Can Messaging Applications Prevent Sexting Abuse? A Technology Analysis

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Abstract—The digital and mobile revolutions have changed the way people live their sexuality. Sexting, the practice of sending or receiving any sexually explicit content through mobile devices, has gained popularity, especially amongst teenagers and young adults, bringing several concerns, such as the uncontrolled spread of personal nude or semi-nude media without the owner's consent. Moreover, messaging applications generally used to communicate (and practice sexting) are not safe enough, e.g., they permit to send and forward any received content to anyone else. In this scenario, we believe that, beside education, technological solutions should be devised to avoid or limit sexting abuse. To this aim, we have developed *SafeSext*, a proof of concept messaging system, which also implements an image forwarding control feature. Through it, we have analyzed possible solutions, as well as their limits, in supporting a safer messaging environment where users retain some form of control over the forwarding of their self-generated sensitive contents.

Index Terms—messaging application, mobile, sexting

1 Introduction

According to the World Health Organization (WHO), sexuality is one of the essential aspects of being human. In the last decades, the growing spread of mobile devices and social media platforms have changed the way people communicate, search for new information, and create new relationships [1]. These revolutions have not spared sexuality, bringing several new opportunities and concerns. Indeed, the Internet and mobile devices provide access to new ways of interacting with each other (even sexually) and to an almost endless storage of erotic material. In this scenario, *sexting* is a practice that has gained popularity especially, but not only, amongst teenagers and young adults and represents an interdisciplinary topic of interest involving psychology, medicine, sociology, and computer science.

We can define *sexting* as the practice of sending or receiving any sexually explicit content (e.g., text, images, audio, videos) through social media platforms, such as instant messaging systems, dating applications, social networks and so on [2]. Sexting allows to have sexual interaction without being physically close to each other, which may be an important feature in particular situations. Consider, for instance, long-distance relationships, pandemic related lockdowns or people looking for sexual interactions with strangers without fully exposing themselves and avoiding the risks of any kind of contagion, both well known sexually transmitted diseases and COVID-19. The pandemic itself has increased sexting: the outcome of the survey is presented in Section 7, but we can anticipate here that we have collected some data through a questionnaire administered to 46 people in Italy aged 20 - 55 and discovered that about 15% of participants have done sexting for the first time during the COVID-19 lockdown months, in 2020, when couples not living together could not express sexuality in a physical way.

In general, sexting is a widespread phenomenon as revealed by a survey presented during the American Psychological Association's 123rd Annual Convention [3]. The authors asked to 870 heterosexual adults (age between 18 and 82, with an average of 32) to answer to an online survey about sexting: 88% of the respondents had sexted at least once in their lives, with 82% having done it even during the past year.

Unfortunately, practitioners of sexting can become victims of the unwanted spread of their sensitive contents, when the receiver of these contents forwards them to others without consent. Clearly, the worst case is when images or videos are involved and this non-consensual pornography may happen after a relationship breakup (aka revenge-porn), maliciously done by hackers, by mistake, or even selfishly done by the receiver to boost her/his pride.

The relevance of the phenomenon is difficult to assess as it depends on whether the victims eventually become aware of it and whether they decide to report it to the authorities. Unfortunately, many factors can influence a victim towards not reporting this type of crime despite the suffered damage such as, for instance, the fear of further victimization and the embarrassment due to the private nature of the images.

Online studies conducted in Australia and in United States allowed to estimate the prevalence of non-consensual pornography; the results showed that about 10% had experienced the dissemination of their sexual images without having given consent [4], [5]. This is a very high percentage if we consider that non-consensual pornography has similar health consequences to sexual violence committed in person, such as dysfunctional behaviors (self-harm and alcohol abuse), anxiety, post traumatic stress disorder, depression and suicidal thoughts [6]. It can be a never-ending damage in which the victims constantly experience the fear of being recognized, not knowing who and how many may have seen their photos. Often, the victims feel a sense of powerlessness due to the impossibility of being certain to

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be no longer the object of dissemination. Clearly, the longer the sexual images have been out in the Internet without the victim knowing and acting upon it, the less it will be possible to block their spread.

For this reason, although education is the main weapon to prevent the risks of sexting and to fight against non-consensual pornography, we believe that technology should be investigated as well to determine whether it could be used to block the forwarding of sexting images or, at least, to promptly inform the owner of those images. Unfortunately, the current scenario is disheartening as commonly used messaging applications permit to send any content to anyone and, although some of them implement some features for a safer user experience (e.g., images that can be seen only once, i.e., Whatsapp, or expires after a predefined time interval, i.e., Snapchat), their safety with respect to non-consensual pornography is far from ideal.

Highlights and Main Contributions. We have developed *SafeSext*, a proof of concept of a messaging system contrasting non-consensual pornography thanks to a forwarding control algorithm. Our system recognises sexual images exploiting the Google Cloud Vision API and applies a perceptual hash function to associate an owner to each image. Then, it defines a forwarding policy that could block the forwarding attempt and/or alert the owner if the image is forwarded to someone else. To the best of our knowledge, this is the first attempt in this direction.

Structure of the Paper. The rest of this paper is organized as follow. Section 2 describes the scientific background of this work. A review of the safeness of the forwarding policies of some commonly used messaging applications is discussed in Section 3. Section 4 provides some background information about perceptual hashing functions. The general assumptions our work is based on are described in Section 5. Section 6 describes *SafeSext*, our forwarding control algorithm and some technical challenges along with possible solutions and their limitations. An evaluation of our system is reported in Section 7. Finally, we draw our conclusions and present some future directions in Section 8.

2 Related Works

Nowadays, teens spend more and more time online, and this habit has brought to light several concerns about their online safety. Some works try to understand the best approach to guarantee safety and security while adolescents use social media and Internet-enabled mobile devices. For instance, Wisniewski *et al.* [7] analyzed 42 features of 75 Android applications and mapped them against the Teen Online Safety Strategies (TOSS) framework. They considered mobile applications that have the purpose of promoting adolescents online safety and figured out that most of the considered applications favoured parental control over teen self-regulation. However, a teen-centric approach would be more effective in teaching teenagers the skills necessary to engage correctly and safely with others through mobile devices and online. In addition, these applications have a low adoptions rate. Indeed, Ghosh *et al.* [8] observed that teenagers and children often dislike these applications, especially those adopting the parental control, because they find them too restrictive and too invasive for their privacy. Some works tried to co-design such applications with teenagers and children to find a balance between their need for privacy and their safety [9], [10].

The relationship between the Internet, social media and sexuality has gained the interest of the Human-Computer Interaction research community. Indeed, teens live part of their sexual experiences through the Internet, raising several concerns about their safety. For instance, sexting can have serious consequences, such as the spread of personal contents without the owner's consent, which may lead to psychological issues, (cyber)bullying, self-harm behaviours, or even suicide [11], [12]. On the other hand, online sexual experiences have become an important part of teens' lives. Hence, we need to rethink social media used everyday to face the new challenges posed by this particular use case [13]. Hartikainen *et al.* [14] focused on some messaging applications describing the design implications that emerged from their analysis of comments in a teen peer mental health support forum. According to their findings, messaging applications should allow to easily obscure faces in images containing nudity, as well as support their users in case of sexting abuse and advise them on how to behave correctly online. Particularly noteworthy is the recommendation of involving teenagers and sexual health experts in the design process of such applications.

Some researchers proposed computational approaches to detect nudity and/or skin. For instance, Wang *et al.* [15] developed a nude image recognizing algorithm based on the navel and some high-level hardcoded body features, which is able to detect nudity only if a body is completely nude. Santos *et al.* [16] presented a solution that allows recognizing exposed private parts of one's body even when mostly covered, mixing high- and low-level features. Instead, Sevimli *et al.* [17] described an approach able to classify images in five different classes (normal, swimming suit, topless, nude, and sexual activity), employing four descriptors in their algorithm. A comprehensive survey on algorithmic and computational approaches to detect nudity and skin that can be used to prevent sexting adolescent behaviours is presented in [18]. Razi *et al.* [19] reviewed 73 papers on computational approaches for online sexual risk detection, employing a human-centered lens.

Some works proposed serious games designed to tackle sexuality-related topics with teenagers. For instance, Wood *et al.* [20] presented a multiplayer mobile game to encourage talks about sex and sexuality in a group of teens, acknowledging that a permissive approach is more effective to improve teenagers' sexual health than a restrictive one. Instead, Guava *et al.* [21] developed a serious game to educate players about contraception and sexually transmitted diseases. However, education has poor results in a short time. Hence, teens need systems to safely explore their sexuality. In [22], we proposed some guidelines for developers to design safe messaging applications that allow for some form of control in the forwarding of media.

