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A Cognitive Analysis and Life Prediction Through AI Algorithm of Control Arm Using Manufacturing and Vehicle Driving Data

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ABSTRACT

This study aims to enhance vehicle safety by predicting the life perdition of control arms, critical suspension components. Traditional inspection methods have limitations in accurately predicting failures, leading to unexpected accidents occurring both before and after the vehicle's expected lifespan. The increasing complexity of control arm manufacturing, coupled with the growing volume of vehicle driving data and heightened competition, necessitates a more sophisticated approach to quality and safety. This system implements autonomy and intelligence of the production system by utilizing intelligent production system, big data, and artificial intelligence technologies, and supports optimal decision-making in real time. Data collection: There collected various sensor data from the production site, system data, MES system data, etc. In data refinement, data analysis and algorithm extraction of the Control Arm are performed, and the collected data is refined and preprocessed to be processed into a form suitable for analysis. Database construction: We build a relational database or NoSQL database to systematically manage data. This study represents a crucial step towards a more proactive and data-driven approach to vehicle safety and manufacturing. By integrating AI and big data technologies, the automotive industry can move towards a future characterized by minimized accidents and optimized production processes. Finally, we derived the results of predicting and optimizing the remaining useful life prediction of the remaining product.

Keywords: Control arm, cognitive analysis detection technique, AI data analysis, intelligent production system, life perdition, smart factory.

INTRODUCTION

The control arm, one of the automobile parts, is one of the core components of the suspension system and acts as a direct connection point between the front wheel assembly and the vehicle frame. It is a component used in the suspension of the control arm, and it connects the body and the wheels to absorb the shock of the road surface. The control arm may look simple in appearance, but it is one of the core components that plays an important role in the overall stability and driving performance of the vehicle. The control arm, which can be seen in almost all road-driving suspension systems, is located on the front axle of each of the two front wheels. In the manufacturing process, the suspension control arm is made of cast iron, and the same material was used in this study. The cast iron control arm is a component that provides strength, rigidity, and damage resistance.

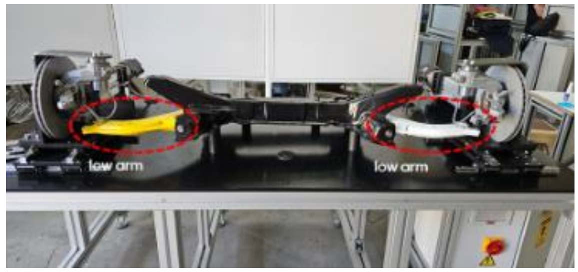


Fig 1: Installing the control arm system

The present invention relates to the control arm that constitutes the suspension of an automobile, and in particular, to a manufacturing method of a control arm manufactured by extrusion using a material such as aluminum, and to an extruded material and a control arm manufactured by this manufacturing method. In the manufacturing process of the present control arm, the control arm is manufactured by an extrusion process of extruding an aluminum billet through an extrusion die equipped with an extrusion hole along the horizontal cross-sectional shape of a control arm to form an extruded material extending in a direction matching the vertical height direction of a control arm to be manufactured, a cutting process of cutting the extruded material in a direction perpendicular to the vertical height direction of the control arm to be manufactured to form a plurality of primary intermediate materials, a processing process of forming a joining portion for joining parts to the primary intermediate materials to form a secondary intermediate material, and an assembly process of separately manufacturing a spring seat cup on which a seat of a coil spring to be coupled to the control arm is to be placed, and assembling the spring seat cup and the seat to the secondary intermediate material.

CONTROL ARM SYSTEM

Control Arm Manufacturing Proces

By installing it on the control arm, which is a suspension component, we attempted to predict the remaining lifespan due to vehicle component defects and fundamentally prevent vehicle accidents based on this. In the past, only simple inspections and tests were conducted, but now we need a guarantee for accelerated life accidents that occur before and after the vehicle's durability life. To this end, we individually installed complex sensors on important vehicle parts to prevent accidents during driving in advance through non-contact sensors that cannot physically interact with people, such as autonomous driving.

