

Toward CanvasChain: A Block Chain and Craquelure Hash Based System For Authenticating and Tracking Fine Art Paintings

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Abstract

Determining the authenticity of a painting is not an easy task. First, distinguishing fake paintings from originals is challenging, and often even art experts cannot reliably identify forgeries. Counterfeiters can also create spurious documentation to support the “authenticity” of fake paintings. In this work, we present work toward CanvasChain, a system for authenticating/tracking paintings that uses a blockchain in combination with a robust hash of the crack patterns (craquelure) on the surface of paintings. The robust hash is used as a painting’s fingerprint, which is used in a blockchain to validate and authenticate the painting. We present an initial realization of CanvasChain using a robust hash based on the BRISK feature descriptor and the neo blockchain, which supports smart contracts for basic required transactions. We present results from tests conducted on the proposed system to assess both the robust hash and the blockchain. Cost estimates obtained from the prototype realization indicate that the system is cost effective: e.g. it costs approximately US \$1.85 to register a painting and benefit from the blockchain. As future work, we identify additional components required to make CanvasChain a full-fledged solution.

Introduction

It is understandable that someone without experience in art can end up buying a fake artwork. However, even in places like museums, forged paintings have been found. For example, in the Musée Terrus (Elne, France), there were 142 artworks being displayed from which 82 were forgeries (with an estimated economic damage of US \$190,000) [1]. An exhibition, in the Palazzo Ducale (Genoa, Italy), was also showcasing fake paintings, where it was determined that among 21 paintings only one was authentic [2]. The artwork was declared as original because it had provenance; that is, documents showing the painting’s history of transactions.

The presence/absence of provenance can alter drastically the value of an artwork. In fact, there are services available dedicated to authenticate pieces of art. For instance, the International Foundation for Art Research offers an authentication research service for US \$3000 (basic fee) [3]. Nonetheless, counterfeiters can also create artificial provenance. For example, a criminal was caught selling false paintings that had spurious documentation, which made the paintings appear “authentic” [4]. Thus, authenticating an artwork can be challenging.

Alternatives to traditional artwork authentication and provenance management have been proposed. In particular, ArtChain [5] uses the Bitcoin blockchain to provide provenance for the chain-of-ownership. The approach, however, has the limitation that there is no authentication of the artwork itself. The Blockchain Art Col-

lective (BAC) uses a physical certificate of authenticity (COA) [6], which can be attached to an artwork, and the provenance management is handled by a permissioned private blockchain [7–9]. Users can interact with a COA to register or verify the originality of an artwork. However, BAC authenticates the COAs and not the artworks themselves. On the other hand, the work in [10], presented an image processing based method to authenticate paintings via craquelure pattern matching. A craquelure pattern is the crack structure formed in the surface of materials and the term usually refers to the fine cracks on the surface of a painting. The approach was shown to be robust for authentication but it does not offer any provenance management.

To accomplish the objective of providing a secure and verifiable record of the transactions dealing with the sale/transfer of paintings, we introduce CanvasChain. CanvasChain combines a robust craquelure hash for authentication of the actual painting with a blockchain protocol for managing provenance. CanvasChain takes advantages of the discrimination capability of craquelure patterns to link a user with the actual physical painting in a blockchain. Additionally, by using a blockchain smart contract, CanvasChain allows the execution of various transactions for a painting, which get recorded in a secure and verifiable manner. A prototype is developed using the neo blockchain [11] where smart contract functions provide the ability to register, query, transfer ownership, and/or remove a painting in the blockchain. We estimated CanvasChain costs of operation by testing the CanvasChain smart contract in a private blockchain setting and found that the registration fee is around US \$1.85, which should allow users to register multiple paintings (over a wide range of price points) in CanvasChain.

The structure of the rest of the paper is as follows. In the following section, we present CanvasChain and describe its components, including the proposed hash, the blockchain protocol and details of the prototype implementation. We discuss desired features for a more full-featured version of CanvasChain in the following section before concluding the paper in the final section.

