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NOVELTY DETECTION OF RADAR SIGNAL USING SUPPORT VECTOR DATA DESCRIPTION

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Abstract

Recently it becomes safer and comfortable to drive a car owing to rapid progress of electronic device. One of the intelligent transportation systems (ITS), cruise control, is developed to assist driver. Cruise control is a system that maintains fixed distance and velocity against proceeding car. In cruise control system, it is important to reduce the irregular noises in RADAR signal. Corrected RADAR signal is important parameter to maintain distance and velocity in driving a car. The car with a built-in cruise control system can avoid a rear-end collision using RADAR signal. Noisy signal in cruise control system may lead rear-end collision with proceeding car. In the study, SVDD (Support Vector Data Description) technique is utilized to determine whether the RADAR signal is correct or not. Also abnormal condition of RADAR sensor can be confirmed via the technique.

1. INTRODUCTION

As technology advances, human enjoys comfortable life. The development of car is regarded as one of the best inventions contributes to modern civilization. The car is one of a means enables mankind to move long distance. In spite of rapid progress of car technology, man is still exposed to various traffic accidents. In order to offer the extreme convenience and to provide protection for human beings, many intelligent traffic systems are studied in various fields.[1][2] Intelligent transportation systems (ITS) provide many conveniences and safes for human being to use a car. These systems enables human drives a car more convenience. Such intelligent transportation system as cruise control systems offer convenience to driver moves long distance. Cruise control system maintains constant speed and RADAR system also maintains fixed distance, which are helpful to driver. Cruise control system protects the traffic accident using proper speed and distance between preceding cars. Cruise control system is developed to guarantee the security of life and to provide convenience to driver in complex roads. In the cruise control system, it is important thing to correctly acquire the information of speed, distance between preceding car and traffic condition using RADAR sensor. Incorrect data analysis of traffic condition can cause traffic accidents. In the study, various noises can be generated to acquire RADAR are considered with built-in cruise control system in car. And novelty detection algorithm of noisy signal is studied. The main algorithm using SVDD (Support Vector Data Description) is used to decide the abnormality of sensor with irregular noisy. Noisy signal in cruise control system may lead rear-end collision with proceeding car. In the study, SVDD technique is utilized to determine whether the RADAR signal is correct or not. Also the technique can confirm the abnormal condition of RADAR sensor signal.

II. NOVELTY DETECTION ALGORITHM

2.1 SVM (Support Vector Machine) Method

In recently, SVM is widely used to classify the input data and in regression of function. [3] SVM comes to a conclusion to find the solution of QP (Quadratic Programming) in pattern recognition. In the study, SVDD, one of SVM methods, is used to distinguish abnormality from normal data. Fig. 1 shows the simple data classification using SVM method. [3][4][5]

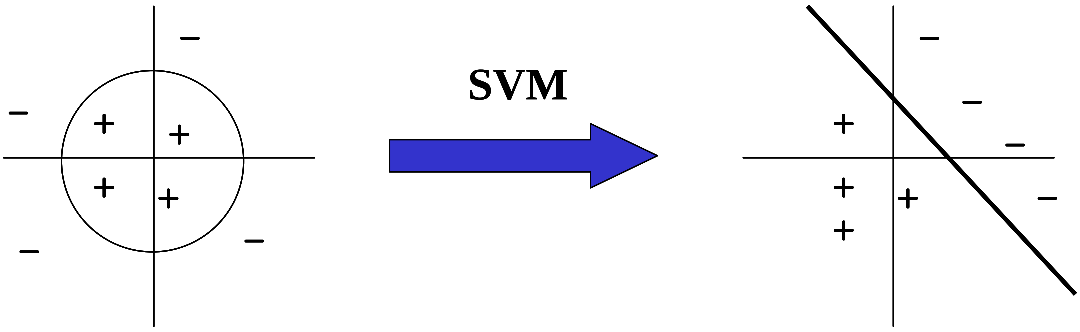


Figure 1. A Simple Data Classification using Support Vector Machine

2.2 SVDD Method

The SVDD is used to describe the data in the study. SVDD, one of a unit class support learning method, is to decide normal and abnormal region using a unit-circle in feature space. Assume a data set containing N data objects, and the sphere is described at center ($x_i = a$) and with radius R. In order to minimize an error function containing the volume of the sphere, following equation can be revealed to satisfy the objective.

$$\begin{aligned} &\min. \quad R^2 + C\sum_{i=1}^{N}\xi_i \\ &s.t. \quad \left\|\underline{x_i} - \underline{a}\right\|^2 \le R^2 + \xi_i,\ \ \xi_i \ge 0,\ \ i = 1,\cdots,N \end{aligned} \tag{1}$$

In equation (1), the variable ξ_i is a penalty related to i-th learned data escaped from the sphere. Trade-off constant C regulates the relative and important value of each term. Since it is difficult to deal in input space, R^d , it is dealt with in feature space. The main idea of the SVDD is to find the sphere with minimal volume which contains all data and is like to solve the QP (Quadratic Problem). Using the Lagrange function equation is shown as follow.

