

Design and Experimental Dynamic Evaluation of an All-Terrain Vehicle Prototype

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Abstract. All-terrain vehicles (ATVs) are widely used in off-road transportation, recreational activities, and races, where vehicle stability and dynamic performance are essential for people's safety. This study presents the design, prototype fabrication and experimental evaluation of a single-rider ATV. The frame shape, dimensions, and chassis arrangement were adapted from an existing ATV design. Autodesk Inventor was used to build the three-dimensional model, which was then reduced in scale and produced by 3D printing. The prototype was tested both on smooth and rough roads under similar environmental and recording conditions. Its motion was recorded by video, and time, vertical position, and velocity were obtained from the frames divided from the video. The results of the test on smooth road are used as a baseline for the result of the rough road test. The study therefore provides a simple, cost effective method for checking the basic dynamic behavior of an ATV prototype before more optimization method is carried out.

Keywords: All-Terrain Vehicle (ATV), CAD Modeling, Prototype Fabrication, Motion Analysis, Vehicle Dynamics

1. Introduction

1.1. Background

An ATV is a lightweight off-road vehicle designed for rough terrain, with good mobility and ability to get through tough spots. It is widely used in agriculture, forestry, mining transport, military support, and other fields [1]. As the use of ATVs continues to expand, people are paying more attention to how stable they are to drive on rough roads, how comfortable they are to ride, and how safe they are. The vehicle's dynamic performance directly affects its off-road capability, structural reliability, and driving safety [2]. Therefore, analyzing and testing an ATV's dynamic response is really important for optimizing its design and improving overall performance [3].

1.2. Existing research

In recent years, research on ATVs has mainly focused on designing the overall vehicle structure, optimizing suspension systems, designing steering mechanisms, and analyzing vehicle dynamics.

Shrivastava proposed a design plan for a single-rider ATV, combined with finite element analysis, providing a reference framework for ATV design [1]. In addition, some researchers further optimized the ATV frame lightweighting, suspension performance, and overall vehicle dynamics characteristics through multi-body dynamics simulation and CAD modeling techniques, improving structural safety and off-road performance [4-6]. With the development of digital design technologies, CAD modeling combined with Rapid Prototyping has gradually become an important tool in vehicle product development, effectively shortening development cycles and reducing manufacturing costs [7].

1.3. Research gap

However, although existing studies have analyzed vehicle vertical motion and overall dynamics using multi-body dynamics simulations, real vehicle tests, and embedded sensor systems, these methods usually rely on specialized software, measurement equipment, or complete vehicles, making them costly and technically demanding [5, 8]. In comparison, research that provides low-cost preliminary dynamic testing for ATV prototypes is still relatively limited. Testing the prototype can solve some design problems at the beginning. Therefore, it is necessary to establish a simple experimental process that connects CAD modeling, prototype manufacturing, road testing, and video motion analysis.

1.4. Objectives and contributions

This paper aims to establish a low-cost design and dynamic testing process suitable for scaled-down ATV prototypes. First, based on existing ATV design methods, Autodesk Inventor was used to create 3D models of the main vehicle structure and then made scaled sample of ATV using 3D printing. The model was then tested on smooth and rough roads. Vertical displacement and velocity were obtained frame by frame from the recorded video. By linking design, manufacturing, testing, and data analysis, the study provides a practical reference for early-stage ATV evaluation and later improvement.

2. Methodology

2.1. ATV design

Figure 1 illustrates the overall workflow of this study. The ATV prototype in this study is based on the design method proposed by Shrivastava. The vehicle uses a space frame chassis to balance structural strength and lightweight. The main material for the frame refers to AISI 4130 chromoly steel, which has a high strength-to-weight ratio. The suspension system uses a front double-wishbone and rear trailing arm with mono-shock setup to absorb impacts from rough roads and improve wheel contact and vehicle stability. The steering system refers to a centralized four-link mechanism and the Ackermann steering geometry is used to design the turning angle of each wheel. They all reduce tire slip during turns and improve mobility in tight conditions [1]. This paper does not redo full structural calculations, but applies the above design principles to the CAD model and scaled prototype's overall structure.