Safety issues are particularly important for people with disabilities that could be stakeholders of the proposed system [22]. Indeed, although little is known about the relationship between sexting and disability, it is not true that they do not have sexual experiences, fantasies and expectations

TABLE 1
Summary of the Features of the Analyzed Applications

Name	End-to-End Encryption	Deletion	Auto deletion Timer	Screenshot Notification	Forwarding
Badoo	No[a]	No	No	No	Yes
Instagram	No	Yes	Yes[b]	Yes[e]	Yes[f]
Snapchat	No	Yes	Yes	Yes	Yes
Telegram	Yes[c]	Yes	Yes[c]	Yes	Yes[f]
Tinder	No[a]	No	No	No	No
Tumblr	No[a]	No	No	No	Yes
Whatsapp	Yes	Yes[d]	Yes[b]	No	Yes

[a] not available [b] only for photos and videos [c] only for secret chats [d] only within 7 minutes from message generation [e] only for time-limited media [f] unless for time-limited media

like people without impairments often think [23]. In this scenario, sexting can be helpful for people with disabilities, especially physical ones, to gain confidence with their bodies and as a first step toward sexual experiences in real life. Moreover, through sexting, they can show only what they want of their body, which is not possible in real life [24].

In this context, we proposed some guidelines to build messaging systems safer by design for sexting in [22]. In the current work, we analyze possible solutions as well as their limits, thus opening new research directions, in creating a messaging environment where users retain control over the forwarding of their self-generated sensitive contents. Consequently, another important contribution is the demonstration that problems related to non-consensual pornography are not just a matter of how people use a (supposedly) neutral-by-nature tool but, rather, that technological solutions can be employed to improve the safety of popular applications and, thereby, at the time of writing, the inertia of social platforms can be considered co-responsible for possible sexting-related abuse harming users.

To the best of our knowledge, this is the first attempt in this direction. Therefore, our work advances the current state of the art, proposing a proof-of-concept messaging system which provides technological support to contrast the forwarding of sexting-related images. Through our study, we discuss technical challenges and possible solutions, also analyzing their effectiveness/limits and opening new research directions for scientists and social media creators.

3 Analysis of Existing Applications

Many popular mobile applications contain some messaging functionality. Some of them are introducing features to provide a safer user experience. We have hence analyzed the messaging functionalities of some commonly used social media applications from the standpoint of sexting safety. In particular, we considered the following features:

- whether the application is end-to-end encrypted or not;
- the possibility to delete messages already sent for both the parts of a conversation;
- whether it is possible to set an auto deletion timer for messages;
- whether the application notifies the users when someone takes a screenshot or starts a screen recording;
- whether it is possible to forward content or not.

Since pure messaging applications (e.g., Whatsapp, Telegram) are not the only ones that contain messaging features, we also selected dating and social networks apps: in alphabetic order we analysed Badoo, Instagram, Snapchat, Telegram, Tinder, Tumblr, and Whastapp as representative of the vast plethora of possible choices.

Although all these applications provide some messaging functionalities, there are several differences in their features and the underlying philosophies: e.g., Tinder does not allow to send media (i.e., images, videos, etc.) at all, while all the others platforms permit to send different kinds of media.

Several applications have introduced end-to-end encryption, making the contents readable only to the sender and the receiver. For instance, Whatsapp is end-to-end encrypted, whilst Instagram has planned to introduce this additional guarantee for privacy and security in 2023. Telegram provides this further level of encryption only for secret chats. On the other hand, Tumblr serves all over HTTPS by default. Hence, all the content is encrypted only between client and server, without any further level of security. Many applications lack transparency on their policies, especially for privacy and encryption, making it difficult for users to acquire information [25] [26]. For instance, we did not find this information in the official description of Badoo, Snapchat, and Tinder.

Among the considered platforms, Instagram and Telegram, let users delete already sent messages for both sides of a conversation, providing a helpful tool in case of regret. This feature is not provided by Badoo, Tinder, and Tumblr, whereas Whatsapp permits such operation within 7 minutes from the message generation. Snapchat adopts a more complex behaviour: the application automatically deletes all the messages already read by the receiver when the user closes the chat. However, users can save messages and, in this case, the deletion requires explicit action, such as the tap on a dedicated button to unsave (and hence delete) messages.

This functionality for non-saved messages is a sort of auto-deletion timer. Some other platforms provide similar features. For instance, on Instagram, it is possible to send media (images and videos) that can be viewed only once or twice. Similarly, Whastapp recently introduced the same feature but limited the number of views to one. On the contrary, users can set an auto-deletion timer for any message on Telegram secret chats.

Another important issue is the control against screenshots or recording of a conversation since such actions can be a threat when dealing with personal and sensitive content. Snapchat is the only application that shows two

different alerts for screen recording actions and screenshot actions so users can be aware of what is happening. Instagram notifies users only when time-limited media are involved, whilst on Telegram, such functionality is available only for secret chats. The others platforms do not inform the user at all. Table 1 shows a summary of the analyzed functionalities of the considered applications.

Except Tinder, all other considered applications permit forwarding[1] any content to anyone, providing an easy way for a malicious user to disseminate personal content (e.g., self-generated nudes). Indeed, none of such applications implements some form of control on the forwarding of media. Instead, our system proposes a step forward in this direction, advancing the current state of the art as well as opening new research directions.

4 Background on Perceptual Hashing

Our *SafeSext* system needs a computationally efficient way to represent and compare images. To this aim, our platform uses perceptual hashing, letting to detect not only bit-level identical image copies but also edited ones.

4.1 Theoretical Foundations

In recent years, the rapid development of capable multimedia technology and the popularization of image manipulation tools (e.g., Photoshop) have made it possible to easily modify images, even considering the capabilities of current mobile devices. If we consider the scenario where a malicious user edits a personal photo of someone else, the consequences could be dangerous. Therefore, in many applications, including our *SafeSext*, verification of the authenticity of images has become a relevant issue.

A hashing function is a one-way mapping that can transform an image (in general some data) into a short sequence of bits of fixed length (image hash that is also known as image fingerprinting). Several functions can map input information into a fixed-length string, such as MD5 and SHA-1. However, they are highly susceptible to content-preserving operations, also for small or imperceptible changes in the images. Hence, they are not suitable as image perceptual hashing functions.

Perceptual hashing functions have to fulfil the following requirements (where P denotes probability, X, $\hat{X}$, and Y are images, α and β are hash values, and $\{0,1\}^L$ represents binary strings of length L) [27]:

1) Equal distribution of hash values, $\forall \alpha \in \{0,1\}^L$

$$P[H(X) = \alpha] \approx \frac{1}{2^L} \quad (1)$$

2) Pairwise independence of visually different images X and Y, $\forall \alpha, \beta \in \{0,1\}^L$

$$P[H(X) = \alpha | H(Y) = \beta] \approx P[H(X) = \alpha] \quad (2)$$

3) The distinction of visually different images X and Y

$$P[H(X) = H(Y)] \approx 0 \quad (3)$$

1. By forwarding, we intend either the presence of a forwarding feature or the possibility to save and send content later (e.g., images, videos, etc.).

4) Invariance for visually similar images X and $\hat{X}$

$$P[H(X) = H(\hat{X})] \approx 1 \quad (4)$$

The last two requirements are the fundamental properties of perceptual hash functions. In other words, an image perceptual hashing function maps visually similar images to similar hash values and visually different images to different fingerprints. Hence, not only do we identify bit-level identical photos, but we also detect visually similar ones. As a consequence, by using a perceptual hashing function, our system becomes more effective and safer.

Over the years, scientists have proposed several functions for perceptual hashing that address different applications and transformations of the images. The most representative examples are the Block Mean Hash [28] and the Color Moment Hash [29], both implemented by the OpenCV framework, one of the most important in computer vision. Such type of function, hereafter referred to as a conventional hashing function, requires designing and extracting the features manually, and hence it does not represent the image content properly. Consequently, traditional hashing schemes cannot obtain the optimal trade-off between robustness against image manipulations techniques and discrimination capabilities, whilst both properties are fundamental when facing the challenge of image authentication. Furthermore, Monga *et al.* [30] have proven that the problem of simultaneously optimizing a features extractor and a hash generator separately designed is NP-complete.

Thanks to the explosion of the number of new approaches based on deep learning and the excellent representation capabilities of neural networks, several new perceptual hashing schemes have been proposed [31]. Some representative examples are [32], based on Convolutional Neural Networks (CNNs), and [33], based on autoencoder and feedforward neural networks. This kind of approach represents the state-of-the-art solution in reaching remarkable results in both robustness and discrimination capabilities; we hence decided to employ it at the core of our system.

4.2 The Fingerprinting Function of SafeSext

Since *SafeSext* needs a hashing function with excellent performance to be effective and have good scaling capabilities, we have chosen a function based on neural networks. In particular, we have adopted the state-of-the-art model proposed in [33], which possesses characteristics useful for our system (e.g., good robustness and discrimination capabilities, few false positives, etc.). Moreover, the code is available. However, we had to port it from MATLAB to Python using the framework PyTorch, one of the most famous for deep learning.

This solution allows us to not manually code the backpropagation algorithm, the optimizers, and the loss functions, by using all the features available out of the box in PyTorch, and a desirable effect is that we produce less error-prone code. Furthermore, such a choice is in line with the deep learning research community.

