The effectiveness of JPEG images produced by a standard digital camera to detect damaged tyres

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Abstract: Many people die each year in car accidents because of damaged tyres. There are some techniques that have been suggested during the years to detect such tyres. In this paper, we suggest a new technique for detecting damaged tyres employing a standard digital camera that produces JPEG images. The camera takes pictures of the tyre and if the image size is too large, the tyre is deemed to be with a damage and dangerous for use. In such a case an automatic system will draw the driver attention to the tyre condition before a severe accident may happen. The system was checked on many tyres and has high accuracy of damage detection.

Keywords: tyres; JPEG; DCT.

Biographical notes: Yair Wiseman obtained his PhD from Bar-Ilan University and completed two Post-Doc – one at the Hebrew University of Jerusalem and one in Georgia Institute of Technology. His research interests include vehicular systems, intelligent transportation systems, process scheduling, hardware-software codesign, memory management, and real-time operating systems.

1 Introduction

Damaged tyres are a critical reason for many fatal accidents. A new warning of National Highway Traffic Safety Administration (NHTSA) from June 2011 notifies the drivers: that "The latest data from the Department's National Highway Traffic Safety Administration show that over the five-year period from 2005 to 2009, nearly 3,400 people died, and an estimated 116,000 were injured, in tire-related crashes" (Aldana, 2011).

NHTSA also assesses there were 2,188,970 crashes in all the USA. Approximately 9% which are 189,917 of the estimated total accidents were tyre-related crashes. According to NHTSA, there were 3,894,507 vehicles involved in these crashes. 5% which are 197,421 of the estimated total involved vehicles are tyre-related crash.

About 50% of the tyre-related crashes were single vehicle crashes whereas only about 31% of other crashes were single-vehicle crashes (Choi, 2012).

These worrisome numbers motivated researchers to find ways to find ways to detect below standard tyres. Some of them used special equipment like eyefish lens (Hirose et al., 2009) or a complex intelligent wireless sensor network inside the tyre (Ergen et al., 2009; Gustafsson et al., 2001; Giustino, 2000).

Actually, automatic tyre inspection is a very old objective and a patent for using an X-ray device for tyre inspection can be found at the very old date of 1939 (Capen et al., 1939). Some other devices have been presented during the years and have used many other mechanisms like a hardware for interferometric analysis of the tyres (Wright et al., 1981), thermal cameras (Gray et al., 1999), acoustic emission sensors (Schumacher et al., 2010) or a laser-based illumination device (Wilson, 2006).

Some other works aim at simulating accidents and estimate the potential damage (Feng et al., 2009; Grinberg and Wiseman, 2007; Yong et al., 2008). This is not the aim of this work. Our work aims at detecting a potential exposition to danger and notify about it.

During the years detection of vehicular elements was an attractive filed of research (Sun et al., 2006; Wang et al., 2005) and the use of signal processing for this purpose was quite intensive (von Seelen et al., 2000; Sun et al., 2005). We would like to continue this course of research by suggesting a technique of automatic detecting damaged tyres using a signal processing analysis.

We suggest using an ordinary digital camera to find below standard tyres. Nearly all digital cameras can produce JPEG pictures. JPEG is a very common method for image compression and it is also extensively used by electronic devices like scanners and digital cameras (Khanna et al., 2008) as well as vehicle equipment like GPS (Hongyan et al., 2010).

JPEG images have many advantages like the ability of being decoded in parallel (Klein and Wiseman, 2003), the straightforwardness of adaptation for new compression methods (Wiseman, 2007; Klein and Wiseman, 2005) and the capability of flexible implementation for hardware from different vendors (Wiseman, 2001).

Images are often stored in a compressed standard. A naive approach for image processing on compressed images would be to decompress the image and then running the image processing algorithm on the original image data. Instead, for some image operations, we can act on the compressed data directly. This gives us two benefits: first, we can use the standard digital cameras without a need to adjust the digital camera; second, we can use the frequency information embedded in the compressed data.

The rest of the paper is organised as follows: Section 2 describes the JPEG compression standard. Section 3 explains how JPEG can be used for detecting damaged tyres, Section 4 gives some results. Section 5 expands the method by using Motion JPEG-2000 and Section 6 concludes the paper.

