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A Fast Laser Motion Detection and Approaching Behavior Monitoring Method for Moving Object Alarm System (MOAS)

Haiwei Dong*, Nikolas Giakoumidis, Joseph B Juma, Dmitriy A Tretyakov, Nikolaos Mavridis

New York University, 70 Washington Square South, New York, NY, 10012, USA

Abstract

It is very dangerous for elderly people or workers to be hit or even knocked down from fast moving object moving behind them. To avoid such circumstances, we want to build a Moving Object Alarm System (MOAS). This paper focuses on obtaining a fast solution to monitor the moving behavior of the objects by laser for MOAS. Compared with previous work in motion detection and tracking, we are interested especially in monitoring the approaching behavior of such objects, and quickly providing an alarm in the case the situation is dangerous. A boundary within which the objects are monitored was defined. Under this assumption, fan-shaped grid was chosen to get special partitioning. Based on our algorithm, continuous objects can be detected with very high efficiency. By updating a deviation matrix, the object association solution can also be quickly found. Three categories of outdoors experiments were performed: objects passing, approaching as well as crossing, which empirically verified the effectiveness of our proposed method.

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Keywords: Moving object detection; object association; approaching behavior

1. Introduction

For most elderly people, especially those that might have a hearing impairment, walking outside safely is not easy to guarantee. Especially when objects (humans, vehicles etc.) move behind them, the situation can be very dangerous for elderly people. A similar situation exists not only for the elderly or other people with hearing impairments, but also for people in very noisy environments, for example construction sites. To avoid accidents under such circumstances, we have built a Moving Object Alarm System (MOAS) to monitor the motion of moving objects behind the endangered people, and to alert them by providing a special vibration signal on his/her neck. By modulating the position of the strong vibration, this signal can also indicate to the human the general direction from which the object is moving towards him. Thus, the Moving Object Alarm System is composed of two main parts: the moving object monitoring subsystem, and the alarm subsystem. As a first step, here we propose and evaluate empirically a computationally efficient fast method for detecting moving objects, monitoring their trajectories and speed of approach, and detecting where the approach is potentially dangerous.

There has been some existing research on laser-ranging-based motion detection and tracking: for example focusing on human detection and tracking [1], which has a very wide applications from surveillance [2], sports [3], or on human robot interaction [4]. In our research, we are proposing and evaluating a general approach that can handle many types of moving objects, especially suitable towards fast moving objects, and which is computationally very efficient. Furthermore, our method can simultaneously track a number of different types of targets (like human, vehicle, etc.) in a given scene.

* Corresponding author.
E-mail address: haiwei.dong@nyu.edu

The key issues in this detection and tracking problem include object segmentation/association and object tracking. As the measurement of laser is a series of points, it is necessary to segment them into different clusters, which is called spectral clustering. There is a measure in spectral clustering named scaling parameter. It is a common measure of similarity. Ng et al. first propose a method to automatically calculate the best value for scaling parameter [5]. Zelnik-Manor and Perona analyse the eigenvectors of the normalized affinity matrix by minimizing the cost function using gradient descent [6]. Although these methods are very powerful, the computational burden is huge.

The other key issue is object tracking. A common method is optimal estimation. Schulz et al. uses particle filter to track moving objects [7]. Tao et al. propose a sampling algorithm to track multiple objects [8]. Bobruk and Austin applies Kalman filter to estimate the velocity of objects [9]. The method series of optimal estimation can have a very good performance but it also takes much time to get the optimal tracking results.

In our research, we focus on proposing an efficient method to solve motion detection and tracking problem for general objects. As we are interested in the approaching behaviour, we first assume that the objects very far away are not dangerous for the subject. Hence, we first define a boundary within which the objects are monitored. Under this assumption, we choose a fan-shaped grid to get spatial partitioning. Based on it, we can detect continuous objects very efficiently. By updating a deviation matrix, we can quickly find the object association solution. Three outdoors experiments sequences, for the cases of passing, approaching, and crossing, were carried out to empirically verify the proposed approach.

