特集 Development Strategy of Sensing System*

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This paper presents a development strategy of sensing system for Advanced Driver Assistant Systems (ADAS) to spread ADAS into the society. We believe that main issues for the sensing system are to improve performance and to optimize costs. We introduce sensing system development process to achieve these requirements effectively, and two examples of function development based on the process are shown.

Key words ： Development strategy, Sensing system, Advanced Driver Assistant Systems (ADAS)

1. INTRODUCTION

In late years user needs for safety, environmental friendliness, comfort and convenience of automotives are rising very much, and various ADAS to correspond with these needs are suggested by many automotive manufacturers. For example, Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA) and Pre-Crash Safety (PCS) are already introduced into the market. In the future, further improvement of safety will be made by new ADAS, such as Forward Collision Avoidance Assist System (FCAAS) and pedestrian protection. We recognize that an important factor to realize and spread these systems is to improve performance of peripheral sensing technology and to optimize costs of them. Therefore, we are pushing forward development of sensing systems such as Lidar, millimeter wave Radar, Vision and Navigation system, and fusion technology of these independent sensing systems.[1)]

In this paper, we report about our development strategy of sensing system and examples of our development on sensing system with some aspects.

2. TREND OF ADAS AND SENSING SYSTEM

Figure 1 shows the trend of ADAS. ACC was introduced into the market in the latter half of '90. Recently, PCS and LKA are in the market by several automotive manufacturers.[2)] An example of PCS and LKA configuration are illustrated in **Fig. 2**. The brake system and the seat belt motor are activated by detection result of the radar in PCS. The electric power steering system is controlled based on the lane marker information detected by the vision sensing system in LKA.

System support level by ADAS will be enhanced in the future, and this will provide drivers with safety, comfort and convenience. To realize this, requirement for sensing system is to improve the following functions. That is, object detection, classification, tracking, road detection and quality and visibility management of sensing system itself. It is said that the performance of sensing system would strongly affects total system performance or function.

On the other hand, the market will not accept expensive ADAS. We believe that not only complicated sensing system with many components but also simple sensing system is important. Because ADAS should widely spread

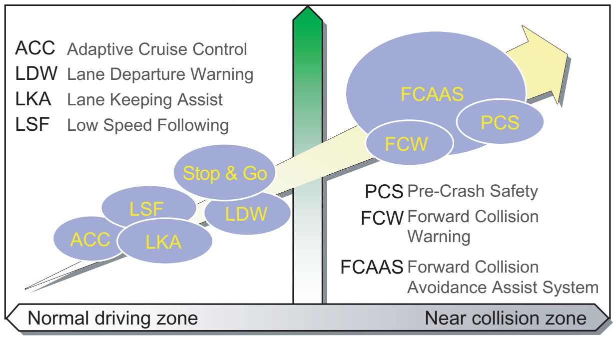

Fig. 1 Trend of ADAS

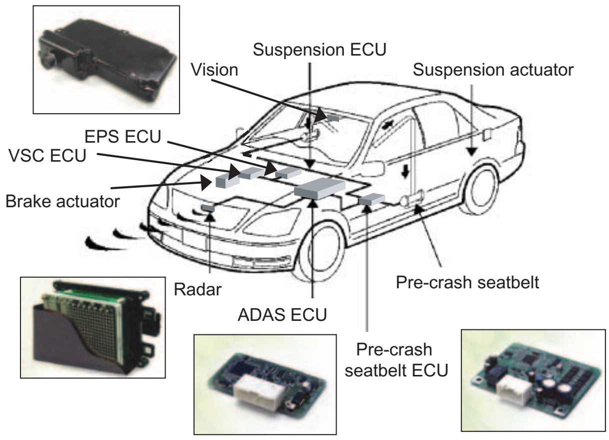

Fig. 2 An example of ADAS configuration

*Reprinted from "Proceedings of the 11th World Congress on ITS in Nagoya (2004)" over even small or compact class vehicles for decreasing traffic accidents efficiently. As shown in **Fig. 3**, small vehicles have 60 % share of automotive market in Japan. From this point of view, we are surveying optimal choice or configuration of sensing systems.