CanvasChain

We present in Fig. 1 the elements that constitute CanvasChain. That is, the integration of craquelure based physical validation with a blockchain protocol for transactions, which also handles the provenance management. We describe both components in the following subsections.

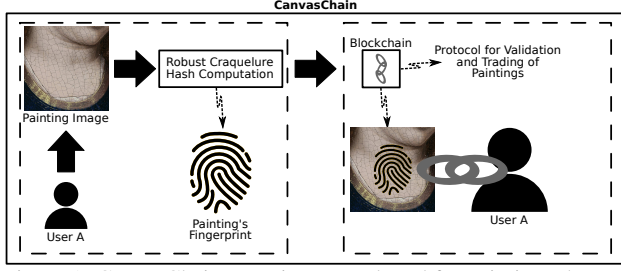


Figure 1: CanvasChain overview. Developed for paintings that exhibit craquelure patterns, CanvasChain has two main components. The computation of a robust hash for paintings and a blockchain transactions protocol. The hash acts as a fingerprint that connects the physical painting to the digital world of blockchain. The protocol offers users the ability to validate and trade paintings while benefit from the security and provenance management of blockchain.

Proposed Hash & Painting Authentication

There are various image hashing methods that work well for general purpose applications [12–14]. Nonetheless, these robust perceptual hashes have trouble distinguishing between similar paintings. Thus, we propose a hash that particularly exploits the discrimination ability of the craquelure patterns [10, 15].

We first extract the craquelure pattern from the image of a painting via morphological operations. Specifically, we use the approach from [16] (originally used for retinal vessel extraction). We proceed to normalize the scale of the extracted craquelure image, which is common in other image hashing methods to gain robustness against changes in scale, while preserving the original aspect ratio. To find the unique features in the craquelure pattern, we use a feature detector. Once the features have been found, we apply a descriptor to represent each feature of the craquelure pattern in a compact format. In the present work, we use the binary robust invariant scalable keypoints (BRISK) detector/descriptor [17] because of its performance and low computational complexity [18]. Additionally, BRISK determines how reliable the feature points are and assigns a robust value to each descriptor.

The proposed robust hash combines the BRISK descriptors (based on their robustness) into a single integer vector. Specifically, we compute the center of mass of the descriptors, i.e.

$$\mathbf{d}_{\text{COM}} = \left(\left[\frac{\sum_i^I m_i x_1}{\sum_i^I m_i} \right], \left[\frac{\sum_i^I m_i x_2}{\sum_i^I m_i} \right], \dots, \left[\frac{\sum_i^I m_i x_j}{\sum_i^I m_i} \right], \dots, \left[\frac{\sum_i^I m_i x_J}{\sum_i^I m_i} \right] \right), \quad 1 \leq i \leq I, 1 \leq j \leq J \quad (1)$$

where I is the number of descriptors obtained by BRISK from the extracted craquelure image; J is the number of elements (length) of each descriptor; x_j is the j^{th} element of a descriptor; $[\cdot]$ is the rounding operation and m_i is the mass of the i^{th} descriptor. In our context, the mass is the robustness value determined by BRISK. Therefore, the proposed hash is a vector of integers with length J in which each element have a value in the range $[0, 255]$. The hash's robustness relies on the high number of unique features found in the craquelure. An overview for the proposed hash computation is shown in Fig. 2.

We authenticate a painting based on hash similarity. The

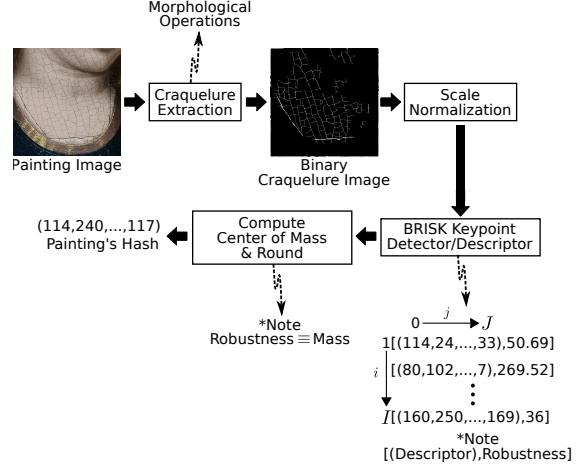


Figure 2: Proposed robust hash computation overview. Given an image of a painting, the first step is to extract its craquelure pattern via morphological operations and normalize its scale. BRISK is then used on the craquelure image to locate features and compute their descriptors. Lastly, the proposed robust hash is obtained by calculating the center of mass of the descriptors and rounding the result.

