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# ROAD SURFACE HEIGHT ESTIMATION FOR PREVIEW SYSTEM USING ULTRASONIC SENSOR ARRAY

Min-Hyun Kim*; Seibum B. Choi;
Korea Advanced Institute of Science and Technology, Republic of Korea

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ABSTRACT – Active suspension system has been employed by the auto industry in order to improve ride-quality and handling. Only a little betterment, however, is obtained without road preview sensor in building active or semi-active suspension system. In these days, sensors such as stereo camera, laser, and ultrasonic sensor have been employed when previewing surface height of road for active or semi-active suspension system. However, there are disadvantages with camera and laser sensors as they are high in price and need complex algorithms. Thus, the parallel information processing devices are required to compute tangled calculation in real-time which adds more budgets. On the other hand, the ultrasonic sensor uses ToF (Time-of-Flight) method to measure the distance and the sensor is sensitive to ambient noise. Therefore, this makes hardware and software calibrations of sensor essential steps. More robust measurement on noise is possible by using ultrasonic sensor array which consist of multiple receivers and a transmitter. Furthermore, information gathered from the sensor array installed in a vehicle can differ by the moving speed of a vehicle. Therefore, ICP (Iterative Closest Point) logic is used for optimization. To test the proposed algorithms, experimental bench is produced and the height of road is intentionally designed to be continuously different. The result obtained from the cost-efficient MCU and ultrasonic sensor array is analyzed. The purpose of this study is to test a cost-efficient ultrasonic sensor array to mapping the road surface in real-time.

## INTRODUCTION

The suspension in vehicle takes a critical part in enhancing ride-comfort and handling of a land vehicle by supporting not only the mass of a vehicle, but also suppressing vibrations from various road condition. Though, there has been a challenge in optimizing the setting of suspensions for handling and ride-comfort as there is a trade-off point between these two. To solve the problem, researchers developed active and semi-active suspension systems [2].

The issue with this approach is the tardy response of actuator of suspension systems. This gets it hard to adjust the systems movement in real-time. Another issue is that it is not available of using road surface information in advance without preview sensors. Therefore, it is impossible to optimize active and semi active suspension systems for every road condition. They preferably take the normal road condition and this confine the employment of active or semi-active suspension on various roads. Consequently, if the controller of a suspension system is designed in a method that is able of giving knowledge of a road ahead, controlling of the suspension system well on diverse road profiles becomes feasible.

A look-ahead sensor can acquire height of road surface ahead, and devices such as stereo camera[5,7] and laser[4,9] system are applied. One benefit of these system is that it utilizes ray to obtain the knowledge of a road that is comparatively in a long range from a vehicle. However, its performance is generally influenced by vision and wrong data can be sent out in certain situations. Furthermore, these sensor systems are relatively expensive in costs and demand rapid processing unit which adds more expense.

In this study, therefore, road mapping method using low-priced ultrasonic sensor array with appropriate algorithm is presented. Not only the ultrasonic sensor itself is cost-effective but also its algorithm is not heavy. Previous study[3] was limited to using just one receiver which is vulnerable to noise. However this study is proposing receiver array which can be more robust to noise and more precise estimation available. Also, environmental correction method is introduced in this paper. Therefore, using this sensor module, it is possible to preventing a vehicle or a robot from agitating their body by previewing road surface[1,6] in dynamic environment.

## SENSOR SYSTEM

This section explains the sensor that is employed for mapping of road profile.

### Sensor Array Module

The sensor array module is constituted of an ultrasonic sender, two or more receivers, and a sensor control unit. The sender fires a signal by vibrating piezoelectric unit. When the element of the receiver is vibrated by its echo, the receiver casts an answer sign. The measurement of distance from ultrasonic sensors uses flight time measuring method. The range moved by ultrasonic wave could be calculated using the next equation.

$$D = v \cdot T \quad (1)$$

where, $D$ and $T$ are the lengths sound-wave moved and flight times from each receiver, and $v$ denotes the sound speed where the wave was measured surroundings.

The attenuation of wave power and the environmental noise let the accurate measurement of ToF tough. To solve the problem, therefore, threshold value identification is used. This method identifies sound waves when the power of received signal is beyond specific threshold. This method still has variance however it could be diminished when the flight range and the road profile variation of an object that it is targeting for mapping are bounded.