2. Method

2.1. Equipment

The Moving Object Alarm System (MOAS) is composed of two main parts: approaching speed and trajectory monitoring, and alarming. The equipment we utilize includes a laser sensor and a special vibration belt. The laser we used is of type LMS100 produced by SICK Sensor Intelligence. It scans the environment anticlockwise repeatedly and outputs range information for different angles in pairs. Its maximum radial range is 20m/18m (at 10% reflectivity), while its maximum angular range is 270°. It has two working modes, with either 0.5° or 0.25° angular resolution, and with 50Hz or 25Hz scanning frequency. We chose the working mode as (50Hz, 0.5°), given that speed is very important for our application. Thus, for each measurement taken in a certain moment (every 25msec), we have 541 samples corresponding to the range data for 0° to 270°.

2.2. Continuous object detection

As we focus on monitoring the speed of moving object behind the elderly, the first step is to determine the range in which we should pay attention to. Here, we chose a variable $r_{\text{interested}}$ as the range. By dividing the planar space according to angular resolution, we obtained 540 fan-shape grid segments. Supposing the laser measurement for one moment is (r_i, α_i) where $1 \leq i \leq 541$, to determine if the segments are occupied or not, we use

$$Grid = \begin{bmatrix} grid_1 & grid_2 & \cdots & grid_{541} \end{bmatrix}, \text{ where } grid_i = \begin{cases} 1 & \text{if } r_i \leq r_{\text{interested}} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Then, we divide the laser measurement into different groups. Each group representing a continuous object corresponds to a number of continuous “1” values in *Grid*. Based on the object detection above, we can get an object index vector with the following format

$$Object_index = \begin{bmatrix} n & ind_{1,\min} & ind_{1,\max} & \cdots & ind_{n,\min} & ind_{n,\max} \end{bmatrix} \quad (2)$$

where n is the total object number. $ind_{i,\min}$ and $ind_{i,\max}$ ($1 \leq i \leq n$) are the index terminal for the i th object.

2.3. Object association

The laser scans the environment repeatedly. For each moment, we obtain a number of regions corresponding to objects through the continuous object detection method outlined above, which in essence is a very simple region segmentation method. A crucial issue, though, is to be able to identify the relation between objects obtained in adjacent moments: i.e. to answer the question: to which region that we have detected in the previous moment is the current region that I detect? Of course, there are often more than one region detected, and the number of regions changes over time, as objects enter and exit the field of view of the laser. Thus, we need to perform region association across time frames, a process which is usually called object association. Fig. 1 illustrated three basic states of object association, where the laser is in the center, and the

“0” or “1” values around the circular sector illustrate whether the corresponding sector of the fan-shaped grid is occupied or not.

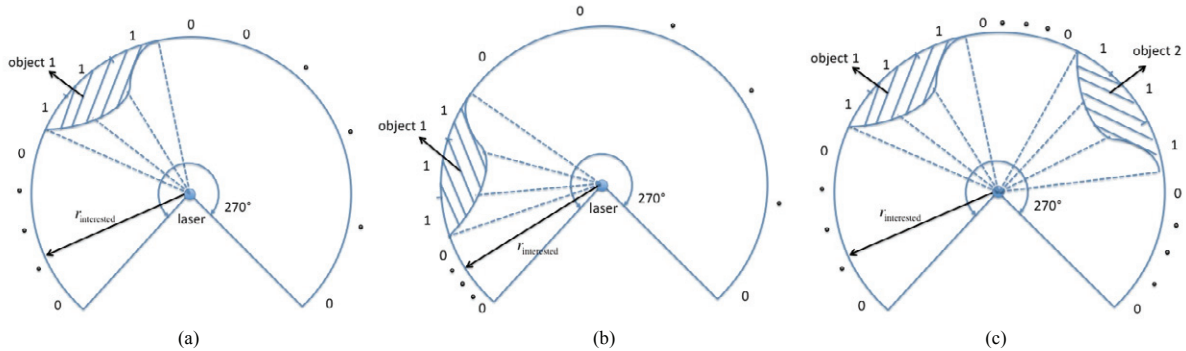


Fig. 1. Motion detection pattern. (a) situation 1; (b) situation 2; (c) situation 3 – kindly see text below

In general, there exist three distinct possible cases that can occur during object association.

