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In this issue



# Technology Developed in GICE

## Infrastructure-less Intelligent RF Spatial Positioning Service at Ming-Da Hall

*from Electromagnetics Group*

**INTRODUCTION**

Previous indoor localization approaches usually rely on extensively deploying extra positioning infrastructure such as Bluetooth beacons or proprietary 'anchor' stations to function accurately. Such infrastructure-based approaches tend to induce extra provisioning and maintenance cost, and are naturally infrastructure disturbance-prone. Worse, positioning-only infrastructure always faces the risk of obsolescence due to the contending from evolving, wireless communication standards in both the frequency spectrum and the business aspects. Some alternatives resort to scene analysis including fingerprinting on received signal strength (RSS) of e.g. Wi-Fi signals to avoid extra infrastructure deployment overheads. However, most previous fingerprint-based approaches only utilizing a small fraction of the available signals, resulting in unsatisfactory positioning accuracy.

**INFRASTRUCTURE-LESS POSITIONING SYSTEM**

We propose a novel infrastructure-less, AIoT (AI+IoT) based spatial positioning solution incorporating massive data analysis of available RF signals to overcome the aforementioned obstacles. Unlike previous approaches, our solution leverages existing massive wireless communication infrastructure such as IEEE 802-11 (Wi-Fi) and cellular base stations especially proliferative in the metropolitan areas, by harvesting the abundant information contained in the existing RF signals for intelligent processing. Note that, our solution can be augmented to accommodate futuristic wireless

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# GICE Honors

**Prof. Hung-Yu Wei**

「108 MoST Outstanding Research Award」

**Prof. Shih-Yuan Chen**

108 National Taiwan University Excellent Mentor Award

# Message from the Director

**Hsuan-Jung Su**

*Professor & GICE Director*

In the midst of the global COVID-19 pandemic, we hope that everyone stays safe and healthy. Congratulations to Prof. Hung-Yu Wei for winning the 2020 MOST Outstanding Research Award! What a great achievement! We would also like to congratulate Prof. Shih-Yuan Chen for receiving the National Taiwan University Excellent Mentor Award. It takes a great deal of devotion and patience for good mentoring. We are very proud to have these excellent and caring faculty members with NTU GICE!

In this issue, we invite Prof. Ruey-Beei Wu to share his research progress on Infrastructure-less Intelligent RF Spatial Positioning Service, and Prof. Chun-Lin Liu to present his results on Estimation of the Normalized Scatter Matrix from One-Bit Complex Elliptically Symmetric Distributions. This issue also includes trip notes of NTU GICE and GIEE members' visit to Tampere University in Finland in October 2019. The NTU EECS College has established a Double Master's Degree program with Tampere University. In the Corner of Student News, we have another student of NTU GICE, Yi-Chen Chen, sharing his impression of Facebook in Seattle, where he did his internship. Please grab a coffee, sit back and enjoy reading this issue.

# Technology *(Continued from page 1)*

standards such as 802.11ax (Wi-Fi 6) and/or millimeter wave based 5G networks, to name a few.

Specifically, various characteristics of each perceived RF signal source at a location-of-interest, including (but not limited to) the received signal strength (RSS) and round-trip delay time (RTT) etc., are digitized to extract its information entropy as the basis of further processing. The digitized readings are collectively treated as the fingerprint at that location-of-interest. The local information gains of all perceivable RF signals, as well as the collective global information gain of the fingerprint at that location-of-interest are thus calculated to filter and select the most influential signal sources. The filtered fingerprints will then be fed into a deep-learning based ensemble framework of multiple positioning algorithm modules to match and obtain the most likely spatial position. The spatial models in the positioning algorithm ensembles are trained by a series of spatially calibrated reference fingerprints in an offline manner.

To fulfill the demand of such a computationally intensive positioning task, elastic cloud computing services are employed instead of burdening the limited resources on the devices under targeting (DUTs), effectively enlarged the application scope of our solution as smaller and smaller, inexpensive IoT devices can be used as DUTs. Fig. 1 shows the scalable and reconfigurable backend design for the indoor positioning system (IPS). It is software-container based and thus can meet with the accumulation of the fingerprint big data from abundant Wi-Fi APs at multiple receiving points. The design goal is to accommodate the heterogeneous signal sources, co-existing positioning algorithm, various site-survey and modeling, and different user interface for the data visualization so as to ease the developers on the positioning algorithm development, combination, and optimization.