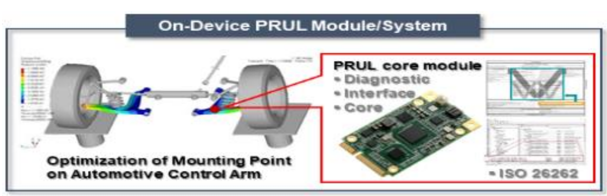


Fig 2: Control arm adjustment device and measurement position of each sensor

Processing of Manufacturing Generated Data

In this study, we attempted to complete the component level by conducting real-time measurement tests on three types of data (sensor/road/vehicle) through T, a suspension parts manufacturer, and control arm parts equipped with sensors, and obtaining measurement data. The acquired measurement data was filtered using the PRUL algorithm technology and completed vehicle level development through field tests at the actual road test site of the Korea Automobile Research Institute, and composite data for five life prediction sensors were constructed. At this time, this study was conducted using the PRUL (Prognostics of Remaining Useful Life) sensor and system on-device. The generated data was processed. As a comparative study of this study, the prospects after the completion of the development of the technology are quite encouraging, such as improving vehicle safety, securing safety solutions, and extending the life of related parts by measuring the status of vehicle driving safety parts that have a serious impact on driver safety and vehicle operation in real time during normal driving of the vehicle, diagnosing failures related to the durability of the parts, and transmitting and controlling preemptive prediction information. In particular, in the past, it was limited to simple predictions based on inspection processes and accelerated life tests, or collecting and notifying information after failures occurred, and in the case of further improvements, it was limited to transmitting information on maintenance consumables such as tires/wheels/oil/brakes. In this way, after the completion of the development of the technology, the initiative in information on vehicle maintenance management was acquired, and based on this, there were similar contents such as identifying responsibility and efficiently managing optimal maintenance of driving parts other than consumables.

Autonomous Driving Safety Technology System for Automobiles

A comparative study examining the future technology system aspect of autonomous vehicles shows that risks have been continuously raised, including the fatal accident caused by Tesla malfunction in the US, 11 minor accidents involving Google's self-driving car in 6 years, and a traffic accident on the first day of fully autonomous driving in the US. In order to ensure safety, a driving platform based on multi-safety technology that can minimize the risk of accidents even if a problem occurs in the vehicle is essential. For Level 0-2 vehicles, a fail-safe system that detects and notifies a failure and relies on manual driver action is required, and for Level 3 and higher, a fail-operational system based on multi-safety design that overcomes the failure itself before driver intervention is required when a failure is detected. In particular, the functional safety standard for automotive electrical components (ISO26262) recommends multi-mode design, the International Forum for Harmonization of Automotive Standards (UNECE/WP. 29) is reviewing strict safety requirement standards for autonomous vehicles, and the US National Highway Traffic Safety Administration (NHTSA) announced architecture recommendations for functional safety of major ADAS systems, and in particular, the steering system recommended redundancy of power, sensors, and actuators. Accordingly, GM introduced multiple motors, multiple controllers, and multiple power supplies for the steering and braking actuators in the Cruise AV. Furthermore, the Safety Of The Intended Functionality (SOTIF) standard (ISO/PAS 21448), unlike functional safety (ISO26262), considers cases where the intended design itself is insufficient to secure safety and is inappropriate rather than malfunctions, failures, and defects.

COGNITIVE ANALYSIS AND LIFE PREDICTION AND SYSTEM CONFIGURATION

Control Arm Model Configuration

In this paper, four control arm samples were used. This model is a part used in the passenger car F company model. As a result of the Halt test using a linear tester, the following areas were damaged. In the case of Sample 1 and Sample 2, the Rear Bracket and Rear Neck areas were mostly damaged. In addition, in the case of Sample 3 and Sample 4, which had different structures, cracks were observed in the center of the control arm as shown in the photo below. As shown in Table 1, each fracture time is shown for each test condition. This is a sensor that measures the remaining life (PRUL: Predicted Remaining Useful Life) of the control arm by installing the PRUL sensor for the installation location and measurement of each position of the control arm. A total of 4 sensors are installed on one vehicle. Each sensor is connected via wireless communication to exchange data in real time, and the data collected from the sensor is transmitted wirelessly to monitor the status of the control arm in real time and provide notifications when a problem occurs.