Lagrange Function:

$$L = R^2 + C\sum_{i=1}^{N}\xi_i + \sum_{i=1}^{N}\alpha_i\left[\left\|\underline{x_i} - \underline{a}\right\|^2 - R^2 - \xi_i\right] + \sum_{i=1}^{N}\eta_i \tag{2}$$

Using the equation (2), it is transferred to dual problem as follow.

$$\begin{aligned} &\max. \quad \sum_i \alpha_i \left\langle \underline{x_i}, \underline{x_j} \right\rangle - \sum_i \sum_j \alpha_i \alpha_j \left\langle \underline{x_i}, \underline{x_j} \right\rangle \\ &s.t. \quad \sum_{i=1}^{N} \alpha_i = 1, \quad 0 \le \alpha_i \le C, \quad i = 1, \cdots, N \end{aligned} \tag{3}$$

In equation (3) using kernel trick, equation (1) can be solved as follow.

$$\begin{aligned} &\min. \quad \sum_{i=1}^{N}\sum_{j=1}^{N} \alpha_i \alpha_j K(\underline{x_i}, \underline{x_j}) - \sum_{i=1}^{N} \alpha_i K(\underline{x_i}, \underline{x_j}) \\ &s.t. \quad \sum_{i=1}^{N} \alpha_i = 1, \quad 0 \le \alpha_i \le C, \quad i = 1, \cdots, N \end{aligned} \tag{4}$$

where, K is a Gauss-Kernel.

$$K(x, z) = \exp(-\|x - z\|^2 / \sigma^2) \tag{5}$$

The condition which satisfies optimal solution of Lagrange function in input space can be equation (6).

$$a = \sum_{i=1}^{N} \alpha_i x_i \tag{6}$$

And the condition which satisfies optimal solution of Lagrange function in feature space can be following.

$$a_F = \sum_{i=1}^{N} \alpha_i \phi(x_i) \tag{7}$$

Because the distance between each support vector $\phi(x_i)$ located on decision boundary and center a_F of the sphere becomes a radius of sphere, following equation (8) can be derived.

$$R_F^2 - \|\phi(x_i) - a_F\|^2 = R_F^2 - \left(1 - 2\sum_{i=1}^{N} \alpha_i K(x_i, x) + \sum_{i=1}^{N}\sum_{j=1}^{N} \alpha_i \alpha_j K(x_i, x_j)\right) = 0 \tag{8}$$

Using above equation, an equation which identifies whether test data is normal or abnormal in feature space can be obtained.

$$f_F(x) = R_F^2 - \|\phi(x_i) - a_F\|^2 = R_F^2 - \left(1 - 2\sum_{i=1}^{N} \alpha_i K(x_i, x) + \sum_{i=1}^{N}\sum_{j=1}^{N} \alpha_i \alpha_j K(x_i, x_j)\right) \ge 0 \tag{9}$$

III. UNCERTAIN SIGNAL DESCRIPTION IN CRUISE CONTROL

In many fields, RADAR is used to detect the object. Using these technology, cruise control system is developed to assist for driver to avoid traffic accident. In cruise control system, RADAR detects the distance between preceding cars and acquires the speed. Its detectable distance is 150 m and its sampling rate is a 20 Hz. In the study, noisy data generated in various conditions is adopted to confirm the detecting algorithm. Each condition is defined as follow. In case 1, uncertain signal is generated by irregular driving of preceding cars. In case 2, interference is adopted by another RADAR sensor. In case 3, irregular road conditions are also taken into account. Using those conditions, simulation is conducted to detect the normal and abnormal data. In general cruise control system, these situations are not occurred. But in the study, irregular conditions are adopted to confirm the feasibility of proposed algorithm at first time.

Case 1 Uncertain signal due to irregular driving of preceding car

Uncertain signal due to irregular driving of side-preceding cars can be acquired by RADAR sensor. However the fatigue of it may be increased in long time driving. Normally around the distance of 150m from driving car, there are many noisy data because of the sensing distance. In the distance, sensor may be so saturated as ECU (Electric Control Unit) not to indicate the driving order.

