A University-Industry Collaboration Case Study: Intel Real-Time Multi-View Face Detection Capstone Design Projects

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ABSTRACT

Since 2011, University of Michigan—Shanghai Jiao Tong University Joint Institute (JI) has established 122 corporate-sponsored Capstone Design Projects (CDPs) with world leading companies such as Covidien, General Electric, Hewlett Packard, Intel, and Siemens. Of these corporations, Intel was the first sponsor, having funded 21 projects and mentored 105 students over four consecutive years. This paper is a longitudinal case study following three Intel-sponsored multi-view real-time face detection CDP teams with 15 undergraduate students during 2013 and 2014. On the technical side, the system design of face detection is based on Intel High Definition (HD) 4000 graphics and OpenCL. With numerous techniques, including accelerated pipeline over CPU and GPU, image decomposition, two-dimensional (2D) task allocation, and a combination of Viola-Jones algorithm and continuously adaptive mean-shift (Camshift) algorithm, a speed of 32 fps was attained for real-time multi-view face detection. In addition, a frontal view detection accuracy of 81% was achieved in Phase I and a multi-view detection accuracy of 95% in Phase III. Furthermore, an innovative application called face-detection game controller (FDGC) was developed. On the other side, this research also addresses benefitsof stakeholders. After graduation, a third(5) of these students worked in multinational corporations (MNCs) and two thirds (10) of these students entered top American graduate schools. At the time of this writing, five of them have finished their master's degrees and are currently working for famous companies, such as Amazon, Facebook, and Google.

KEYWORDS

Multinational corporation (MNC), university-industry collaboration, capstone design projects (CDPs),internet technology (IT), multi-view, real-time,face detection, and Open Computing Language (OpenCL).

1.INTRODUCTION

1.1 International Higher Education and Capstone Design Projects in China

The growing needs of internationalizing Chinese higher education spurred the establishment of numerous joint ventures between American prestigious universities and top-tier Chinese universities, including the Joint Institute between University of Michigan (UM) and Shanghai Jiao-Tong University (SJTU). The mission of the UM—SJTU Joint Institute (JI) is to establish a leading international research institute which educates innovative future leaders and to construct a model university which emulates a successful UM experience.

The Capstone Design Projects (CDPs) is an undergraduate project-based capstone course required for all JI seniors. Compared to the relatively innovative and mature CDP model in major universities around the world, the CDP structure in China is conventional. In most cases, government funding project or faculty's idea is the primary source to sponsor a CDP in Chinese major universities, including top-tier Peking University, Tsinghua University, and SJTU. The scope of a CDP tends to focus more on in-depth knowledge and skills in one or two disciplines[1].After CDP's training, Chinese college graduates do not have enough experiences of exposing to what J. Widmann et. al. points out "recognizing the complexities of modern engineered products and systems[2]."

There are three purposes for initiatingmultidisciplinary industrial-strength CDPs at JI. The first purpose is to set an example for innovative engineering education, influence Chinese higher engineering education, and better integrate Chinese higher education to global communities. Second, Accreditation Board for Engineering and Technology, Inc. (ABET) accreditation requires undergraduate students have such a practical knowledge integration experience. ABET points out "a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints[3]." This also explains why Ohio Northern University invested a 10-year continuous effort to increase the number of students engaged in multidisciplinary CDPs [4]. Third, it should be a strong sense among academic administrators/educators and industry stakeholders/professionals that graduates need to be better prepared at school for future industry challenges [5], [6].

Inspired by the vision and practices of International Business Consulting Projects (IBCPs) of International Business Education and Research (IBEAR) MBA Program at USC's Marshall School of Business, JI initiated innovative MNC-sponsored multidisciplinary industrial-strength CDPs in 2011 [1]. Over the past five years, JI has developed 122 corporate-sponsored CDPs since its inception, which include multinational corporation (MNC) sponsors such as Covidien, Dover, GE, HP, Intel, NI, Philips, and Siemens. Of these 122 projects, internet technology (IT) accounts for 27%, healthcare 26%, energy 22%, electronics 15%, and other industries 10%. An accumulated 590 JI students have been teamed up based on their individual backgrounds, specifically computer science, computer engineering, electrical engineering, mechanical engineering, and biomedical engineering. The corporate-sponsored rate grew from 0% in 2010 to 84% in 2015.

1.2.Industry Challenges

Mobile commerce has reached an unprecedented height: global smart phone shipments were over 1.16 billion in 2014. Meanwhile, the competition in mobile processor chip market was fierce between Qualcomm, MediaTek (MTK), Samsung, and Intel. Qualcomm and MTK each achieved above 30 percent market share, followed by Samsung's 20 percent. Unlike its predominant advantage in the PC fields, Intel only achieved 2.81 percent market share in 2014, nearly missing the mobile revolution.