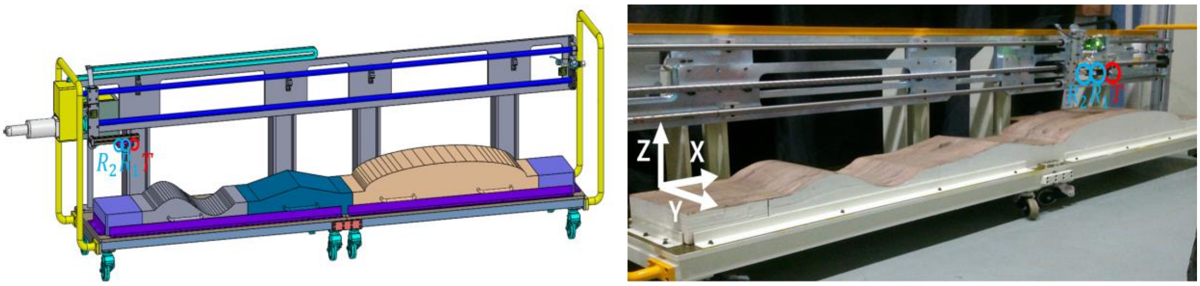
In this study, the ultrasonic sender is placed at the head underside of a moving vehicle and two receivers are fixed at the right back of the sender as a look-ahead sensor for the preview control.

Furthermore, a control processor is needed for managing ultrasonic sensors, calculating road information, and sending the estimated road profile to the suspension control unit.

Therefore, a cheap AVR MCU is employed which has CAN network capability and affordable for calculating road height using ToF method from the ultrasonic receivers.

## Experiment Bench Description

A road model that is made for evaluating performance of sensor array module that was explained, is shown in fig. 1. The experimental bench has concavo-convex road shapes, for example sinusoidal and triangular shape. The sensor array module is built on a moving vehicle which is attached to a motorized lead screw like the travelling car. A motor driver in the bench rotates a lead screw which controls vehicle's speed as well as its location.



(a) (b)

*Figure 1: (a) describes the outlined experimental bench and (b) indicates a real experimental bench with installed vehicle. It has more than 3meters road shape so that can evaluate the proposed sensor array in real-time. In figure (b), red and blue circle point to ultrasonic sender and two receivers.*

# SENSOR ARRAY CALIBRATION

Even an identical sensor model could vary in particular qualities which makes sensor module calibration an inevitable process. In this section, therefore, sensor calibration process is explained.

## Hardware Calibration

When the sender transmits one ultrasonic signal, 5 maximum echo could be acquired as shown in fig. 2 in a particular hardware threshold. The earliest received signal is the signal that traveled straight from the sender to the receiver. Using this first signal, the surrounding environment adjustment can be possible such as temperature changes. The second earliest signal is the echo that is returned from the closest road surface. The echoes that return after are the multi-reflected waves from surrounding road or objects. Thus, it is able to be presumed that the returned wave that is needed for road profile mapping is the second returned wave. Therefore, the receiver is adjusted by mechanically modifying the threshold in which the interrupt is recognized to acquire 2 signals maximum to robustly ignore environmental noise.

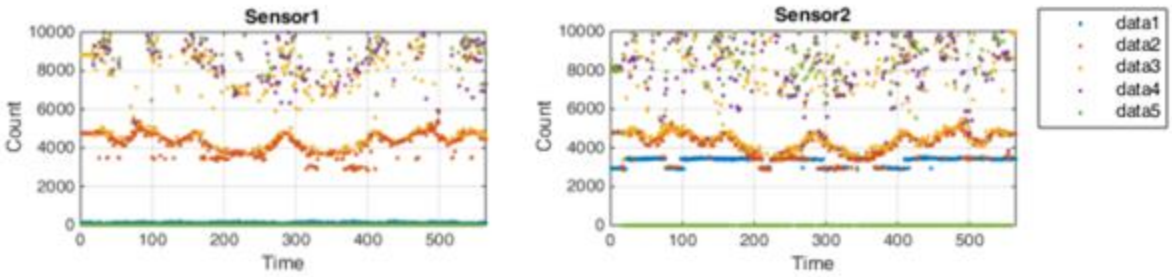


*Figure 2: acquired interrupts when the motorized vehicle is running in the experimental bench at the constant speed. The data 1 to 5 are showing multi acquired returned waves from one fire of the sender.*