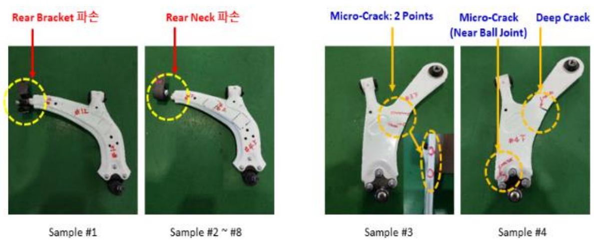


Fig 3: PRUL Sensor layout of Control Arm

For Sample 3 and Sample 4, the sample was measured to derive the algorithm using the one with the bush, and the phenomenon of the middle part breaking occurred only once out of about 50, and in most cases, the bracket was broken or the neck part was cut as shown in Fig. 3 below.

Table 1: Control Arm failure cases for each condition (HALT Test)

Sample 1/ Sample 2	#1	@400kgf(60s)→@1,500kgf(120s)→ @400kgf(60s) →@1,800kgf(600s) /Push only, 4Hz, 45°	1:01	14,444	Bracket fail
	#2		1:18	19,481	Neck fail
	#3		1:29	21,427	Neck fail
	#4		1:10	16,610	Neck fail
	#5		1:30	21,753	Neck fail
	#6		1:16	18,370	Neck fail
	#7		1:34	22,701	Neck fail
	#8		1:05	15,723	Neck fail
Sample 3 Sample 4	#3	@400kgf(60s) →@1,200kgf(120s)→@400kgf(60s)→@1,500kgf(600s) / Push only, 4 HZ, 45°		305,155	Middle part Micro crack
	#4	@400kgf(30s)→@1,500kgf(600 초)/ Push only, 4 HZ, 45 °	16:17	251,716	Middle part Deep Crack

Sensor Measurement System of The Control Arm

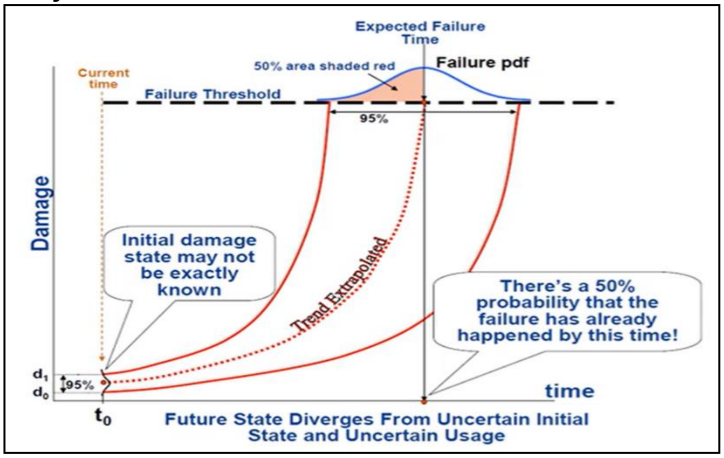
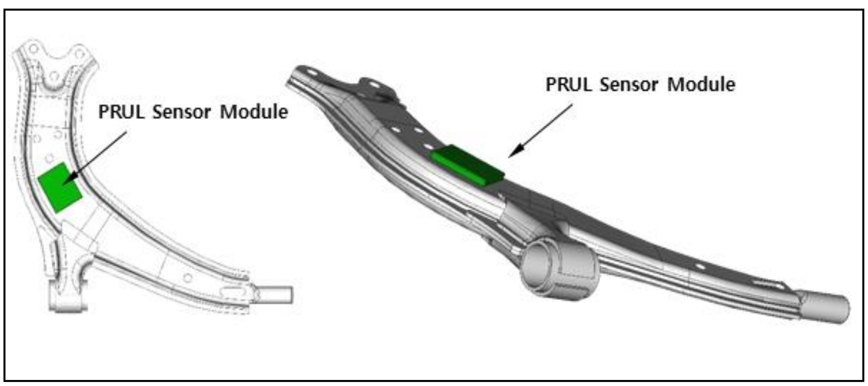