Intel's core competitiveness hinges upon advanced semiconductor design technology and fabrication process. In addition, effective and powerful software solutions make Intel the semiconductor industry leader. Furthermore, Intel has various System on a Chip (SoC) for

different platforms and billions of expenditures in Research & Development every year. Advanced technologies such as SoC fabrication, Bluetooth, and wireless charging are widely used in Intel Inside® wearables and mobile devices [7]-[9].

As one of the world's largest semiconductor chip manufacturers, Intel Corporation (Intel) intends to strengthen its competitiveness in GPU and mobile market through innovating in face detection technology and improving its chip performance, including detection speed and accuracy [10]-[14]. In 2014, Renée J.James, the President of Intel Corporation,commented that"Today we are announcing leading communications products as well as new computing platforms. As a result, Intel is well-positioned to shape the future of mobile computing and the Internet of Things[10]."

RealSense technology, which incorporates face recognition and three-dimensional (3D) cameras, is used on robots, unmanned aerial vehicles, as well as new interactive mode of 3D immersive experience [15]-[17]. Such innovation could eventually free users from the constraint of keyboards and passwords. Therefore, face detection has been intensively developedat Intel.Li commented that"given the breakthrough of face detection in terms of improved accuracy and throughput, the success is partly due to the fact that the semiconductor industry has been able to deliver faster microprocessors clocked at higher frequencies[11]."

1.3 Research Collaboration

Established in 2005, Intel Asia-Pacific Research and Development Ltd. (Asia-Pacific R&D), located in Shanghai Zizhu High-Tech Industrial Park, China, is devoted to promoting the development and innovation involved in the main products of Intel Channel Platform Group (CPG). Intel CPG is one of the 5 divisions established after Intel's restructuring. It is the first of Intel's divisions where its global headquarters is established outside the US [18].

Situated in an advantageous location, Shanghai provides a globally unique environment that allows JI to reach out to world-class MNCs and target at MNC R&D centers located in three industrial parks, including Zhangjiang High-Tech Park, Shanghai Zizhu High-Tech Industrial Park, and Caohejing High-Tech Park [6]. Through the JI-Intel collaboration, Intel hassponsoredJI's CDP with 21projects, a total of 105 students,for four consecutive years.The 21 projects include Wi-Fi based proximity detection (2011), image recognition (2012), face detection (2013-2015), GPU acceleration (2014), and deep-learning, vector rendering engine,and OpenKinect project (2015). Of the 21 Intel-sponsored CDPs, three real-time multi-view face detection projects are conducted serially in three different phases, Phase I, II, and III, during 2013 and 2014.

This paper is a longitudinal case study tracking these threereal-time multi-view face detection CDPs in both educational and technical perspective.On the educational side, there are 15 undergraduate seniors involved in this study. On the technical side, this work presents how the technology is improved, mainly on accuracy and speed.

This paper is structured as follows. The university-industry collaboration model for developing CDPs is introduced in Section 2, which includes a dual-track process for managing the CDPs. Section 3 illustrates how the three projects are integrated and improved through three different groups of seniors.For example, with the combination of image decomposition and two-dimensional (2D) task allocation in Phase II, thespeed is increased by 3 times reaching 30 fps. Combining the Camshift tracking in Phase III, multi-view face detection speed reached 32 fps. A

detection accuracy of 81% was obtainedin Phase I and eventually reached 95% in Phase III. In addition, aninteresting interactive application called Face-Detection Game Controller (FDGC) was developed.Section 4 introduces benefits of stakeholders, students' learning curves through different phases, and educational outcomes, including students' progress in both academia and industry post-graduation. The conclusion isgiven in Section 5.

2.THE UNIVERSITY-INDUSTRY COLLABORATION

This 3-phase undergraduate industrial-strength research work follows the collaboration model in Figure 1 [19]-[20].TheCDP collaboration is driven by the needs on both sides, including the university's needs of developing real-world problem-solving curriculum and the industry's needs of researching innovative engineering solutions or testing new ideas. After the CDP contract is signed, both parties pourthe resources into a CDP, such as financial and mentoring from the industry side and instruction and manpower from the university side, and then follow a so-called dual-track process: A university process and an industry one [6].