2   The JPEG standard

JPEG is a well known standardised image compression technique. JPEG loses information, so the decompressed picture is not the same as the original one. By adjusting the compression parameters, the degree of loss can be adjusted. The wide use of JPEG is

because of two fundamental reasons: reducing the size of image files, and storing full colour information.

Reducing image files will be an important procedure when we transmit files across networks (Wiseman et al., 2004) or when we archive libraries. Usually, JPEG can remove the less important data before the compression; hence JPEG will be able to compress images meaningfully, which produces a huge difference in the transmission time and the disk space. The processing time of the compression can be overlapped with the disk access time (Wiseman and Feitelson, 2003).

The second advantage of JPEG is the capability of storing full colour information: 24 bits/pixel or 16 million colours, while for example the GIF format, can store only 8 bits/pixel or 256 colours.

Here in below is a brief overview of the JPEG algorithm:

The first step transforms the image colour into a suitable colour space. There are several methods to transform the image into a colour space (Hearn and Baker, 1986; Jain, 1986). The most common methods are the split into RGB components (Hunt, 1995) or the split into YUV components (Laplante and Stoyenko, 1996). These components are interleaved together within the compressed data. The ratio between these components is usually not one to one. When YUV components are used, usually the Y component will have a four times weight. The human eye is less sensitive to the frequency of chrominance information than to the frequency of luminance information which is represented by the Y component in the YUV format. Hence, the Y component gets a higher weight (Awcock, 1996).

The second step groups the pixels into blocks of 8×8 pixels. Then, it transforms each block through a forward discrete cosine transform (FDCT) (Rao and Yip, 1990). The DCT gives a frequency map, with 8×8 or 64 elements. The transformation keeps the low frequency information which a human eye is sensitive to. In each block the DCT coefficients are composed of: A single direct current (DC) coefficient number, which represents the average intensity level value in each block and the remaining 63 are named alternating current (AC) coefficients. They reflect the frequency information of their row and column.

The next step is the quantisation. The 63 AC coefficients are ordered into a zig-zag sequence which arranges them into a one dimensional array. In each block, each of the 64 frequency components is divided by a separate 'quantisation coefficient'. The quantisation coefficients are set according to the desired image quality. The results of the division are rounded to integers. This step loses some information because of the rounding. Furthermore, it can be noted that even if the quantisation coefficient is 1, some information will be lost, because typically the DCT coefficients are real numbers.

The last step encodes the reduced coefficients using either Huffman or arithmetic coding. Usually a strong correlation appears between DC coefficients of adjacent 8×8 blocks. Therefore, JPEG encodes the difference between each pair of adjacent DC coefficient. Baseline JPEG model uses two different Huffman trees to encode the data, one for the DC coefficients' length and the other for the AC coefficients' length.

Finally, the compression parameters are written in the file header, so that the decoder module will be able to decode the compressed image. JPEG's procedure is summarised in Figure 1.

Figure 1   JPEG model for a lossy image compression
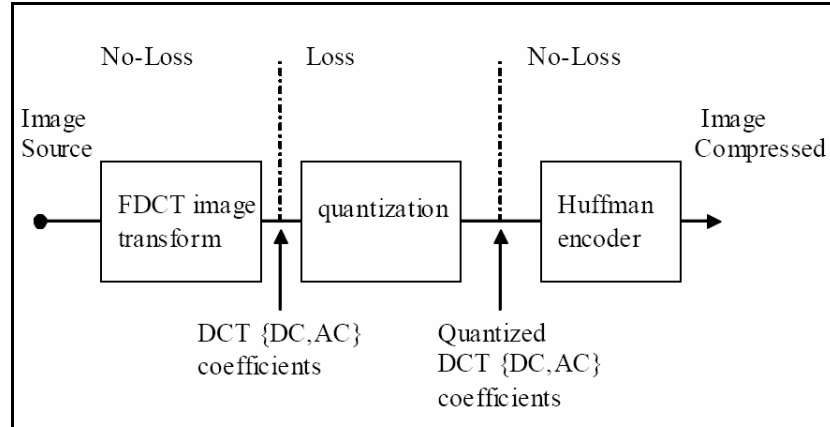
The decompression process performs an inverse procedure:

- It decompresses the Huffman or the arithmetic codes.