process is illustrated in Fig. 3. Specifically, the Manhattan distance d between a pair of hashes is computed and compared against a decision threshold τ to decide whether or not to declare a match. This distance was chosen based on the type of the elements in the hash (8 bit integers) and the computation capability of the blockchain (see details in the next section).

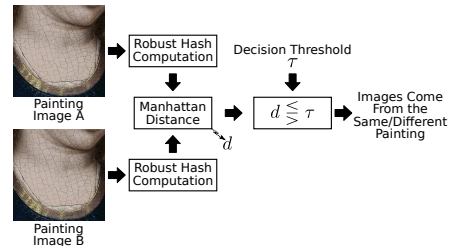


Figure 3: Painting authentication. The authentication is based on similarity between hashes. In specific, the Manhattan distance d is computed and compared against a decision threshold τ to declare if the images of two paintings are a match or a non-match.

Blockchain Transactions Protocol

In this first iteration of CanvasChain, the registration, status query, ownership transfer and deletion of a painting from the blockchain are part of the CanvasChain protocol of transactions. All paintings' transactions are stored and protected in the blockchain. A smart contract, which we also call CanvasChain, manages and enforces the protocol of transactions. In the following subsections we present the details for each operation.

Registration

The registration transaction allows a user to associate a physical painting to the blockchain and become its owner. The registration requires the user to take a photo of a painting (for the robust hash computation) and provide the user's address. The latter

identifies a user in the blockchain and is created/managed by a software, which is known as a wallet. Additionally, the user can provide additional information of the painting during the registration, e.g. name, author, etc. The communication between users and the blockchain is handled by the CanvasChain client. The client computes the robust craquelure hash and combines it with the painting information to create a data array for the blockchain. Once the data array is received by the CanvasChain smart contract, the transaction is determined and the user identity is verified (to block unauthorized transactions if needed). Then, a search is made in the blockchain to check that the painting is not already registered. A successful registration transaction stores the painting information, including the robust hash, in the blockchain and links it to the user who performed the registration. The registration process is shown in Fig. 4, which includes an overview of the CanvasChain client/smart contract.