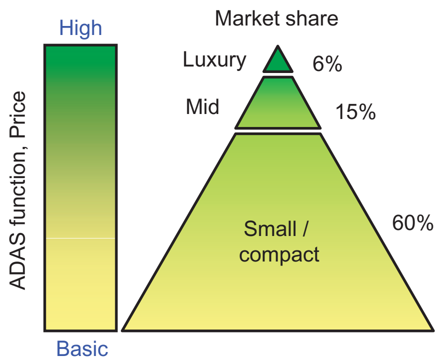

Fig. 3 Vehicle class share of Japan market (2002)
*Commercial vehicles are not shown

3. DEVELOPMENT STRATEGY OF SENSING SYSTEM

To develop sensing system effectively, we should understand requirements from ADAS application as precisely as possible. From this point of view, we introduce our process of sensing system development in this section. Moreover, development policy of sensing system is discussed.

3.1 Process of sensing system development

Requirements of functions or specifications for sensing system are derived from ADAS application. Requirement for a sensing system applied to ACC is clear because ACC has been introduced in the market for almost a decade and is spreading. However, other ADAS applications are still at the beginning of introduction to the market or under development, and requirements for sensing system are not obvious generally. I mean that development of ADAS applications and sensing systems for them are progressing simultaneously.

Therefore, we adopt the following process for developing sensing system to verify functions and specifications precisely.

- Test scenario definition to evaluate sensing system
- Facility construction to evaluate sensing system
- Function survey to verify specifications
- Test vehicle implementation to evaluate system
- System Evaluation to verify sensing system function

Test scenario is defined for each ADAS in the view of application requirement. For PCS, it is based on analysis of traffic accidents, and accident models are defined in the scenario.

A facility for tests is built in our test track to enable to represent accidental situation against a pedestrian. An example of test scenario and the facility is shown in **Fig. 4**.

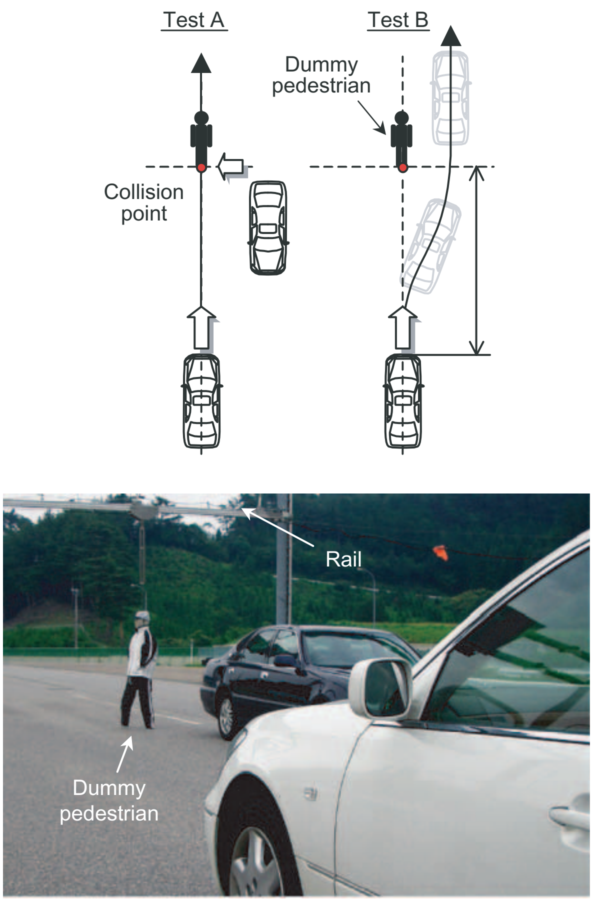

Fig. 4 An example of test scenario and facility for pedestrian sensing test

Function survey is for verifying the requirement for the sensing system in terms of application and cost optimization. In this point, we will discuss later in this paper.

