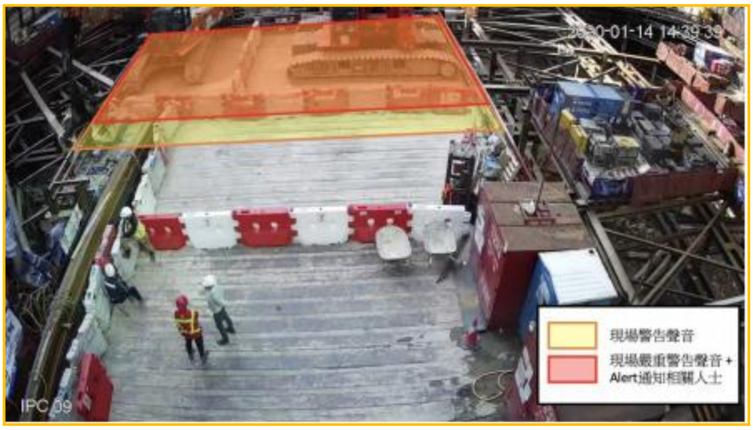

Fig 6: Drawing/defining different layers of danger zones

c) Audio-visual alerts on machine collision instances

After the cameras are installed on the machine and danger zone is drawn, the edge processing unit powered by viAct's smart cloud automatically detects if there is any human/object/machine walking/working/standing in very close proximity (within 0.5m) to the machine within the marked danger zone demarcated by the user. In case of any such incidence, automatic audio-visual alerts are sent to the machine operator to stop immediately and to the on-site managers as well enabling them to initiate immediate action to avoid collision-related accidents. In the meantime, connecting to viAct's cloud platform, a real-time alert is sent to the stakeholders at remote sites via SMS, email or instant messaging app for instant surveillance of the construction site.

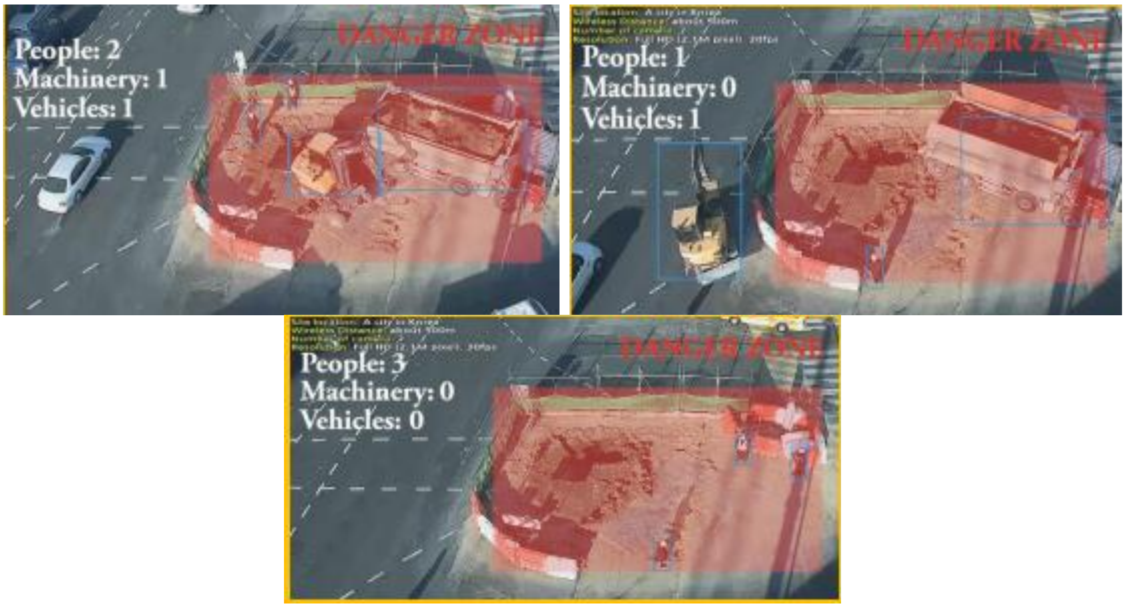

Fig 7: Audio-visual alerts on machine collision instances

d) Record-keeping in the dashboard

The final step towards collision detection is record-keeping. viAct's integrated dashboard records the pictures & videos of all instances of human/object walking or standing near machines/vehicles. The dashboard provides trend oriented reports of the alerts that can be viewed for a particular date range, and can be used later for training workers to avoid any machine collision related accidents and for better monitoring and management of the construction site.

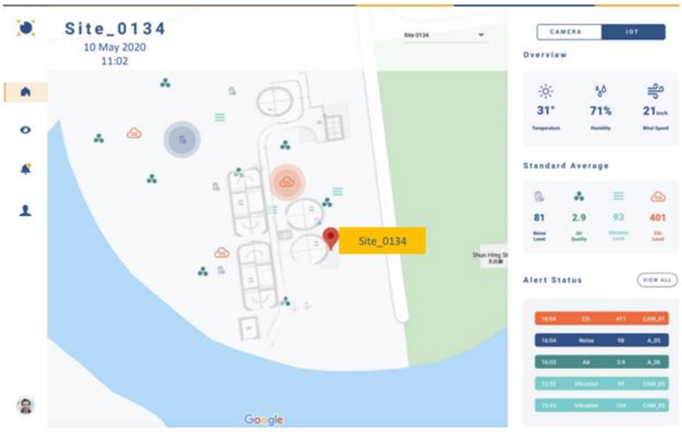

Fig 8: Record-keeping in the dashboard

IV. CONCLUSION

Accidents related to machine collision is in fact, a matter of great concern in the construction industry. Accidents in the construction sites generally occur due to three scenarios viz. human-machine collision, machine object collision, and machine-machine collision which not only is the a reason for workforce injuries but also a cause for defaults in machine leading to delayed work timelines. In lieu to this issue viAct has developed its scenario based collision detection system through viAct's tailor-made, self developed AIoT product viz. Danger Zone Alert Sensoring System (DZASS). The module uses the convolution neural network for image recognition and processing and creation of danger zones for detection any collision in the jobsite. The mean average precision of the model was evaluated to be 76.5 in working environment demarcating the effectiveness of the model in construction job-site. Furthermore, after detection of potential collision scenarios, viAct powerful cloud sends audio-visual alerts to machine operators for urgently taking appropriate action to prevent collision. On the same time real time alerts are also sent to jobsite managers as well as remote stakeholders for transparent functioning of construction sites. Moreover, viAct's smart dashboard keeps a track of all such non-compliances for effective planning of collision risk mitigation efforts.

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