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

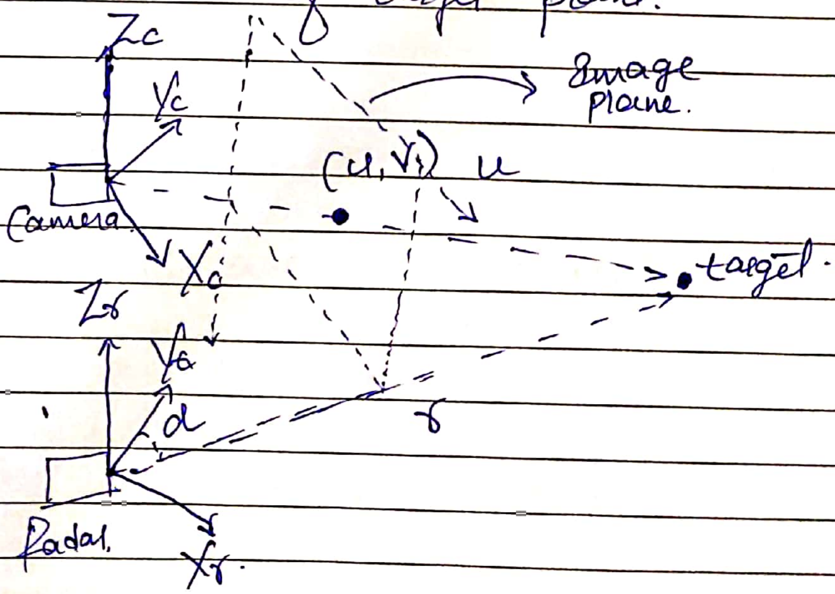
Proposed Fusion Approach

Fusion Scheme of MMW Radar and a monocular vision sensor.

Radar → | Point Alignment → Region Searching for target detect → Real Obstacle detection
Vision → |

Radar-Camera Coordinate Calibration

X_r, Y_r, Z_r → MMW Radar Co-ord.
X_c, Y_c, Z_c → Camera Co-ord
u, v → Image Co-ord.
r → Range of targets in the radar coordination
α → azimuth of target point.



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,

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

$U = [u_1\ \ u_2\ \dots\ u_n]'$,

$V = [v_1\ \ v_2\ \dots\ v_n]'$

$I_{n\times1} = [1\ \ 1\ \dots\ 1]'$ 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) $j = 1, 2 \dots n$ $(n \geq 4)$ → 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,
$$T_1 = (P P^T)^{-1} P^T U$$
$$T_2 = (P P^T)^{-1} P^T V$$
$$T_3 = (P P^T)^{-1} P^T I_{n\times1}$$

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

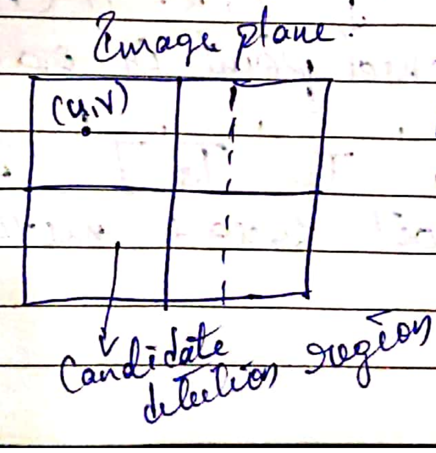
$$u_c = \frac{\sum_w w \cdot I_{w,h}}{\sum_{w,h} I_{w,h}}$$

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

where, $w, h \rightarrow$ width & height of the image of the panel.

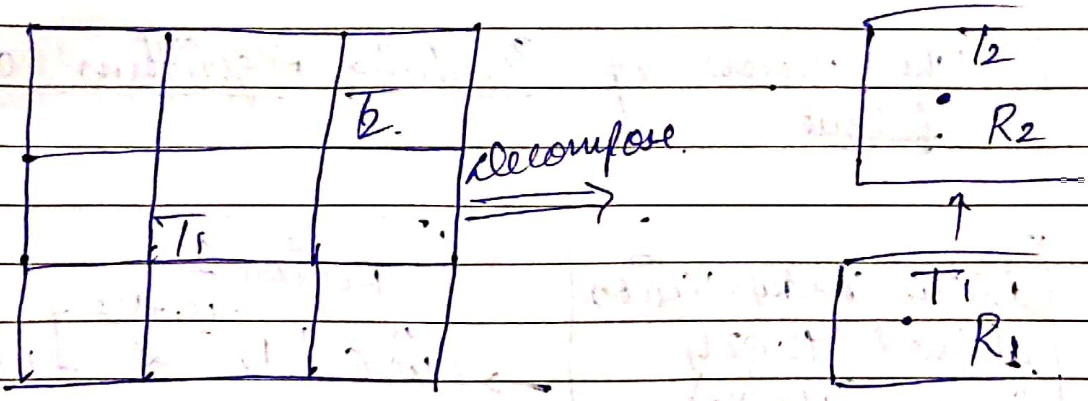
$I_{w,h} \rightarrow$ Pixel Value.