- Then, it makes the inversion of the quantisation step. In this stage, the decoder raises the small numbers by a multiplication of them by the quantisation coefficients. The results are not accurate, but they are close to the original numbers of the DCT coefficients.

- Finally, an inverse discrete cosine transform (IDCT) is performed on the data received from the previous step.

JPEG has some disadvantages. Unfortunately, even with a JPEG viewer, it takes a longer time to decode and view a JPEG image than to view an image of a simpler format such as GIF, BMP, etc., however it is still a very short time as can be indicated in every digital camera. Another disadvantage is the compression method that does not take into account the temporal correlation of the coefficients.

3   Using JPEG for damaged tyre detection

This section describes the Damage Tyred Detection algorithm using the JPEG format. As mentioned above the JPEG standard is based on the DCT paradigm. The DCT changes the picture into frequency space. The frequency coefficients, which are very low magnitude, are rounded to zero. When most of the coefficients in a block are zero or very low magnitude: The compression algorithm will give a very short bits sequence for such a block. Zero sequences are treated very efficiently by JPEG compression and the results will be only few bytes.

When there is a drastic change in a block of 8×8, the value of many frequency coefficients will be high. Such a sequence will be compressed into many more bits. JPEG's standard stipulates that the block's size will be 8×8 pixels, but the algorithm will be obviously good for other small NXN pixels size too.

When looking for the contour of an object, the goal will be to find the object's border. The idea is to break the compressed file into its original blocks, then look in the compressed file for long bit sequences. The blocks which are compressed into long bit sequences, are presumed to be the object's border. In our implementation we took a simpler approach. We take many pictures of each tyre. We actually take a close picture of each part of the tyre. If the entire size of a picture is above a certain threshold, we will consider this part of the tyre as a damaged part.

If we have no idea what the threshold value should be, we can examine the probability density function (PDF) of the block representation to select a suitable value. In the uncomplicated case the PDF should be mono-modal and we set the value in the inflection point.

Many pictures are taken by rolling the tyre and in each picture suspected objects are searched. The process is automatic, i.e., the pictures are incessantly taken in the smallest possible gap. Usually a camera can take few pictures each second. There is no point to move the camera. The tyre turns around anyway, so the camera will take a picture of another part of the tyre. The device is linked to a plain light in the car. Several automakers have technology already that tells the driver if he is over-inflating tyres or if tyres are losing pressure (Barbanti, 2009); this would seem to be the next step. A mechanic could detect both of the problems, but he could not check the tyres innumerable times a day like an automatic device could.

Note the method does not use the spatial information in the blocks, so it would identify any sequence of bits as a contour of the object, which is a weakness of the algorithm. Our assumption is that the resolution is large enough to describe the shape's character.

Figure 2 demonstrates how JPEG is used for contour extraction. The original image was compressed in greyscale baseline JPEG format with 75% quality. The left image shows the original image, which is a high-resolution picture of $1,000 \times 1,000$ pixels. The upper-right image shows the JPEG format in the white or black area. The lower-right image shows the JPEG format in the upper left corner of the black square. The size of the black square is 200×200 pixels and the square is not aligned relative to JPEG's 8×8 blocks.
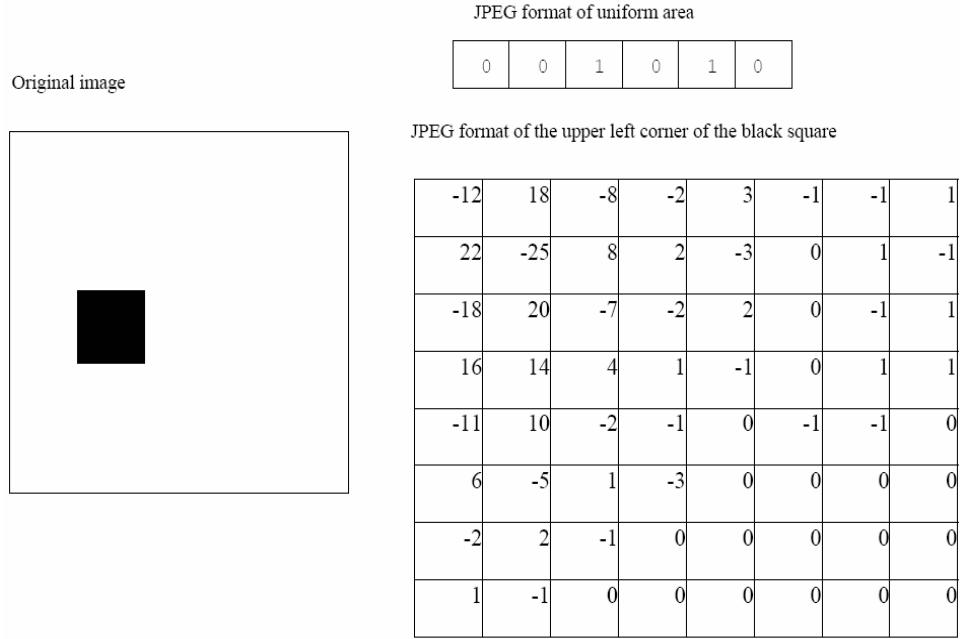
The JPEG file reports the difference of magnitude between the DC's coefficients of a previous block relative to the current block. In the case of a white or black area there are no changes in the coefficients' magnitudes. This type of block is encoded as six bits by the JPEG standard (Capen et al., 1939).