Case 2 Interference by another RADAR sensor

Uncertain signal is acquired by another RADAR sensor or thunder. If there are cars moving ahead in the situation, abnormal operation of the sensor can cause traffic accident. Due to those irregular disturbances, sensor does not operate properly, which may transfer disordered signal to ECU.

Case 3 Uncertain signal by irregular road condition

Because of irregular road condition or vibration of cars, sensor does not operate properly against preceding cars. In this case, RADAR sensor doesn’t correctly decide to recognize the preceding cars.

In case of sensor saturation, abnormal data can be transferred to ECU, and then because of incorrect information about the preceding cars the driving car may be accelerated or decelerated to maintain prefixed conditions which are not supposed to be. Then there are lot of chance of occurring traffic accidents. Therefore detection of correct data in the situation is important to assists driver more convenience and safer way. In the study, simulations under each condition are conducted to confirm the proposed novelty detecting algorithm explained in chapter 2.

IV. SIMULATION AND RESULTS

4.1 Simulation

In this chapter, simulation is conducted using SVDD algorithm to detect abnormal data with built-in cruise control system. Since measurable distance for sensor is 150m, thus sensor may be saturated after that. If the preceding car is in the situation, then traffic accidents may occur.

Figure 2 shows main algorithm using SVDD to detect the normal and abnormal data region. In Figure 2, normal data and abnormal data are transferred to corresponding region by SVDD algorithm. In Figure 2, solid line is an abnormal case and dot line is a normal case. In simulation abnormal data is evaluated with respect to normal data then SVDD is utilized. Simulation is conducted by three condition explained in chapter 3. In each case, firstly normal data is adapted to SVDD algorithm and next same algorithm is implied with abnormal data. In simulation the distance between preceding and driving car is decided by user. And abnormal condition is generated by program. In abnormal condition, sensor saturation value is added to a normal data. In this study, abnormal data is regarded for sensor to be in saturation condition.

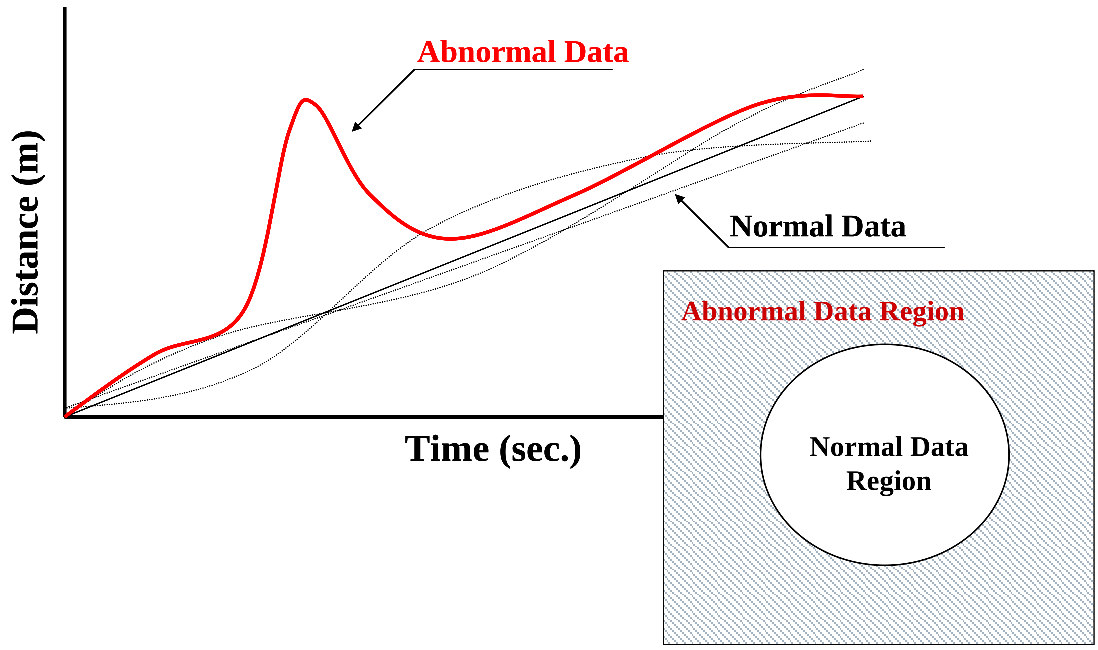
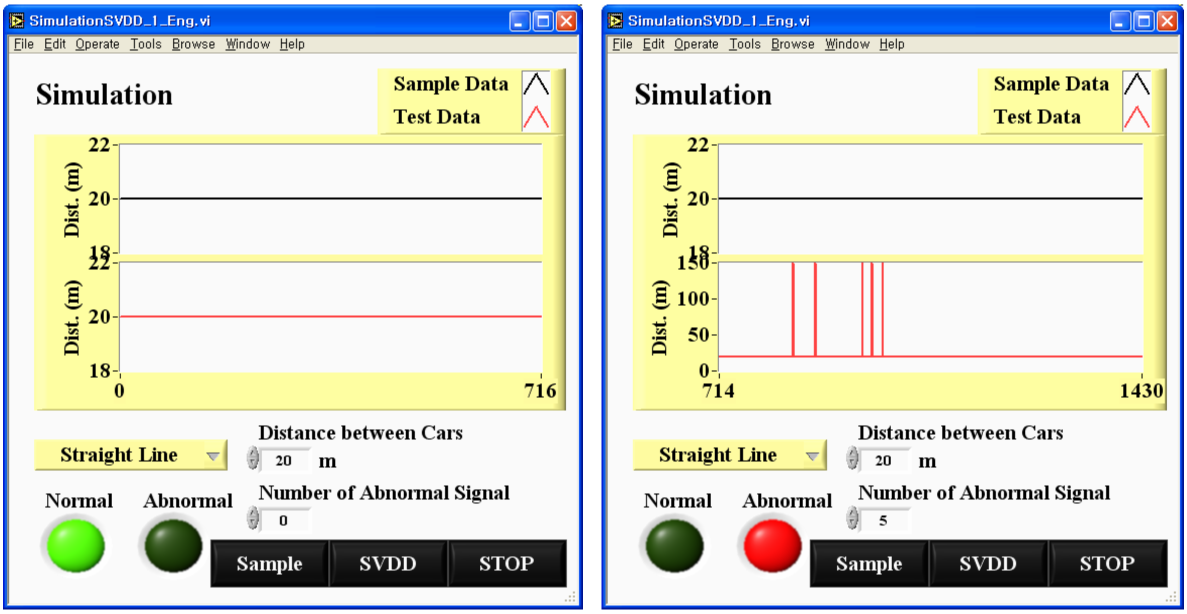