→ 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



$u, v \rightarrow$ Radar – Camera aligned (calibrated) point.

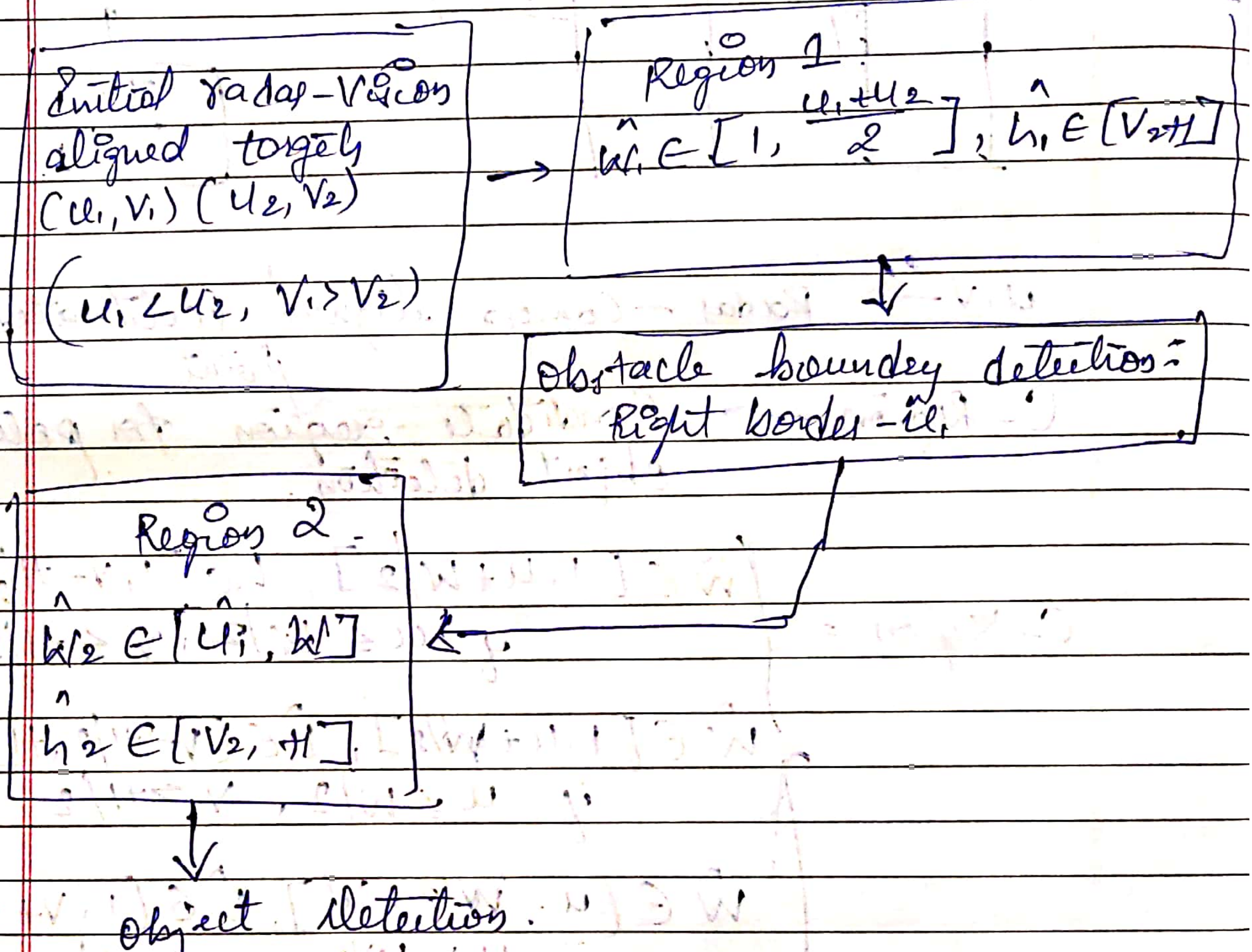
C-Region $\rightarrow$ Candidate region for potential object detection.

