Calculation of Mountain Bike Suspension Setup through Mobile Image Analysis

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Abstract

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1 Introduction

1.1 Context

The suspension on a mountain bike plays a vital part in the rider's performance, comfort and overall enjoyment of the sport. With some suspension units costing upwards of £1000 it is vital that they are setup to function correctly. The objective of this thesis is to research the characteristics of mountain bike suspension, look at methods and applications of image analysis, and produce a prototype mobile application which utilises image analysis to aid the user in setting up their suspension.

1.2 Background

A survey carried out by the International Mountain Bike Association shows the average price of mountain bikes owned in Europe to be €2546 (£2206) (IMBA Europe, 2015). Starting at approximately £1000 (Giant Manufacturing Co. Ltd., 2017), enthusiast level mountain bikes can be purchased with suspension for both the front and rear wheels, known as Full Suspension (FS) bikes whereas Hard Tail (HT) bikes have only front suspension. Even at this comparably low cost, the suspension units have multiple adjustments available to optimize and personalize how they operate.

Figure 1: Full suspension and hardtail mountain bikes

To ensure the fork and shock function correctly they must be set up for the rider's weight and intended use of the bike. As this is considered a specialist area, many entry and mid level riders will lack the knowledge of this process or be unsure of how the suspension should operate meaning the rider could use the bike without the suspension set up correctly.

It has been proven that using a FS over a HT offers a performance advantage to the rider (Titlestad, Fairlie-Clarke, Davie, Whittaker, & Grant, 2003). However if the suspension fork and/or shock have not been set up, it can be detrimental to the rider's performance and potentially lead to injury. For example, if a shock has too little rebound damping set and the rider goes off a jump, the excessive speed at which the rear of the bike extends can create forwards rotation, causing the rider to go over the handlebars of the bike.

Additionally, an incorrect suspension setup can cause excessive wear and tear on the bike's frame and components. Suspension which is set too soft can allow for bottoming out which expends excess forces into the frame and potentially cracks the frame's structure. Suspension set too hard forces energy, which it would normally soak up, into the wheels and tires causing denting and warping of the wheel rims. Further effects of suspension setup will be explained in following sections.

Many bicycle retailers will set up the suspension on a newly purchased mountain bike for the customer on delivery. Most of the time this will be enough to avoid incident but due to the extra weight of the equipment riders use, i.e. helmet, hydration pack, body armor which the customer will not be wearing at the time of delivery, this setup is regularly inaccurate. Furthermore, with some manufacturers choosing direct sales over local retailers (Harker, 2010; Staff, 2015), this setup can be circumnavigated altogether.

Since the birth of the modern smartphone in 2007 brought along by the first generation Apple® iPhone® and introduction of the Android™ mobile operating system, the use of mobile computing in everyday life has grown rapidly. Google™ stated that there were approximately 1.4 active Android users worldwide in 2015 (Callaham, 2015).

The introduction of activity tracking devices and mobile applications such as FitBit (Diaz et al., 2015) and Strava (West, 2015) and their growing popularity (Formosa, 2012) shows that individuals are welcome to the idea of using smartphones to aid or augment their participation in hobbies or sports. Due to this popularity and in a bid to give every rider the ability to setup and tune their own suspension, either at home or while out on a ride, companies have set about producing small devices (Aston, 2016; Hwang, 2016) and mobile applications (Benedict, 2012) which aid riders in the process.

1.3 Aims and Objectives

The aim of this project is to create a prototype mobile application for the Android operating system capable of providing the user with a suggested suspension setup using image analysis techniques. This will be achieved by meeting the following objectives:

- Complete a literature review of mountain bike suspension and image analysis techniques.
- Investigate current applications and products with similar aims
- Design the prototype application
- Implement the prototype application
- Evaluate the produced application against current products

1.4 Thesis Structure

Chapter 1 - Introduction - Outlines the context of the project and states the major aims and objectives

Chapter 2 - Literature Review -

Chapter 3 -

2 Literature Review

2.1 Mountain Bike Suspension Concepts

The purpose of suspension on a mountain bike is to divert energy from bumps and rough features in a trail away from the rider to improve comfort and performance by maintaining contact between the tires and the ground. This requires the use of a spring and damper, collectively known as a shock absorber, which allows the wheel to move away from the feature when it makes contact and make a controlled return once it has been passed.