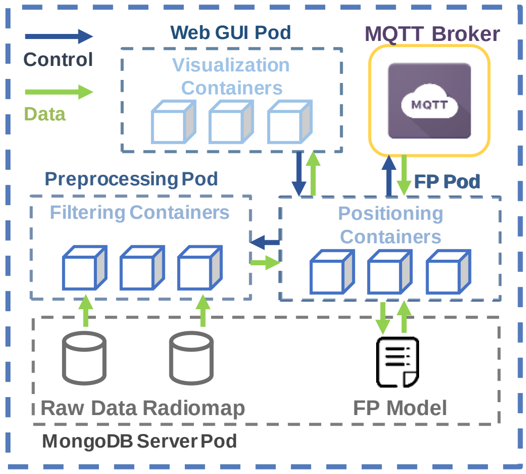


*Fig. 1 A scalable computing backend design for IPS.*

Our prototype, built upon the scalable Google Kubernetes *(k8s)* containerization framework, has been operational on a 3-node, 10Gb Ethernet-connected private Linux cluster with dual 64-bit Intel Xeon processors with totally 8 physical cores, 64GB RAM, 6TB mass storage space, and a single NVIDIA Quadro P1000 GPU on each server node.

To validate our proposed positioning solution in the real world, we designed and implemented a prototype IPS equipped with the ensemble of both conventional positioning algorithms including Weighted K-nearest neighbors (WKNN) and supporting vector machines (SVM), as well as various deep neural networks (DNN). We conducted a series of experiments on our prototype using Ming-Da Building at National Taiwan University, a 7-story, 12,500m2 RC concrete educational building as our test site, with no less than 500 residential W-Fi perceivable signal sources. Fig. 2 shows an example of the deployment in the fifth floor of the

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building. In addition to the hundreds of residential Wi-Fi sources, 32 UWB transponders and 13 Wi-Fi APs are intentionally deployed in the whole building (blue and yellow triangles, respectively) for both the calibration and the performance evaluation of different positioning algorithms.

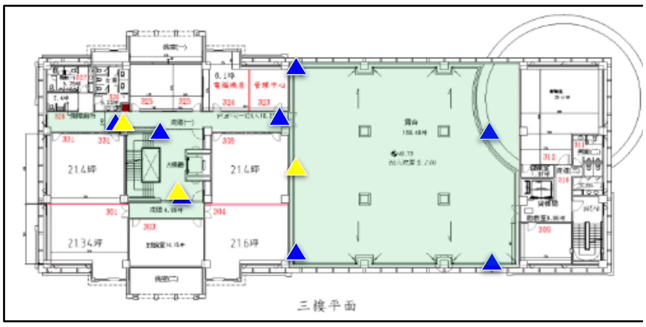


*Fig. 2 A test IPS deployment.*

The prototype's complement of ROBOTIS TurtleBot3-based robots with enhanced Lidar and attended SLAM capability are responsible to gather authenticate reference fingerprints for training and updating the spatial models of the algorithm ensembles in the prototype as shown in Fig. 3(a). In the site map construction, the SLAM data is combined with the BIM floor map and calibrated using dot-matrix software GIMP to obtain a global static map for Odometry-Lidar AMCL real-time positioning as shown in Fig. 3(b). The extracted data is then uploaded to the backend and stored in a MongoDB Server. To facilitate the data analysis, a visualizer is established to demonstrate the heatmap of the number of Wi-Fi stations, RSS strength, occurrence frequencies, receiving points, and information entropy.