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

$W, H \rightarrow$ 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.



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

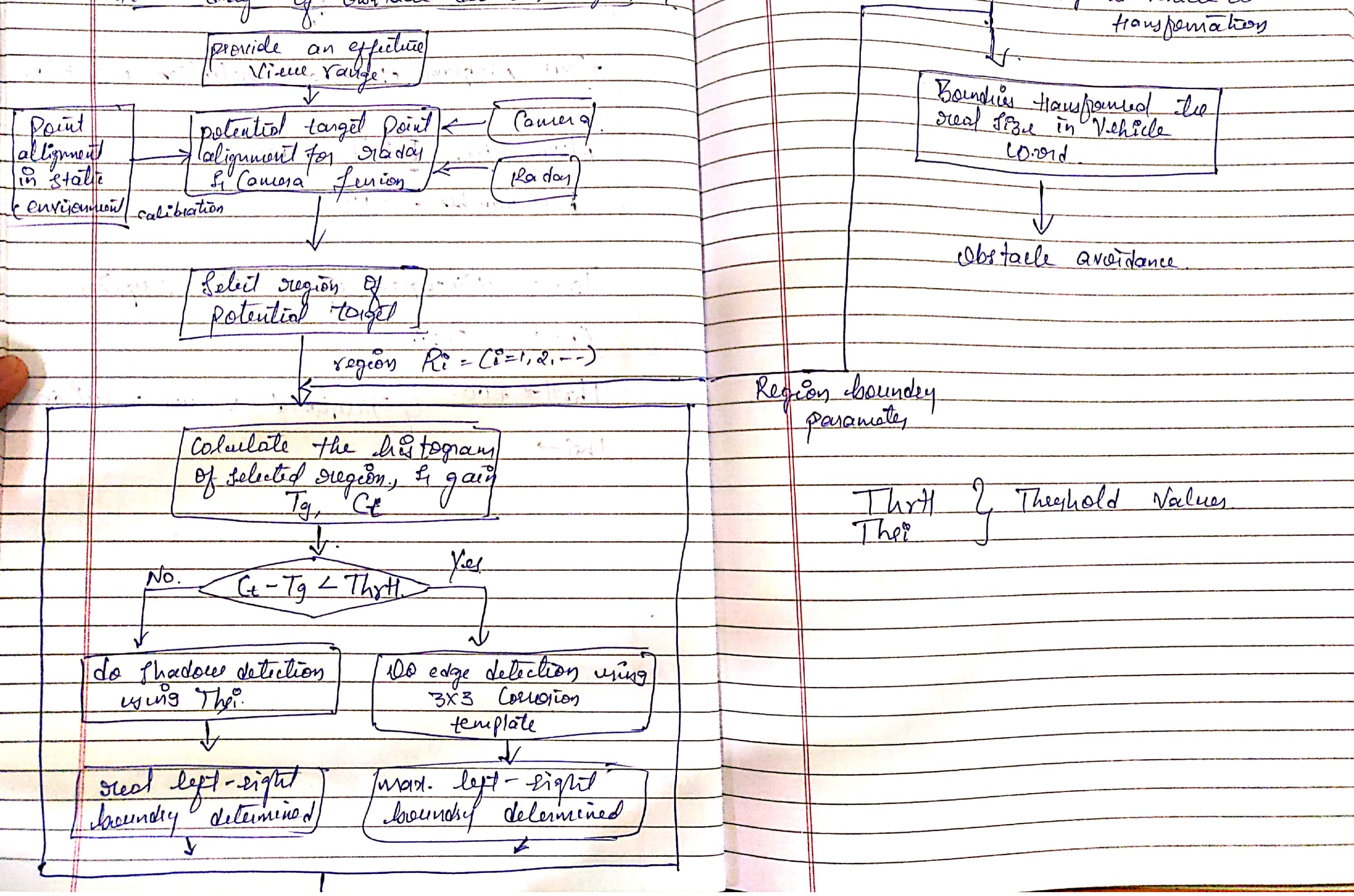
$i = 0, 1, 2, \ldots 255$

$N =$ 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



ThrTl } Threshold Values
Thei