2.1.1 Travel and Stroke

Travel is the distance which the bike's fork or frame allow the wheel to move in and upward direction. Stroke is the distance that the shock absorber can compress before it bottoms out. Travel is measured in inches or millimeters and can range from 80mm to 210mm. The amount of travel which a bike has normally denotes which discipline it was intended for. Typically less suspension is required for endurance oriented riding and more for aggressive and rough situations.

Table 1: Table of common suspension travels and intended disciplines

Travel (mm)	Cross Country	Trail	Enduro	Downhill
80				
100				
120				
140				
160				
180				
+200				

2.1.2 Front Suspension

Front suspension commonly employs a linear telescoping shock absorber, known as a fork due to it's dual sided construction. On nearly all suspension forks the stroke is 1:1 with the potential travel of the wheel. Front suspension is found on all FS and HT bikes.

2.1.3 Rear Suspension

Rear suspension uses a shock absorber much smaller than a fork and does not operate on a 1:1 ratio. Bike frames incorporate one or more pivot points and linkages which allows the wheel to move and act as multipliers for the suspension. Rear ratios are expressed as n:1 where n is the distance the rear wheel moves for every 1mm the shock compresses through its stroke. Though this is only the average leverage ratio

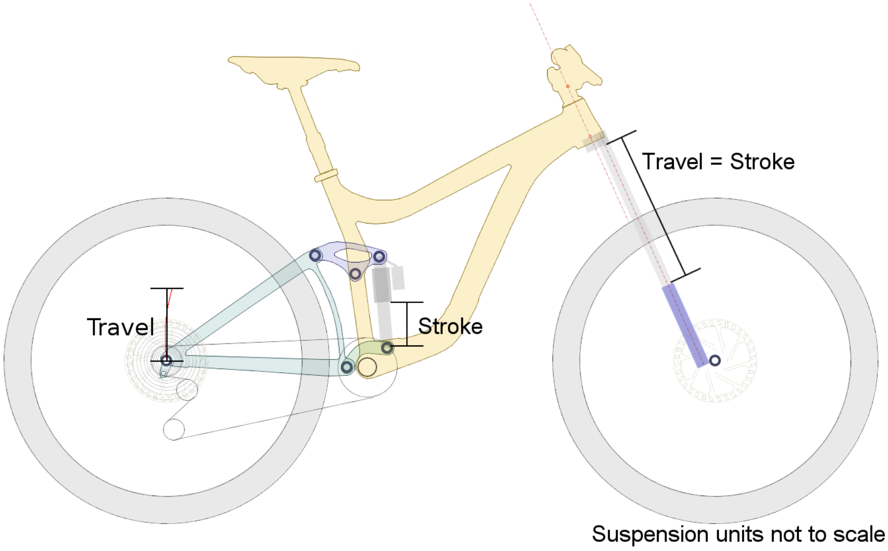

Figure 2: Diagram showing travel and stroke on a full suspension bike

for the entire travel.

As all rear suspension designs are different and the rear wheel must rotate around the main pivot, or in some cases virtual pivot, as opposed to moving linearly, the frame will behave differently through its travel and depending on the type of shock it is using. Because of this the average ratio is normally dismissed in favour of a leverage curve.

Figure 3 shows the leverage curves of three modern suspension designs. Each of these designs has between 150mm and 170mm of travel and uses the 27.5 inch wheel size however it can be seen that their suspension hosts drastically different characteristics.