Fig 4: Run to failure of life predition model using HALT (High Acceleration Life cycle Test) of the Control Arm

This shows a schematic diagram of the control arm PRUL sensor system. It is a component used in the suspension of the control arm, and it continuously monitors the status of the control arm of the PRUL sensor to analyze the installation location of the PRUL sensor module according to the position that connects the vehicle body and the wheel and absorbs the shock of the road surface, thereby ensuring the safety of the vehicle and increasing the usability of the system to increase maintenance efficiency.



(a) PRUL Sensor with sensor module (b) Sensor with sensor module
Fig 5: Control Arm model equipped with sensor module

This is a sensor that measures the remaining life (PRUL: Predicted Remaining Useful Life) of the control arm by installing the PRUL sensor for the installation location and measurement of each position of the control arm. A total of 4 sensors are installed on one vehicle. Each sensor is connected via wireless communication to exchange data in real time, and the data collected from the sensor is transmitted wirelessly to monitor the status of the control arm in real time and provide notifications when a problem occurs. This shows a schematic diagram of the control arm PRUL sensor system. It is a component used in the suspension of the control arm, and it continuously monitors the status of the control arm of the PRUL sensor to analyze the installation location of the PRUL sensor module according to the position that connects the vehicle body and the wheel and absorbs the shock of the road surface, thereby ensuring the safety of the vehicle and increasing the usability of the system to increase maintenance efficiency.

Fatigue Durability Analysis of FEM

Fatigue analysis of the control arm (von miss stress) FEM maximum von Mises stress occurrence location and size, the maximum von Mises stress of the control arm occurred at the lower connection of the part, and its value was expressed as 250 MPa.

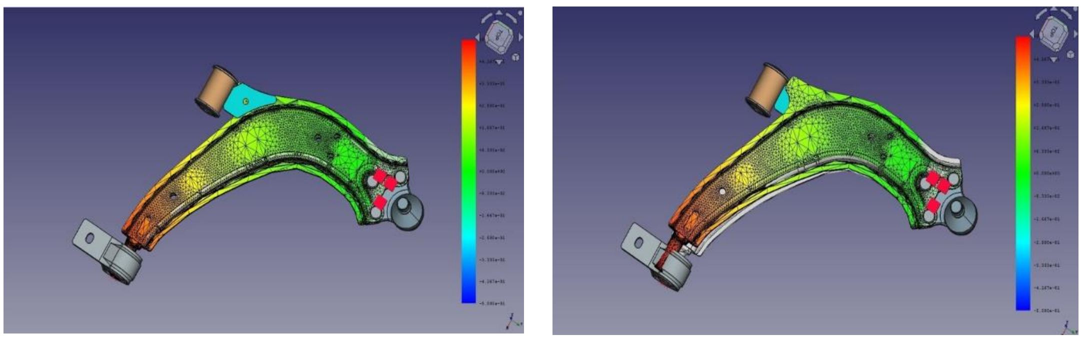


Fig 6: Fatigue analysis of control Arm with Von-Mises stresses of model equipped with PRUL Sensor sensor module