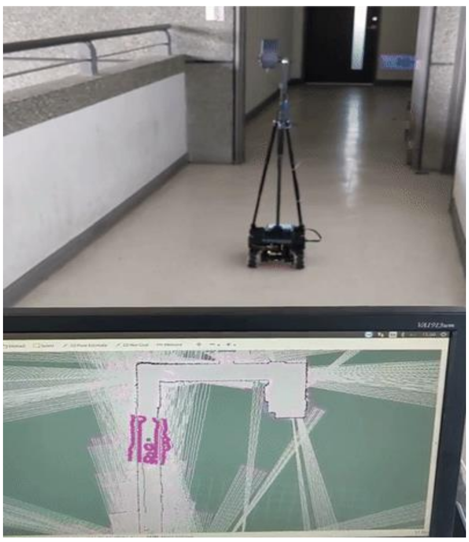

*Fig. 3 (a) Data extraction by Robot and (b) SLAM.*

The extracted Wi-Fi signal database can be used in off-line training for positioning by various machine learning algorithm. Fig. 4 shows the simultaneously positioning by DNN for a mixture of multiple Raspberry Pis and Google Pixel 4 phones in the test site of Fig. 2. Preliminary results showed that, our prototype can achieve within 2.1m (7 ft.) accuracy within 90% cumulative distribution by solely utilizing 802.11ac (Wi-Fi 5) RSS fingerprints. We also exploited the indoor positioning by incorporating the Wi-Fi RTT information (802.11mc), and 90% cumulative distribution within 1.2m (4 ft.) accuracy is noticed.

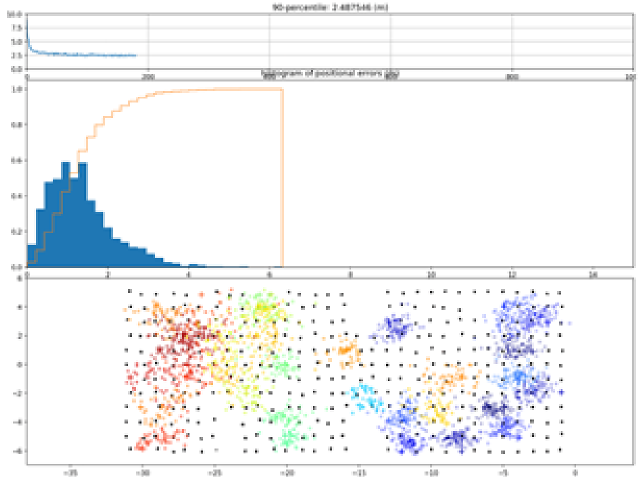

*Fig. 4 Typical positioning performance by DNN.*

The prototype system exploits the positioning through the abundant Wi-Fi signal, without resorting to the setup of additional devices such as iBeacon. It is infrastructure-less and can get rid of the device charging or maintenance. The software setup in a scalable, configurable cloud backend system can extend various further IoT applications in smart medi-care and logistics, to say a few.

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# Technology

## Estimation of the Normalized Scatter Matrix from One-Bit Complex Elliptically Symmetric Distributions*

*from Communication and Signal Processing Group*

### INTRODUCTION

One-bit quantization has recently attracted attention in massive MIMO systems, radar systems, and array processing. From the hardware perspective, one-bit analog-to-digital converters (ADCs) feature low cost, low power consumption, and simple hardware designs, compared to the high-resolution ones. From the one-bit samples, it is possible to estimate parameters of interest such as channel state information or direction of arrivals.

A diagram for one-bit quantization is shown in Figure 1, where sgne represents the entry-wise sign function. It is known that the second-order statistics of the unquantized data and the quantized data are specified by the arcsine law [1] and the Bussgang theorem. These relations assume that the unquantized data is Gaussian distributed. However, the Gaussian assumption might not be valid due to the presence of outliers in the observed data.