Figure 2. Basic Concept of Proposed Algorithm with SVDD

4.2 Results

In result 1, simulation shows that distance and speed of preceding car and user car are same in straight line. Figure 3 (a) shows normal condition and Figure 3 (b) shows abnormal condition. In the case distance between the cars is put as 20 meter, and then abnormal conditions are occurred 5 times. Proposed SVDD algorithm is applied in the case to detect the abnormal data properly. In result 2, the trends in varying distance between preceding car accelerating and user car in fixed speed are shown. Figure 4 (a), (b) show the normal and abnormal conditions of trends in varying distance respectively. In Figure 4 (b), the distance of proceeding cars and user car is increasing uniformly with adding 7 abnormal data on purpose. In this case, simulation reveals good performance of recognizing abnormal situation around the user car. In result 3, the distance between two cars is generated using sine wave function. Figure 5 (a) and (b) show normal and abnormal conditions for the trends of varying distance. In Figure 5 (b), 4 abnormal data is added. Based on the results, proposed detecting algorithm shows its good performance.

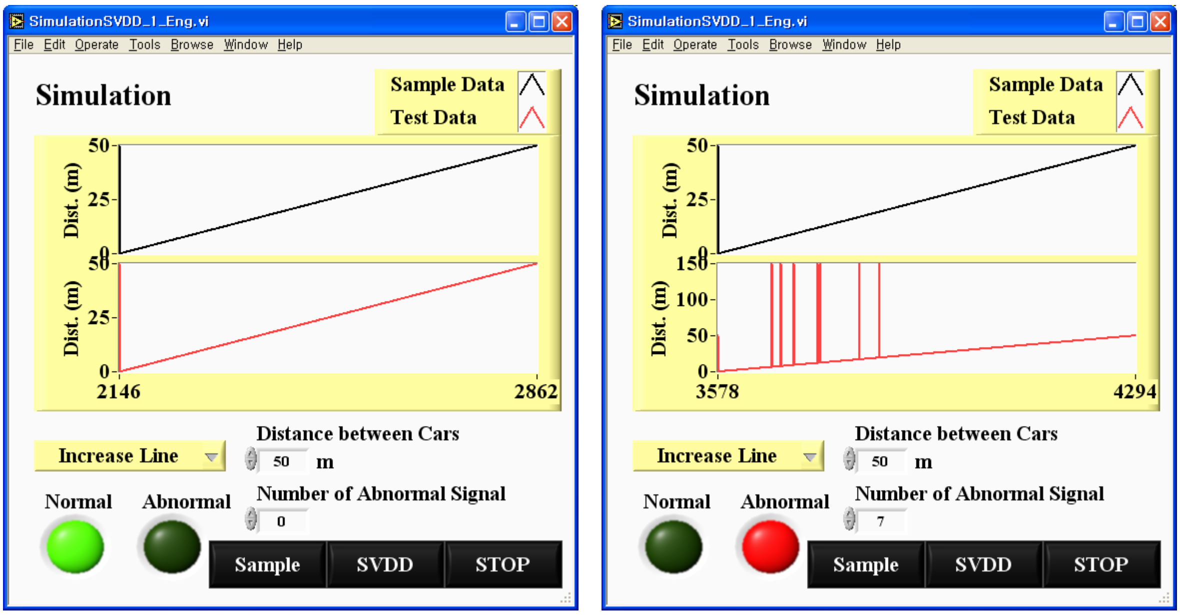
Result 1 The distance between cars in Straight Line