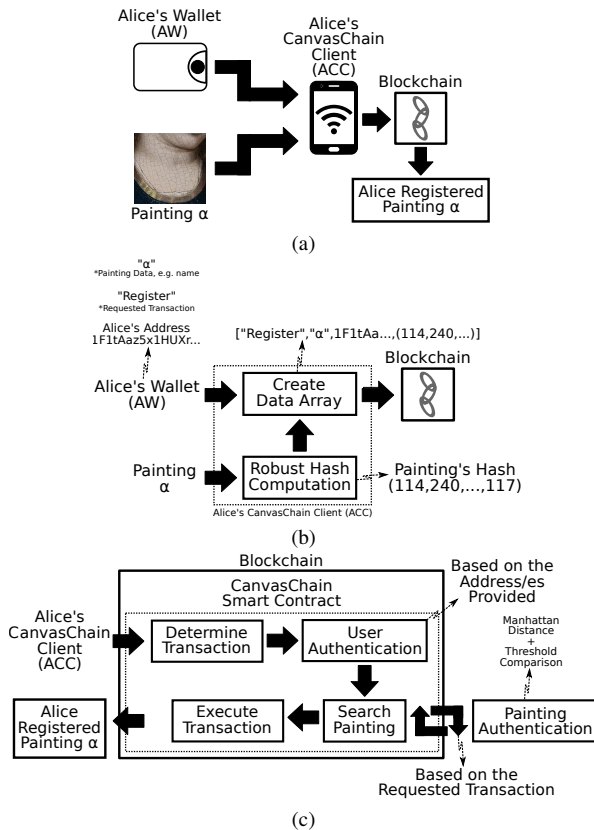


Figure 4: Registration transaction example. (a) Alice registers painting α by using her CanvasChain client and wallet (application that creates/manages blockchain ids); (b) the client allows Alice to communicate with the blockchain, computes the robust craquelure hash and prepares a data array for the blockchain, which indicates the transaction and painting information (e.g. name); (c) the data array is received by the CanvasChain smart contract, which is deployed in the blockchain. Once the transaction is initiated, then the user identity is verified (to prevent unauthorized operations). After checking that the painting is not already registered, Alice is registered as the owner in CanvasChain. *Note: painting authentication is performed instead of a search for the other transactions of the protocol.

Status Query

The status query performs painting authentication and reports the painting's current status in the blockchain (registered/unregistered). Users only need to compute the robust hash of a painting and provide the search parameter (e.g., name) to perform this transaction.

Ownership Transfer

This transaction changes the ownership of a painting from one user to another, enables the sale of paintings. Fig. 5 illustrates the transaction between two parties (buyer/seller) that get together for the sale. The buyer uses the status query to authenticate the painting, check its provenance and verifies that the seller actually owns the painting. Then, the transfer of the painting is initiated, subject to a payment and only proceeds if the seller takes the payment, in the same blockchain transaction. Finally, after the payment and ownership transfer transactions have been posted in the blockchain, the seller gives the painting to the buyer.

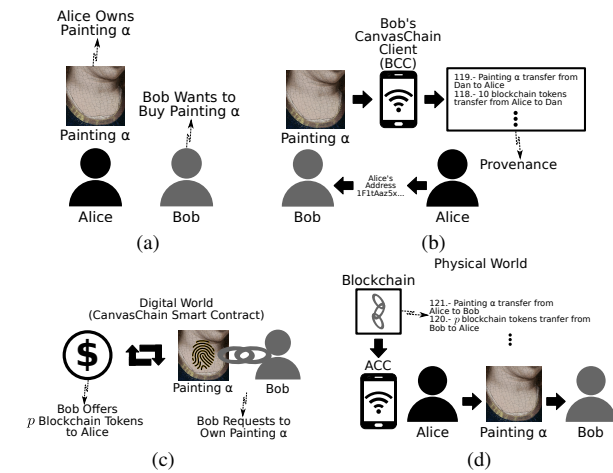


Figure 5: Ownership transfer example (sale). (a) The buyer (Bob) and seller (Alice), who brings painting α to be traded, get together to start the transaction; (b) Bob verifies the identity of Alice as the owner of painting α and gets access to the provenance of the painting; (c) the ownership transfer is conditioned on Alice accepting a payment from Bob, which is managed/enforced by the CanvasChain smart contract; (d) Once the payment and ownership transfer transactions have been processed and recorded in the blockchain, then Alice gives painting α to Bob.

Update/Delete

An update/delete transaction is implemented to allow CanvasChain to handle variations in the craquelure pattern. The crack patterns change over time depending on different conditions (weather, age, etc.). Thus, it is possible for a painting's hash to change and be significantly different than when it was registered. The update/delete transaction allows users delete an outdated hash and register the painting with an updated hash.

Experimental Settings & Results

We performed a test to assess the authentication performance of the proposed hash by capturing 20 images of 8 different paintings from a museum that were still on display (i.e. in an uncon-

trolled environment). The images have a resolution of 4656×3492 pixels and were encoded in JPEG format at a quality factor of 95. Following the approach used for assessing performance for human fingerprint verification [19], the authentication is assessed by plotting the False Acceptance Rate (FAR) and False Rejection Rate (FRR) as the decision threshold τ is varied. In our context, the FAR indicates the probability of a false acceptance, which happens when different paintings' images produce hashes that are declared a match. The FRR is the probability of a false rejection, i.e. images from the same painting generate hashes that are declared a non-match. The tests results, shown in Fig. 6, demonstrate that the proposed hash can achieve an $\text{FAR} = 0$ with $\text{FRR} = 0.36$ at a threshold $\tau = 155$.