Other differences regard the training procedure, which is composed of a pretraining step and a fine tuning one as described in [33]. Yet, we have modified the learning rate of the fine tuning from $2 * 10^{-3}$ of the original proposal to $5 * 10^{-5}$

TABLE 2
Details of Content-Preserving Image Operations

Manipulation	Strength
JPEG Compression	Quality Factor $\in \{1, 5, 10, 30, 50, 70, 90, 100\}$
Scaling	Ratio $\in \{0.2, 0.4, 0.5, 2, 4\}$
Flipping	All the possibilities
Rotation	Angle $\in \{0, 5, 15, 30, 45, 90, 135, 180, 225, 270, 315\}$
Brightness	Brightness Offset $\in \{-80, -60, -40, -20, -10, 10, 20, 40, 60, 80\}$
Contrast	Contrast Offset $\in \{-80, -60, -40, -20, -10, 10, 20, 40, 60, 80\}$

of ours since we empirically observed better performance with our set of image manipulations (JPEG Compression, Scaling, Flipping, Rotation, Brightness, Contrast). The data used for the training procedure and for testing the model are a subset of the COCO dataset [34].

Before presenting the results achieved by the model, we define the concept of distance between two hash values. Given two image hash values h_1 and h_2, their distance indicates how similar the corresponding images are and it is computed as:

$$D(h_1, h_2) = \sum_{i=0}^{N} (h_1^{(i)} - h_2^{(i)})^2 \tag{5}$$

where N denotes the length of the hash values, and $h_1^{(i)}$ and $h_2^{(i)}$ are the i-th elements of h_1 and h_2, respectively. If the distance D between the two hash values is smaller than a prefixed threshold, the two images can be considered perceptually identical, otherwise, they are perceptually distinct.

The main difference with respect to the original work in [33] is the transformations of the images used to train the network. Ideally, we would want a model robust against all possible modifications; unfortunately, this is not possible. Regarding our scenario, we have restricted our expectations in training a secure model against manipulations commonly available on mobile devices, as it is easier for users to access them. Table 2 shows the details of the transformations used to train and test the neural network of our system.

To perform our test campaign, we adopted a method generally employed when considering image authentication. We computed the distances between the five original images shown in Figure 1 and their perceptually identical versions obtained through the operations reported in Table 2. We report the results in Figures 2, 3, 4, 5, 6, 7, where each chart shows the distances between the hash value of the original images and the hash value of the same photos edited with the specified transformation, using the values specified in the x-axis. Generally, the shorter the distances are (i.e. the closer their values are to 0), the better the perceptual hashing function behaves. For instance, we can see in Figure 2 and Figure 3 (JPEG Compression and Scaling, respectively) that distances are close to 0, meaning that the hash values of the original image and its corresponding manipulated version are almost the same. Instead, our perceptual hashing function is not so robust against rotation since the distances shown in Figure 5 are not close to 0.

Furthermore, to assess the robustness of our hashing function, we randomly selected 100 images from the COCO dataset and computed the minimum and maximum, the mean and the standard deviation of the distances between the original image and the result of every considered operation. We report the results in Table 3, which shows that the mean of the distances for almost all the manipulations is below 0.40, meaning that our perceptual hashing function has good robustness against the considered content-preserving manipulations.

To evaluate the performance of our fingerprinting function, we use a fixed set of thresholds τ_i, which embody the possible distances between the hash values used to classify whether images as similar or not. In our case, we employed 1000 values between the minimum and the maximum distances obtained with our test set. We compute the F_1 score for each classifier (i.e. considering each possible τ_i as threshold) as:

$$\frac{2 * [1 - FAR(\tau_i)] * [1 - FRR(\tau_i)]}{[1 - FAR(\tau_i)] + [1 - FRR(\tau_i)]} \tag{6}$$

Then, we select the classifier with the best score. In other words, we choose the threshold that maximizes the F_1 score. The model selected by this procedure has an F_1 score equal to 0.90 and suggests 0.35 as the threshold. It has a *FAR* of $4.04 * 10^{-2}$ and a *FRR* of $1.46 * 10^{-1}$. These values show that the model performance is acceptable. However, our system needs to have strong scaling capabilities, and these results could not be enough. We have also tried to use the same parameters for the neural network as the ones used in [33] but they generate a higher *FAR* and a less stable course of the loss, error and F_1 score curves during training and validation. Indeed, the complexity of the image manipulations we consider requires proper settings of the parameters as the one we used to improve the performance of the system. We have also considered another possible modification, an empty circle above an image, and retrained the fingerprinting model including it among the possible content-preserving image operations. This choice is due to the fact that such kinds of transformations are very popular, especially among teenagers. As expected, in this case, we have obtained worst results than in the previous scenario. Indeed, the F_1 score is equal to 0.89, slightly worst than the previous one, yet the *FAR* is 6.98 * 10^{-2}, whereas the *FRR* is 1.37 * 10^{-1}. Understanding which is the minimum set of modifications to consider is an open research problem. Yet, it would allow us to optimize the performance of the perceptual hashing function on that set.

Indeed, the neural network at the basis of our fingerprinting function does not reach the results shown in [33]. We believe that the reason is that we use more complex manipulations than the ones used in the original paper. However, a formal proof of this assumption is out of the scope of this work.

(a) Airplane (b) Baboon (c) Boat (d) House (e) Peppers

Fig. 1. Standard test images

TABLE 3
Statistics of Hash Distances based on Content-Preserving Operations

Manipulation	Min	Max	Mean	Standard Deviation
JPEG Compression	$2.87 * 10^{-8}$	$9.69 * 10^{-2}$	$1.73 * 10^{-3}$	$6.67 * 10^{-3}$
Scaling	$1.12 * 10^{-6}$	$2.03 * 10^{-1}$	$3.74 * 10^{-3}$	$1.30 * 10^{-2}$
Flipping	$2.21 * 10^{-3}$	1.58	$3.73 * 10^{-1}$	$3.78 * 10^{-1}$
Rotation	0.0	3.32	0.56	0.58
Brightness	0.0	0.36	$1.28 * 10^{-2}$	$3.34 * 10^{-2}$
Contrast	$1.01 * 10^{-7}$	$9.77 * 10^{-2}$	$3.03 * 10^{-3}$	$1.02 * 10^{-2}$