The output of the JPEG file is shown in Figure 2. The '00' reflects that there are no differences between the values of the previous and the current block's DC coefficients, and '1010' symbolises the end of the block. If there is a difference between the intensity of the DC coefficients of the previous and the current blocks, the size of the encoding block will be slightly bigger. For example, a block which encodes a sharp change from white to black is represented by a wide range of frequency coefficients. It is easy to select a threshold that delimits the edges of the shape from the rest of the image.

Figure 2 shows a sample of the block, which contains the upper left corner of the black square. In order to compress these values in JPEG standard, 243 bits are needed. The difference between 6 to 243 is obviously significant. By using three parameters the length of the block, its magnitude and the number of consecutive blocks the threshold can

extract the contour with a range of scalar values (Wiseman and Fredj, 2001; Fredj and Wiseman, 2001). The extra parameters allow more control over the resulting mechanism.

Figure 2   A sample image and how JPEG can be used for contouring

JPEG format of uniform area

0	0	1	0	1	0

Original image

JPEG format of the upper left corner of the black square

-12	18	-8	-2	3	-1	-1	1
22	-25	8	2	-3	0	1	-1
-18	20	-7	-2	2	0	-1	1
16	14	4	1	-1	0	1	1
-11	10	-2	-1	0	-1	-1	0
6	-5	1	-3	0	0	0	0
-2	2	-1	0	0	0	0	0
1	-1	0	0	0	0	0	0

The algorithm is very simple and can be described as follows:

- Take a picture of the tyre and create image I
  1 Set L = size_of_image (I)
  2 (L > T)
    - then the tyre is deemed to be damaged and should be checked.

where T is a threshold and its value will be discussed below.

4   Results

We examined our technique on 1,032 tyres and succeeded to find most of the damaged tyres. Clearly, obvious cases like in Figure 2 do not exist in real tyres, but we still succeed to find most of the damaged tyres by rolling the tyre and take many picture of it in all of its parts.

We used an Olympus FE-170 digital camera. The images with no damage in the tyre produced images in size of less than 1.3 MB; whereas images in size of more than 1.5 MB usually had damage in the tyre.

Figures 3(a) to 3(c) show some damaged tyres that our system has found. All of these pictures were on vehicles of volunteers. Driving a vehicle with such damages can be a substantial risk of life!

Figure 3   Damaged tyre (see online version for colours)

(a)

(b)

(c)

The images between 1.3 MB–1.5 MB sometimes had a small scratch and sometimes it was only a change in the colour shade. Also the caption on the tyre can increase the size of the image; however, the caption typically increases the image size less than the increase that a real damage makes; however, it may make the size above 1.3 MB.

Figures 4(a) and 4(b) show two cases where a change in the colour shade of the tyre made the result above the threshold of 1.3 MB and caused an uncertain result.

