1 Introduction: an algorithm supporting a nail polish try-on mobile application

We often cannot judge based on the appearance of a product worn by a model how that product will actually look on ourselves. Compared to users, models may have very different skin colour and other bodily features. Ideally, to help the user make a better informed purchasing decision, the model demonstrating the product should be customized to each user. To achieve this, there are already many applications developed for the virtual trying on of products in the beauty, cosmetics and garment industries which digitally modify the images of models to take on the appearance of the user [1] [2, 3].

For this project, we have a video in a mobile app demonstrating nail polish on a model hand to allow virtual try-on of different nail polish colours. We would like to edit this demo video so that the model appears to have the user's exact skin colour, to help the user better determine whether the nail polish colours look pleasant on the user's own hand. While it is possible to manually prepare a series of demo videos with models of different skin colours, preparing even a single video for virtual try-on is an extremely time intensive task. Moreover, each person has a particular skin colour and it's preferable to be able to tailor the video exactly to the skin colour of the user while the user is using the app.

To address these challenges, we propose developing an algorithm to incorporate into the app that quickly and automatically performs the image editing task. The user should be able to provide an image of their own hand as input, and the resulting edited model hand should be convincing and accurate to the skin colour of the provided user image. A wide range of user skin colours should be supported by a single model of mid-toned skin. Finally, the process should be quick to run on a mobile device, such that the user notices no significant time lag to see the resulting video frames upon inputting their own skin colour.

Currently, we aren't aware of an existing algorithm that satisfies all our specific requirements. While there has been a large body of work done addressing transfer of colour between images in general [4–8], only a smaller set of work specifically addresses transfer of skin colour [9–11]. All such studies address face skin colour rather than hand skin colour, which often means that more of the study is devoted to handling colour transfer of different, more complex aspects of the face [11]. Skin colour transfer of the whole body are sometimes performed in other, more general imaging processing applications, but in those cases, since the skin colour transfer is often only a small part of the whole process, the algorithm used is often relatively simple and not heavily designed for achieving accuracy to the user skin colour [2, 3]. In the related field of skin colour enhancement applications, the methods used often are not meant to make large changes to the user skin colour [12, 13]. Finally, algorithms developed by most of the prior studies do not appear to be meant for use with the limited resources on a mobile device. We further discuss other methods of

1.1 The goals, constraints and requirements for an effective skin colour transfer algorithm

Our project is intended to manipulate image frames in a video of a model hand demonstrating nail polish product so that the model hand takes on the user's skin colour. The images we must process will mostly consist of the back of a single hand shown prominently in the image. We expect image sizes the algorithm should be able to handle to be approximately 800 x 800 px and larger. We show in the Table **??** an example of the desired output of our algorithm.

We list below several important aspects of the scope and constraints of our project:

No skin detection: To narrow the scope of our project, we will not include skin detection as part of this project and assume that our algorithm is already given a mask of the skin areas of all the images. We will focus solely on the transfer of the hand skin colour.

Compatibility with mobile device: Our algorithm is ultimately intended to support and application on a mobile device, so we must ensure that the algorithm we develop can operate quickly with the limited resources of a mobile device so that the user will be able to see instant results.

Fully automatic: Since the goal of our project is for the user to be able to change their

Based on the needs of our project, we list several design paradigms against which we will evaluate our algorithm:

Realistic skin colour transfer. Since the goal of our project is to perform skin colour transfer for model images that are meant to demonstrate beauty products to users, and the results are meant to invoke for the user the impression that the user's own hand is wearing the product, our final images must look as realistic as possible to avoid a displeasing, uncanny valley effect. Further more, the images we process will be large and feature a the skin on the back of a hand very prominently, so we can expect the realistic appearance of our result will be very heavily scrutinized by the user.

Accuracy of colour transfer Since the project is meant to demonstrate

use of a target image, , speed of the colour transfer on a mobile device, range of colour transfer

2 Background and Literature Review: existing methods for skin colour transfer and enhancement

2.1 Changing and matching skin colour in Photoshop

The are a wide range of online video tutorials available for adjusting human skin tone in individual images using Photoshop. The purposes of these videos include giving the subject of an image the appearance of a tan, matching the skin tone of the subject to a desired skin tone on another individual, or matching the skin tone of a subject's face to the rest of the subject's body, which is often a slightly different colour [14] [15] [16]. We surveyed a range of these videos and summarize the techniques of the most relevant videos with reasonably realistic results. See Appendix **??** for a more detailed description of three of these Photoshop processes.