The Virtual Pivot Point (VPP) design of the Giant Reign (shown blue) has an initial falling rate, meaning the shock can be compressed easily, but slows down and even rises slightly towards the end of its travel. This means the suspension will feel soft most of the time but feel stiffer on large compressions. This is emphasised by the horst link system of the Lapierre Spicy (shown magenta) which has a large rise at the end of its travel.

In contrast, the curve of the single pivot Empire MX-6 Evo (shown green) is considered linear. This is due to the MX-6 having only one pivot and swinging arm, as opposed to multiple pivots and linkages of the VPP and horst link designs, so there is an almost direct input from the rear wheel to the shock.

For this project the bike used for development and testing of the application will be a 2015 Giant Reign, shown on figure 3 in blue, as there will be constant access to it during the project. The frame uses Giant's Maestro™suspension system which is a variation of VPP. Like all VPP systems Maestro uses two links, an upper and lower, to create a virtual main pivot point, however unlike other VPP systems, Maestro creates its virtual pivot as close to the rear of the frame as possible. Indicated by the red circle

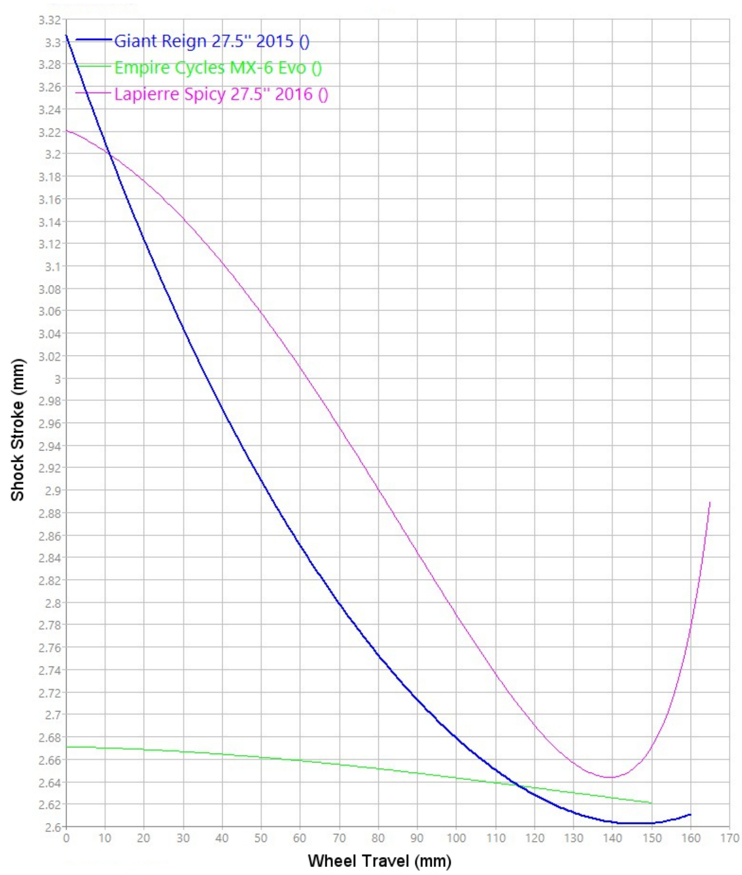

Figure 3: Leverage curves of three modern suspension designs

in figure 4, the location of this virtual pivot is unique and, many believe, creates the most efficient suspension system on the market.