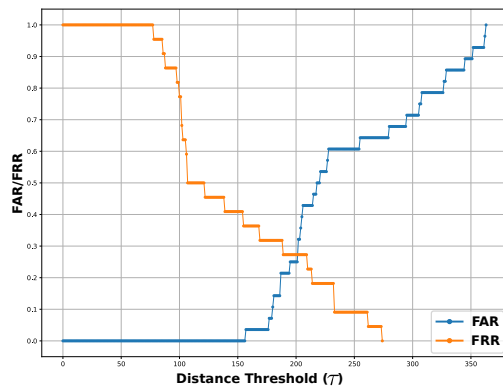


Figure 6: Proposed hash performance. The plot shows the trade-off between the false acceptance rate (FAR) and the false rejection rate (FRR) as a function of the decision threshold τ .

We chose the neo blockchain to implement and test the CanvasChain smart contract [11]. The transactions and processes of CanvasChain are defined as functions in the smart contract with the exception of the payment logic, which is not yet implemented. The user authentication function is already available for neo smart contracts. The painting authentication consists in computing the Manhattan distance and comparing the results with the decision threshold τ (both performed in the neo blockchain). We use the Manhattan distance because the square root operation is not supported in neo smart contracts. To estimate costs of operation, we deployed the CanvasChain smart contract in the *neo-privatenet* [20] and tested it by using *neo-python* [21]. The former is a private network of the neo blockchain and the latter is composed of a software developer kit (SDK) for smart contracts; a node that communicates with the private network of the neo blockchain and a basic wallet application. We found that the costs of the registration, status query, ownership transfer and delete are 1.62, 1.864, 2.939 and 1.991 GAS, respectively. GAS is the neo's blockchain token used to pay fees associated with the use of the blockchain resources (e.g. smart contract operations) [22]. The price of GAS is not fixed, e.g. 1 GAS costs US \$1.137 according to Cryptocompare [23]. Thus, it costs about US \$1.85 to register a painting in CanvasChain and benefit from blockchain's security and provenance management.

Discussion

The work we present in this paper represents a proof-of-concept preliminary demonstration of the CanvasChain capabilities.

In our limited tests, the rather simple hash that we propose can provide authentication. While the FRR is high, that may not pose a particularly big concern because the actual owners are likely to be cooperative rather than antagonistic and can be both guided in the craquelure capture process by the CanvasChain client application and can perform repeat attempts for authentication, for example, assuming independent tries, the FRR at the third attempt is estimated to be ≈ 0.047 . In future work, we aim to improve the hash and to also add new elements to the blockchain smart contract for making CanvasChain a more complete solution. For instance, lending a painting is common specially among museums and at the moment it is not supported because the ownership transfer is absolute. Additionally, the current option to update a painting's hash is not adequate because the provenance for the paintings gets divided (each update requires a new registration) and thus the next version of CanvasChain requires a better update functionality. The implementation of the payment logic is crucial to make a CanvasChain viable authentication and provenance management solution. Finally, while our current solution aims to integrate both the authentication and provenance management within the blockchain itself, it would also be of interest to explore alternative architectures where the authentication is performed in a separate secure environment, and therefore less subject to the constraints of the limited number of operations available in a typical blockchain.

Conclusions

This paper introduced a preliminary version of CanvasChain that combines robust-hash based physical authentication and blockchain provenance management. The former is achieved by exploiting the discrimination power of craquelure pattern (pattern of cracks on the surface of a painting) with a BRISK based robust hash while the latter is accomplished by a blockchain transactions protocol, which is enforced and manage with a smart contract. Using our rather simple proposed hash, we found promising results for authentication; with a suitable decision threshold the hash achieved zero false acceptance probability with a 36% false rejection probability. We also presented a CanvasChain's proof of concept in a private network of the neo blockchain. The estimated cost of registering a painting within CanvasChain is a fairly modest US \$1.85, significantly below prices for current art appreciation services (even if additional/guided captures are required). The work shows how blockchain solutions can substantially lower the cost while simultaneously improving the traceability and validation of the provenance of paintings with craquelure. Additional enhancements of the proposed hash, the blockchain transactions protocol and smart contract functionality (e.g. payment system) are topics for further investigation and development.