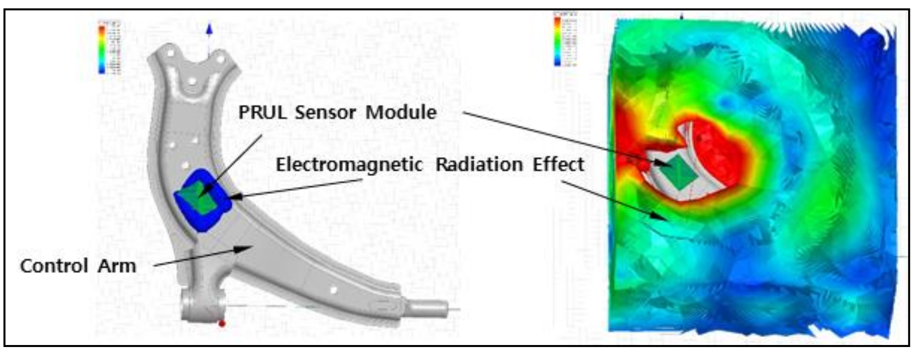


Fig 7: Fatigue analysis of control Arm defect by PRUL Sensor

ARTIFICIAL INTELLIGENCE PROCESSING

Data Acquisition, Data Analysis and Data Quantization

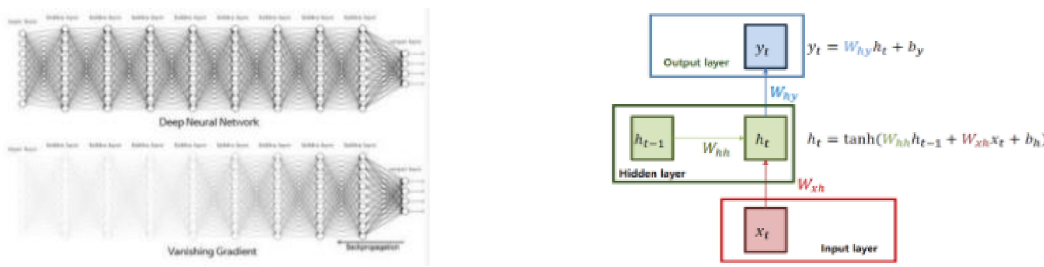
It samples sensor values that measure actual physical conditions and converts the resulting samples into digital numeric values that can be manipulated by a computer. Then, through the process of collecting or creating data to build learning data, it removes bias and noise and performs attribute display work to create the desired AI learning model depending on the type of data. In AI algorithm implementation, failure prediction and health management (PHM) is the step of continuously monitoring the health of a system or equipment, detecting abnormal signs at an early stage, predicting failures in advance, and performing necessary maintenance.

Cognitive Analysis and Life Prediction

cognitive analysis and failure prediction and health management (PHM) is a step that continuously monitors the health status of a system or equipment, detects abnormal signs early, predicts failures in advance, and performs necessary maintenance. Predicting the remaining life of an operating facility means predicting the time from a specific point t0 until the facility reaches a limit point t1 at which it can no longer be used. In other words, predicting the remaining operating time of the facility plays an important role in establishing an efficient maintenance plan and preventing production interruptions or safety accidents due to unexpected failures.

RNN (Recurrent Neural Network) and LSTM (Long Short-Term Memory model)

RNN can encounter the vanishing gradient problem when learning long sequences. RNN is a powerful tool for effectively learning and analyzing sequential data. In particular, it can increase learning efficiency through parameter sharing and can be applied to various sequential data processing problems. However, various modified models such as LSTM and GRU are being developed to solve problems that may occur when learning long sequences. The following figure <8> shows the structure that shows the basic operation of RNN.



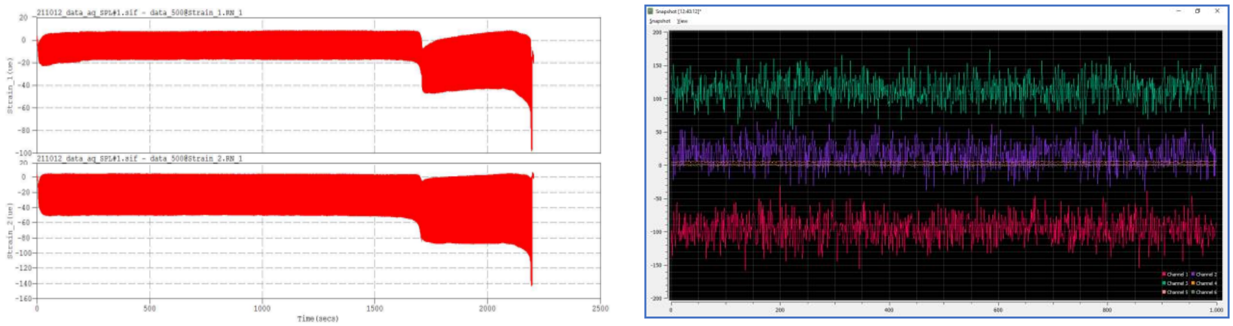
(a) Basic operation of RNN **(b) Basic operation of LSTM**