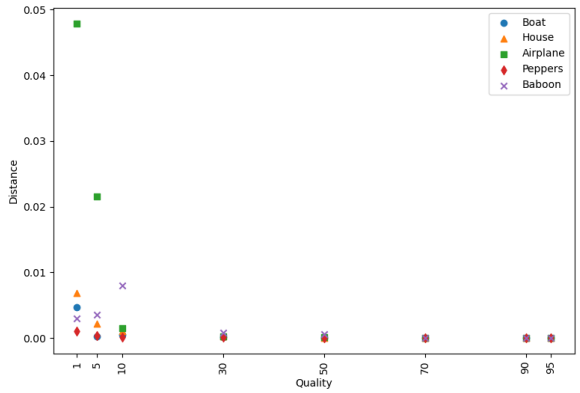


Fig. 2. Distances for JPEG Compression

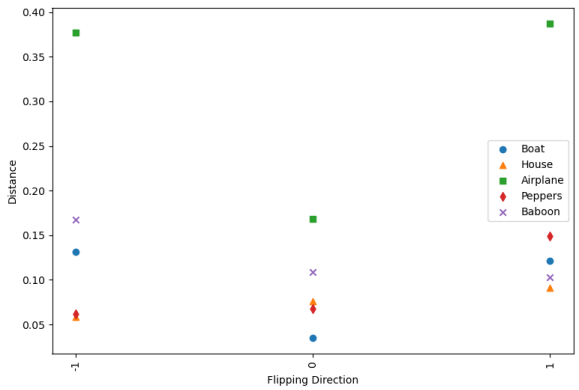


Fig. 4. Distances for Flipping

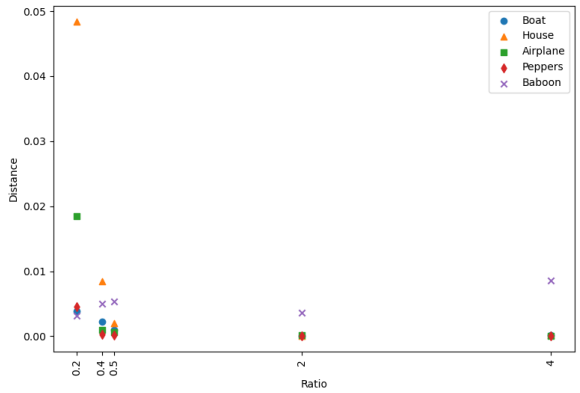


Fig. 3. Distances for Scaling

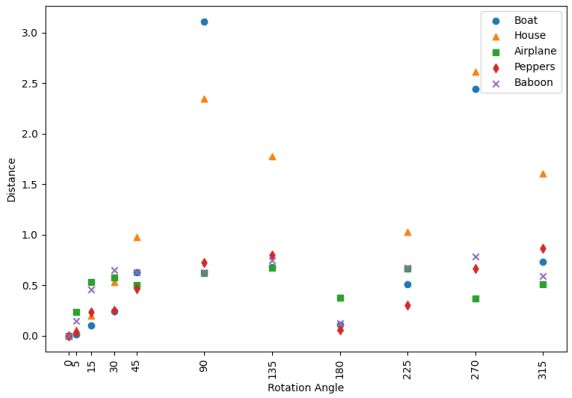


Fig. 5. Distances for Rotation

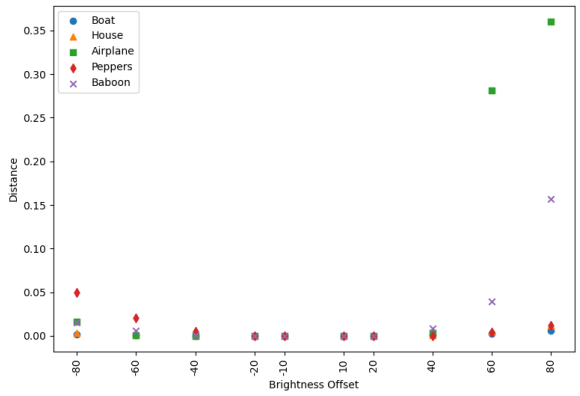


Fig. 6. Distances for Brightness

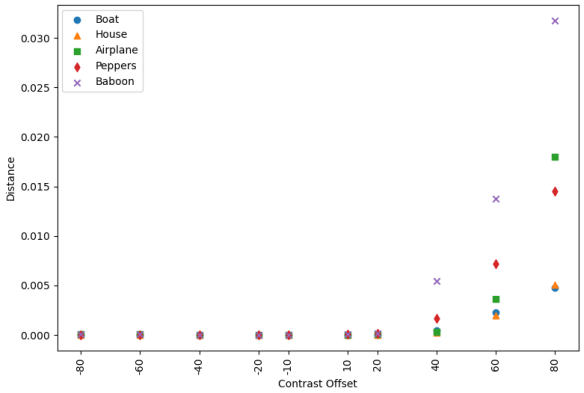


Fig. 7. Distances for Contrast

5 Assumptions

Sexting-related issues are mainly due to unauthorized forwarding of personal content. Forwarding can happen either thanks to an ad-hoc functionality of a messaging application or to the possibility of saving content on the device and sending it later. Thus, a messaging platform that does not offer these features would clearly help solving the problems related to sexting. Conversely, it would also not be possible to forward content which is not sensitive (e.g., a sunset, a landscape, etc.), thus jeopardizing the experience expected by users from a messaging application. Similar, even just the absence of the possibility to save content on the device would simplify the design of a safer system. However, in this work, we decided to consider the most general case, which is the one where the user can save the content on his/her device (e.g., in the gallery application). In this way, we aim to propose a solution that addresses difficult scenarios, avoiding unrealistic simplifications, while minimizing the negative effects on user experience.

6 Description of SafeSext

We designed and developed a proof of concept of a messaging system (including an Android application) attempting to be safer by design for sexting thanks to a forwarding control feature for images. Its goal is to reduce, and hopefully prevent, the spreading of photos containing self-generated nudity without the consent of their owners. We hence investigated technological solutions that could provide some protection against sexting abuse in the form of non-consensual pornography.

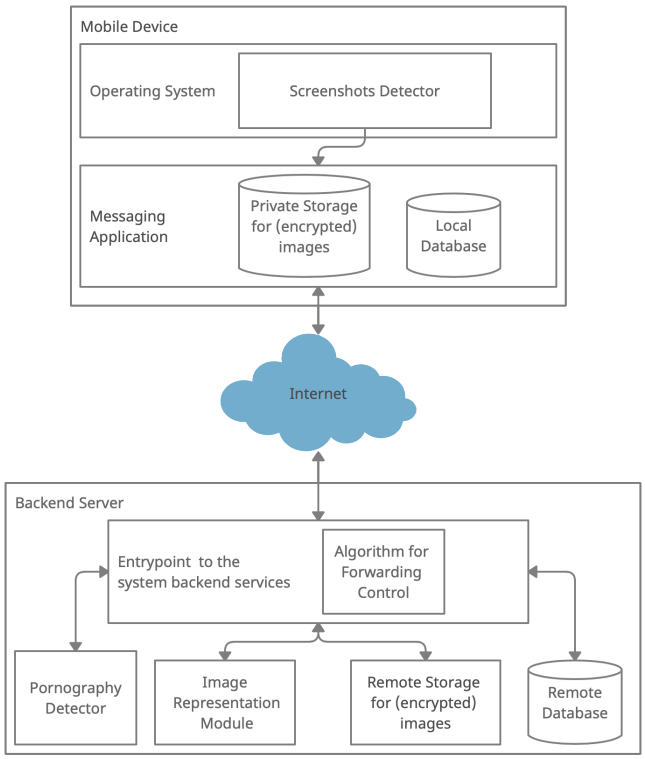


Fig. 8. Architecture of SafeSext

Besides the forwarding control functionality, *SafeSext* also includes other features to support users during their experience with our platform. For instance, our system lets them delete messages in a conversation for both sender and receiver, controls and reports screenshots activity (e.g., log of the actions, screenshot actions disabled), and supports users in case of issues related to sexting.

Our system includes a mobile application that allows the exchange of messages between users by communicating with a backend server through the Internet. Both the mobile application and the server contain several components, as shown in Figure 8.

The mobile application includes a local database and a private storage. *SafeSext* saves messages and contacts in the former, while the latter is employed to store images. Moreover, it provides some form of control on the screenshot actions. For instance, thanks to a notification triggered by the screenshot detector of the operating system, it is possible to know when users take one and log the actions in our system. However, such an operation could not be always possible. For example, Android does not provide any official API to detect screenshots (even if there exists a workaround). In our specific Android implementation, it is not possible to take screenshots; however, the same is currently not implementable in iOS and requires further

investigation or some policy change by Apple.

Mobile application interacts with our backend server by calling the right HTTPS endpoint, a sort of entry point to all the services of our system. For instance, the API permits registering users into the system, sending messages, requesting the deletion of content, etc. The most important features of the backend server are:

a) the forwarding control algorithm;
b) the forwarding policies;
c) the selection of images whose sharing have to be restricted;
d) the image representation module, which implements a perceptual hashing function to compute the representation of the images.

The remote database contains information about users of the system and hash values of the images and their owner. The forwarding control algorithm uses the hash values to check the owner of an image and apply the forwarding policies. The system saves the photos in remote storage thus permitting the update of the fingerprinting module in the future, as described in Section 6.4. Yet, we can anticipate here that other design choices are possible, even considering the possible privacy drawbacks of this part of the system. For instance, users can be asked to upload images on the fly when the fingerprinting function has to be updated.

Our system, and in particular our forwarding algorithm, is completely transparent for the users until a suspicious action happens. Indeed, no preliminary photo upload or user action is required.

6.1 Algorithm for Forwarding Control

Our system imposes restrictions on the forwarding of images thanks to the algorithm for forwarding control, which is the core of *SafeSext*. In this section, we describe it in detail.

When a user sends an image, the algorithm checks whether such an image is relevant for the system or not. Section 6.3 discusses what this means for a photo in *SafeSext*, but we can anticipate that the algorithm considers relevant a picture when it contains nudity of any sort. If the image is not relevant, the system sends the image to its receiver since it is not sexual-related, and hence it does not carry damage considering the aim of our system. Otherwise, the image representation module computes the hash value of the considered photo and the hash values already known by the system are retrieved.

The system calculates the distances between the new hash value and the ones previously retrieved[2]. If an image with a distance below a predefined fixed threshold exists, the system controls whether the sender or the receiver of the image is its owner. In such a case, the algorithm proceeds to send the photo as shown in Figure 9. Otherwise, if the distance is below a predefined threshold, and the owner of the considered photo is neither the sender nor the receiver, the system could adopt different behaviours according to the implemented forwarding policies. For instance, one approach could specify to not proceed with the sending,

2. The only case in which the system does not retrieve any hash value is when the first user sends the first image, so we can assume that the set of retrieved hash values is not empty.

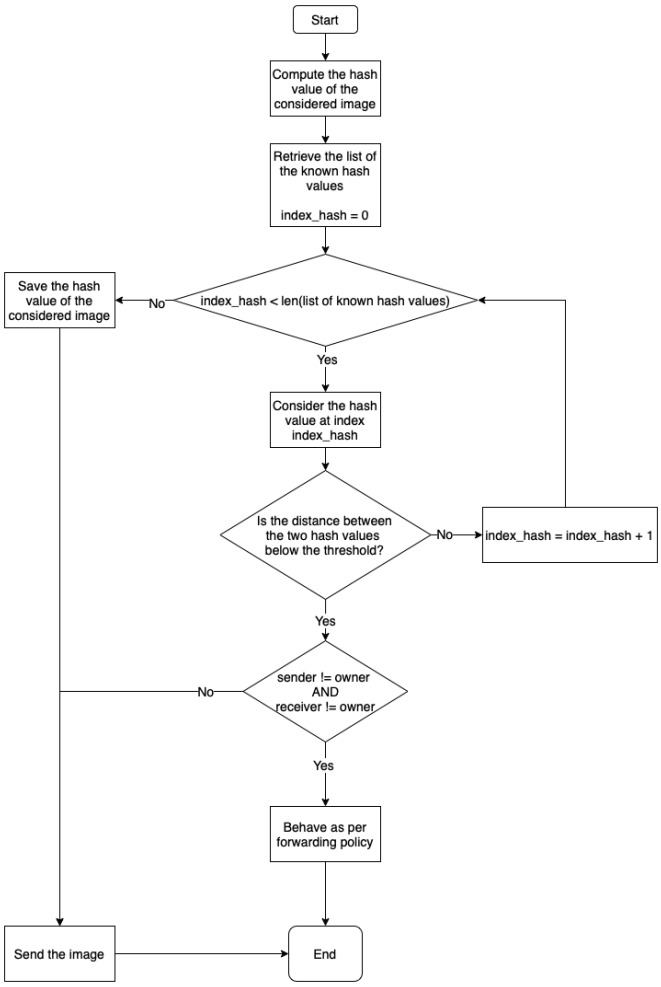


Fig. 9. Core of the Forwarding Control

while another policy could impose to notify the owner of the considered image but send it anyway as discussed in the next section. If none of the distances between the hash value of the considered image and the ones known by the system is below the fixed threshold, the system saves the hash value of the currently considered picture and sets the sender as its owner. Then, the image is sent out to the receiver.

