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A compendious study of super-resolution techniques by single image

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ABSTRACT

Single-image Super-resolution (SISR) is the process of reconstructing a high-resolution (HR) image by artificially creating the information and frequency details from a single available low resolution (LR) image. Availability of limited number of images in the practical circumstances has motivated researchers toward this area. Plethora of techniques has been proposed over the years for SR reconstruction. In this paper, the SR process has been classified and the degradation model has been discussed. It also comprises the extensive survey of SISR techniques, including the latest developments in this field. Lastly, it covers the limitations and problems of existing techniques of SISR.

1. Introduction

Super-resolution (SR) is a part of image restoration processes. It is used as a major tool for enhancing and restoring the quality of images which are degraded due to manufacturing limitations of imaging system. Technical progress has increased the importance and demand of high quality multimedia content. Super-resolved (SR) images are used in almost all area of technical endeavors. Some of them are listed here. Images and videos available on internet and mobiles are normally of thumbnail size and degrade in quality due to compression during transmission. TV industry is shifting toward high-definition videos and picture quality. Doctors need high resolution images for accurate diagnosis and surgeries. Face hallucination and biometric (fingerprint and iris recognition) applications are getting stronger day-by-day. Surveillance, remote sensing and satellite communication require conversion of LR to HR images due to limitations of on-board installation of advanced imaging system and requirement of high data rate transmission. Some other real life applications include number-plate identification, microscopic view, forensic science, target recognition and detection, electronic imaging, etc.

High resolution images can either be obtained by hardware improvements in existing imaging system or by applying software techniques. Hardware improvements require less software processing and normally have fast computation. It involves increase in chip size or decrease in pixel size/sensor size. These improvements have its own limitations during practical implementation. Increasing of the chip size is a costly process and causes high capacitance generation. High capacitance results in slow charge transfer rate. The latter solution i.e. to decrease the pixel size or sensor size causes less availability of light on each sensor. This results in shot noise generation and is more sensitive toward diffraction phenomena. In imaging system, spatial-frequency response, optical system distortion, hardware design of cameras like lens type, power supply, clock system, shuttering, etc., also affects its resolution. Hardware improvement techniques require re-installation and sometime

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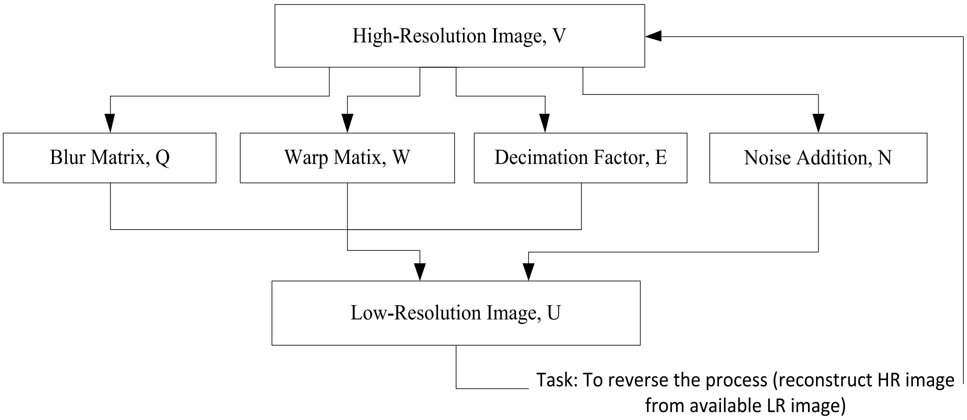

Fig. 1. Image Degradation Model in SISR.

cause unmanageable imaging system due to its bulkiness which is costly and troublesome. Therefore, software techniques i.e. super-resolution techniques are used as alternative method to increase the image resolution. These techniques are preferred over the hardware improvements due to ease in its implementation and capability to utilize existing setup of imaging system.

Super-resolution is the procedure of obtaining a high resolution image from one or more low resolution images. SISR, a special case of SR methods need only single image for the reconstruction of high resolution image. It can be considered as ill-conditioned and ill-posed inverse problem. Researchers are active in this area for past few decades. 'Super-resolution' word first appeared around 1990 [1]. Many review papers [2–4] capsulizing the SR techniques are also published in the past. Survey papers emphasizing the SISR methodologies and classifications are limited. This paper comprises the classification of existing SR algorithms specially focusing on the SISR techniques. Overview of recent advancement of SISR giving special attention to learning based SISR is included in the paper. Further the paper is organized in sections. Section 2 explains the imaging system degradation model. Section 3 gives brief about the broad classifications of SR algorithms. Section 4 describes the techniques used in single image super-resolution (SISR) over the years. Section 5 discusses about the major challenges related to SISR and in Section 6 the paper is briefly concluded.

2. Image degradation model

The image acquisition techniques used in different existing imaging systems generally result in degraded observed image. Thus, to reconstruct a SR image, the first step is to formulate the degradation model i.e. to model the relationship between the original HR image and its observed LR counterpart. Same LR image can be obtained from different HR images due to different degradation functions. So, mathematical modeling [1,4] is very important for efficient SR reconstruction. Fig. 1 shows a simple image degradation model which can be used to solve SISR problem. As shown in it, the basic processes of SR methods are to reverse the degradation process i.e. to have a solution for highly ill-posed inverse problem. For multi-image super-resolution (MISR) also, same degradation model is used but in that case observed LR image are more than one. Image captured by existing imaging system generally degrades due to blurring, warping (i.e. geometric transformation), down-sampling and noise addition. It is modeled in (1).

$$\boldsymbol{U} = \boldsymbol{QWEV} + \boldsymbol{N} \quad (1)$$

$$\boldsymbol{U} = \boldsymbol{MV} \quad (2)$$

Consider {**U**} and {**V**} be the observed HR and LR image of size $s_1 \times s_2$ and $r_1 \times r_2$ respectively (where $r_1 = s_1/e_1$ and $r_2 = s_2/e_2$). Decimation factor {**E**} is the down-sampling operators consisting e_1 and e_2 in vertical and horizontal direction. {**W**} is the warp or geometric transformation metric and {**Q**} is the blur metric. The noise addition is give by {**N**} which is generally considered to be white Gaussian noise. To simplify the SISR problems mostly the process is considered to be noiseless. So the degradation model for the system can be represented as given in (2). Here a common degradation factor {**M**} is used in place of blurring, warping and decimation.

Sometimes, image degradation model, represented by (1) and (2), fails to explain the complete degradation process of the observed image. Thus, researchers have also considered other factors like dimensional complexity, noise type, domain transfer, etc. in their proposed degradation models [5–8].