(a) Normal Case (b) Abnormal Case

Figure 3. Signal Detection with Straight Line Condition: (a) Normal Case, (b) Abnormal Case.

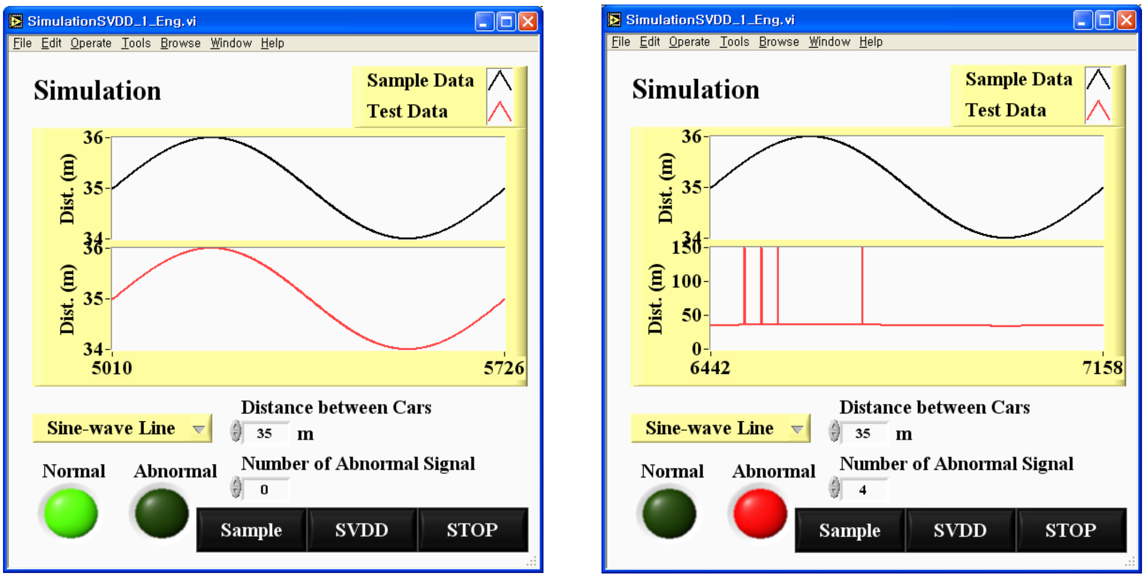
Result 2 The distance between cars in Increase Line



(a) Normal Case (b) Abnormal Case

Figure 4. Signal Detection with Increase Line Condition: (a) Normal Case, (b) Abnormal Case.

Result 3 The distance between cars in Sine-waveform Line



(a) Normal Case (b) Abnormal Case

Figure 5. Signal Detection with Sine-wave Line Condition:
(a) Normal Case, (b) Abnormal Case.

V. CONCLUSION

A technique for a cruise control car system to inform abnormal outside situation has been developed firstly and successfully in a systematic way. Uncertain signal is assumed three cases in chapter 3. A novelty detection algorithm is proposed to distinguish the normal and abnormal condition in cruise control system in improper driving conditions. Simulation results reveal good performance and its feasibility are confirmed. The performance of proposed algorithm turns out to be robust against uncertain RADAR signal used in cruise control system. SVDD method is applied successfully to detect abnormality in the signal obtained from RADAR system. The proposed algorithm implemented to RADAR sensing system within cruise control system is proved to be efficient and powerful, which enable cars to operate in more convenience and safe way in complex road conditions.

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