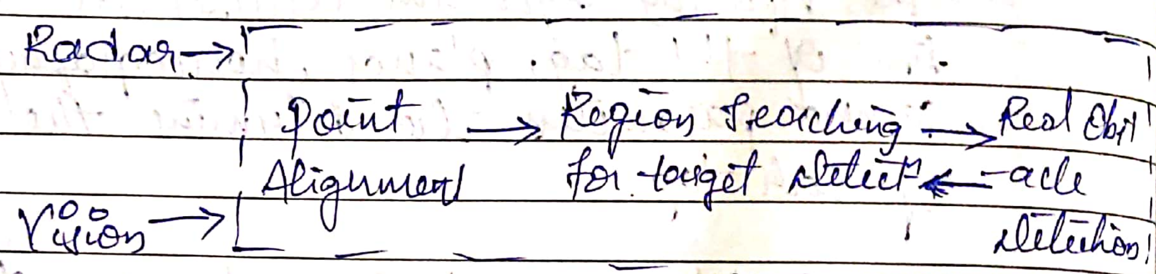
Integrating Millimeter Wave Radar with Monocular Vision Sensor for On-Road Obstacle Detection Applications

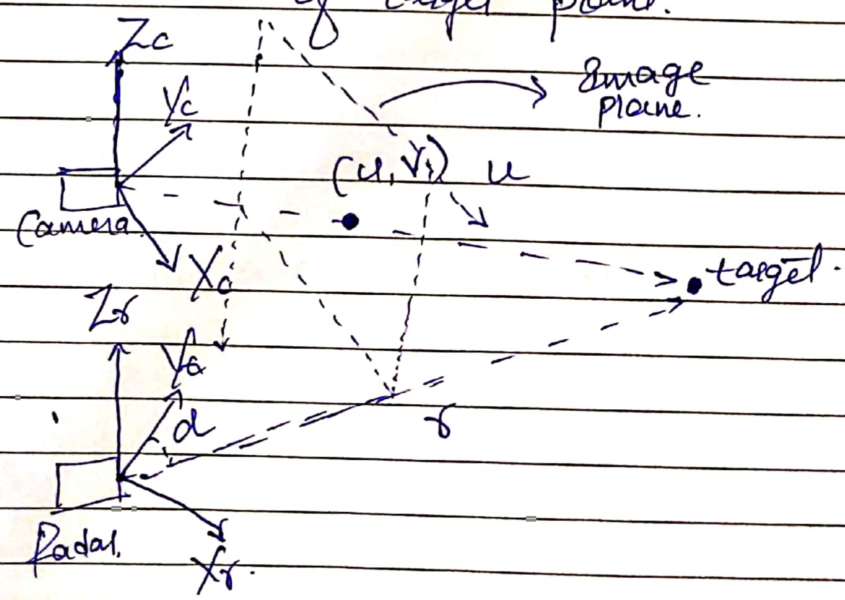
Proposed Fusion Approach

Fusion Scheme of MMW Radar and a monocular Vision Sensor.



Radar-Camera Coordinate Calibration

$X_r, Y_r, Z_r \rightarrow$ MMW Radar coord.
$X_c, Y_c, Z_c \rightarrow$ Camera co-ord
$u, v \rightarrow$ Image coord.
$r \rightarrow$ Range of targets in the radar coordination
$\alpha \rightarrow$ azimuth of target point.



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Transformation relation of Radar to Image coord. frame.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{21} \\ t_{31} & t_{32} & t_{33} \end{bmatrix} \begin{bmatrix} r \cdot \sin\alpha \\ r \cdot \cos\alpha \\ 1 \end{bmatrix}$$

→ Transformation matrix (T_I^R).

6 Parameters of Transformation matrix can be solved through following calculation.

Let,

$T_i = [t_{i1} \; t_{i2} \; t_{i3}]'$,

$U = [u_1 \; u_2 \; \ldots \; u_n]'$,

$V = [v_1 \; v_2 \; \ldots \; v_n]'$

$I_{n\times1} = [1 \; 1 \; \ldots \; 1]'$ and.

$$P = \begin{bmatrix} x_r^1 & y_r^1 & 1 \\ \vdots & \vdots & \vdots \\ x_r^n & y_r^n & 1 \end{bmatrix}$$

n = number of aligned points.

(x_r^j, y_r^j) $j = 1, 2 \ldots n$ $(n \geq 4)$ ⟶ Position of the aligned point in radar coord.