- Case 1: The number of objects does not change, but their appearance does
For example, the Object1 in previous scan (Fig. 1 (a)) and present scan (Fig. 1 (b)) is the same object. But it changes the position and orientation.
- Case 2: The number of objects changes
There are two occasions here: appearance and disappearance. One is some new objects appear in the next moment. For example, in the previous scan, we only detect Object1 (Fig. 1 (a)). But at the next moment, we detect another object, i.e. Object 2 (Fig. 1 (c)). The other is that some objects disappear in the next moment.
- Case 3: Both the number, or the identities, as well as the appearance of objects changes
This is the most complex case: not only the objects change position and orientation, but also some objects appear and disappear with time.

The key point for the object association problem is to update a relation of object matching across consecutive time samples. Here, we consider three matching criteria for object matching: range deviation, angle deviation and size deviation. For each deviation, we built a deviation matrix as follows. Suppose we detect n_j objects and n_{j+1} objects in two moments j and $j+1$. The deviation matrixes definitions are

$$Div_{range} = (div_{range})_{n_j \times n_{j+1}} \tag{3}$$

$$Div_{angle} = (div_{angle})_{n_j \times n_{j+1}} \tag{4}$$

$$Div_{size} = (div_{size})_{n_j \times n_{j+1}} \tag{5}$$

where

$$div_{range} = w_1 \cdot \left\| r_{ind_{p,mid}} - r_{ind_{q,mid}} \right\|_2, r_{ind_{p,mid}} = \frac{r_{ind_{p,min}} + r_{ind_{p,max}}}{2}, r_{ind_{q,mid}} = \frac{r_{ind_{q,min}} + r_{ind_{q,max}}}{2}$$

$$div_{angle} = w_2 \cdot \left\| \alpha_{ind_{p,mid}} - \alpha_{ind_{q,mid}} \right\|_2, \alpha_{ind_{p,mid}} = \frac{\alpha_{ind_{p,min}} + \alpha_{ind_{p,max}}}{2}, \alpha_{ind_{q,mid}} = \frac{\alpha_{ind_{q,min}} + \alpha_{ind_{q,max}}}{2} \tag{6}$$

$$div_{size} = w_3 \cdot \left\| size_p - size_q \right\|_2, size_p = ind_{p,max} - ind_{p,min}, size_q = ind_{q,max} - ind_{q,min}$$

for $1 \leq p \leq n_j, 1 \leq q \leq n_{j+1}$. w_1, w_2 and w_3 are weight coefficient. Then we can define an overall derivation matrix as

$$Div = Div_{range} + Div_{angle} + Div_{size} \tag{7}$$

It is noted that derivation matrix Div is a square matrix only when the object number does not change for the two adjacent moments. We define a vector Ass to store the object association information. Specifically, for an element $Ass_i = k$, it means the i th object at j moment corresponds to the k th object at $j+1$ moment. We give Algorithm 1 to do object association.

In Algorithm 1, we solve the object association problem by considering two cases, i.e., new object appearing, or not appearing. We search the minimum element in Div or Div^T row by row. The minimum element indicates the best matching according to the range, angle and size criteria. Thus, we can use the row number and column number to find the object

association information. There are two issues need to be clarified. First, if there exists new objects at the $j+1$ moment, $Ass_i = 0$ for $n_j < i \leq n_{j+1}$, meaning there is no matching for the new objects. But at the next moments, if these unmatched objects still exist, they can be matched. Second, this object association algorithm is a local optimization algorithm. Its computational burden is much smaller than computing all the possible matching possibilities. This algorithm is suitable for most cases in practical applications.

Algorithm 1 Object Association (in Matlab style)

```

if(object_index(j)<=object_index(j+1)) % new objects appear or object number does not change
    temp=Div(1:object_index(j),1:object_index(j+1));
    for p=1:object_index(j)
        [val,ind]=min(temp(p,:));
        % eliminate same matching
        temp_ind(p)=ind;
        if(p>2)
            for q=1:p-1
                if(ind~=temp_ind(q))
                    ;
                else
                    temp(p,ind)=500000; %500000 means a very large number
                    [val,ind]=min(temp(p,:));
                end
            end
        end
        Ass(p)=ind;
    end
else % the existing objects disappear
    temp=Div(1:object_index(j),1:object_index(j+1));

    for p=1:object_index(j+1)
        [val,ind]=min(temp(:,p));
        % eliminate same matching
        temp_ind(p)=ind;
        if(p>2)
            for q=1:p-1
                if(ind~=temp_ind(q))
                    ;
                else
                    temp(ind,p)=500000; %500000 means a very large number
                    [val,ind]=min(temp(:,p));
                end
            end
        end
        Ass(ind)=p;
    end
end
end
  
