**Description**

Title of the Invention: System and Method of Adaptive Synchronization between Sensors

In this patent, a method of adaptive synchronization between radar and camera with a varying frame rate is devised. The method includes the following processing steps. In the first step, the image is processed by image segmentation to classify dynamic or in motion targets and static or stationary targets. In the second step, the point cloud of radar is processed by point cloud segmentation system to classify dynamic targets and static targets. This is achieved by applying the Doppler fitting based on the target information of Doppler and direction of arrival. In the third step, given a radar frame-k, required sets of image frames from k-L to k+L will be used to overlap with the radar point cloud. Since radar point cloud and image have different formats, firstly the radar point cloud is converted into 2D image in this case. For each radar-camera frame pair, the overlapped radar and camera images is assessed by the metric of rate of overlay (ROO). ROO evaluates the number of dynamic points in the point cloud that are overlapped with dynamic targets in the image. Based on the maximum ROO, the synchronization is determined.

Brief descriptions of the drawing

Component 01 stands for the data of image captured by camera. The image data may consist of multiple frames that will be synchronized with radar point cloud data.

Component 02 stands for the data of radar point cloud captured by radars. The point cloud data may consist of multiple frames that will be synchronized with camera image. For example, in this invention, we illustrate how a single frame of radar point cloud is synchronized to camera images, i.e., finding the image frame that is best matched to the radar frame of interest.

Component 03 stands for the processing applied to image data, i.e., image segmentation. In this patent, unlike conventional segmentation in image processing, we only concern about two classes. One is dynamic object and the other is static object. The image segmentation is applied to image frames from k-L to k+L.

Component 04 stands for the processing applied to radar point cloud data, i.e., point cloud segmentation. In this patent, radar point cloud segmentation only consider two classes. One is dynamic object and the other is static object. The segmentation is achieved through fitting the Doppler and direction information of target into a relative motion model between radar and target. The outliers of this model fitting are labeled as dynamic target and the rest static target.

Component 05 stands for the processing of overlaying radar point cloud and camera image. In this patent, we illustrate the overlay of radar point cloud frame-k with multiple image frames from k-L to k+L.

Assuming that camera and radar are aligned properly through extrinsic calibration and camera itself is calibrated through intrinsic calibration, the process of overlay may consist of the following steps. First, the radar point cloud is projected to 2D image format. That is, each point of radar point cloud data will be assigned one discrete pixel in the 2D image domain according to its azimuth and elevation values. Second, the 2D point cloud image is overlapped with camera image. Overall, the k-th frame of radar point cloud will be overlaid with image frames from k-L to k+L.

Component 06 stands for the step to determine the maximum overlay between radar point cloud frame-k and camera image frames k-L to k+L . The criterion used is the maximum ratio of overlay. Suppose there are p dynamic points detected in the radar frame and pi dynamic pixels detected in image frame k+i, i=-L,..., L. If one dynamic points in the radar point cloud is overlapped with one dynamic pixel in the image, then we count this as one overlay points. Through checking each dynamic point in the radar point cloud we can determine the number of overlapped point for frame k+i as p(i). Then the maximum ratio of overlay (MRO) can be defined to determine the best matching frame. One method as illustrated in this patent is to define the MRO as below:

$$\text{MRO}=\max_i \text{p(i)}/(p+p_i)\ i=-L,\ldots,L \quad (1)$$

This criterion in practice, heuristically, may achieve good result because when the radar point cloud and camera image are perfectly matched, there will be as many points as possible in the radar point cloud being assigned to the pixels in image. This criterion is effectively the maximum intersection over union (IOU).

The image frame with the MRO will be selected as the synchronized frame to radar frame

## Claims

Claim 1: An adaptive system synchronizing radar and camera with varying frame rate is developed.

Claim 2: A subsystem of image processing from claim 1 that segments the image into dynamic and static targets.

Claim 3: A subsystem of point cloud processing from claim 1 that segments the radar point cloud into dynamic and static targets.

Claim 4: A claim 1's subsystem of overlapping the radar point cloud with images and evaluating the rate of overlay.

Claim 5: In claim 4's system, radar point cloud is converted into 2D (two/2 dimensional) or ND (nth dimensional) image and then overlapped with the respective image.

Claim 6: In claim 4's system, for the evaluation of the rate of overlay, the dynamic targets are used.

Claim 7: In the final step the synchronization is determined based on the frame of image which has the maximum rate of overlay with the radar point cloud.