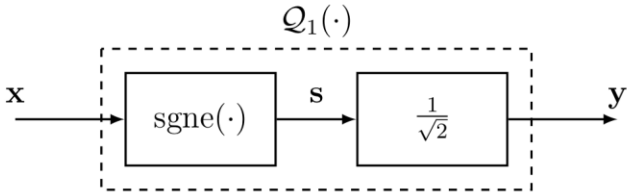


*Figure 1: A system diagram for one-bit quantization*

### The Arcsine Law for CES Distributions

We consider the complex elliptically symmetric (CES) distributions [2], which are widely used for modeling outliers with heavy-tailed distributions. A CES distribution $\mathrm{CE}(\boldsymbol{\mu}, \boldsymbol{\Sigma}, g)$ can be parametrized by the symmetric center $\boldsymbol{\mu}$ (analogous to the mean vector), the scatter matrix $\boldsymbol{\Sigma}$ (analogous to the covariance matrix), and the density generator $g$, which determines the shape of the probability density function. In the literature, CES distributions generalize many distributions such as complex Gaussian distributions, complex t-distributions, complex generalized Gaussian distributions, and so on. Figure 2 illustrates the probability density functions of some CES distributions.

We have shown that the arcsine law remains applicable to CES distributions. More specifically, let $\mathbf{x} \sim \mathrm{CE}(\mathbf{0}, \boldsymbol{\Sigma}_{\mathbf{x}}, g)$ and $\mathbf{y} = Q_1(\mathbf{x})$. The covariance matrix of $\mathbf{y}$ satisfies $\mathbf{R}_{\mathbf{y}} = (2/\pi)\mathrm{sine}^{-1}(\overline{\boldsymbol{\Sigma}}_{\mathbf{x}})$, where $\overline{\boldsymbol{\Sigma}}_{\mathbf{x}}$ is the normalized scatter matrix and sine-1 denotes the entry-wise arcsine function. The details for the arcsine law for CES distributions can be found in [3].

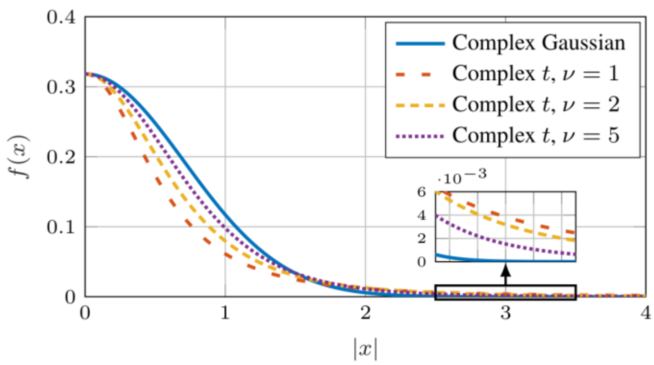


*Figure 2: An illustration of the probability density functions of CES distributions*

### Application in Normalized Scatter Matrix Estimation

The arcsine law for CES distributions provides insights into the estimation of the normalized scatter matrix $\overline{\boldsymbol{\Sigma}}_{\mathbf{x}}$ from CES data $\tilde{\mathbf{x}}(k)$ for $k = 1,2, \dots, K$. The proposed method is called the normalized scatter matrix estimation from CES distributions and the complex one-bit arcsine law (CES-COBASL). In CES-COBASL, we first process the CES samples by one-bit quantizers, and then we estimate the covariance matrix of the one-bit data. The final step is to estimate the normalized scatter matrix by the arcsine law.

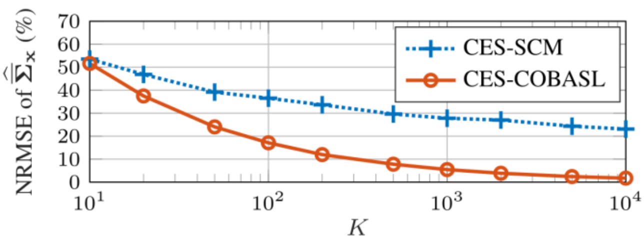


*Figure 3: The estimation performance of the normalized scatter matrix against the number of snapshots K.*

We compare CES-COBASL with CES-SCM. The latter is based on the sample covariance matrix of the CES samples. The normalized root-mean square errors (NRMSEs) of CES-SCM and CES-COBASL are shown in Fig. 3 (See [3] for the simulation parameters). We observe that CES-COBASL tends to be more robust to

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heavy-tailed distributions and outliers than CES-SCM.