```

2.4. Approaching speed monitor

We monitor the moving speed of the object by tracking the range change of the center of the object. Supposing the range of the center of the object at j th moment is $r_{ind_k, mid}$ where $1 \leq k \leq n_j$, we can get the estimated approaching speed as

$$\hat{v}_{app,k} = \frac{r_{ind_k, mid}}{\Delta_{t_j}}, \quad \Delta_{t_j} = t_j - t_{j-1} \quad (1 \leq k \leq n_j) \quad (8)$$

If v_{app} is larger than a certain speed, we trigger the vibration system to alarm the subject, i.e.

$$\begin{cases} S_{ala} = 1 & \text{if } \hat{v}_{app,k} \geq v_{app,thr} \\ S_{ala} = 0 & \text{else} \end{cases} \quad (9)$$

3. Results

3.1. Experimental setting

We did three outdoor experimental sequences to evaluate the proposed approach: a passing experiment, an approaching experiment and a crossing experiment (Fig. 2). Specifically, in passing experiment, one subject moves from right to left; in approaching experiment, one subject approaches the laser; in crossing experiment, two objects moves face-to-face, pass each other, and move away from each other. These three experiments are the typical occasions in practice. Complex occasions are combination of these three. Thus, we choose these three experiments to verify our algorithm. The trajectories of the moving objects in the three experiments are shown in Fig. 3.

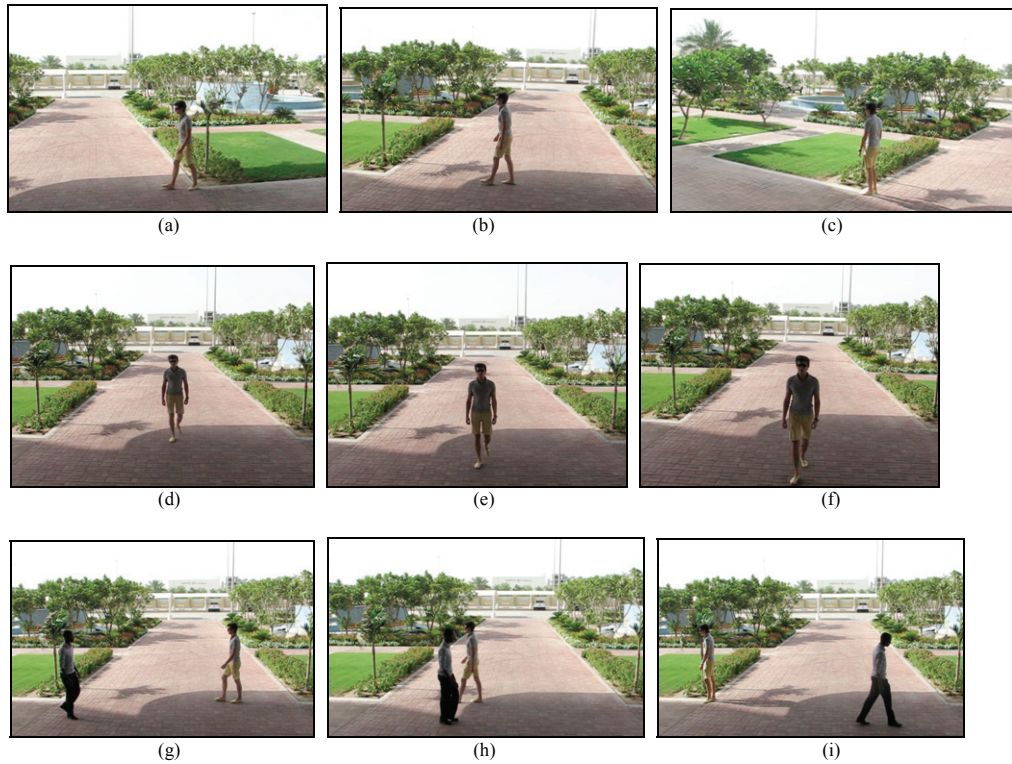


Fig. 2. Experiment snapshots. (a), (b), (c) show the passing experiment; (d), (e), (f) show the approaching experiment; (g), (h), (i) show the crossing experiment