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References

- [1] E. Zachos, "How More Than Half the Art in This French Museum Was Forged," May 2018, Accessed on: Dec. 12, 2018. [Online].

- Available: <https://news.nationalgeographic.com/2018/05/fake-art-france-culture-spd/>
- [2] N. Squires, "Modigliani paintings once thought to be worth tens of millions now denounced as fakes," Jan. 2018, Accessed on: Dec. 12, 2018. [Online]. Available: <https://www.telegraph.co.uk/news/2018/01/10/modigliani-paintings-thought-worth-tens-millions-denounced-fakes/>
 - [3] "Authentication research service," Accessed on: Jan. 26, 2019. [Online]. Available: <https://www.ifar.org/authentication.php>
 - [4] "Forging papers to sell fake art many victims may unknowingly own phony works," Apr. 2017, Accessed on: Dec. 12, 2018. [Online]. Available: <https://www.fbi.gov/news/stories/forging-papers-to-sell-fake-art>
 - [5] "ArtChain: How it works," Accessed on: Feb. 6, 2019. [Online]. Available: <https://artchain.info/content/>
 - [6] Blockchain Art Collective, "Creating the new art economy," Accessed on: Apr. 8, 2019. [Online]. Available: <https://blockchainartcollective.com/>
 - [7] W. Cai, Z. Wang, J. B. Ernst, Z. Hong, C. Feng, and V. C. M. Leung, "Decentralized applications: The blockchain-empowered software system," *IEEE Access*, vol. 6, pp. 53 019–53 033, 2018.
 - [8] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," *Cryptography Mailing list* at <https://metzdowd.com>, Mar. 2009.
 - [9] N. Szabo, "Formalizing and securing relationships on public networks," *First Monday*, vol. 2, no. 9, 1997. [Online]. Available: <https://journals.uic.edu/ojs/index.php/fm/article/view/548/469>
 - [10] J. R. B. Taylor, A. Baradarani, and R. G. Maev, "Art Forgery Detection via Craquelure Pattern Matching," in *Computational Forensics*, U. Garain and F. Shafait, Eds. Cham: Springer International Publishing, 2015, pp. 176–187.
 - [11] "neo - an open network for smart economy," Accessed on: Jan. 30, 2019. [Online]. Available: <https://neo.org/>
 - [12] J. Fridrich and M. Goljan, "Robust hash functions for digital watermarking," in *Proc. IEEE International Conference on Information Technology: Coding and Computing (ITCC)*, 27-29 March 2000, pp. 173–178.
 - [13] C. D. Roover, C. D. Vleeschouwer, F. Lefebvre, and B. Macq, "Robust video hashing based on radial projections of key frames," *IEEE Trans. Signal Proc.*, vol. 53, no. 10, pp. 4020–4037, Oct 2005.
 - [14] Z. Tang, X. Zhang, X. Li, and S. Zhang, "Robust image hashing with ring partition and invariant vector distance," *IEEE Trans. Info. Forensics and Security*, vol. 11, no. 1, pp. 200–214, Jan 2016.
 - [15] S. Bucklow, "The description and classification of craquelure," *Studies in Conservation*, vol. 44, no. 4, pp. 233–244, 1999. [Online]. Available: <http://www.jstor.org/stable/1506653>
 - [16] L. Ding, A. Kuriyan, R. Ramchandran, and G. Sharma, "Multi-scale morphological analysis for retinal vessel detection in wide-field fluorescein angiography," in *Proc. IEEE Western NY Image and Signal Proc. Wksp. (WNYISPW)*, Rochester, NY, Nov. 2017.
 - [17] S. Leutenegger, M. Chli, and R. Y. Siegwart, "BRISK: Binary robust invariant scalable keypoints," in *IEEE Intl. Conf. Comp. Vision.*, Nov. 2011, pp. 2548–2555.
 - [18] H. Chatoux, F. Lecellier, and C. Fernandez-Maloigne, "Comparative study of descriptors with dense key points," in *IEEE Intl. Conf. on Pattern Recog.*, Dec 2016, pp. 1988–1993.
 - [19] "Benchmark area: Fingerprint verification," Accessed on: Jan. 23, 2019. [Online]. Available: <https://biolab.csr.unibo.it/FVConGoing/UI/Form/BenchmarkAreas/BenchmarkAreaFV.aspx>
 - [20] City of Zion Developer Group, "Private network of the NEO blockchain," Accessed on: Jan. 20, 2019. [Online]. Available: <https://hub.docker.com/r/cityofzion/neo-privatenet/>
 - [21] City of Zion Developer Group, "Python node and SDK for the NEO blockchain," Accessed on: Jan. 20, 2019. [Online]. Available: <https://github.com/CityOfZion/neo-python>
 - [22] "NEO documentation: Transaction fees," Accessed on: Dec. 9, 2019. [Online]. Available: https://docs.neo.org/tutorial/en-us/3-transactions/4-NEO_transaction_fees.html
 - [23] "Cryptocompare neo GAS price chart (GAS/USD)," Accessed on: Dec. 8, 2019. [Online]. Available: <https://www.cryptocompare.com/coins/gas/overview/USD>