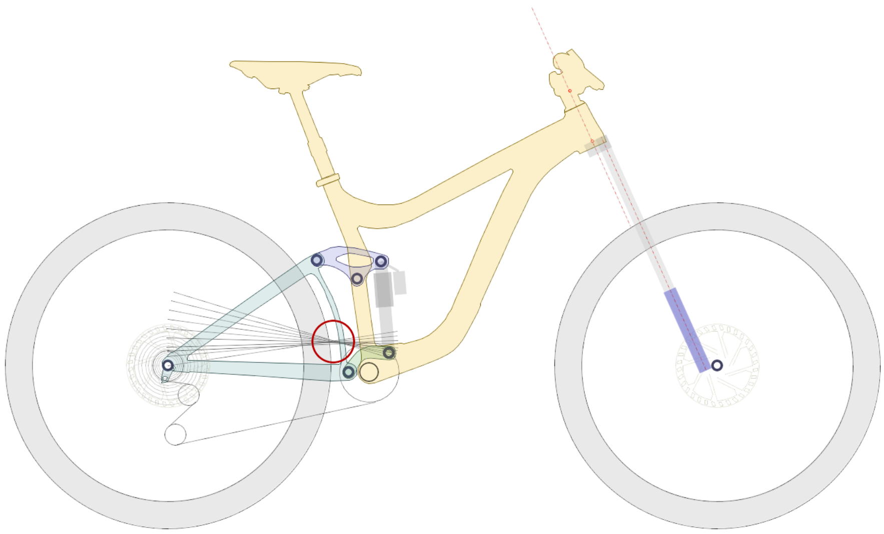

Figure 4: Maestro suspension

2.1.4 Sag

Sag is the amount that the suspension sits into its travel when the rider is in their neutral position, it is calculated using the rider's weight, available travel, and intended riding style. Sag is required so the suspension is able to drop into holes as well as soak up bumps.

To adjust sag, the stiffness of the spring must be adjusted as required. This is done by changing the air pressure when using an air spring or replacing the coil and adjusting the spring pre-load on traditional coil shocks. Depending on discipline and the amount of travel the bike has, sag can vary between 15% and 40% of the available travel though is commonly set between 25% and 35% for the average rider. 15% and 40% are reserved for competitive situations.

2.1.5 Damping

Suspension damping is carried out by forcing oil within the shock absorber through an arrangement of holes in the absorber's damping circuit. Reducing the size or number of holes making the travel of oil through the circuit slower and therefore increases the damping effect making compression or rebound slower.

2.1.5.1 Compression Damping This is applied while the shock absorber is being compressed. More damping forces the wheel to remain in contact with the ground which makes the suspension feel stiffer. Too much compression damping can make the suspension too stiff so it does not soften bumps or rough sections correctly. Too little can cause the suspension to ”blow through” its travel prematurely potentially leaving none when it would be required.

2.1.5.2 Rebound Damping This is used to control the speed at which the shock absorber extends once it has been compressed. An optimal setting will allow the suspension to track the ground, returning after a bump as well as dropping into any holes. Too much rebound damping causes the suspension to return slowly and sometimes pack down meaning the absorber gradually runs out of travel. Too little can cause the suspension to buck the rider and lead to an accident.

2.1.5.3 High and Low Speed Damping Depending on the manufacturer and model of the shock absorber, the unit can include up to two adjustable speeds for each damping circuit making four adjustable damping settings in total. High speed adjustments are used in high impact situations such as large jumps or drops, compression tends to be set softer to remove impact and rebound slower so rider has time to recover and the bike is not made unstable.

Low speed adjustments are used against small movements such as rider weigh shifts or long, slow compressions. Optimally compression is set stiffer as this type of feature can use a lot of travel and rebound damping set faster to deal with multiple features in quick succession.

2.1.6 Optimal Setup

Although setups will vary between rider, suspension system, and discipline there are some key aspects which all riders should aim to achieve. Sag should be set to an appropriate measurement by adjusting the air pressure on air shocks or spring rating on coil shocks. Compression damping should feel soft and soak up bumps efficiently without excessive bottoming out. Rebound damping should be set to return as fast as possible without bucking the rider, this is normally in the middle of the two extremes of setting with a slight bias to the fast option.

2.2 Image Analysis

Image Analysis (IA) is the use of various techniques such as pattern recognition, geometry calculations, and signal processing to extract information from digital images for later use. Image processing however is the application of various processes on an image to change or improve the way it looks. The processing stage normally comes before the analysis stage in an effort to simplify the analysis processes and improve their success.