Test vehicle is implemented as shown in **Fig. 5**. Sensing systems are installed in this vehicle, and they are connected to 500 kbps CAN-bus. A rapid prototype ECU is also connected to this CAN-bus to supply vehicle dynamics

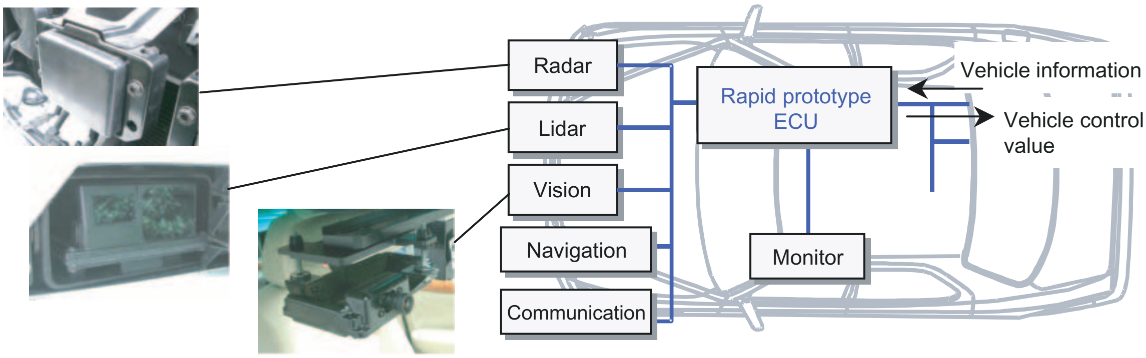

Fig. 5 Test vehicle configuration

information to sensing systems. Sensing systems are evaluated with this vehicle to verify their performance

3.2 Develpoment for function enhancement

As described above, it is important for developing sensing system to have an aspect of application. We have listed basic functions required to enhance ADAS application as shown in **Table 1**. We understand that to enhance ADAS is to activate them exactly as drivers expect, or to enlarge condition under which they are activated. In the table, each independent sensing system is evaluated on its current ability for each sub function.

As shown above, each independent sensing system has advantages and disadvantages. Therefore, combination of sensing system has a potential to enhance functions. We recognize that function development of independent sensing system, i.e. radar, lidar and vision, is fundamentals. Based on these fundamentals, fusion of each sensing system is developed for realizing enhanced functions.

3.3 Effort for cost optimization

We think that it is a significant issue for spreading ADAS to decide what kind of sensing system we supply for compact class vehicles. To survey this issue, the process we adopt would be necessary to analyze function sufficiency. If it is possible to substitute a lower cost sensing system with sufficient functions for a higher cost one, or if it is possible to abandon specifications that require costs, it can be a solution for the issue.

For example, a sensing system for PCS is considered. PCS is one of remarkable application of ADAS for improving collision safety of vehicles. A radar or a lidar is usually applied to the sensing system for PCS, and its cost could prevent PCS from spreading in the market. A key

Table 1 Functions of sensing system for ADAS

Function	Sub function	Sensing system			
		Radar	Lidar	Vision (Mono)	Navigation
Object detection	Position detection	+	++	-	NA
	Velocity detection	+	-	-	NA
	Availability	++	+	-	NA
Object classification	Shape detection	-	+	++	NA
	Property decision	-	+	++	NA
Object tracking	Target selection	+	+	-	NA
	Collision prediction	+	++	-	NA
Road detection	Road profile detection	-	-	++	+
	Road classification	NA	NA	-	++
Ability management	Visibility estimation	-	-	-	+
	Quality estimation	+	+	-	-

function of sensing system for PCS is "Collision Prediction", and this function must be analyzed carefully whether its ability is necessary and sufficient.

Cost performance should be carefully considered in fusion sensing system as well, of course. We are developing each independent sensing system and fusion sensing systems with the cost point of view.

4. EXAMPLE OF DEVELOPMENT

In this section, two examples are shown to illustrate how sensing system is developed through the process discussed above. The first example is on functions of "Road Detection" to enhance ACC, and the second one is on a function of "Collision Prediction" to survey specifications.

4.1 Sensing system involving navigation system

"Road Profile Prediction" is a function to estimate curvature, or shape of the road or lane on which host vehicle will proceed. It is an important function that ACC requires of sensing system, and its result is mainly used for "Target Selection" and speed control. A "basic" ACC realizes this function by applying information of vehicle dynamics sensors such as a yaw rate sensor or a steering angle sensor.