On the university side, there are five processes involved:

1) *Grouping:* JI instituted a grouping policy, which prioritizes in the following order: the institution's interest, sponsor/faculty recommendation, and students' preferences.
2) *Lectures:* The lectures focus on several common core subjects, such as design process, customer requirements vs. engineering specifications, quality-function deployment (QFD), concept selections, and art of presentation.
3) *Faculty Meetings:* Each CDP project team is required to meet weekly with their section instructor and faculty advisor. The section instructor is responsible for monitoring team progress and the contribution from each member, while the faculty advisor is responsible for technical guidance.
4) *Design Review (DR):*JI's CDP requires every project team to go through four milestones, including three DRs and Design Expo. During each DR, a team needs to conduct an oral presentation and write a report. For instance, DR#3 encompasses modeling, analysis andvalidation of the final design, in which the team presents the prototype progress through animations and video clips.
5) *Design Expo:* Design Expo is a one-day campus event consisting of Oral Defense, Prototype Demo, Design Expo Competition, and Award Ceremony.
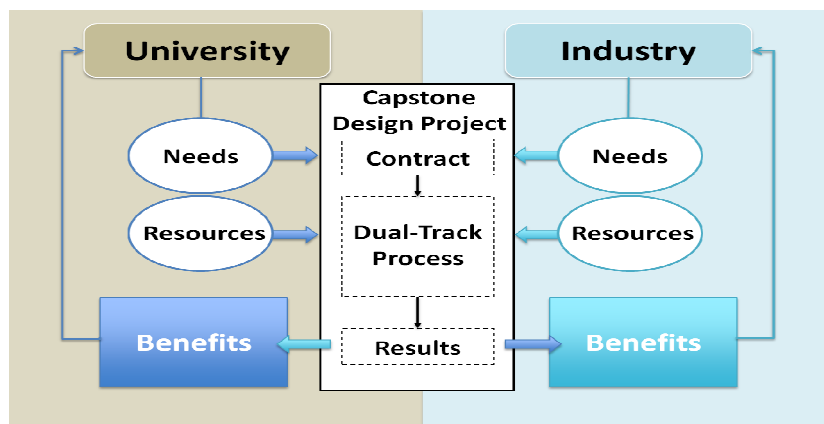

Figure 1. The university-industry collaboration framework for developing Intel-sponsored CDPs.

On the industry side, there are also five sub-processes as follows:

1)   *Agreement & Payment:* Once a corporate decides to sponsor a CDP, it is imperative for the university and corporate to sign an agreement.
2)   *Project Scope Seminar:* The purpose of this meeting is to define a proper scope for the project in terms time length and difficulty level.
3)   *Kick off Meeting:* The purpose of this meeting is to make sure everyone on the team understands the problems and needs of their project.
4)   *Mentor Meeting:* JI CDP course require students to regularly, weekly or biweekly, go to the companies and meet with mentors. The purpose of these meetings is to report to the mentor and seek advices.
5)   *Final Delivery:*The Final Delivery is an effort beyond JI's curriculum's requirements in order to exceed corporate's expectation, which has a tremendous impact on business relationships, marketing, and promotion.

When it comes to making deals with MNCs and creating a sustainable partnership, there is one thing above marketing strategies—having a win/win mentality [6]. Ideally speaking, significant efforts of each stakeholder should benefit the other. On the industry side, the benefits include research and development task force, talent management, entrepreneurial innovation, and

Table 1. Overview of all the tasks involved in developing this 3-phase work during 2013 and 2014. The task marked with * represents the key tasks contributing acceleration.

Week(nth)	Phase I (Summer, 2013)	Phase II (Fall, 2013)	Phase III (Summer, 2014)
1	Literature Survey, Objective Analysis		
2	Function Decomposition &Algorithm Choosing	Previous Work Rebuilding	
3	Image Face Detection		
4	Video Stream Face Detection	Analysis & Design	Skin-Color-Based Image Segmentation Implementation*
5			
6	Performance Improvement	**Pipeline of Accelerated Concept over CPU and GPU & Image Decomposition and Task Allocation***	
7	Innovative Applications Design		**Viola-Jones detection + Camshift tracking Pipeline Building***
8			
9	Debug & Test		**Tuning Face Recognition using Principal Components Analysis***
10			
11	Final Delivery	UI Design, User Feedback and Update	**Detection Box Merge Optimization & Image Preprocessing Pipeline Tuning***
12		Final Delivery	

corporate branding. On the university side, the welfares cover industrial-strength education, influencing China's higher education, and funding. On the student side, the benefits cover an internship or job opportunity and industry experience. The benefits of the stakeholders are presented in details in Section 4. This collaboration model can be sustained only when the results meet expectations or both parties receive substantial benefits. If so, the results or benefits become a driving force to promote continuous collaboration between two parties. This has been the successful model working between Intel and JI for the last 5 years.