Summary of Photoshop techniques

Levels and curves are frequently used for small brightness adjustments [17] [16] [15]. For large brightness adjustments, one technique was found (see Appendix **??**), where the skin area is brightened in a conversion to black and white, and then the luminosity blend mode is used to place the colour back into the image. Sometimes highlights and shadows are adjusted separately; curves or the "blend if" function (which blends in an effect only if the original pixel is above a certain threshold of brightness) can be used to achieve this effect [14].

There are many different methods to match colour, and the colour can be adjusted separately from the brightness or simultaneously - often one would affect the other [16] [15]. Methods for matching colour include matching the ratios of cyan, magenta and yellow by making adjustments with the selective colour tool, or using curves or levels on individual colour channels. Adjustments are made either by eye or to numerically match a target color [18] [16] [15]. Often to reduce the vividness of the colour adjustments the saturation must be slightly decreased [17] [16].

After all other effects are applied, the opacity of the overall effect is often reduced from 100% for a more natural appearance [17] [16].

Limitations of Photoshop techniques

These Photoshop techniques are generally meant to be tailored to each specific image that a human is adjusting. There are many junctures where the specific numerical amount of an adjustment often have to be judged by eye. While Photoshop has a method for automating processes using actions, the processes are meant for increasing ease of use by artists who can make additional adjustments and are familiar with the tool, rather than in commercial applications where the process is entirely automated [19].

Another limitation is that Photoshop operates at a higher level of abstraction than image processing software making use of libraries such as OpenCV. Image processing code has much more control over processes that can be applied to images, and the regions on the image that processes are applied to.

Finally, some Photoshop effects may be proprietary and are of course limited to the platforms that Photoshop supports, while a program developed with a platform such as OpenCV can be made open source and adapted to uses on a variety of different platforms.

2.2 Academic work related to color transfer and skin color enhancement

Relevant prior work fall into four rough categories.

Colour transfer for general images. There is a large body of work on the subject of automatically transfering the "style" or specific colours in an example image to another image. Though the work is focused on

Colour transfer for human skin color. There have also been several prior studies transfering color specifically for images wherein skin colour is prominent. These are most similar in purpose to our project we will discuss each study in detail.

Skin colour transfer as part of other applications We have also found several examples of practical application of skin transfer algorithms, where different application demonstrate practical uses of usually relatively simple skin transfer algorithm that is part of a larger project; we will discuss several of these projects.

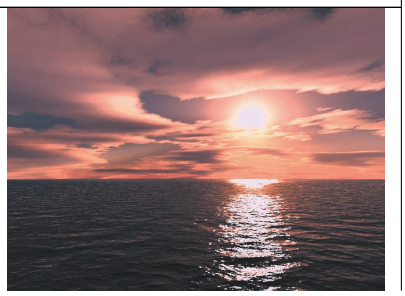
Skin colour enhancement mobile applications. Finally, there is the related field of skintone enhancement software, where algorithms are usually intended to adjust the user skin colour towards a more pleasing tone and not to a specific target colour. We include the latter because unlike the other categories of prior work there are several studies of adjusting skintone on a mobile device, which is part of the requirements for this project.

2.2.1 Colour transfer by example image for general images

Colour transfer refers to modifying the colours of an image to give it the desired appearance and style demonstrated by an example image, which we will refer to as the *target image*. Table **??** illustrates an example of this effect.

There have been a wide range of studies done in this area beginning with the seminal work of Reinhard et al. in 2001 [4]. The authors convert the image into $l\alpha\beta$ colour space, a colour space designed for natural scenes and based on research into human perception to reduce the correlation between each channel and remove the need to consider cross-channel effects when performing transformations on each channel. The authors then perform a simple operation to match the average and standard deviation of each channel of the original image to that of the target image. The resultant image is then converted back into rgb space.

Table 1: Example of image colour transfer using the algorithm from Reinhard et al. All images from [4]

No.	Original	Target	Result
1.1			

In a later study, Pitié et al. developed a method for entirely transfering the exact statistical distribution of the colours of the target image to the original image [5], and later improved on the technique with the motivation of automating film grading, or the process of enhancing frames

in films to ensure consistency of colour and "feel" [20]. We show an example the effects they acheive in Table 2

Table 2: Example of film grading based on an example image using the algorithm from Pitié et al. All images from [20]

No.	Original	Target	Result
2.1			
2.2			

More recently, Bonnel et al. conducted a further study on color transfer for film grading considering both spacial and temporal information [21] and Chang et al. created a tool for user editing of image based on a automatically generated colour palatte [7].