## Software Calibration

The traveled flight of waves could be derived from the second returned ultrasonic wave. In a usual situation, the traveled distance is able to be estimated by substituting the equation (1) but a cheap and low performance MCU that employs threshold recognition method to calculate the traveling distance, could have an offset both time and a flight distance related. Thus, equation (1) is emended into equation (2) and (3).

$$D = v \cdot (T + T_o) + D_o \quad (2)$$

In this equation, $T_o$ indicates the offset from each receiver related to time, whereas $D_o$ corresponds to the offset related to flight distance.

$$d_{1,2} = a_{1,2} \cdot c_{1,2} + b_{1,2} \quad (3)$$

Equation (2) is revised into (3), therefore, that the calibration parameters $a_{1,2}$ and $b_{1,2}$ can be derived from two recognized flight distances $d_1$ and $d_2$ which are acquired from the different distances setting. Where $c_{1,2}$ represents the counted numbers which is related to time and from MCU.

Thereafter these calibration process, following trimmed result could be achieved.

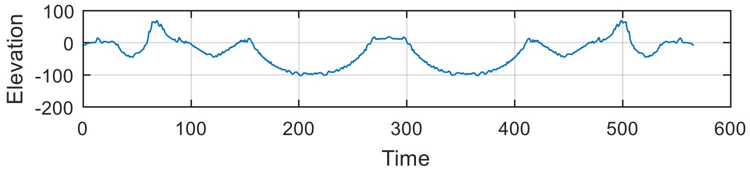


*Figure 3: road profile mapping output afterwards using calibration parameters when the motorized vehicle is running.*

## Environmental Correction

The ultrasonic range finder employs air as a medium. Thus, the speed of sound is affected by surrounding temperature or air pressure. To solve this issue, the very first received signal can be used as an environmental corrector.

$$D_e = \frac{E_c}{E_s} \cdot D \quad (4)$$

$\mathrm{E_c}$ represents the very first interrupt that is received during software calibration whereas $\mathrm{E_s}$ represents the first interrupt in every circumstance. This calibration allows robust road surface height estimation even when surrounding environment is changing.

## LONGITUDINAL DISPLACEMENT CORRECTION

If ultrasonic array module is built in the foreground-underside of moving apparatus, its road surface calculated location could be different by vehicle's speed and moving direction. Consequently, longitudinal displacement correction process is unavoidable.

The interval between the sensor array and center of tire contact patch in longitudinal axle is fixed, and the period it takes to derive the road profile mapping is also not changed as well nevertheless of a vehicle's speed. Therefore, road profile mapping point from the tire contact patch in longitudinal axle equation could be represented like following equation (5).

$$X = L_1 \cdot v + L_2 \quad (5)$$

In this equation, $v$ indicates a velocity of vehicle and $X$ denotes the location variances where road profile is approximated from the sensor array. $L_1$ and $L_2$ represent optimized calibration parameters. Using this equation, it is feasible to derive the longitudinal displacement for an estimated road point in real-time.
Parameter $L_1$ and $L_2$ could be selected using the sensor array output by making a comparison with known road. For deriving these parameter, Iterative Closest Point algorithm[8] can be employed to comparing two different point cloud which is acquired from precise lidar sensor and suggested sensor array module.

## EXPERIMENTAL RESULT AND CONCLUSION

Figure 4 to 6 are the graph that represents the experimental result of proposed road profile mapping under the experiment environment. Sky-blue line marks the ground truth road profile of the experiment bench, and red dots represent estimated profile from the sensor array.

This proposed algorithm showed 2.45% to 4.17% of errors in different velocities of vehicle. And the calculated profile is typically greater than the real road profile in a sheer falling roadway.