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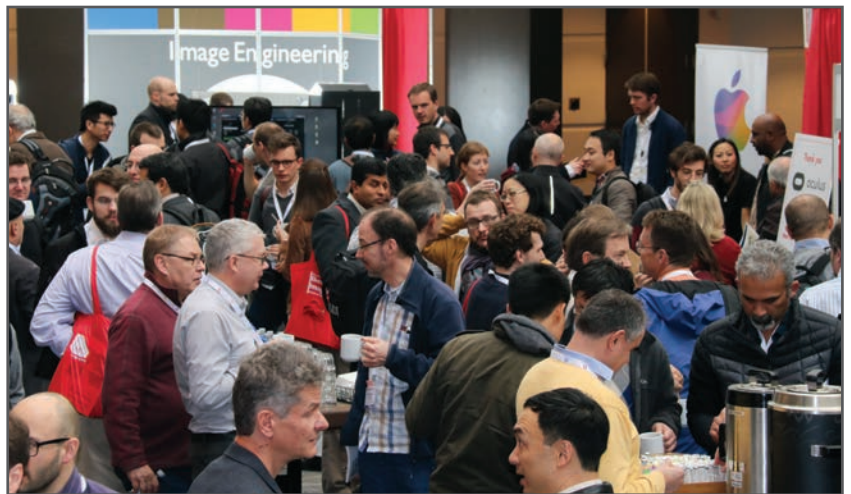
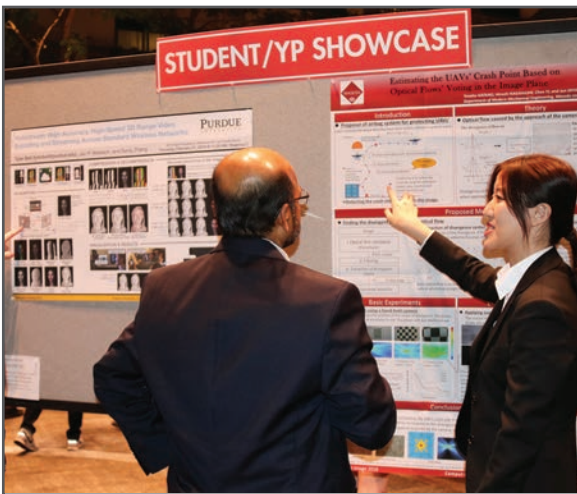
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