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Architecture and Working of viAct's Danger Zone Alert Sensoring System (DZASS): Safety Monitoring for Construction Machineries

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ABSTRACT
DZASS is a well crafted AIoT solution for monitoring heavy construction vehicles by Asia's leading ConTech startup; viAct. As the nature of construction is extremely complex, manual monitoring of workplace hazards associated with heavy vehicles and machineries is extremely inaccurate. Such a situation is not only detrimental to the workers but also adds up to accidental costs and project delays as well. Thus, DZASS is specifically crafted solution to prevent clash of heavy machineries with humans, other machineries and surrounding objects in a construction job site. It uses the real-time object detection model viz. Yolox-tiny as the model architecture for higher accuracy in detection. The AP50 of the model was evaluated to be 92.4% in working environment demarcating the effectiveness of the model in construction job-site. Furthermore the system has additional benefits like high reliability, flexible usage and seamless connectivity that make DZASS an extraordinary product of viAct for making operations of heavy vehicles and machineries safer in construction sites.

I. INTRODUCTION

In lieu with the great number of occupational hazards that are witnessed in the construction sites every day, viAct has introduced an exclusive AI monitoring for construction machineries viz. Danger Zone Alert Sensoring System (DZASS). DZASS makes machine operations 10X safer than traditional monitoring technologies through its enhanced monitoring abilities. Enabled with the power of AI powered vision technology, real time audio-visual alert system along with a remote tracking dashboard; DZASS becomes a powerful, reliable and effective system to boost safety of construction operators operating huge machineries as well as workers from any unprecedented event. It helps in preventing clash of these machineries with humans, other machineries and surrounding objects like traffic cones, animals, water barriers and fencing during its operations. Thus, DZASS is viAct's AIoT solution with collection of hardware/equipments that is installed on a heavy machineries and vehicles like crane to maintain operational safety of these vehicles.

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Fig 1: Safety monitoring of heavy machinery operations

DZASS provides a safety monitoring solution for construction sites to prevent accidents related to heavy machinery. It helps all tiers of human resource involved with machine operations to from workers to operators to supervisors. When any person is detected in danger zone, light & sound alarm is generated to alert nearby people. For those entering in a danger zone wearing personal alarms, they are alerted by a buzzing sound and vibrations. For vehicle operators, an alert is also shown on the monitor inside the cabin so the operator can react and prevent more severe damage. Furthermore, for on-site and remote supervisors instantaneous email and SMS alert is send in case of any non-compliance. Apart from this, the moment of accident is recorded as video clips and is sent to the supervisors directly.

Thus, the current paper depicts the working and architecture of viAct's advance monitoring system; DZASS with special reference to its utility in preventing construction accidents

II. EXPERIMENTAL FRAMEWORK OF DZASS

1.1. Hardware Components

DZASS contains an AI system for AI processing and an IoT system for peripheral sensors. The AI system performs computer vision analysis on camera or LIDAR image. When a person is detected, it triggers a series of alert system, such as email alert and SMS alert. It also communicates with IoT system to form unique triggering conditions. The IoT system is responsible for controlling all IoT sensors. Depending on different situations, the IoT system triggers alert based on the data returned from the IoT sensors. It in turn communicates with AI system to form unique triggering condition. Thus, IoT sensors provide more information of the working environment. Furthermore, an Inertial Measurement Unit is used to capture all movements and postures of the heavy machinery. Ultra Wide-Band Real Time Location System provides much more accurate location information of the heavy machinery. Working with near UWB stations, the UWB devices records the daily movement path of the heavy machinery. In addition to preventing collision of heavy machineries, it also provides data for analyzing daily utilization and efficiency. Additionally, DZASS supports interaction with ibeacons. This is an alternative of UWB RTLS to provide location information of the heavy machinery. Even though the accuracy of ibeacons is less than UWB RTLS, it is however easier to be deployed in construction site.

For outdoor scenario, DZASS provides GPS location of the heavy machinery. It supports interaction with LoRaWAN making it possible to integrate with other LoRaWAN sensors deployed even by other companies. In terms of connectivity, DZASS has embedded LTE modem and WiFi modules. For construction sites that can provide WiFi for internet access, they also have access to the live stream of the cameras connected to DZASS. However for construction sites that cannot provide WiFi for internet access, DZASS can still work as standalone system using the embedded LTE modem to access the internet

In an ideal scenario, a DZASS system consists of 4 cameras. These 4 cameras cover at least 180° angle of view and a distance of 6m from the heavy machinery. However in specific scenarios, a LIDAR will be added to a DZASS system which creates a 3D profile of the region of

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interest; combined with camera, the complete 3D model of desired view can be obtained. Furthermore, a wide range of alert systems are supported in DZASS.