$T_I^R = [T_1 \; T_2 \; T_3]'$ is obtained through linear least square method.

where, $T_1 = (PP^T)^{-1} P^T U$
$T_2 = (PP^T)^{-1} P^T V$
$T_3 = (PP^T)^{-1} P^T I_{n\times 1}$

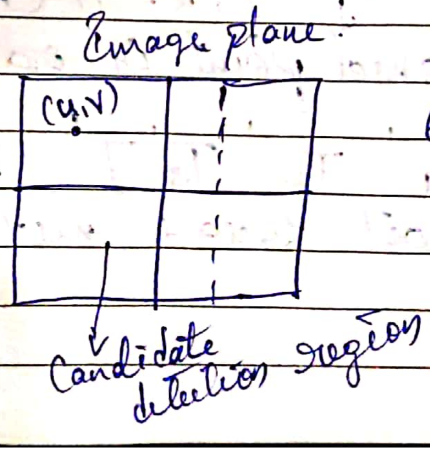
$(u_c, v_c) \rightarrow$ Centroid of the image of panel.

$$u_c = \frac{\sum_{w} w \cdot I_{w,h}}{\sum_{w,h} I_{w,h}}$$

$$v_c = \frac{\sum_{h} h \cdot I_{w,h}}{\sum_{w,h} I_{w,h}}$$

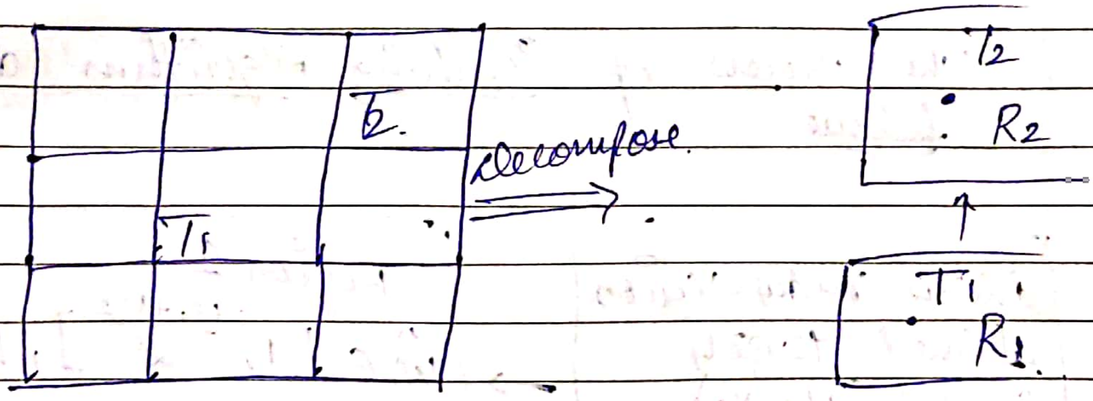
where, $w, h \rightarrow$ width & height of the image of the panel.
$I_{w,h} \rightarrow$ Pixel value.

→ The search strategy for potential obstacle detection in order to decrease the image processing time, especially for large image sizes.



6.a) Candidate region for single target detection

6 b.) Candidate region for 2-target detection



u,v → Radar-Camera aligned (calibrated) point.

C-Region → Candidate region for potential object detection.

$$\text{C-Region} = \begin{cases} \hat{w} \in [1, u + W/2],\ \hat{h} \in [1, v + H/2] & \text{if } u \le W/2,\ v \le H/2 \\ \hat{w} \in [1, u + W/2],\ \hat{h} \in [v - H/2, H] & \text{if } u \le W/2,\ v > H/2 \\ \hat{w} \in [u - W/2, W],\ \hat{h} \in [1, v + H/2] & \text{if } u > W/2,\ v \le H/2 \\ \hat{w} \in [u - W/2, W],\ \hat{h} \in [v - H/2, H] & \text{else} \end{cases}$$

W, H → Total width & height of panel image.

6. b) It describes region searching scheme in the image with 2 targets.

The process of searching Algorithm described below.

Initial radar-vision aligned targets (u_1, v_1) (u_2, v_2)

$(u_1 < u_2,\ v_1 > v_2)$

Region 1

$\hat{w}_1 \in \left[1, \frac{u_1+u_2}{2}\right]$, $\hat{h}_1 \in [V_2, H]$

Obstacle boundary detection: Right border $-\tilde{u}_1$

Region 2

$\hat{w}_2 \in [\tilde{u}_1, \hat{W}]$

$\hat{h}_2 \in [V_2, H]$

Object Detection.