However, this kind of "basic" ACC has a problem that it cannot realize vehicle behavior like usual human drivers are making. This problem comes from the following reasons. One is that travel path can be predicted only at the present position and cannot be predicted forward because prediction is made based on vehicle dynamics sensors. The other is that function of "Road Classification" is not associated with "Road Profile Prediction". Lack of road characteristics information such as highway or lamp sometimes makes driver feel uncomfortable. For example, when an ACC vehicle exits the highway and proceeds to a lamp, these two problems happen at once. In this situation, missing detection of a possible curve and driver's will cause acceleration of the vehicle, and make driver feel uncomfortable as a consequence.

To solve this kind of problem, a method using navigation technology is proposed.[3] However, just utilizing navigation information does not solve the situation described above because of two reasons. One is that accuracy of global positioning system (GPS) and map-matching technology is not enough. A worst-case error is estimated up to around 30 meters today. The other is that the map database of navigation system is not accurate enough for our purpose. These facts result in difficulty in judging a vehicle to proceed to an exit way. The first reason would be overcome in around 2010 when quasi-zenith satellite system will be in service in Japan and the accuracy of GPS will be improved dramatically. However, the latter reason has no clear way to be overcome now.

We propose a method that combines navigation system with other sensing system for solving this problem. We have a choice of several sensing systems for combining with navigation system. In this paper, we choose a lidar because sensing system consists of a lidar and a navigation system is a basic level configuration rather than one of including other sensing systems as ACC.

The requirement for the sensing system is to make an accurate "Road Profile Prediction" and "Road Classification" even when the host vehicle will exit a highway. To realize this requirement, we have built an exit possibility estimation algorithm based on distance against highway exits by navigation information and a lane position detection decided from relative position between delineator or preceding vehicles and the host vehicle. The idea of this algorithm illustrated in **Fig. 6**.

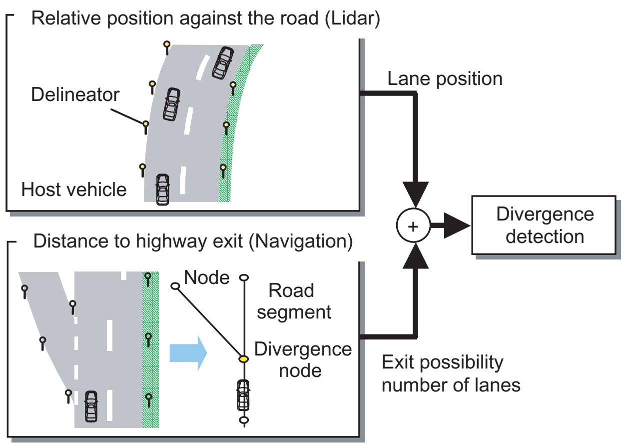

Fig. 6 Outline of divergence detection algorithm

The result of divergence detection algorithm is shown in **Fig. 7**. "T_1" shows the time when navigation system detected an approach to an exit. "T_2" shows the time when the algorithm decided that the host vehicle would proceed to a lamp. On "T_3", present position of navigation system itself is judged to be on the lamp, but it reverted soon on the highway and finally settled on the lamp on "T_4" in this example. Scenery on "T_2" is shown in **Fig. 8**, and this shows that the requirement is satisfied in this case.

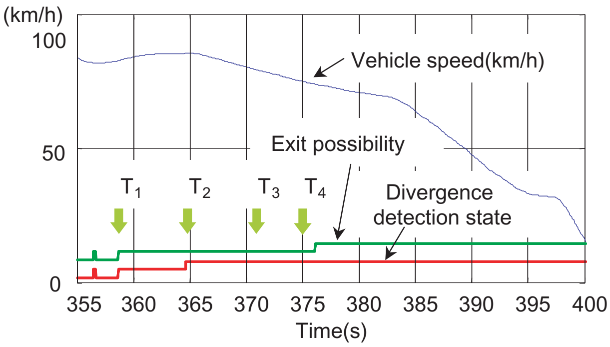

Fig. 7 An example of divergence detection result

Fig. 8 Scenery when divergence is detected

This method still has some issues to be improved. If there are no delineators or preceding vehicles, this method does not work because relative position between the host vehicle and the road cannot be determined. Moreover, the width of roadside strip affects the accuracy of the judgment. Therefore, we need to give the algorithm a tendency to judge safer result in case of uncertain situation. That is, functions of "Road Profile Prediction" and "Road Classification" should provide ACC with the result of possibility of exit for suppressing acceleration of ACC.