2.2 System Architecture

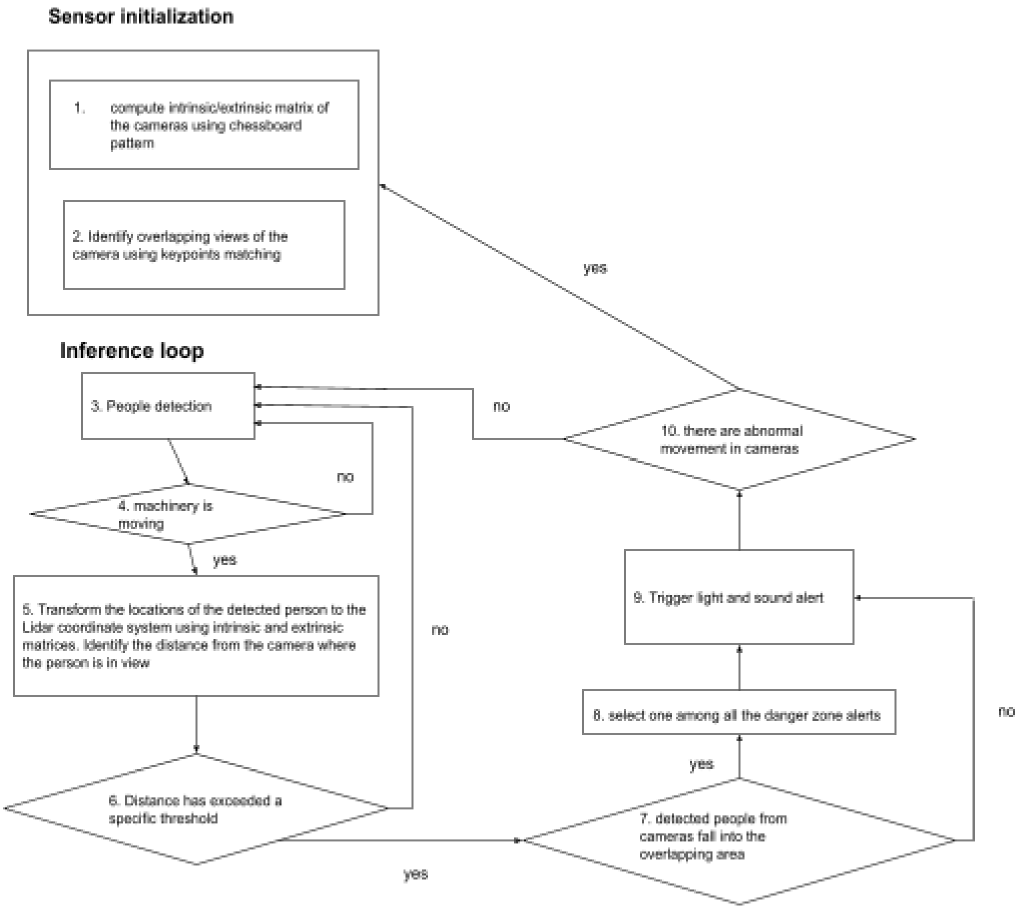

Fig 2: System Architecture of DZASS

2.2.1 Sensor Initialization

Calibration of the cameras is done by employing the methodologies described in https://docs.opencv.org/3.4.15/dc/dbb/tutorial_py_calibration.html. It begins with taking photos of a chessboard pattern with the cameras under various camera angles. Intrinsic matrix and distortion matrix and the rotation matrix with respect to the chessboard are computed using the functions implemented in opencv. With those parameters, 3D coordinates of the detected corners of the chessboard can be calculated.

The calibration procedure then proceeds with performs PCA analysis on the 3D coordinates of corners under different cameras views, as described by Kim & Park, 2020

$$A = \begin{bmatrix} x_{C_i}^1 & y_{C_i}^1 & z_{C_i}^1 & 1 \\ x_{C_i}^2 & y_{C_i}^2 & z_{C_i}^2 & 1 \\ & \vdots & & \\ x_{C_i}^m & y_{C_i}^m & z_{C_i}^m & 1 \end{bmatrix}$$

m refers to camera view 1 and i refers to the ith detected corner on the chessboard pattern.