While these techniques are interesting possibilities to try when transfering human skin colour, because the these prior studies are all concerned with different problems that can arise with general images but not specifically for human skin colour, studies that specifically relate to human skin colour demonstrate that the general colour transfer techniques can be improved upon.

2.2.2 Transfer of human skin colour

Several studies have been done specifically on the transfer of human skin colour.

Seo et al. [10] has a purpose closest to the purpose of this project, to transfer human skin colours. The authors show results that improve in realistic appearance compared to the Reinhard's algorithm. The authors model the skin colour as an elogated distribution around a line refered to as the principle line in rgbspace. To perform the colour transfer, the authors transform the distribution of the original image such that the line

It is not clear how fast the algorithm can run particularly on a mobile device, nor the range of colours that the algorithm can transform a single skin colour, and it is in these areas that our project will attempt to improve upon.

Yang et al. performed the most recent study of colour transfer for human portraits [11]. However, this study focuses on the effect on the whole image, and places emphasis on transfering colour for different features of the human face. The actual algorithm used to transfer skin colour remains Reinhard's algorithm. This method also ranks the preferred target image for similarity to the

original image before performing the colour transfer, which differs from our project where a key issue is that we have no control over the target image that the user will provide us.

Yin et al. performed a study on the transfer of skin colour between races in order to aid a psychological study [9].

We include this study because it is one of the few that explicitly tries to transfer colour between a large difference of skin colour.

2.2.3 Skin colour transfer as part of other applications

Several applications performing different functions make use of skin colour transfer.

Shilkrot et al. published a study on transfering identity of the user on to a model image wearing garments the user may desire to purchase to create the virtual experience of the user trying on the garment [2]. The purpose of this article is fundamentally related to the purpose of the application that is this project's goal to support, and so this article is of great interest to us.

In fact, as part of the identity transfer, this article performs skin colour transfer on the model image to take on the skin colour of the user. Shilkrot uses a Gaussian Mixed Model for transfer skin colours and seems to use it for a relatively wide range of color differences.

The difference between Shilkrot's study and ours is that skin is only a small part of their final image, and the skin transfer process is only a small part of their study, which also places emphasis on the transfer of the user's head and the reshaping of the model's body proportions. In our case, the hand will be the only object of interest in our inputs and outputs. While we need not devote our efforts to any aspect but the skin colour change, any flaws in the color transfer causing unrealistic results will be much more noticeable.

Another interesting case of skin colour matching is the work Bitouk et al to create a face swapping software that seamlessly changes faces in photos to stock photo faces [22]. Since the skin colour of stock photo face does not exactly match the rest of the skin colour in the original photo, the authors adjust the lighting and skin colour until they do match. In their case however, the author specifically state large skin colour changes cannot be made, and to support a wide range of skin colours, the authors rely on having a large library of stock photos of every lighting position and skin colour. On the other hand, in our case, we are motivated by that fact that it is difficult to prepare videos for the full range of user skin colours.

Another application we've found is the work Baba et al. to develop a software that edits portraits in yearbook photos to all have a uniform skin colour given an example skin colour image [23]. The algorithm that the authors use to acheive this uses Piti's colour grading algorithm and guided image filtering. However, the goal of the project in terms of skin colour appears to be to have skin colours close to the target image but not necessarily exactly the same; the authors are focusing on the overall appearance of the set of portraits rather than the accuracy of the skin colour transfer for each individual image. On the other hand, the goal of our project is to ensure that the transformed skin colour of the model is as accurate as possible to the user's skin colour.

2.2.4 Skin colour enhancement mobile applications

For the most part the studies we have found are not meant to be run on a mobile platform and there are few specifically devoted to human skin colour. There are however many skin colour enhancement applications that modify human skin colour and several studies that perform this on mobile devices. The difference between those studies and ours is that we have a target

colour that could be very different from the colour that skin enhancement is aiming for, and our requirements for accuracy to the target colour is more stringent.

2.3 Summary of differences between prior studies and this project

In summary, we find that the prior work can some but all of our requirements for this project.

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