**Concluding Remarks**

The arcsine law is applicable to the CES distribution, which is a much broader family than the Gaussian distribution. This property has led to an estimator for the normalized scatter matrix based on one-bit data and CES-COBASL. CES-COBASL not only enjoys low computational complexity (due to one-bit data processing) but also is robust to heavy-tailed CES distributions.

References

[1] J. H. Van Vleck and D. Middleton, "The spectrum of clipped noise," Proc. IEEE, vol. 54, no. 1, pp. 2–19, Jan. 1966.

[2] E. Ollila, D. E. Tyler, V. Koivunen, and H. V. Poor, "Complex elliptically symmetric distributions: Survey, new results and applications," IEEE Trans. Signal Process., vol. 60, no. 11, pp. 5597–5625, Nov. 2012.

[3] C.-L. Liu and P. P. Vaidyanathan, "One-Bit Normalized Scatter Matrix Estimation For Complex Elliptically Symmetric Distributions," ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Barcelona, Spain, 2020, pp. 9130-9134.

* Work published at the IEEE International Conference on Acoustics Speech and Signal Processing (ICASSP 2020) [3].

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# Activity

## GICE Professors Visiting Tampere University

On Oct. 23rd, three GICE professors, including Director Hsuan-Jung Su, Prof. Yu-Chiang Frank Wang, and Prof. Hung-Yi Lee, plus the former director of GIEE Prof. Andy Wu, visited Tampere University at Finland. The purpose of this visit is to promote the Dual Degree Program between the GICE of National Taiwan University and the Faculty of Information Technology and Communication Sciences of Tampere University.

With warm greetings by the International Relation Manager Dr. Ilkka Virtanen, NTU professors arrived at the Tampere University campus at 9am. The visit started from the research workshop, in which faculty members from both universities shared their research focuses and achievements. Known for this research works on deep transfer learning for visual analysis, Prof. Frank Wang went over a number of his recent works on person re-identification and image manipulation using deep learning techniques. On the other hand, Prof. Hung-Yi Lee talked about his works on voice conversion, unsupervised speech recognition, and natural language processing. From the TU side, Prof. Vladimir Katkovnic shared his works on hyperspectral and muli-array image processing. Prof. Vladimir Katkovnic is known for this image denoising algorithm of BM3D, and is very active in the area of image processing. On the other hand, Dr. Okko Räsänen talked about the works done by the TU teams on audio and speech signal processing and analysis.

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# Activity

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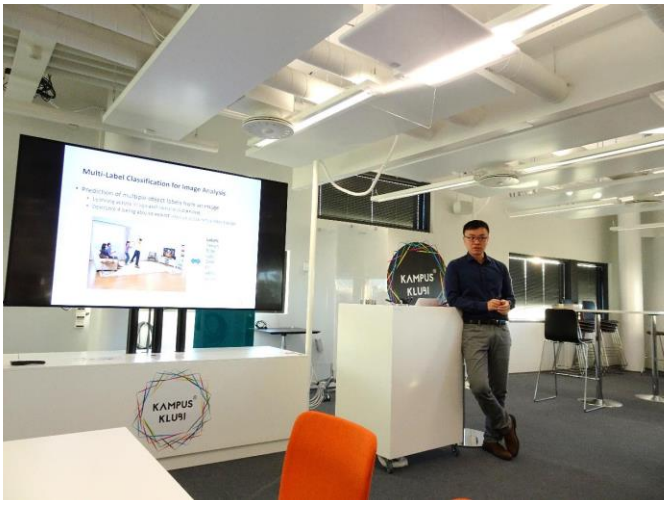
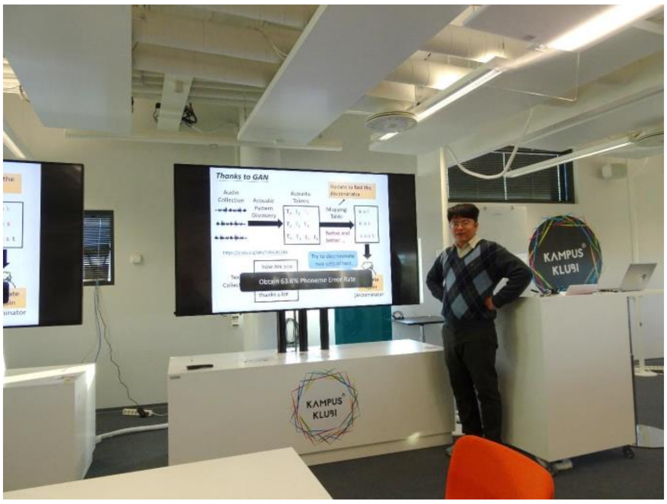
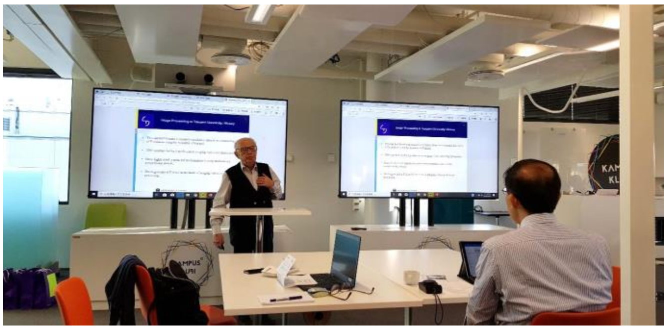