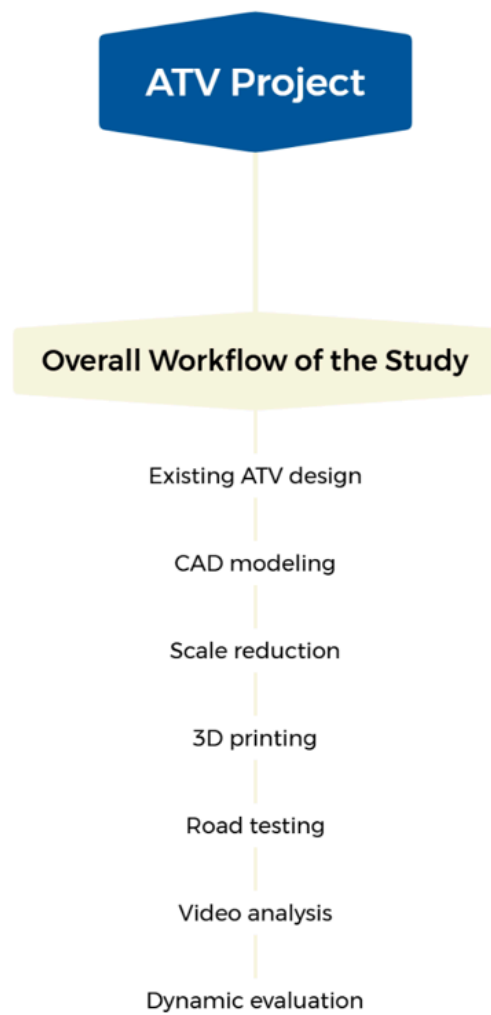


Figure 1. Overall workflow of the study

2.2. CAD modeling and prototype fabrication

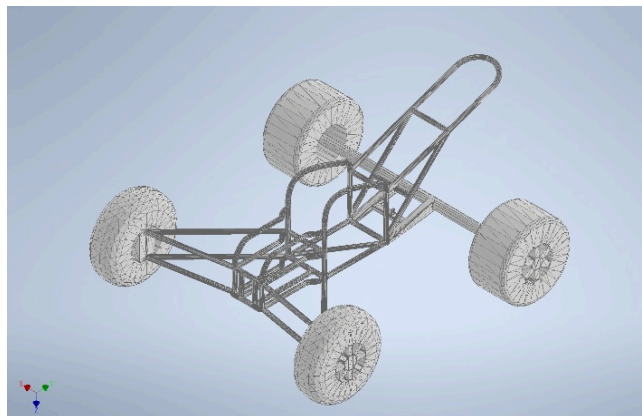


Figure 2. Three-dimensional CAD model of the ATV prototype

After finalizing the overall structure, Autodesk Inventor was used to create a 3D model of the ATV, shown in Figure 2. The modeling process mainly included the frame, chassis, wheels, and its connecting structures, and each part was scaled according to the design dimensions. Then, using Inventor's assembly function, all the parts were put together into a complete ATV model and checked for any interference between components to ensure the ATV could be assembled properly. Because of the limited project time and available manufacturing methods, the power system, braking devices, and part of the suspension were simplified. However, the main structures related to vehicle motion were retained. Also, for ease of manufacturing and testing, the CAD model was reduced to approximately 1:20 for fabrication and testing: the body length changed from about 2000 mm for a real ATV to about 100 mm for the prototype. The completed model was then 3D printed, as shown in Figure 3.

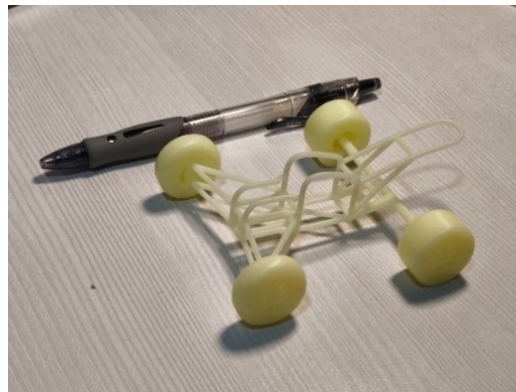


Figure 3. 3D-printed ATV prototype at an approximate scale of 1:20

2.3. Experimental setup

To evaluate the dynamic performance of the scaled ATV prototype under different road conditions, tests were carried out on a smooth road and an artificially rough road. The smooth-road test provided a baseline for vertical motion, whereas the rough-road test was used to observe vibration caused by surface irregularities. The two test scenes are shown in Figure 4. During each test, the vehicle was moved at an approximately uniform speed so that changes in speed had less influence on the results. The camera remained at the same side position and angle, and the vehicle condition and measurement procedure were kept unchanged. The rough-road recording lasted for more than one minute so that more motion could be observed and the influence of occasional random error could be reduced.



Figure 4. Experimental setup of smooth road test and rough road test

2.4. Motion analysis

After finishing the experiment, the VLC Media Player software was used to divide the rough road test video into 45 frames at fixed time intervals. Then, a fixed "reference point" was picked on the car body and used in the Measure software to record the vertical pixel coordinates of the ATV in each frame, shown in Figure 5. Video target tracking usually describes an object's motion by comparing the position changes of the "reference point" across consecutive frames [9]. To convert pixel difference into actual distance, this study uses the real diameter of the ATV prototype's wheel and its pixel length in the image as references to calculate the scale between millimeters and pixels. The vertical displacement at each moment is obtained by multiplying the pixel difference of the "reference point" relative to its initial position by the scale. A similar pixel-to-actual distance conversion method has been used for non-contact displacement measurements, but the camera's position and shooting angle must remain stable [9]. Finally, vertical velocity is calculated by dividing the displacement difference between two consecutive frames by a fixed time interval. Also, the time, displacement, and velocity are organized into a table to plot displacement-time and velocity-time curves, intuitively showing movement trends.