3.TECHNICAL DESIGN AND IMPLEMENTATION

During 2013 and 2014, Intel sponsored three real-time multi-view face detection CDPs conducted serially in three phases, Phase I, II, and III, and teamed up totally by 15 students.Every phase lasts about 12 weeks and involves 5 students.Table 1 shows an overview of all the tasks involved in developing this 3-phase CDP research, including two phases in 2013 and one in 2014. The development of all the three projects is based on Open Computing Language (OpenCL), a framework of writing programs which executes across various platforms consisting CPUs, GPUs and others.These three OpenCL based face detection CDPs are introduced in sequence below.

3.1 Phase I: OpenCL Accelerated Face Detection(Summer, 2013)

According to the technical aspects of Intel HD 4000 graphics and Intel's requirements on functionality, accuracy, efficiency, and innovative application, the engineering specifications was developed in the beginning of each phase, as shown in Table 2[21], [24], [26]. The specifications for Phase I include 85% of the detection accuracy with frontal view, 10fps-15fps of the efficiency for 480p videos, and an innovative application with a single-effect face [21].

Figure 2 shows the video processing flows including three main functional blocks: video pre-processing, face detection and accelerated process & innovative apps [22].

1)   The video processing block comprises of a series of preprocessing on the input video, which changes the video stream into a different type of data which makes subsequent computation easier.
2)   The face detection block deals with the computation of images in order to locate human faces and find the accurate sizes.

Table 2. Engineering specifications and technical outcomes of the multi-view real-time face detection CDPs developed in 3 phases.

Description		Functionality	Accuracy	Speed	Innovative Application
Phase I	Specifications	Frontal view	85%	10-15 fps	Single-effect
	Outcomes	Frontal view	81%	9 fps	Bulged face
Phase II	Specifications	Frontal view	90%-95%	20-30 fps	Multi-effect
	Outcomes	Frontal view	94%	30 fps	Square, mosaic, and comic relief faces
Phase III	Specifications	Multi-view	90%-95%	Over 30 fps	Interesting
	Outcomes	Multi-view	Over 95%	32 fps	Face-Detection Game Controller

Unprocessed Video **Video with Face Detected**

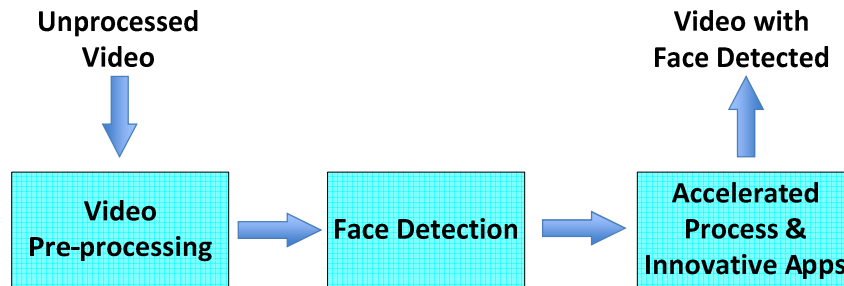Video Pre-processing → Face Detection → Accelerated Process & Innovative Apps

Figure2. The block diagram showing video processing flow.

3) Thelast block accelerates the video process and improves speed. It also involves innovative applications after face detection job is done.

Through the quality function deployment (QFD) framework, brainstorming, and the concept selection process, the Phase I chose the followings as their final design.

1) *Segment into shots:* The purpose of using this method is to reduce total number of the extracted images and remove the irrelevant ones.

2) *Viola-Jones algorithm:* The algorithmis the main stream in the area of OpenCL face detection, which provides a fast and efficient face detection framework[23].

3) *GPU acceleration:*Through a parallel computation along with a GPU, the OpenCL processing speed can be increased.

Due to slow data exchange rate between CPU and GPU and many sub-images to be processed, the speed and accuracy of running initial version on the Intel HD 4000 graphics did not meet the specification. Three solutions helps improve its performance: Processing all sub-images in parallel, exchanging data only when necessary, and buffering small exchanges. After applying these solutions, the frontal view face detection reached 9 fps ofspeed for 480p videos and 81% of accuracy in average.