4.2 Function analysis of collision prediction

In this section, function of "Collision Prediction" is discussed based on simulation.

4.2.1 Example of PCS concept

An example of PCS system general concept is shown in **Fig. 9**. This concept is derived from traffic accidents statistics in Japan. The concept is focused on rear-end collision against standstill vehicles or collision against pedestrians, because these situations are major or crucial and this leads to system effectiveness.

4.2.2 Requirement for sensing system

For the PCS concept described above, function of "Collision Prediction" based on lap rate estimation and position prediction of each object plays a key role in sensing system. If this function is provided accurately enough, giving a driver warning in appropriate timing and suppressing an unnecessary warning become possible.

4.2.3 Simulation analysis

An example of simulation analysis on "Collision Prediction"

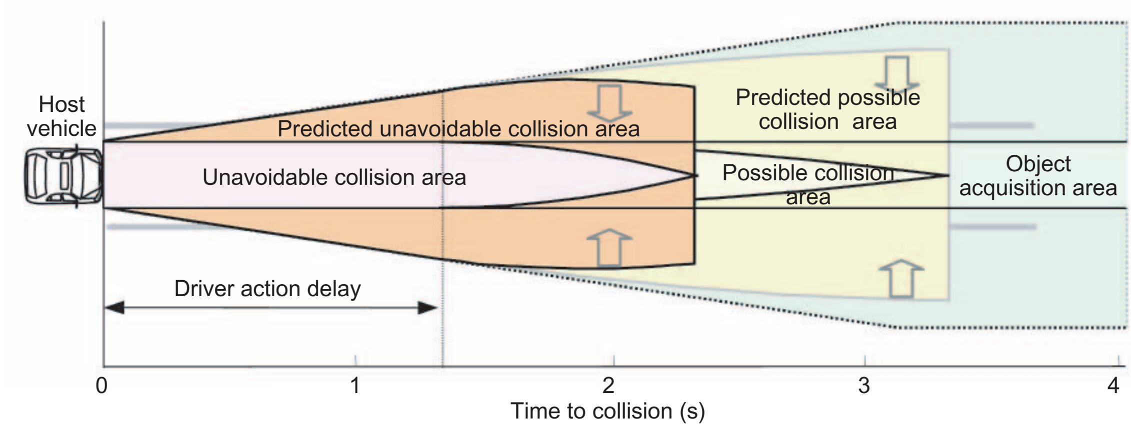

Fig. 9 An example of PCS concept

is shown here. In the analysis, how accuracy on position detection affects the function is discussed. Through the analysis, we can consider the relation between "missing activation ratio" or "unnecessary activation ratio" of PCS and the accuracy on position detection. It will result in requirement for sensing system. The simulation method is a tool for analysis, and is not a "Collision Prediction" function itself.

At first, definitions of words in the simulation are given. "Collision judgment" is made when collision against an object is judged to be unavoidable even if the host vehicle makes maximum deceleration or turn. "Collision probability" is a probability in which collision judgment is given. The collision probability is calculated under the condition of given sensing error, which is provided as standard deviation, of position and width of an object. "Collision probability map" is a plane that describes contours of collision probability. In the map, the origin is the position of sensing system and the axes correspond to position of an object. "Missing activation ratio" means a ratio in which collision judgment is not made even against an object to collide. "Unnecessary activation ratio" is a ratio in which collision judgment is made even against an object not to collide.

The result calculated by the simulation is shown in **Fig. 10**. These figures are collision probability maps derived when different position detection errors are given. Compared with two maps, it is understood that size of intermediate area between 100% and 0 % of collision probability depends on error. This means that if error is large, missing activation ratio or unnecessary activation ratio increase.

Moreover, relation between position error, existence of width information and the missing activation ratio is calculated as shown in **Fig. 11**. This simulation is carried out on the assumption that an object and host vehicle will collide with the lap of 0.1 m. The simulation for no width information is computed under the condition of an object being a point with no width. Another simulation on unnecessary activation ratio results in the **Fig. 12**. This simulation is calculated on the assumption that an object and host vehicle will pass with the gap of 0.1 m.