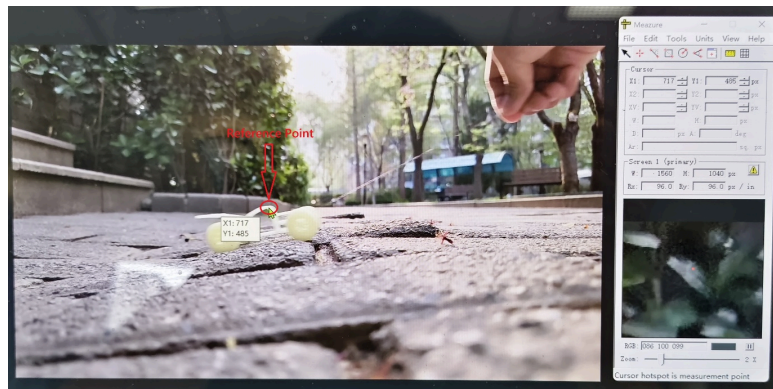


Figure 5. Video-based procedure for extracting the vertical motion of the ATV prototype

3. Results and discussion

3.1. Smooth road test

The smooth road test is used to set a baseline for the vehicle's vertical motion. The results show that the scaled ATV remains generally stable during driving, with only minor fluctuations in vertical displacement and speed, and no obvious continuous vibrations were observed. These could be due to speed changes while dragging the vehicle, small road unevenness, or video coordinate measurement errors. Since this test was mainly to check that the prototype could move normally and to set up analysis references, it was not a long, frame-by-frame analysis like the rough road test, keeping the process simple, but the results can still serve as a reference for evaluating the vehicle's dynamic response on rough roads.

3.2. Rough road test

The rough-road test produced larger changes in vertical displacement and velocity than the smooth-road test. Figure 6 shows both quantities over time. The highest measured position of the reference point was 8.946 mm and the lowest was -14.413 mm. The total range was therefore 23.359 mm,

corresponding to an approximate vibration amplitude of 11.679 mm. Its mean position was -1.976 mm, which shows that the vehicle remained slightly below its initial level during the later part of the test. The maximum upward velocity was 5.913 mm/s, while the largest downward velocity was -6.608 mm/s. The mean vertical velocity was -0.182 mm/s, a value close to zero; therefore, the body repeatedly moved upward and downward without a clear long-term vertical drift.

Most local peaks in the displacement and velocity curves appeared when the wheels crossed bumps and the body rebounded. Because the bumps were not identical in shape or height, the resulting oscillations were irregular. The downward velocity reached a slightly greater magnitude than the upward velocity, suggesting that the body sometimes dropped more quickly after reaching a high position. Wheel size, mass distribution, frame stiffness, and the simplified suspension may all have affected this response.

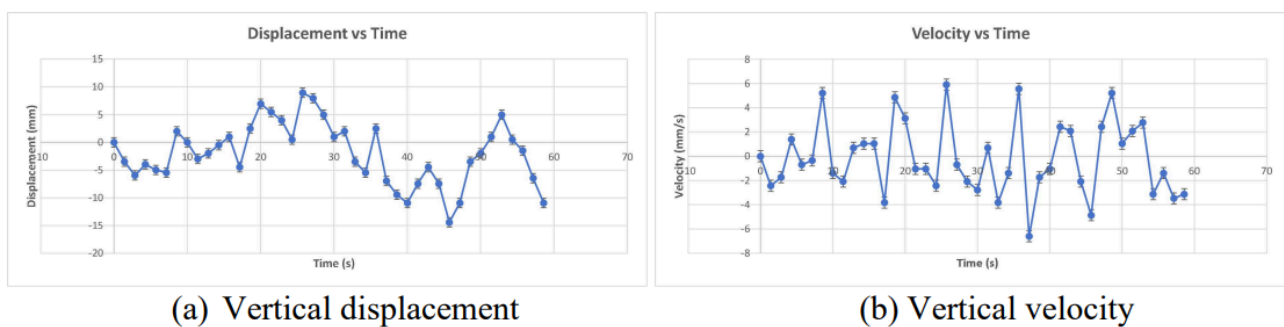


Figure 6. Rough road response of the ATV prototype

3.3. Discussion

Tests on different roads show how road conditions affect ride comfort and stability. According to vehicle dynamics theory, the suspension and tires should work together to absorb road shocks, keep the wheels in contact with the ground, and limit body vibrations [3]. Recent ATV studies show that the suspension structure and related dynamic parameters can significantly affect the ride comfort, handling performance, and overall stability of the vehicle [5]. Larger vertical vibrations can also reduce driving comfort and increase whole-body vibration experienced by the driver [10]. Thus, the suspension structure in this method will be further improved in the future.

4. Conclusion

This process is based on an ATV design plan and covers CAD modeling of the vehicle's main structure, 3D printing of a roughly 1:20 scale prototype, and dynamic testing on both smooth and rough roads.

This paper lays out a complete low-cost engineering process from CAD modeling and prototype manufacturing to experimental testing and data analysis, showing that regular videos can be used for a preliminary dynamic evaluation of prototype vehicles. Future research could add a full suspension system and simple power sources like a small motor, and use IMUs or accelerometers to conduct repeated tests at controlled speeds on different road surfaces, improving measurement accuracy and further analyzing vehicle dynamics.

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