Fig 9: Comparison of basic operations of RNN and LSTM

It consists of three gates that control the degree of input, memory, and output, and unlike the basic RNN, it has an additional cell inside. Also, unlike the RNN, it solves the long-term dependency problem by introducing an input gate, forget gate, and output gate. Input Gate determines whether to reflect new information in the current memory, and Forget Gate determines whether to reflect previous state information in the current memory, and controls the output value of the updated memory in output Gate.

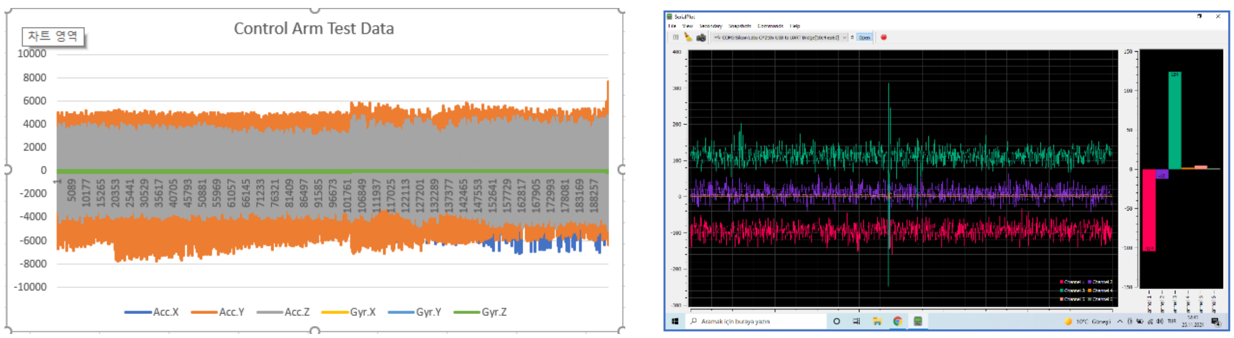
Artificial Intelligence Deep Learning Life Prediction Simulation

Data-driven RUL prediction was simulated based on Run to Failure data, that is, the authorization condition sensing data for what happened to the control arm during the execution from the last maintenance activity to the next activity. In addition, simulations were performed based on sensing data before and after the harsh authorization HALT (High Acceleration Life Cycle Test) test based on Run to Failure data, to measure the sensing status over time.



(a) HALT Test results of strain **(b) Mounting Work before testing (strain, displacement)**

Fig 11: HALT Test results of strain gauge (2 channel) and before testing (strain, displacement)



(a) Control arm test results **(b) Control arm test results (e-DAQ Plus)**

Fig 12: HALT Test results of Gathering the data

Based on the regression model and time series model that use time as the main independent variable, the failure behavior of the life curve over time can be predicted in the regression model, and the failure behavior was predicted with linear and polynomial-based curves and the time variable was used according to the cumulative fatigue. The simulation was performed considering the dependency of PRUL on the operation time of the control arm parts of the model as well as the dependency on several related factors such as the severe operating temperature of the parts and the severe multi-axis vibration.

CONCLUSION

By attaching multiple sensors to mechanical parts to predict the lifespan, data analysis must be performed using the reliability data of the parts. Accordingly, it was confirmed that the theoretical method for predicting the lifespan operates using an algorithm that analyzes the measurement data. This is a function that detects defects in the control arm during driving of automobile safety function parts and perfectly controls/prevents safety accidents. Instead of using measuring equipment used in the inspection process, a technique was used to integrate it into the control arm unit. Through the optimization method technology through fault analysis, a fault analysis process was performed to measure and verify the assumption of FMEA, which is one of the life prediction techniques, and through this, the essential elements for safety were identified. In addition, a list of block constraints (debugging, testing, operation mode) and a fault injection list were created. Through this, the safety goals and essential influencing elements in the control arm were analyzed and verified.

ACKNOWLEDGMENT

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