Although the evaluation of the relevancy of an image may be wrong, an error in the decision on whether two hash values correspond to the same image or not (i.e. is their distance below the threshold?) is way more disrupting. In case of a false positive, the system executes the predefined forwarding policy even though not necessary, and the hash value of the image is not inserted. Instead, in case of a false negative, the system inserts the hash value of the image along with its owner, thus leading to the presence of two owners for the same photo. For these reasons, as discussed in Section 4.2, we need to lower as much as possible the error rate of our fingerprinting function.

We must note here that this approach can be generalized to several other kinds of media, applications and scenarios. For instance, it could be interesting to add the forwarding control of videos in *SafeSext*, as videos are actually frequently used for sexting. The algorithm does not need to change significantly; just some of the steps need to be

adapted to the video scenario. In particular, it is necessary to define when two media have to be considered as similar and specify a function to represent them, along with a proper distance measure.

6.1.1 Time Complexity

The algorithm for forwarding control is a very central part of our system. Its execution time directly impacts the user experience and hence the diffusion of our proposal. Therefore, both theoretical and empirical analyses of its time complexity are necessary.

As can be easily understood from Figure 9, our forwarding control algorithm has time complexity O(n) in the worst case, which happens when the considered image is not already known. Indeed, the algorithm iterates over all the known hash values in that case. Yet, this time complexity can be prohibitive in case a large number of hash values is present into the system, especially considering the nature of our application which requires a small slowdown so that people would like to use it. We can hence adopt other searching strategies (e.g., binary search) and/or appropriate data structures.

We now report the results of some empirical experiments where we calculated the computation time of various parts of our algorithm. The first step of the forwarding algorithm is deciding whether an image is relevant or not, thanks to the Google Cloud Vision API. We have hence computed the maximum, minimum, mean and standard deviation of the response time (that is, the computation time plus the network delay) of such an API, applying it to 1000 images at different times during the day. Table 4 presents the results. Furthermore, if an image is considered sensitive, the system computes its hash value using our fingerprinting function. Therefore, we have calculated the computation time of the hash value generation, including the preprocessing time of the image, considering the same 1000 photos used in the evaluation of the previous step. Our experimental results show that the time needed for this step ranges from $4.67 * 10^{-3}$s to $2.30 * 10^{-1}$s, yet it is $9.95 * 10^{-3}$s on average and presents a standard deviation equal to $8.60 * 10^{-3}$s. Finally, we have computed the time necessary to search amongst the known hash values, considering the worst-case, which should be the most frequent one (i.e., when the search fails). To this aim, we have considered both a linear search in the list of known fingerprints and a dichotomic search. In the latter case, if the search fails, the insertion has time complexity O(n) in the worst case since the list is ordered (with respect to O(1) amortized in the former case). Yet, the insertion may be deferred and executed in the background. Thus, as demonstrated by our experimental results, the binary search increases the performance of the algorithm. We report our numerical results in Table 5 and Table 6. The mean of the computation times of the linear search increases by a factor of 10 every time the input increases by the same factor, in accordance with its theoretical time complexity. Instead, considering the binary search, the mean of the computation times maintains the same magnitude order for all the considered input lengths, thus confirming our hypothesis and theoretical analysis.

We must note here that the search can be parallelized, thus lowering the its computation time. Furthermore, the system can employ some heuristics in the search (e.g., consider the contacts of the sender before other users).

TABLE 4
Computation Time of the Evaluation of Relevancy of an Image

Time	Min (s)	Max (s)	Mean (s)	Std (s)
9 A.M.	$2.02 * 10^{-1}$	8.21	$3.31 * 10^{-1}$	$2.59 * 10^{-1}$
6 P.M.	$2.48 * 10^{-1}$	1.32	$4.00 * 10^{-1}$	$8.80 * 10^{-2}$
9 P.M.	$2.43 * 10^{-1}$	2.43	$4.04 * 10^{-1}$	$1.21 * 10^{-1}$

TABLE 5
Computation Time of the Linear Search

Values	Min (s)	Max (s)	Mean (s)	Std (s)
1000	$1.74 * 10^{-2}$	$1.00 * 10^{-1}$	$1.91 * 10^{-2}$	$3.33 * 10^{-3}$
10000	$1.71 * 10^{-1}$	$5.71 * 10^{-1}$	$1.92 * 10^{-1}$	$3.33 * 10^{-2}$
100000	$1.54 * 10^{-1}$	4.33	2.22	$4.39 * 10^{-1}$

6.2 Forwarding Policies

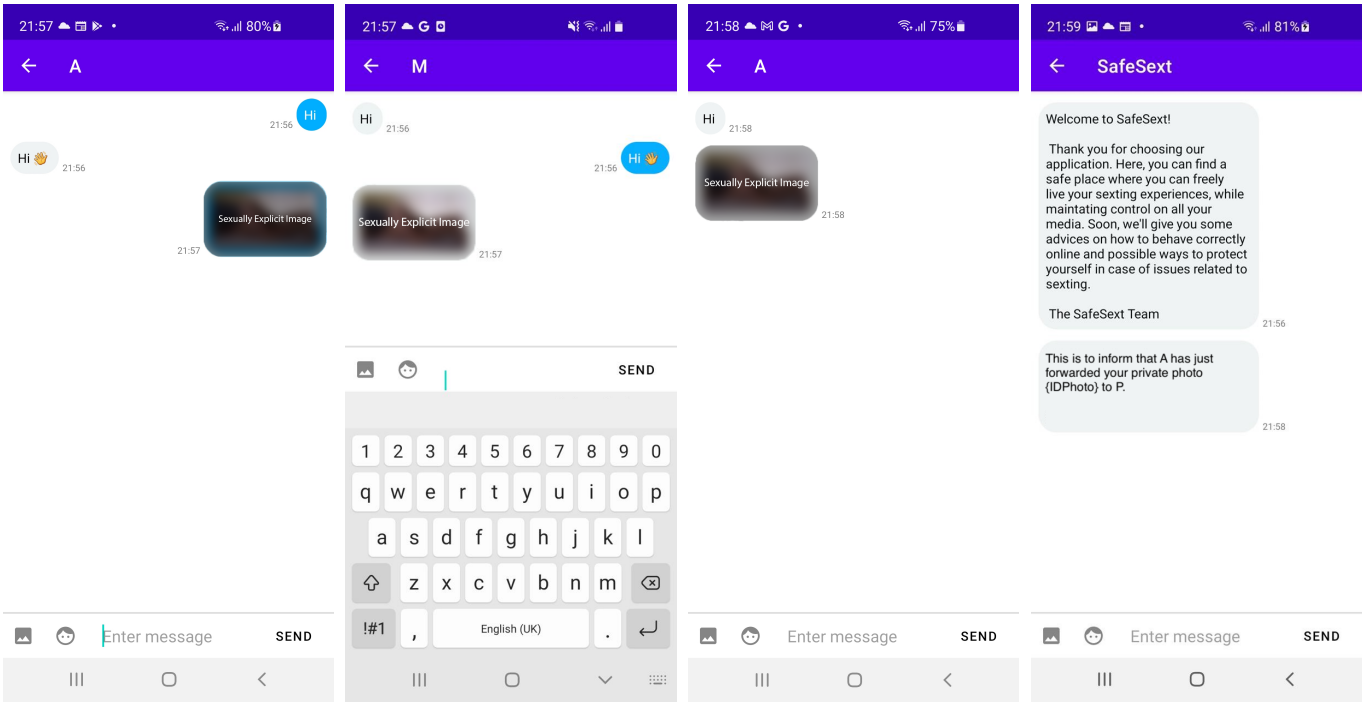
Our system can adopt different policies to contrast the attempts of forwarding a sexting-related image without being the owner. The optimal behaviour can depend on several factors, such as the performance of the fingerprinting function. Therefore, we have included in our system two possible forwarding policies, forwarding notification and forwarding blocking. Probably, the combination of the two is the best option in an ideal system, although other ones might be proposed even in combination.

The first policy, if adopted alone, allows the forwarding of any image but notifies its owner when such a photo is a personal/sensitive one and someone who is not the owner is sending it out. In Figure 10, we show a sequence of events that triggers a notification. Basically, M sends a self-generated nude image to user A (Figure 10a), who receives it (Figure 10b) and forwards it to another user (Figure 10c). As a consequence, the system notifies user M (Figure 10d).