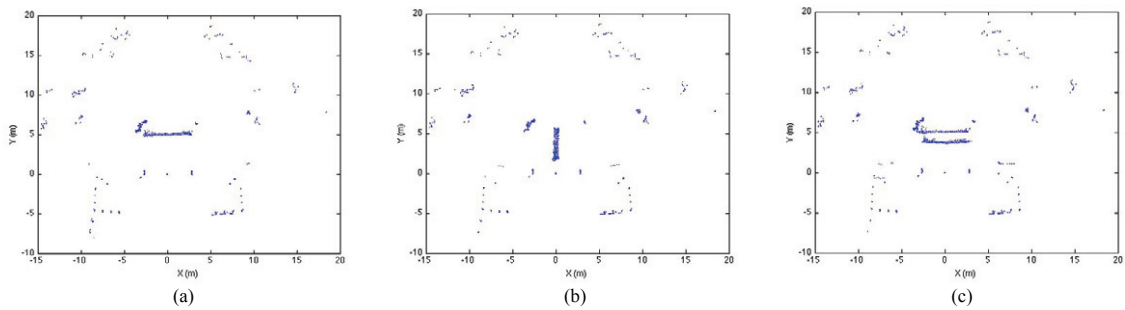


Fig. 3. Moving trajectory. (a) shows the passing experiment; (b) shows the approaching experiment; (c) shows the crossing experiment

3.2. Angle tracking of the objects

In these three experiments, we set $r_{\text{interested}}$ as 6000mm, a good initial distance taking into account the velocities of common moving objects and the reaction time of subjects. The number of the moving objects always changes between adjacent moments. In our experiments, the number of the moving objects changed from 4 to 14. Fig. 4 gives the angle tracking of all the objects where (a), (c), (e) show the 3D grid matrix and (b), (d), (f) show the contour of the corresponding 3D grid matrix.