SVD decomposition gives the coefficients of the plane equation in form of $a_0\ a_1 x + a_2 y + a_3 z = 0$

As for lidar, the plane equation of the chessboard pattern can be found by the RANSAC algorithm. It starts with computing the initial plane equation by sampling points from the region of interest. The process continues to refine the results until it

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satisfies the convergence conditions, one of which is the percentage of inlier points

The transformation matrix from camera coordinates to lidar coordinates divides into translation and rotation matrices. Translation matrix is calculated by minimizing the distance between 2 planes and rotation matrix is found by minimizing the difference in orientation between the transformed plane equation of chessboard pattern of camera and plane equation of chessboard pattern of lidar

$$\varepsilon_R = \sum_{i=1}^{N} \left| \left(RN_{C_i}\right) \cdot N_{L_i} - 1 \right|,$$

ε_R: An error term indicating how the 2 surface normals match

R: Rotation matrix

N_{C_i}: Surface normal of the chessboard pattern of camera

N_{L_i}: Surface normal of the chessboard pattern of Lidar

Furthermore, ORB is selected as a feature detector. It is a combination of FAST detector and BRIEF descriptor. FAST finds keypoints candidates by comparing a pixel with its 16 surrounding pixels in a circle and Harris corner detector is used to identify the top candidate

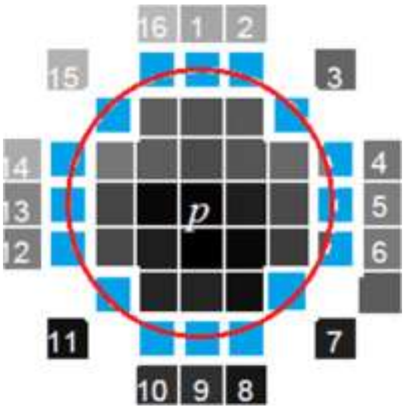

Fig 2: FAST detector

$$M = \sum_{x,y} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}$$

I_x, I_y refers to the image gradients in x and y direction respectively.

Eigenvalues of the matrix are used to identify corner point in an image (https://www.cs.cornell.edu/courses/cs4670/2015sp/lectures/lec07_harris_web.pdf)

After getting the features points and descriptors, pairwise hamming distances are calculated between keypoints to find the best match that minimizes the sum of hamming distances. A minimum bounding polygon of the best n keypoints is estimated as the overlapping area.

2.2.2 Inference Loop

Yolox-tiny is used as model architecture. It achieves a good tradeoff between throughput and accuracy (Ge et al., 2021). The model is retrained using custom training data. Furthermore, IMU data (linear velocities, acceleration, angular velocities) is used to identify movement patterns of the machinery. Sparse optical flow tracks the movement of a subset of pixels. Deviations of average pixel movement of a camera from that of other cameras can be an indication of camera displacement, which calls for sensors recalibration and onsite repair

$$I(x, y, t) = I(x + dx, y + dy, t + dt)$$

Gradient of image pixel with respect to x-axis, y-axis and time

III. RESULTS & DISCUSSION

The precision of the model was measured in AP50 which was estimated to be around 92.4%.

Furthermore, the DZASS system is a tailor-made for the construction site also because of three exceptional features as discussed below:

Reliability

The cutting-edge AI enabled smart machinery is reliable in detection of unwanted objects (i.e. human or vehicles) in the destined zones without any false alarms on irrelevant objects thereby creating an automated anti-collision environment

Flexibility

The simple UX of the AI enabled smart machinery makes it flexible to be used by any non-technical user without expertise in AI and ability of the same system to be deployed in different types of machines makes it extremely handy

Connectivity

The seamless AI enabled smart machinery automatically generates instant audio-visual alerts of unprecedented events for the on-site mangers and message alerts for senior management through SMS, email etc. enabling remote site monitoring

IV. CONCLUSION

DZASS is a well crafted AIoT solution for monitoring heavy construction vehicles by Asia's leading ConTech startup; viAct. As the nature of construction is extremely complex, manual monitoring of workplace hazards associated with heavy vehicles and machineries is extremely inaccurate. Such a situation is not only detrimental to the workers but also adds up to accidental costs and project delays as well. Thus, DZASS is specifically crafted solution to prevent clash of heavy machineries with humans, other machineries and surrounding objects in a construction job site while operating. It uses the real-time object detection model viz. Yolox-tiny as the model architecture for higher accuracy in detection. The AP50 of the model was evaluated to be 92.4% in working environment demarcating the effectiveness of the model in construction job-site. Furthermore the system has additional benefits like high reliability, flexible usage and seamless connectivity that make DZASS an extraordinary product of viAct for making operations of heavy vehicles and machineries in construction sites safe.

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