Such a policy, if used without blocking the forwarding, seems not to be fully coherent with the purpose of our system; yet, some users might prefer it or, as said, the two policies could be used in combination. Employing solely forwarding notifications, without blocking the forwarding of an image, can avoid annoying blocks in case of false positives. Indeed, although *FAR* and *FRR* reported in Section 4 are low, about four photos over one hundred will be considered as false positives. This number has to be considered in the context of a messaging applications where users tend to send and receive hundreds of images every year. Thereby, if we do not leave to the users the possibility to configure the system to only employ forwarding notifications without blocking, these false positives (if felt

TABLE 6
Computation Time of the Binary Search

Values	Min (s)	Max (s)	Mean (s)	Std (s)
1000	$2.06 * 10^{-3}$	$5.41 * 10^{-2}$	$2.62 * 10^{-2}$	$4.04 * 10^{-3}$
10000	$1.76 * 10^{-3}$	$1.33 * 10^{-1}$	$4.05 * 10^{-2}$	$6.83 * 10^{-3}$
100000	$3.15 * 10^{-3}$	$1.06 * 10^{-1}$	$5.08 * 10^{-2}$	$8.77 * 10^{-3}$
1000000	$2.32 * 10^{-3}$	3.48	$5.17 * 10^{-2}$	$1.10 * 10^{-1}$
10000000	$5.20 * 10^{-3}$	3.36	$7.50 * 10^{-2}$	$1.98 * 10^{-1}$



(a) M sends a self-generated nude image to A

(b) A receives the image from M

(c) Someone else receives the M's image

(d) M receives a notification because A just sent the image to someone else

Fig. 10. Example of notification after a forwarding

annoying) may lead users to uninstall *SafeSext* in a period of their life when not thinking of sexting (and its risks) at all and switch to a different platform. As users tend to not continuously switch amongst messaging applications, the latter will then be used when/if the users will engage in sexting, leaving her/him without any protection (not even notifications) against unwanted forwarding. Instead, as already mentioned in Section 1, it is crucial for the victims of non-consensual pornography to become immediately aware of the crime so as to act immediately and block the spread of the images before they get replicated so many times over the Internet to render any counteraction ineffective.

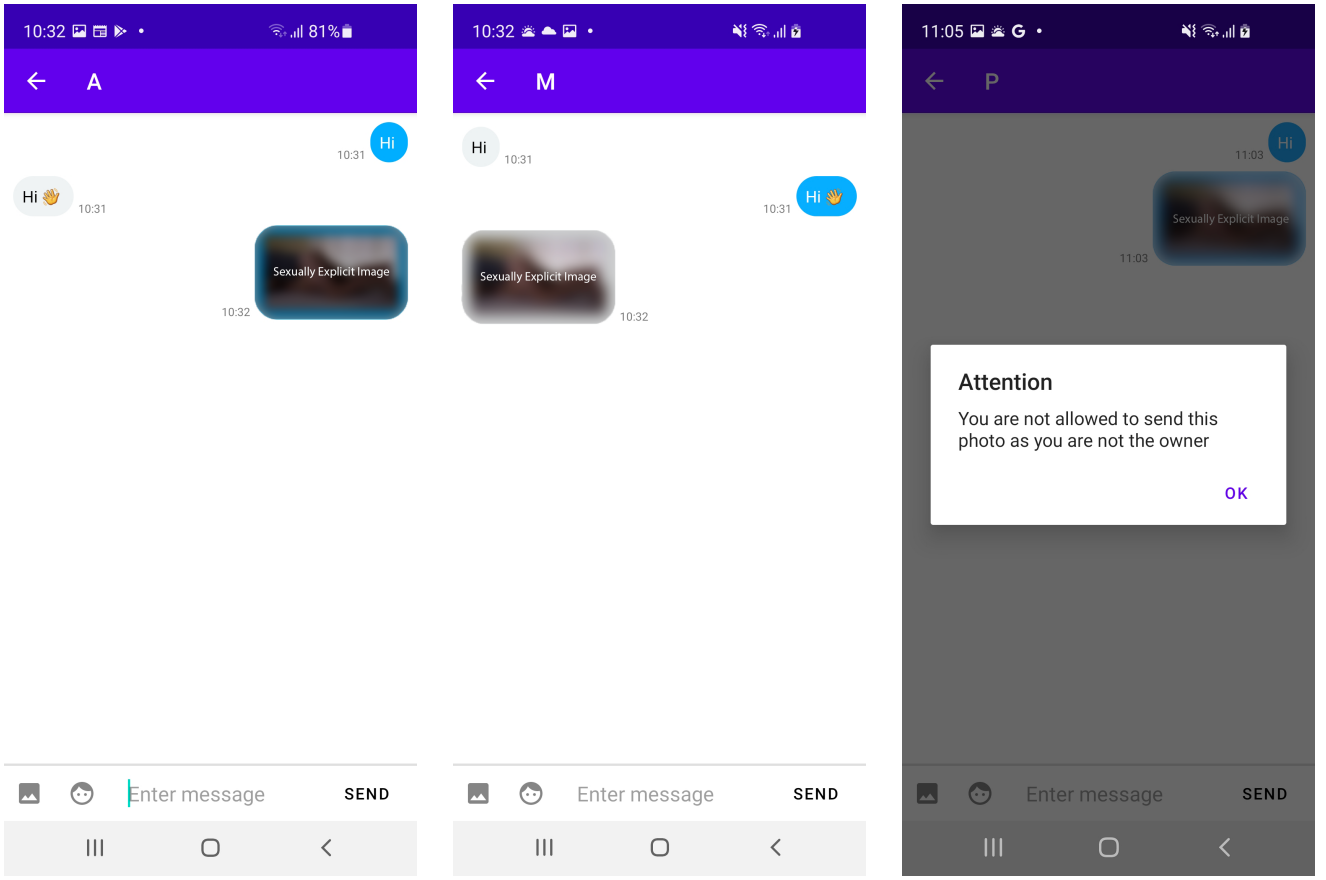
The second proposed policy simply blocks the forwarding of a relevant image (e.g., a self-generated nude), except when the sender is its owner or when the system allows the sender to mark the image as shareable despite of its content. Figure 11 shows an example of implementing such a policy. In particular, user M sends a self-generated nude image to A (Figure 11a), who receives it (Figure 11b) and tries to forward it to someone else. However, the operation is forbidden and simultaneously the system also shows an alert to the forwarder (Figure 11c).

We deem that if all and only sexting related images were correctly identified and the fingerprinting function had perfect (or almost perfect) performance, the blocking forwarding policy would be the most effective one in most cases. Furthermore, this policy can also be combined with a notification sent to the owner of the image to make her/him aware of the attempt ad act accordingly: granting forwarding permission (e.g., if the image is actually a false positive or the owner agrees with the forwarding), contact the police, etc. Other policies are possible as well. For instance, people who share images depicting their faces are more at risk in case of revenge porn as it is easier to identify them; this is also true for people with identifiable marks (e.g., tattoos). In a scenario where there is no identifiable information in the sexual picture, the system can adopt a different forwarding policy. However, we must note more in general that an image can reveal various types of sensitive information and people are unaware of how images can compromise privacy [35], [36]. Therefore, other countermeasures should be adopted to protect users besides a forwarding policy. A comprehensive survey on image privacy in online social network is presented in [37].

Some further considerations are needed regarding notifications. Receiving notifications about such a delicate and harmful subject can be shocking for people, especially when involving teenagers or, in general, fragile people. Consequently, this could potentially cause harm and dangerous reactions. The choices regarding how the system has to deliver the notification, who has to receive it (the user or her/his parents?), and the best moment to send/receive it, should be made by an expert (e.g., a psychologist). Indeed, as already mentioned, this is an interdisciplinary topic and, although we here limit our investigation to the technological tools that could be used to limit non-consensual pornography, experts in other fields should be involved as well before deploying such a system.

6.3 Classification of private/sensitive images

The simplest version of a restricted forwarding algorithm is the one that limits the forwarding of any image generated



(a) M sends a pornographic image to A

(b) A receives the image from M

(c) A tries to send the image to someone else, but the system blocks the operation and shows an alert

Fig. 11. Example of block of the sending

by someone else, no matter how harmless. However, this would have an impact on effectiveness and scalability. For instance, let us consider the case where user A sends out an image of a public place (or a celebrity, some piece of art, a monument, a flyer of an event, etc.) to a user B. Then, if user C tries to send out the same image to user D, she/he will find out that the system triggers the procedure specified by the forwarding policy, even though the photo is not a private/sensitive one. Therefore, considering all the images as susceptible to forwarding control is clearly excessive.

Triggering the behaviour specified by the forwarding policy when not necessary can be a non-trivial problem for users and their experience, which could lead them not to use our application. As a consequence, *SafeSext* would not reach its goals. Also, our forwarding algorithm iterates over all the known hash values in the worst case. So, the more images the system considers relevant, the more iteration will be needed, thus jeopardizing scalability. To overcome such problems, we have analyzed and tested other possible solutions.