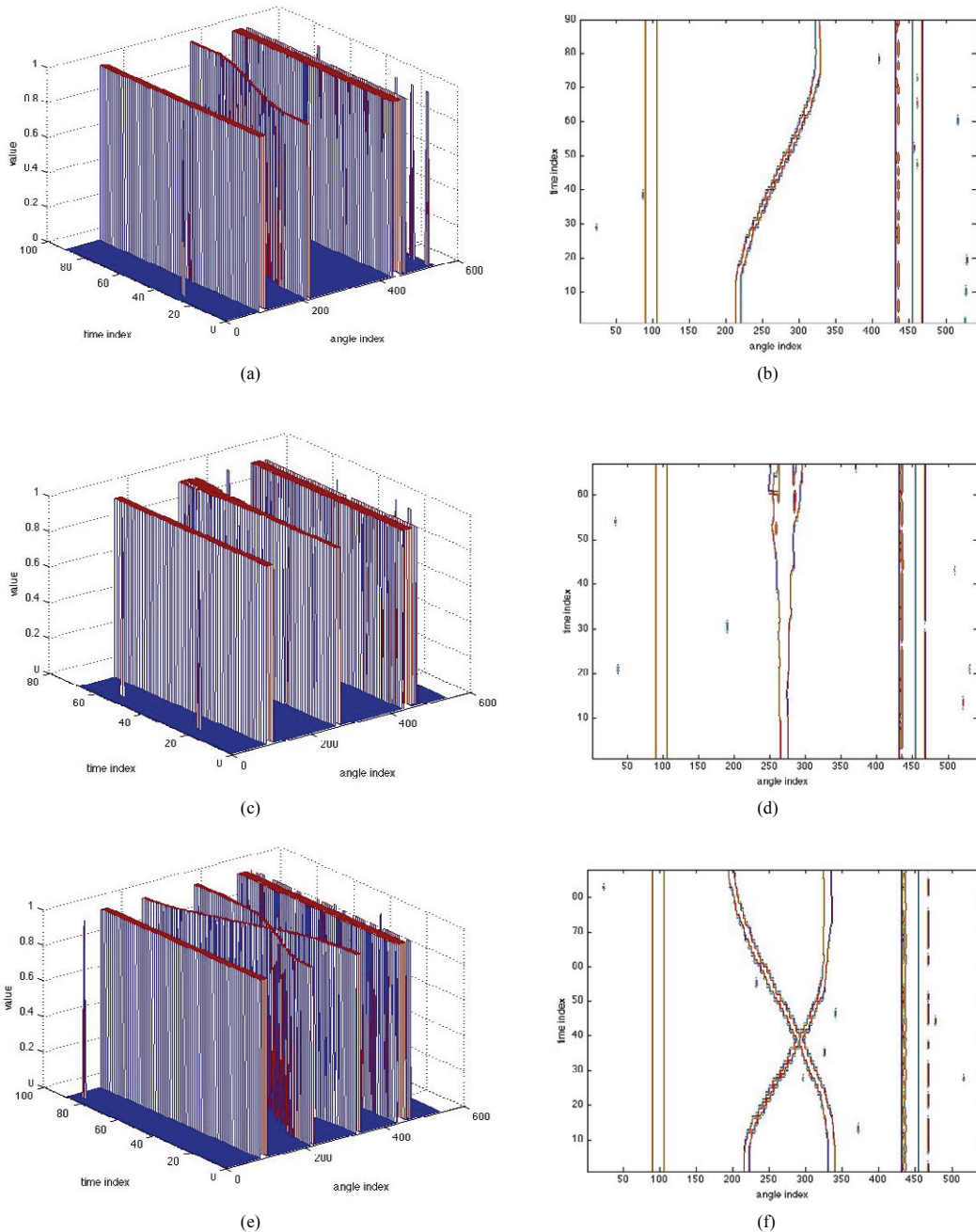


Fig. 4. Angle tracking of the objects. (a), (b) show the passing experiment; (c), (d) show the approaching experiment; (e), (f) show the crossing experiment

The x-axis is angle index from 1 to 541; the y-axis shows the time index at which time moment, we got measurements from laser sensor; the z-axis is the occupation state for the 540 fan-shaped grids. It is very clear about the motion of all the objects, including moving objects and stationary objects. It is noted that, there are four kinds of the objects in these experiments. First is moving human; second is stationary objects, like tree trunks; third is environmental uncertain objects, like flying bird; fourth is the objects caused by laser sensor noise.

3.3. Range tracking of the moving object

In these three experiments, we tracked the range change of the moving objects (Fig. 5) where x-axis is the time index and y-axis is the range data. In passing experiment, as the subject moves from right to left, the trajectory of him is approximately a straight line. Thus, the range reached minimum at about the intermediate position of the trajectory (Fig. 5 (a)). In approaching experiment, the subject starts to move at about 15th moment and stops about 50th moment. The total moving distance is about 3000mm (Fig. 5 (b)). In the crossing experiment, for each subject, the basic moving pattern (i.e. curve shape of range) is the same with that in the passing experiment. However, as the two subject needs to avoid collision between each other, they changed moving trajectories a little (Fig. 5 (c), (d)).