2.2.1 Digital Camera Operation

A digital camera operates by capturing visible light reflected by objects onto the camera's sensor. The light must travel from the object through a convex focusing lens which refracts the light onto a suitable point on the sensor.

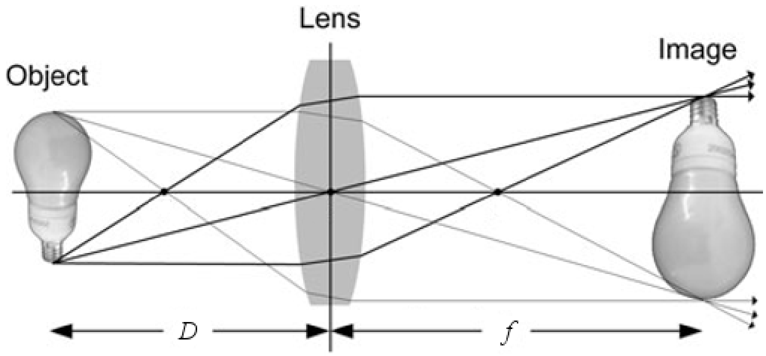

Figure 5: Diagram of camera and lens operation

The distance between where light enters the lens and the point at which it is no longer diffused is known as the focal length, marked f in figure 5. This point can be adjusted by changing the lens optics so that the refracted light hits the sensor creating an in focus image.

A camera's sensor is made up of an array of photosensitive cells capable of collecting light and generating an integer value based on the brightness and colour of the received light. The microprocessor inside the camera takes these values and converts them into the image data, sometimes taking an average of the surrounding values to better understand the light which was captured. Each of the individual sensor cells equates to one pixel on the image produced, for example if a camera produces a 1920x1080 image, the sensor has 1920 cells across by 1080 down, otherwise known as a 2 mega-pixel sensor. The larger the sensor in physical size, the more cells it can contain so the better quality images it can produce.

These integer values in the image data can be manipulated to change the visual image or the values themselves analysed or compared to neighbouring cells in order to locate objects. The processes are known as image processing and image analysis.

2.2.2 Usages

Image processing and analysis has been applied to multiple areas with its value and effectiveness rapidly improving alongside camera technology and computing power. These applications range from recognising faces in social media uploads (Zuckerberg, Sittig, & Marlette, 2011) to the utilisation of satellite imagery to tracking the changing shape of coastlines (Potter, 2013).