*Prof. Frank Wang talked about his work on deep transfer learning for visual analysis.*

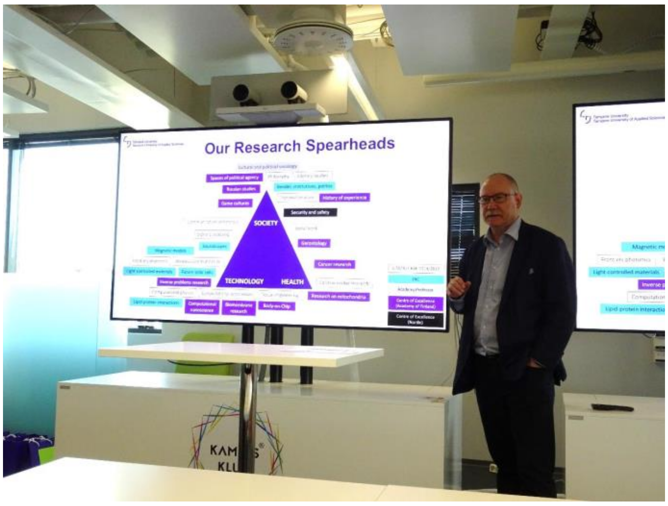



*Prof. Hung-Yi Lee shared this research works on speech processing and voice conversion.*



*Prof. Vladimir Katkovnic talked about his works on hyperspectral image processing.*

Followed by presentation of the research works from both sides, the second part of the workshop continued with the introduction of NTU and TU. Dean Jyrki Vuorinen and Provost Jarmo Takala first talked about the history, mission, and current status of TU. As the Director of GICE at NTU, Prof. Hsuan-Jung Su gave a detailed presentation on GICE, including research focuses and achievements by our faculty members and students. On behalf of GIEE, Prof. Andy Wu also shares the mission and research works of GIEE, along with international recognition and achievements.




*Prof. Jarmo Takala talked about the history and missions of TU.*

*Director Hsuan-Jung Su introduced GICE to TU faculty members and students.*

In the afternoon, Director Hsuan-Jung Su gave a formal presentation on the dual degree program. The attendees were impressed by the friendly yet productive environments of NTU GICE, and showed great interests in this program and collaboration opportunities. After the workshop and the introduction of dual degree program, Dr. Ilkka Virtanen gave NTU professors a campus tour, including the departments/buildings, and particularly Make Lab and Virtualization Lab. All NTU professors