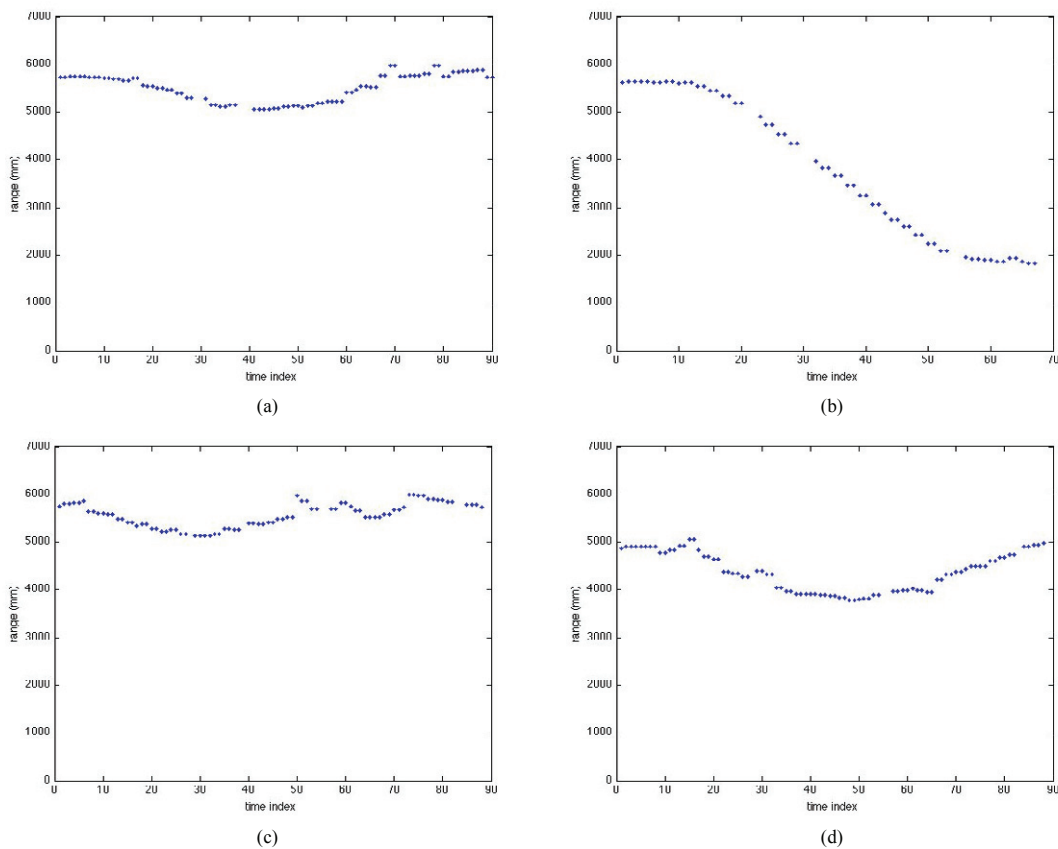


Fig. 5. Range tracking of the moving object. (a) shows the passing experiment; (b) shows the approaching experiment; (c), (d) show the crossing experiment

3.4. Approaching velocity monitoring of the moving objects

Based on the range tracking and angle tracking, we monitor the approaching velocity of the moving objects. In this research, we set the approaching velocity to trigger the alarm is 3m/s. Hence, $v_{app thr} = -3000$ mm/s. The monitoring results of passing experiment and approaching experiment are shown in Fig. 6. As there is noise in the measurement, we used a simple IIR low-pass filter to remove these disturbances.

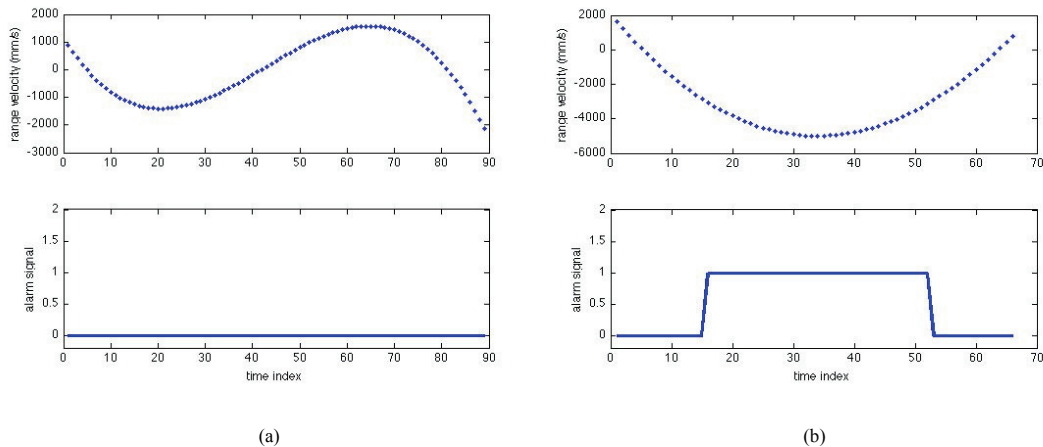


Fig. 6. Approaching velocity monitor. (a) shows the passing experiment; (b) shows the approaching experiment

4. Conclusion

Motivated by the need for safety against collisions with objects approaching from behind humans who are elderly, hearing-challenged, or in noisy environments, we created a system based on a laser ranging sensor and a haptic buzzer neck-mounted alarm. In this paper we described an efficient yet highly effective algorithmic solution for detecting moving objects and tracking their approaching behavior, in order to appropriately trigger the alarm in case of impending danger. In this research, we do not focus on tracking all moving objects in a very large scale, but we only focus on its approaching behavior in a certain scope, dictated by requirements regarding safety. We illustrated how the object segmentation and association can be solved based on fan-shaped grids. The proposed object association is a local optimal algorithm, and for most application cases, it is computationally very effective. Three kinds of outdoor experiments empirically verified the effectiveness of the proposed algorithm in the real world.

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