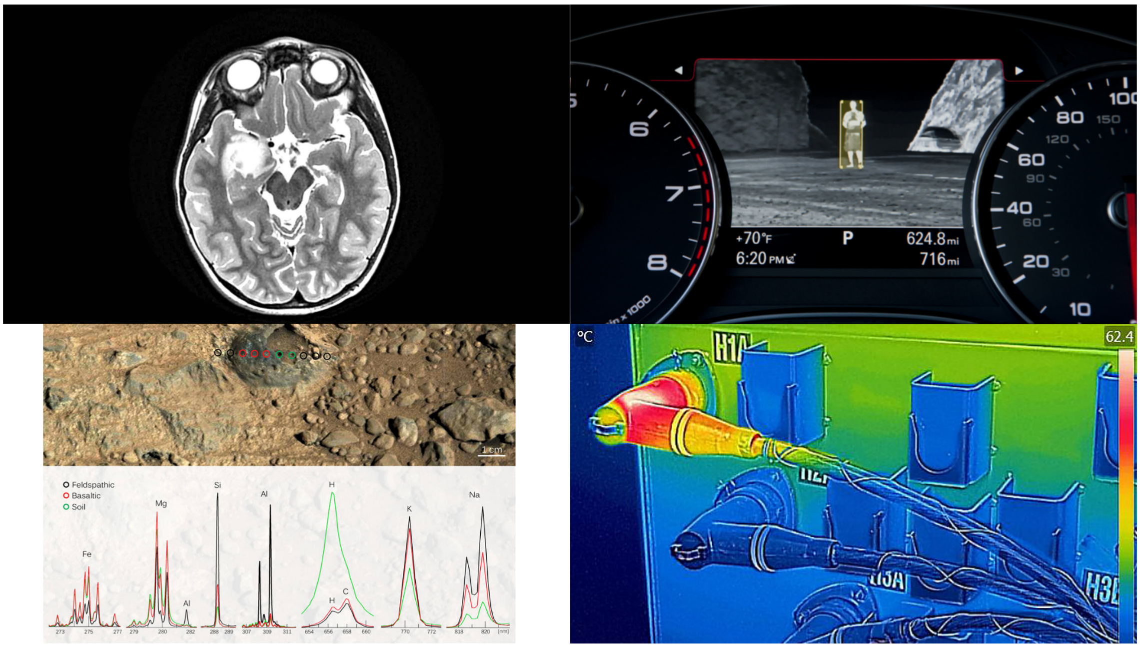

Figure 6: Uses of image analysis, from top left clockwise: An MRI brain scan, automotive night vision with pedestrian recognition, infrared image taken with a smartphone, chemical rock analysis from mars

2.2.2.1 Medical Arguably one of the most important uses of IA, advances in medical imaging have reduced costs, diagnosis time, recovery time, and improved the ability to localise and personalise treatments (European Science Foundation, 2007). Major uses of IA in medical applications are the use of Magnetic Resonance Imaging (MRI) and Computerised Topography Scanning (CT Scan) to create detailed images of the human body and identify illness before most symptoms arise.

2.2.2.2 Transport Image analysis has been included in the consumer automotive market on various models since 2004 when Honda introduced an thermographic night vision camera with pedestrian detection on the Legend (Honda Motor Co., 2004). Since this initial introduction many vehicle manufacturers have included image analysis and recognition features as options such as speed limit sign recognition, lane departure warning systems, and automatic braking systems based on hazard recognition.

2.2.2.3 Engineering The use of image analysis in engineering has pushed to create more stable and efficient structures by looking at the materials used in their construction (Masad, Muhunthan, Shashidhar, & Harman, 1999) and monitoring their stresses and potential weak areas (Kim & Kim, 2013). Using image analysis by engineers on site has become more common with the advances in mobile computing and some manufacturers aiming their products at an engineering demographic with features like improved durability and built in infrared imaging (Liszewski, 2016).

2.2.2.4 Space While some industries make use of satellite imagery to monitor changes on our own planet, agencies such as NASA and ESA make use of image analysis to look at other planets and celestial bodies. The Martian rover, Curiosity, uses multiple cameras for navigation, hazard avoidance, and scientific imaging the products of which are streamed back to Earth for analysis. Major uses for the various types of images returned include identification of geological formations and compositions (Blake et al., 2013; Garvin, Malin, & Minitti, 2014) and chemical location and identification using the ”ChemCam” (Schröder et al., 2015).

2.2.3 Image Analysis Techniques

There are multiple techniques which can be applied to imagery to extract information which include detection of edges or objects and using known data to take measurements. These methods tend to compare data from neighbouring pixels to spot differences which can indicate features.

2.2.3.1 Edge Detection This is the application of mathematical algorithms to locate and highlight the edges of features in an image. There are multiple algorithms which can be used for edge detection including Sobel, Roberts, Canny, and fuzzy logic though all utilise the concept of comparing side by side pixel data to find ”steps” from one brightness to another.

Table 2: Table of pixel data showing an edge

5	7	6	4	152	148	149

Table 2 represents possible pixel values of an edge indicated by the large difference between 4 and 152. The applied algorithm will pick up on this discrepancy and in will be indicated on the resulting image. A common application for edge detection is text recognition such as in automatic number plate recognition (ANPR) (Ahmad, Boufama, Habashi, Anderson, & Elamsy, 2015) as the process can remove unwanted background data and highlight the block shapes of the number plate.