The first solution we considered was to let the users choose which images should be protected by the forwarding control policies. For instance, users could enable the restriction by clicking on a button on the image preview before sending it out. However, such a solution works only in an ideal scenario, where users exclusively select personal photos. Instead, problems arise when users enable the forwarding restrictions on images taken, for instance, during a vacation. Several pictures of the same monument taken from similar locations and angles would result as a violation of the forwarding restriction even if the images have been generated by a different user. Consider, for instance, the millions of pictures taken every year of the Colosseum in Rome or of the Tour Eiffel in Paris: only the first tourist attempting to send such pictures would be enabled to do so, blocking all other tourists from there on. Unfortunately, soon all the images would have an owner, jeopardizing the system and bringing back the aforementioned usability drawbacks. We hence discarded this approach.

The second approach allows to specify the images that could freely go around in our platform. In particular, users could send pictures of public places without any restriction. To do so, we chose the functionalities for detecting landmarks of the Google Cloud Vision API and tested them against a dataset composed of some images downloaded from the Internet. We hypothesized that this API was able to correctly identify pictures depicting some famous monuments, but not general public places (e.g., roads, mountains, beaches, etc.). Hence, to verify such a hypothesis, our dataset contained images of both kinds. The negative part

of our dataset was composed of some photos of people. Our test reached a True Positive Rate of 0.31 and a True Negative Rate of 0.96. Such API showed remarkable results on the negative part of the dataset; yet, it had some problems recognizing images of public places in their more general conception, confirming our hypothesis. Photos of such kind are probably the widest part of the ones that go around on a messaging system. Moreover, such a solution would not permit the detection of images depicting celebrities or some piece of art. For these reasons, we discarded even this approach.

The last considered approach, which is the one actually implemented in *SafeSext*, imposes restrictions only on the necessary images, recognizing the ones that contain sexual contents. In this way, our system can restrict the forwarding only to a limited set of images, preserving the user experience and minimizing the drawbacks described above. To this aim, our system uses the feature for detecting explicit content of the Google Cloud Vision API, which we tested against two different datasets. The first dataset is a subset of the one proposed in [38], which contains pornography images and non-pornography ones (both easy and difficult to detect), while the second one is composed of some softer pornography pictures and some photos depicting people downloaded from some social networks. In the first test, we evaluated the API against 1000 images from each category of the dataset contents proposed in [38] (NPDI Pornography Database). The result for the pornography category is excellent: the classification is correct for all the examples. The performance gets worse with the easy non-pornography pictures where the True Positive Rate is 0.81, which is still acceptable. Instead, the result reached by the last category is a True Positive Rate of 0.36, which is unacceptable. The dataset for the second test was composed of 373 soft-porn images downloaded from public Tumblr profiles and 227 pictures of people. The API under test works very well against such a dataset. Indeed, we obtained a True Positive Rate equal to 0.97 and a False Positive Rate of 0.45. A summary of there results is reported in Table 7. These values highly depend on the definition of what is relevant for the system. In our case, the negative samples contain many images depicting people in beachwear (e.g., bikinis, swimwear, etc.) that are often recognized as adult content by the Google Safe Search API, leading to a high False Positive Rate. However, other definitions of personal content may be considered. For instance, users in Arab regions may have a more strict notion of personal and sensitive content (for instance including naked shoulders) with respect to Western users [39]. Therefore, 0.45 is a worst-case value and can decrease drastically, even close to 0, considering pictures depicting people wearing beachwear as positives and/or employing a more accurate content moderation API (e.g., Amazon Rekognition).

Considering the aforementioned results, our analysis shows that imposing restrictions only on images containing sexual content is the most viable approach amongst the considered ones. In this way, our system stores only the strictly necessary hash values, improving the scalability and the user experience while reducing the chance of error.

TABLE 7
Summary of the Classification Performance of Google Cloud Vision API

Dataset	TPR	FPR
NPDI - Pornography	1.0	/
NPDI - Easy Non-Pornography	0.81	/
NPDI - Difficult Non-Pornography	0.36	/
Tumblr	0.97	0.45

6.4 Updating the Fingerprinting Function

With technical and scientific advancements, the performance of current systems can continue to improve and provide the best possible experience to their users. On the other hand, developers have to design systems that are easy to maintain and update, possibly with transparent procedures from the user standpoint. In this way, developers and system administrators can update their systems, minimizing disservices for users, which is particularly important for all the essential platforms (e.g., life-critical) or those with a minimum set of services that need to be available in nearly any scenario.

Clearly, a messaging system is not a life-critical service, but when one goes down for some issues, people move *en masse* to other platforms, with an economic loss for the company loosing customers. In our case, it is easily foreseeable that the perceptual hashing function will have to be updated every time a more performing one will be available, especially considering that the problem of image authentication is an adversarial one. However, a messaging platform cannot suspend its service every time its perceptual hashing function needs an update. Thereby, we designed a transparent procedure to reach this goal.

Such functionality justifies the presence of private storage for images on the backend server. Indeed, such a choice comes with some privacy and legal concerns. After investigating how popular messaging platforms store messages and pictures, we can claim that this generally done in the field by main companies. The main issue with this solution is that, even with symmetric encryption, we can see the images stored in our system, which could potentially be a serious concern from the user point of view, especially considering the private content our system handles. Moreover, underage users can send sexy photos of themselves, causing our system to store child pornography content, which is illegal in most countries. For these reasons, another possibility is to explicitly ask users to (temporarily) upload their relevant images every time the fingerprinting function has to be updated. Clearly, if someone does not accept or does not have access to Internet connectivity, its pictures will no more be checked by the (updated version of the) forwarding control algorithm until they are uploaded. In this way, the system does not need to store any image on servers, further preserving users' privacy.

To update the fingerprinting function, developers can access a private website to load the new fingerprinting model into the system, starting the update. Our procedure turns off the forwarding control functionality for the necessary time while the rest of the system continues to work regularly. Then, each hash value is computed again through the new fingerprinting function by using the images stored in the private storage (or temporarily uploaded by users in case of

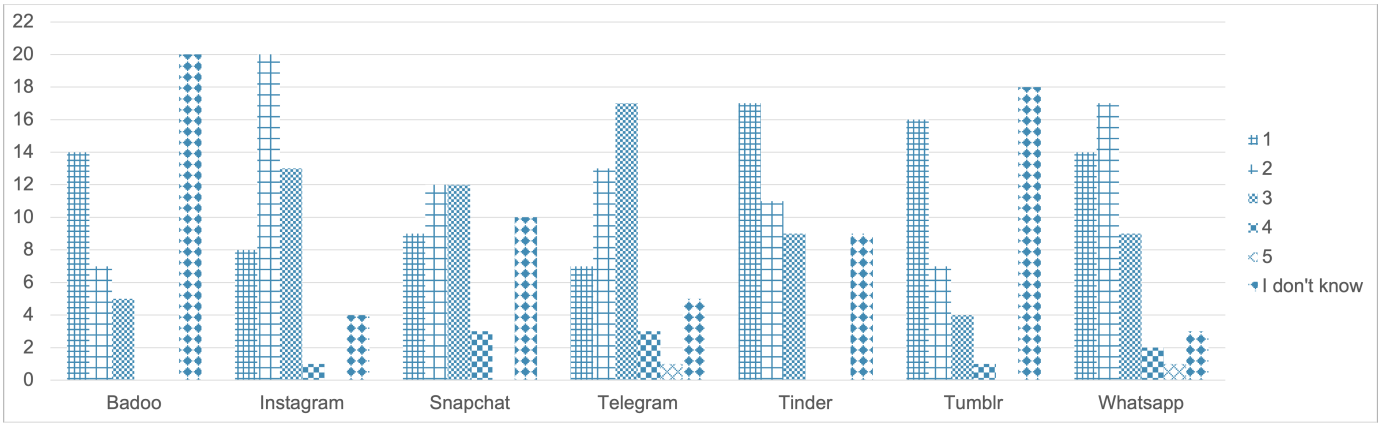


Fig. 12. Users' Evaluation of the Analyzed Applications, from 1 (*very little*) to 5 (*very much*)

private storage). Finally, the system turns on its forwarding control feature again.

6.5 Minors and Child Sexual Abuse Material

Child Sexual Abuse Material (CSAM) and pornography depicting underage people are serious and complex issues related to social media and, hence, also to our system. Indeed, not only do these images and videos report child victims' abuse and exploitation, but when these files are shared across the Internet, victims suffer re-victimization each time the image/video of their sexual abuse is viewed. Fortunately, some services help to prevent the diffusion of such materials and to remove them from the Internet and social media. One representative example is the one offered by the National Center for Missing & Exploited Children (NCMEC)[3]. Thanks to them and Google's Content Safety API is indeed possible to fight child sexual abuse, detecting, removing and reporting offences on various platforms. For example, CyberTipline, the nation's (USA) centralized reporting system for the online exploitation of children, allows people to report incidents. The U.S. federal law requires indeed that U.S.-based electronic service providers (ESPs) report instances of apparent child pornography on their systems to NCMEC's CyberTipline as soon as they become aware of them. Furthermore, it is also possible to report nudes or sexually-exploitative images or videos directly to platforms. In these ways, images/videos can be taken down. Instead, Google's Content Safety API helps platforms classify and prioritize billions of images for review. Indeed, it is sufficient to send the image files to such an API with a simple API call, and the classifier will send back the priority value for each image. In this way, platforms can consider such a value to select which photos need attention first for manual review. Once the image has been manually reviewed, platforms can take action in accordance with local laws and regulations. Google obtains hash values also from NCMEC, thus being able to identify already known CSMA material. Our system can be hence integrated with these collaborative services to improve its effectiveness, demonstrating our commitment in protecting people and guaranteeing them a safer experience on our platform.