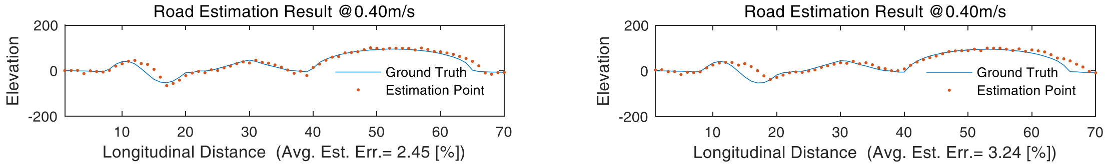


*Figure 4: Road estimation results of 1st and 2nd receivers when velocity of sensor module is 0.4m/s*

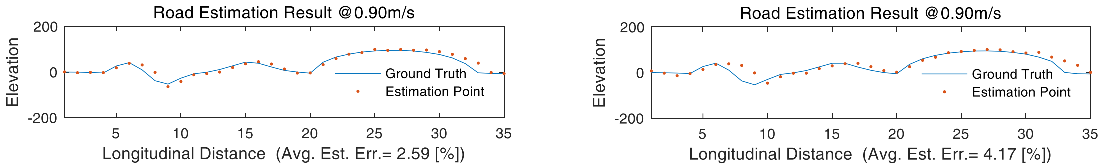
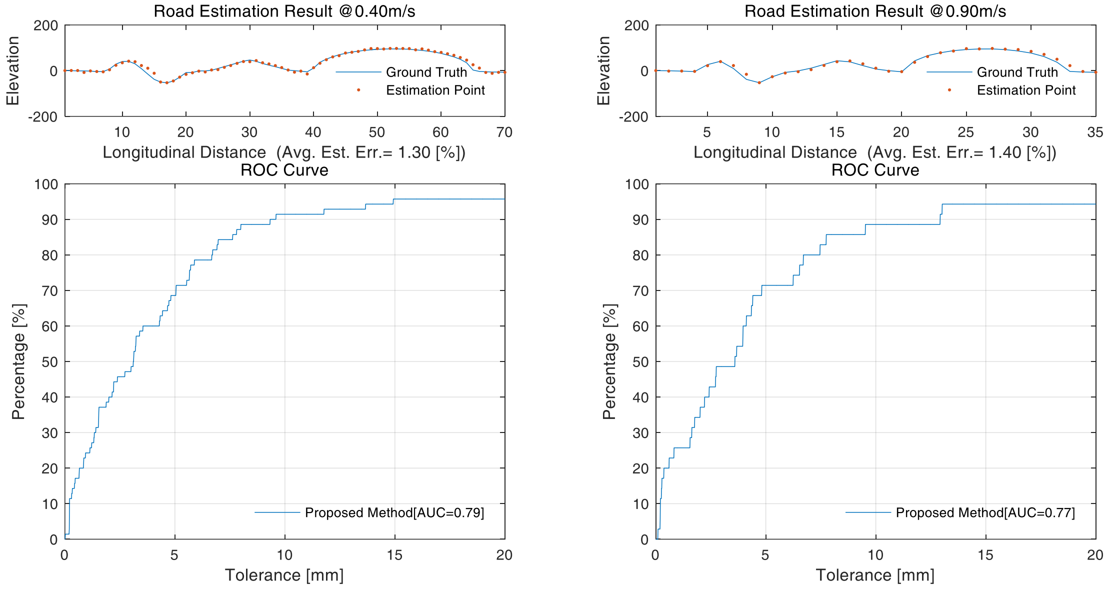


*Figure 5: Road profile mapping results of 1st and 2nd receivers when vehicle moves to 0.9m/s*

When using two or more receivers, not only the distance, but also angle between vehicle and road surface can be calculated. Following figures are the result of fusing two receiver information. When combining the signals from two receivers, it can be seen that the better estimation results come out.



(a) (b)

*Figure 6: Road profile mapping result using sensor array when velocities are 0.4m/s and 0.9m/s*

This study suggests and tests the algorithm that using affordable sensor and micro-controller which can be used as a look-ahead sensor in active or semi-active suspension system in the experiment bench environment. It can be noticed that using sensor array is much more reliable every different vehicle velocity experiments.

The future work will be a scanning road surface in the real vehicle environment and a controlling active and semi-active suspension system for enhancing ride quality and stability performance in various road conditions.

## ACKNOLODGEMENT

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