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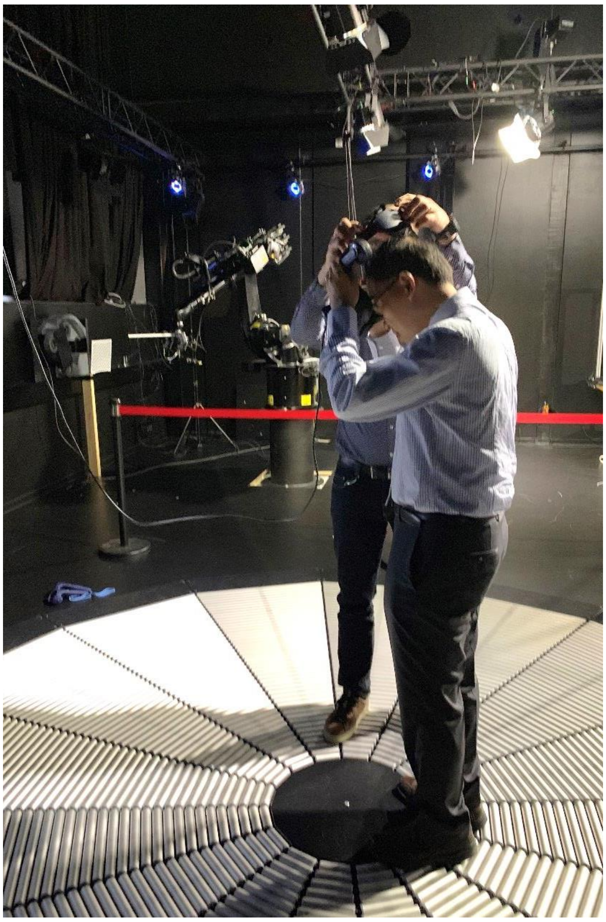
experienced the VR environments, and were amazed by the demos of 3D visualization and robotics. To end the visit, TU faculty members brought NTU professors to the Näsinneula observation tower. While enjoying the magnificent 360 view from the top, all faculty members enjoyed signature Finnish dishes at the Ravintola Näsinneula on the top of the tower, which concluded the visit and set a great start for the dual degree program and research collaboration between both sides.


*Exchange of souvenirs between NTU and TU faculty members.*



Director Hsuan-Jung Su experienced the VR technology at TU.

*Professors Frank Wang, Hung-Yi Lee, Andy Wu, and Hsuan-Jung Su (left to right) at the Tampere University.*

# Corner of student news

## Facebook Internship Experience

Article by CHEN, YI-CHEN

A charming city bathed in the sun was my first impression on Seattle. It is a city with diverse faces, technological, historical, and close to nature as well.

Because many huge tech companies, including Facebook, Google, Amazon, Microsoft and Apple are located in this city, there are many engineers in Seattle coming from different countries in the world. It was my first and a cool experience to live with so many tech people with different backgrounds and nationalities.

In addition to many modern and technological buildings, some historical remains also exist under the ground of this city. After the Great Seattle Fire in the late 19th century, new construction was required and built upon old the towns and streets. After the city was elevated, the old spaces under the ground fell into disuse, but have become a tourist attraction in recent decades. It was really astonishing to realize I stood over a huge ancient city!

On weekends, my friends and I often went hiking at the mountains and trails nearby. Similar to Taiwan, there are also many breathtaking nature landscapes around Seattle, like Mt. Rainier or Mt. Baker. I enjoyed such recreation a lot!

The people here also welcome and respect different kinds of thoughts and rights. I was fortunate to attend the Pride Parade taken place in Seattle last summer. People really engaged in the event and showed support to the LGBTQ community.

Overall, how lucky I was to have a chance to be an intern at Facebook in Seattle. They provided me a very comfortable living place, endless free food in the office, nice wage, and more importantly, a challenging but exciting working environment! My colleagues were very smart and kind, willing to discussing, exchanging ideas and sharing lives.

As a research intern in Applied Machine Learning team, I worked on a research project about speech recognition of English with multiple accents (https://arxiv.org/abs/1911.11935). My mentor helped a lot to discuss with me, review my code and revise my paper. I am glad the paper was finally accepted and published in the conference ICASSP 2020.

It will be good to see more students applying for an internship at good institutes or companies in different countries. This intern experience broadened my horizon and was definitely worth it! It may be good to see more foreign students to come over NTU for internship as well. It would be a good opportunity to exchange insights and bring out more sparks!

*View from where I lived*

*Pride Parade in Seattle*

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