Figure 4   Tyre with a change in the colour shade (see online version for colours)

(a)

(b)

There are also cases where our system has produced false alarms. Figure 5 shows an example for such a false alarm. The dirt on the tyre in Figure 5 can be easily noticed. This dirt made the system assuming that the tyre is damaged; whereas this tyre was undamaged and the vehicle was safe for driving.

Therefore, we recommend washing the tyre before the system tests the vehicle. Dust, dove feces, mud and any other dirt can mislead the system, especially if the dirt is white.

Figure 5 Dirt on the tyre (see online version for colours)

Figure 6 shows the statistics of the experiment results. The graph includes all the cases where the image was larger than 1.3 MB. The graph details the cases of image size less than 1.5 MB (uncertain) and image size more than 1.5 MB (success or false positive). The graph specifies the instance distribution of each magnitude of the damage. The magnitude of the damage was calculated according to the longest measurement of damage regardless of its shape.

Figure 6 Success rate
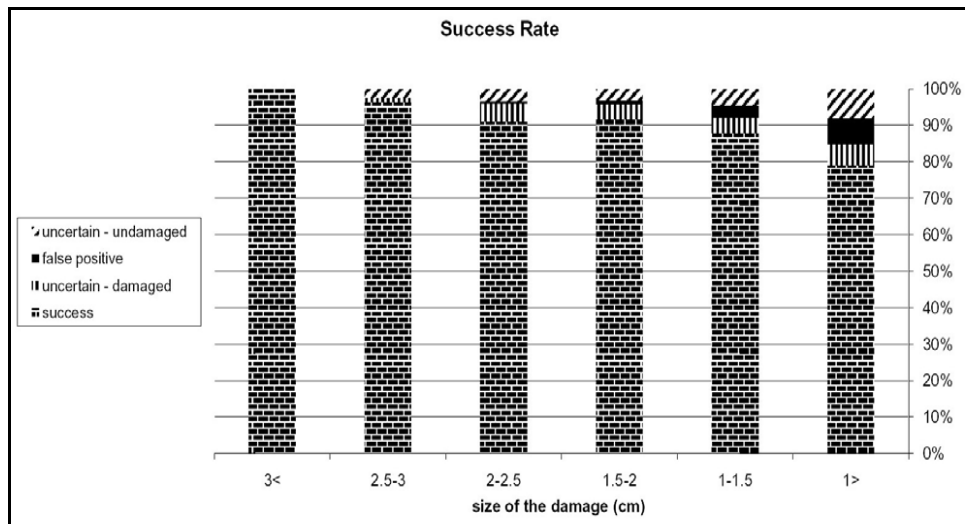
It can be seen that large damages can be confidently detected. Smaller damages can be detected with a high probability of a correct detection, but the accuracy is less precise.

There were only four cases when the image was less than 1.3 MB although there was a real damage in the tyre. In all of these cases the damage was very superficial and the magnitude of the damage was in three cases less than 1 cm and only in one case it was 1.2 cm.

Table 1 details the number of tyres that were examined listed by the magnitude of the tyre.

Table 1   Number of inspected damaged tyres

Damage size	Number of instances
<1	125
1–1.5	242
1.5–2	217
2–2.5	327
2.5–3	84
>3	37

5   Motion JPEG-2000

JPEG-2000 is a new standard for image and video compression (Taubman and Marcellin, 2002; Christopoulos et al., 2000; Skodras et al., 2001a, 2001b; Usevitch, 2001). Several latest digital cameras support JPEG-2000 and Motion JPEG-2000, e.g., Yamauchi et al. (2004), Fang et al. (2004), Liu et al. (2004) and Seo and Kim (2007). Motion JPEG is employed in numerous applications from professional video editing to capture cards in many hardware settings.

By means of JPEG-2000, an image stored on a disk has lower quality levels embedded in the compressed file. If a user asks to preview a JPEG-2000 image, only a lower quality image will be restored. No modification of compressed data is needed. If the user decides to see a better quality image, further information will be restored from the JPEG-2000 image file. There will be no need to redownload the entire image. The overall quality of a JPEG-2000 image is typically higher than a traditional JPEG image. In addition to the advantages of improved quality and scalability, JPEG-2000 also generates about 20% better compression ratio than JPEG and at several cases JPEG-2000 even generates a considerably better compression ratio.

