Title: Three Dimensional Reconstruction of Pavement Surface using Photometric Stereo Technique

Abstract: Pavement surface texture is an important parameter that affects vehicle and pavement characteristics. It has significant impact on rolling friction, tyre wearing, pavement noise and ride comfort. Skid resistance of pavement follows a close relation to its texture characteristics. Size, spacing and distribution of pavement texture or in short, 3D profile of road surface affects its resistance against skid. Insufficient skid resistance is one of the major reason of traffic accidents. Also, higher roughness can also be counterproductive as it will lead to more vehicle wear and noise. Therefore, for the proper functioning of pavement, texture should be within a satisfactory range. Several methods have been developed to measure the pavement texture. Fixed site instruments like British pendulum tester, dynamic friction tester are labour intensive and time consuming to be performed on trafficked roads while some continuous measuring instruments are expensive. Therefore, there is a need for advanced methods that can extract the pavement texture efficiently. Some of the recent advancements in texture measurements are in field of vision based techniques. The photometric stereo method is one of them. Macrotexture of pavement surface can be extracted using three lights in traditional photometric stereo technique. However, traditional photometric stereo using three light sources can acquire macrotexture, but failed to capture precision requirements of microtexture.

Many techniques that measure the texture of surface reduce the information to a single indicator like British pendulum number (BPN) as in case of British pendulum tester, or say mean texture depth (MTD) in sand patch method. Although MTD was correlated to pavement friction and noise, but it must be noted that contribution of texture spacing, size and distribution should also be considered. That is road surfaces having different frictional properties can have same MTD. Therefore, advanced methods that can capture all the texture characteristics in 3D is needed that can help in friction related studies, numerical modelling and other related studies in pavement engineering. Conventional 3D scanning methods such as coordinate measuring machine (CMM) and 3D laser scanner, though precise, are quite expensive and/or time consuming. In such a situation vision-based techniques emerge as an alternative. One of the vision-based techniques is the photometric stereo method, one of the vision-based techniques has extensively been used in computer vision, deep learning, product quality control in industries due to its simple implementation and high

resolution. In the present work, photometric stereo method has been implemented to reconstruct 3D pavement surface. Also, the traditional photometric stereo technique which utilises only light of three sources is improved to reduce noise, effect of highlights and shadow to retrieve complete pavement surface texture efficiently. Photometric stereo technique can reconstruct 3D pavement surface with a set of two-dimensional images. The basic theme behind photometric stereo technique is to keep the viewing direction same and changing the incident light's direction to take multiple images.

The aim of present study is to generate a 3D pavement surface with a set of two-dimensional images and compare the reconstructed surface with the actual measurements across different pavement surfaces. The basic idea of photometric stereo is to vary the direction of incident light between successive images, while the viewing (camera) direction is held constant. The work done can be broken into three broad steps. First, the image setup was prepared to capture images under different lighting conditions. Second, solving the normal vector at all image pixels. Third, normal vector based 3D reconstruction. Two techniques namely, the global integration method and the least square fit are implemented to find best fit surface. Typically, photometric stereo technique assumes the surface to be Lambertian and three images under different illumination conditions are sufficient to determine surface orientation at each image point. However, in this method due to highlight and shadow effect the output is prone to errors. To eliminate these errors, effect of including more images has been studied and photometric stereo using twelve light sources has been presented to analyse pavement surface. To validate the output, tests have been carried out on known surfaces. Scaling of object and error correction was standardised using these known objects. Traditional indices are calculated to compare the obtained results. The results show good agreement of this photometric stereo model for 3D reconstruction of pavement surfaces.