3. https://www.missingkids.org/home

Sharing of self-generated sexually-explicit images among underage people is an issue as well since pedo-pornography is illegal in many countries. Things get even worse if we consider that images are stored in our server (although other approaches are possible). One possible countermeasure could be only allowing people older than 18 to use the application. Yet, we do not believe this is feasible since our platform has not been designed just for sexting purposes. Instead, it is a general-purpose messaging application for everyone, as any currently available one, with a higher level of protection for sexting. Furthermore, overcoming the age limit imposed by currently available social media platforms is straightforward most of the time. Indeed, it is sufficient to declare a false age during the registration, even though this violates the terms and conditions.

7 Users Assessment of the Proposed Solution

Besides the performance evaluation of the various components of our system presented earlier in this paper, we asked 46 people in the age group from 20 to 55 to evaluate *SafeSext*, through an online questionnaire. In particular, participants were asked about the proposed forwarding policies and the necessity of detecting also edited copies of an image. They were asked to evaluate all answers on a scale from *1 (very little)* to *5 (very much)*. Before starting the questionnaire, participants, who were master's students of Computer Science at the University of Padua, were informed about the topic of the survey with a brief presentation. Because of the intimate nature of the questions and the sensitive topic, they could decide not to send their answers and terminate the questionnaire at any moment. In addition, to create the most comfortable situation, they could complete the questionnaire in the context they preferred (e.g., home, etc.). No identifiable data were collected, and the answers were completely anonymous.

Participants were approximately equally distributed between females and males, respectively 22 and 24. 23 of them (50%) are aged 20 to 25, 17 (37%) are from 26 to 35, and 6 (13%) participants are aged between 36 and 55. More than 85% of them had some knowledge about sexting, about 90% of participants confirmed that they did sexting at least once

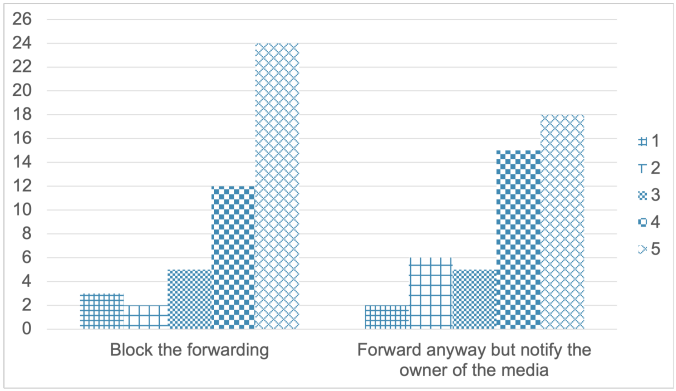


Fig. 13. Assessment of the proposed forwarding policies, from 1 (*very little*) to 5 (*very much*)

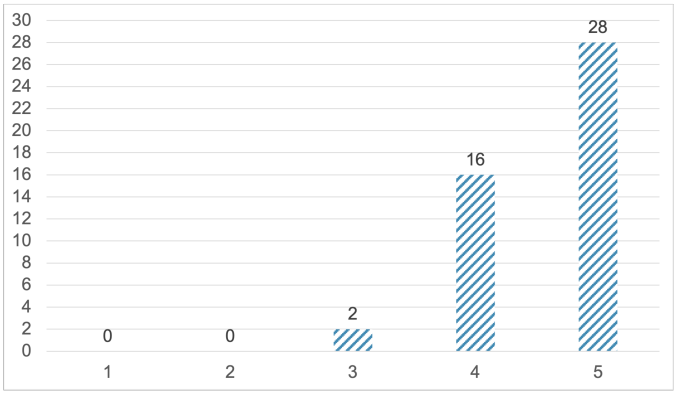


Fig. 14. Assessment of the importance of detecting even edited images, from 1 (*very little*) to 5 (*very much*)

in their life, and 35% of them have done sexting with 4 or more people during their life.

We started by asking to express an evaluation of safeness of the most popular messaging applications. In Figure 12 we report the answers to the question "*How confident would you feel in terms of feeling protected from the abuse of self-generated sexual content?*" using Badoo, Instagram, Snapchat, Telegram, Tinder, Tumblr or Whatsapp. As it is clear from the outcome, participants do not trust these applications, even though there is some heterogeneity in the evaluation. Furthermore, sometimes the perceived safeness of the system is not coherent with the actual features provided by the considered platform. For instance, Tinder has a very low rating despite it does not permit sending media at all; so it could be considered, by design, the safest one.

In Figure 13, we reported the answers to the question "*How much do you agree with the following statement: Any messaging application should implement the following forwarding control policy*". We did not ask to participants to compare the two policies but only to express their agreement on the usefulness of each single policy in comparison with nothing at all The responses show that both the policy which blocks the forwarding and the forward with notification are claimed to be useful features, even though the former received 33% more selections of the option *5 (very much)* and therefore is considered more appropriate. This is expected with users exploiting the application for safe sexting as a well designed and performing blocking system (even in combination with a notification) is certainly safer than one which permits to forward images in any case.

Furthermore, we asked to the participants to assess the importance of detecting edited copies of a private image ("*How important is to detect not only the original media but also copies edited to modify them?*") . Figure 14 shows the answer to this question: about 60% of participants have selected option *5 (very much)*, and options *1* and *2* have not been selected by anyone.

8 Conclusion

Sexting has gained popularity amongst teenagers and young adults; yet, it can have serious consequences, such as non-consensual pornography through the leak of private and sensitive media without the owner's consent [13], [14]. Furthermore, commonly used messaging applications do not limit such a drawback since they permit sending any content to anyone. In essence, they are not safe enough for sexting [22].

In this paper, we have proposed a proof of concept of a messaging system that aims at increase the safety of users engaging in sexting thanks to an image forwarding control feature. We discussed challenges, possible solutions and limits, thus defining a research agenda in this field. We have also demonstrated that social media platforms may be considered co-responsible for issues related to sexting abuse since they could actually adopt possible technological countermeasures to avoid them.

The purpose of our system is indeed to prevent the uncontrolled spreading of personal self-generated nude or semi-nude pictures without the owner's consent, reducing the well-known problems to which their dissemination can lead. In this context, we have designed a forwarding control algorithm and tested each of its parts, including its time complexity. We have also trained a neural network to compute a perceptual hashing function for images, evaluating how its performances influence effectiveness and user experience. Furthermore, to improve performance and interaction with our platform, we have discussed which images our algorithm has to consider relevant (i.e., which are the photos our users want to retain control of?) and how automatically recognise them. We have then presented some possible policies (i.e. behaviours) to use when the algorithm detects suspicious forwardings.

Acknowledging the importance of the topic, we have also discussed the problem of child sexual material abuse (CSMA) and minors. In particular, we have described how our platform can be integrated with Google's Content Safety API and NCMEC's services to protect children, showing our commitment to guaranteeing people a safer experience and in creating a safer online environment.

Future Research Directions. This work also aims at opening new research directions, showing that further work is needed in this context on different problems, requiring heterogeneous expertise. For instance, implications on the security and privacy of our system need further investigation, even considering the compliance to European regulations and United States law (e.g., GDPR, DMCA). The fingerprinting function deserves a more extensive analysis,

ranging from the image manipulations and their impact in a real scenario to the improvement of its performance (e.g., reduction of false positives and false negatives). We must note here that we want to consider image transformations easily accessible by users from a mobile device. Yet, the algorithms for a broad part of the possible modifications are proprietary, or a commonly accepted definition could not exist. For instance, this is the case of brightness, which could have a relevant impact on the performance of the hashing function in a real scenario and deserves further investigation in the future. In addition, an exploration of perceptual hashing functions for other kinds of media would make *SafeSext* more comprehensive. To detect whether an image is relevant for the system or not, Google Cloud Vision API is used. Other APIs could be considered, even solutions that work locally or without employing external services, thus improving the privacy level of the system. Moreover, the management of screenshot attempts and screen recordings needs further research, even considering the differences between devices and operating systems. Indeed, they have a disruptive effect on our system. Yet, only the Android OS allows developers to disable the possibility of taking screenshots. On the other hand, iOS notifies the applications when the user takes one (whereas, in Android, there are only some not-official solutions). The effectiveness of our system needs also to be further investigated from a human-centred perspective. For instance, understanding the motivation behind the numeric evaluations of the forwarding policies provided by participants to our survey would be interesting. Finally, involving teenagers and experts in other fields (e.g., sexual health experts, psychologists, etc.) during the design of a messaging system would be particularly useful in creating an application ready to be actually deployed.

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