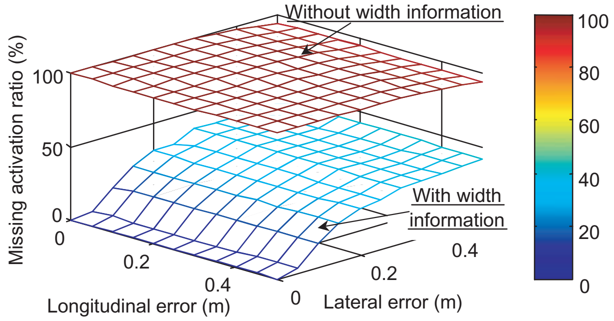

Fig. 11 Missing activation ratio on 0.1m lap collision

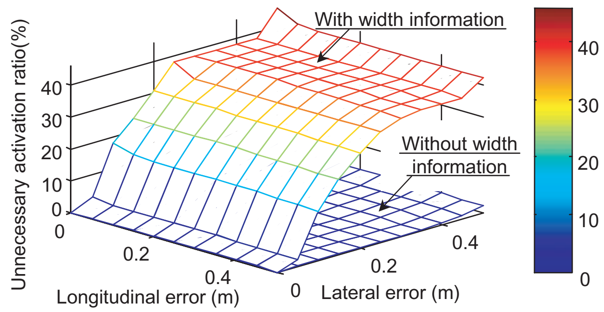

Fig. 12 Unnecessary activation ratio on 0.1m gap passing

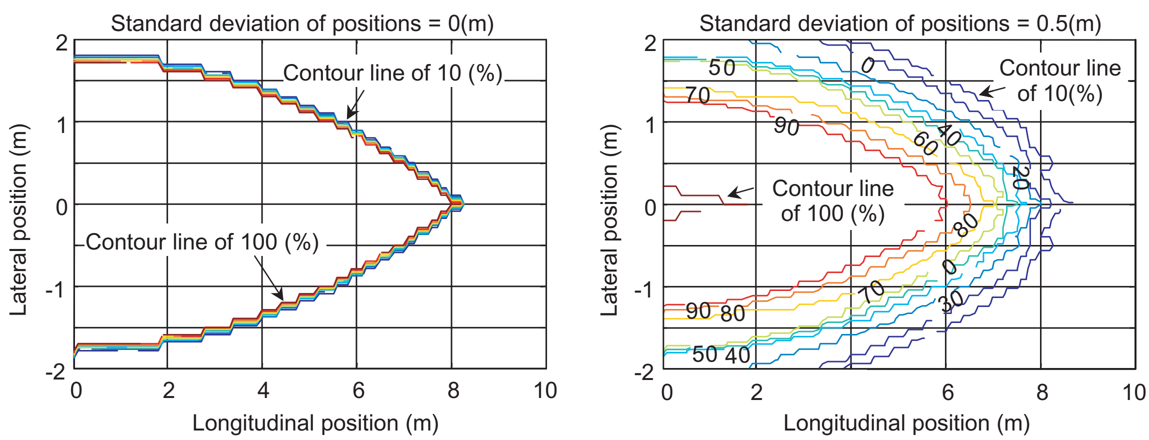

Fig. 10 Examples of collision probability map

From these results, it is said that missing activation ratio increases significantly instead of decrease in unnecessary activation ratio when width information is not available. This result seems to be reasonable because the simulation is based on the assumption of no width object. And the error in lateral position, rather than that of longitudinal position, has a great influence on missing activation ratio and unnecessary activation ratio.

Through these kinds of simulation analysis, we can estimate how much error is allowed for sensing system to supply "Collision Prediction" function, and we can reflect these results to design sensing system configurations or specifications.

5. CONCLUSION

In this paper, requirement for sensing system is discussed especially in view of acceptance of ADAS into the society. To realize optimal sensing systems, a development approach with the view of ADAS application is introduced. From the survey of a fusion sensing system that consists of lidar and navigation, we have recognized its potential to enhance system function. And from the survey of a "Collision Prediction" function, we have understood how lateral position error and width information affect the result of prediction. This kind of survey should be carried out harmoniously with automotive manufacturers, because ADAS application and sensing system will be developed simultaneously.

Further survey will be made to clarify optimal sensing system specifications and configurations in the future.

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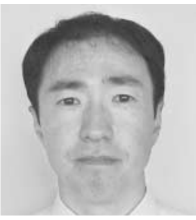

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