$h(i) \rightarrow$ adaptive threshold selection for edge detection

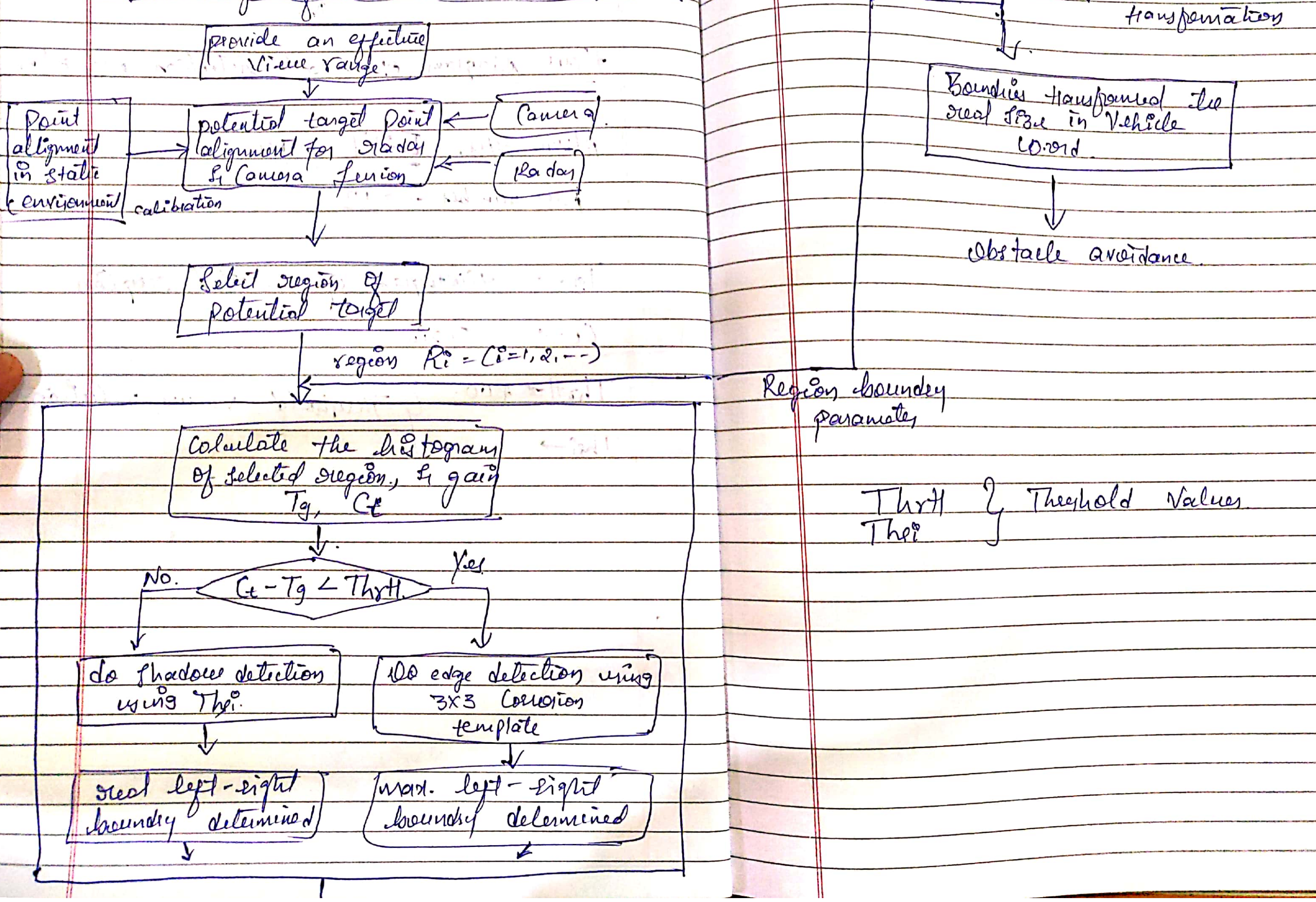
$i = 0, 1, 2, \ldots 255$

$N =$ Total no. of pixels.

$C(i) \rightarrow$ Number of the i^{th} gray-level pixels.

$$h(i) = \frac{C(i)}{N}$$

Flow diagram of Obstacle detection algorithm



ThrH, Thei } Threshold Values