Unlike MPEG, by means of Motion JPEG-2000 each frame is encoded independently. MPEG employs three kinds of frames for encoding:

- I-frames do not need other video frames to be decoded, but the compression ratio is not as good as the other frame types

- P-frames employ data of previous frames to be decoded and the compression ratio is typically better than I-frames

- B-frames employ data of both previous and forward frames for the decoding and typically obtain the best compression ratio.

The three types of frames allow improved compression efficiency but the coding technique is more complex and therefore requires more computation time. Motion JPEG-2000 employs only Intra-frame blocks which let the user the ability to randomly access a file at any fame. In addition, the using of only Intra-frame blocks reduces the complexity of the compression and decompression processes and therefore the decoding time is shorter.

There is another major modification in JPEG-2000. The designers of JPEG-2000 came to a decision to depart form the block-based DCT coding used by the traditional JPEG and MPEG standards in favour of a wavelet-based compression – the discrete wavelet transform (DWT). The DWT provides improved quality than JPEG and also provides scalability without having to store surplus data.

The forward DWT at the encoder is successive functions of a pair of low-pass and high-pass filters, followed by division by a factor of two after each filtering function so that odd indexed samples will be discarded. The low-pass and high-pass filter pair is known as analysis filter-bank. The low-pass filter keeps the low frequencies whereas the high frequencies are significantly diminished and therefore the result is only a vague form of the original signal. Conversely, the high-pass filter keeps only the high frequencies of a signal such as contours, whereas the low frequencies are significantly diminished.

The standard of Motion JPEG-2000 is extremely suitable for the technique of this paper. Since the high pass filter generates much more bits for contours, the compress data of such a region in the picture will be larger. This feature can be used as it has been used with the DCT of traditional JPEG. Furthermore, there is no need to extract the high quality picture. The high pass filter detects a contour even in a low quality picture. In addition, since Motion JPEG-2000 employs only I-frames blocks, the technique becomes even more straightforward because there is no need to process the frame along with nearby frames. Each I-frame contains all the information needed for the damage detection.

However, there is a major difficulty to implement this method with contemporary video hardware. Some researches have been conducted during the years with the purpose of finding the threshold of rate for distinguishing successive still images from a proper continuous video that a human eye would not be able to detect, e.g., MacKenzie and Ware (1993) and Kaff et al. (2001). Researchers are commonly consistent with the rate of 10–20 frames per second. Therefore even though there are some exceptional plentiful frames per second cameras (Chin et al., 2003), the common up to date hardware can support only about 30 frames per second in CIF size (352 × 288 pixels) and about 20 frames per second for SDTV size resolution (760 × 480 pixels) (Tsai and Lian-Tsung, 2008). Pushing a new standard of digital cameras can be full of twists and turns; however the common standard is not enough for a tyre of a moving vehicle, e.g., an everyday private car having ordinary tyres of 225/45R17 travelling in a speed of 45 miles per hour will wholly rotate the tyre ten times each second. 30 frames per second will not be enough for such a system. However, we believe the hardware will be improved and in the future this method will be feasible.

6 Conclusions and future work

Rollover accidents are very dangerous and cause too many loss of life. Since many of the rollover accidents are a result of damaged tyres, the keeping of the tyre in a good shape is more than important. Although there are reports arguing that the human factor is the main reason for rollover accidents (Farmer and Lund, 2002), we would not advise any driver to pay no attention to the shape of his tyres.

In this paper, we explained how a system using simple equipment – digital camera can detect damages in a tyre. In the future we would like to adapt our system to a moving vehicle. Conventional digital cameras cannot take a picture of so fast moving object, so we should find a practical way how the pictures can be taken. A possible solution might be taking the pictures when the vehicle moves slowly before or after stopping. In addition, we would like to adjust our system to be able to detect damages in the tyre tread and also in the tyre inner liner. We will also be happy to improve the technique such that it will be able distinguish between different types of damage.

As a final point, our suggestion to mount a camera with the aim of becoming aware of below standard tyres is easy for implementation and such a simple device can be very beneficial because detecting damages in tyres before an accident happens can save our life!

Acknowledgements

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