Figure 7: Edge detection applied to an image for number plate recognition

2.2.3.2 Object Detection Much like edge detection, object detection is used to pick out features in images, the difference being that object is a more abstracted term than edge and could mean anything from faces to signs to company logos. A common technique is Binary Large OBject (BLOB) analysis which is two techniques combined into one application (Moeslund, 2012), this includes BLOB extraction which is used to isolate large objects in an image, dismissing small objects as noise, which is then followed by BLOB classification, assigning objects a class based on predetermined parameters.

Regularly carried out after grayscaling and thresholding an image, BLOB extraction uses a grass-fire algorithm to locate pixels which display a significant difference to the image background and discover the full extent of this region. As all the pixels of each BLOB in a object are known, certain parameters are also known such as size, area, and boundaries. From these parameters, calculations can be carried out to discover the classification of each BLOB, for example with the boundary and area of each BLOB, the circularity can be calculated to locate all the circular objects in an image.

$$B_c = \frac{B_p}{2\sqrt{\pi \times B_a}} \tag{1}$$

where

B_c is the circularity of the BLOB
B_p is the perimeter of the BLOB's bounding box
B_a is the area of the BLOB

2.2.3.3 Taking Measurements To measure an object in an image, certain data about the camera and camera's location are required. By using digital imagery the majority of this information is provided as each image contains metadata or EXchangeable Image Format (EXIF) data which includes information such as camera manufacturer, focal length, image size, and location.

$$H_o = \left(\frac{f \times \left(\frac{H_i}{H_s}\right)}{D - f} \right) \times H_c \tag{2}$$

where

f is the focal length of the camera lens
D is the distance to the object
H_o is the height of the object
H_i is the height of the image in pixels
H_s is the height of the camera sensor
H_c is the height of the camera from the ground

The process to calculate the height of an object in an image is shown in equation 2. f, H_i, and H_s can be acquired from EXIF data, however D and H_c are not collected by the camera and must be measured. When dealing with image analysis this means that this data must have been collected when the image was taken.

To circumvent the need for this data a reference object of known size can be included in the image, this allows a comparison between the object to be measured and the reference object. The previously mentioned mars rover, Curiosity, carries a United States penny and charts to calibrate its cameras against.

Figure 8: The camera calibration items attached to the mars rover, Curiosity

2.3 Using Image Analysis for Mountain Bike Suspension

Though image analysis has been used for calculations in many engineering applications (Kim & Kim, 2013; Masad et al., 1999), it is relatively unused with mountain bike suspension with only Fox Racing Shox using the technology for setup purposes (Benedict, 2012). The mobile application which Fox created is locked to forks and shocks that the company manufacture though image analysis techniques are adaptable enough to be used on any suspension unit.

By harnessing the image capturing and computing power of modern smartphones, image analysis can be applied to mountain bike suspension to produce a simple method of calculating a baseline setup for any suspension unit. The measurements and calculations required can be removed from the user's responsibility creating a simple and efficient method of generating a safe and reliable suspension setup.

3 Approach

4 Results

5 Critical Evaluation

6 Conclusion

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Acronyms

FS Full Suspension.

HT Hard Tail.

VPP Virtual Pivot Point.

Glossary

Fork The front suspension unit on a mountain bike.

Full Suspension A mountain bike with both front and rear suspension.

Hard Tail A mountain bike with only front suspension.

Horst Link A suspension system utilising a pivot point located near to and below the rear wheel axle.

IA Image Analysis.

Rebound Damping Controls the speed at which a suspension unit extends once it has been compressed. Less damping means the unit extends faster.

Sag The distance which the suspension sits into its travel when the rider is in their neutral position.

Shock The rear suspension unit. Only found on full suspension mountain bikes.

Single Pivot A suspension system which rotates around a physical main pivot point.

Stroke The distance a shock absorber can compress before bottoming out.

Travel The distance a wheel can move before bottoming out.

Virtual Pivot Point A rear suspension utilising an upper and lower link to create a simulated pivot a physical one would be impossible.