In addition, the team was encouraged to think outside of the box to implement an innovative application based on their final design. The team realized a bulge effect on the detected faces, as shown in Figure3. During the video testing, all thedetected faces were all smoothly bulged.One of the unexpected benefits out of this collaboration was that the team found several bugs while running the Intel's hardware and then helped the company improve its hardware design.
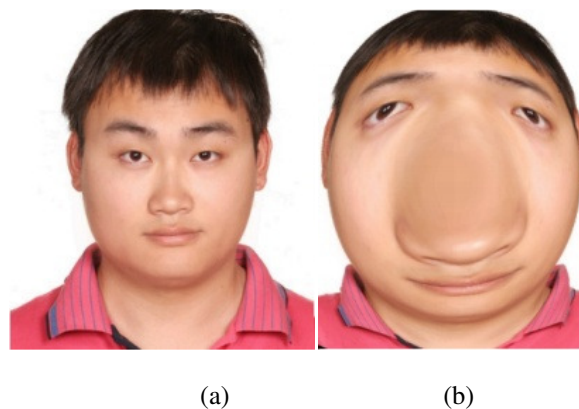
(a)   (b)

Figure3.   An innovative application on the detected face in Phase I: (a) Original image, (b) bulged effect.(Courtesy of Ref. [21])

3.2 Phase II: OpenCL AcceleratedFace Detection (Fall, 2013)

With the support of Intel's Beignet OpenCL, the company challenged the Phase II team to bring the project to a new level [24]. Based on the literature survey, objective analysis, and lesson learned from Phase I team, the engineering specifications for Phase II were defined, as shown in Table 2. The specifications include an accuracy of90%-95% with frontal view, an efficiency of 20fps-30fps for 480p videos, and an innovative multi-effectapplication.

The pipeline of accelerated concept over CPU and GPU was applied to improve the processing speed, as shown in Figure 4. The general process is to first turn video streams into a still frame which is diverted into gray images in CPU. A classifier gets the face image data from those gray images, which includes information of the sizes and locations, and then adds special effects on the faces in GPU. Through this parallel concept of making GPU and CPU work simultaneously, the speed increasedsubstantially and reached 20 fps for 480p videos.

In order to further accelerate the process, some ideas were considered and three of them were used. In this phase, extensive techniques were applied[25], including image decomposition and task allocation:

*1)   Image decomposition:*This technique is used in order tomake pre-processing and classifiers more efficient. Since a GPU possesses a parallel calculation capability, the images aredivided into small parts and then transferred into the GPU together. With the little parts calculated at the same time, the calculated speed is raised remarkably.

*2) Task allocation:*The original problem is that tasks, which refer to binary image data streams, are sorted in a one-dimensional (1D) chain, but the cores of GPUs are distributed as a two-dimensional (2D) matrix. Hence, it is time-consuming to match up each task with a corresponding GPUcore. In this phase, the tasks are put into a 2D task matrix where each task is automatically matched up with a GPU core.Therefore, the task matching time is greatly reduced. In sum, this novel method is used to accelerate face detection over CPU and GPU and make the whole process more efficient.

These two techniques helped boost the speed to 30fps for 480p videos and the accuracy of 94% in average [24].
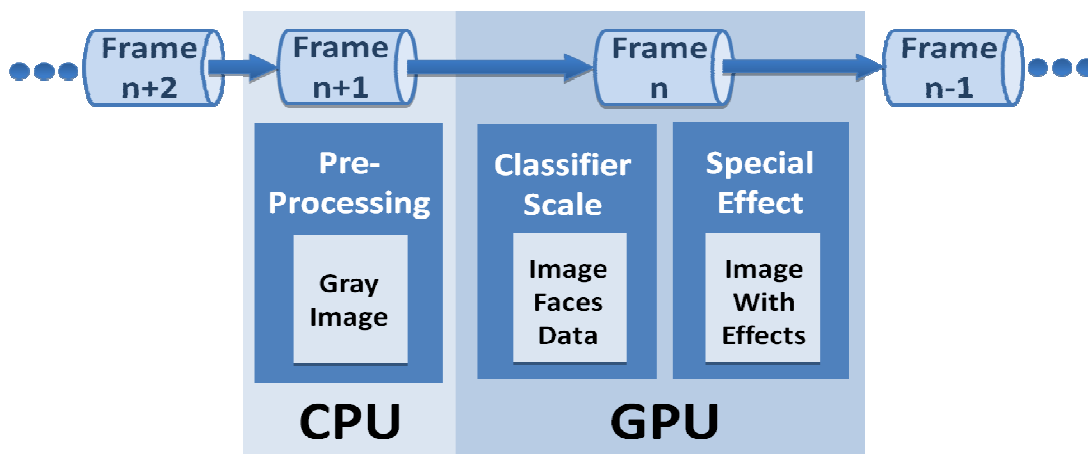

Figure4. Design of the pipeline for OpenCL accelerated detectionover CPU and GPU in Phase II.
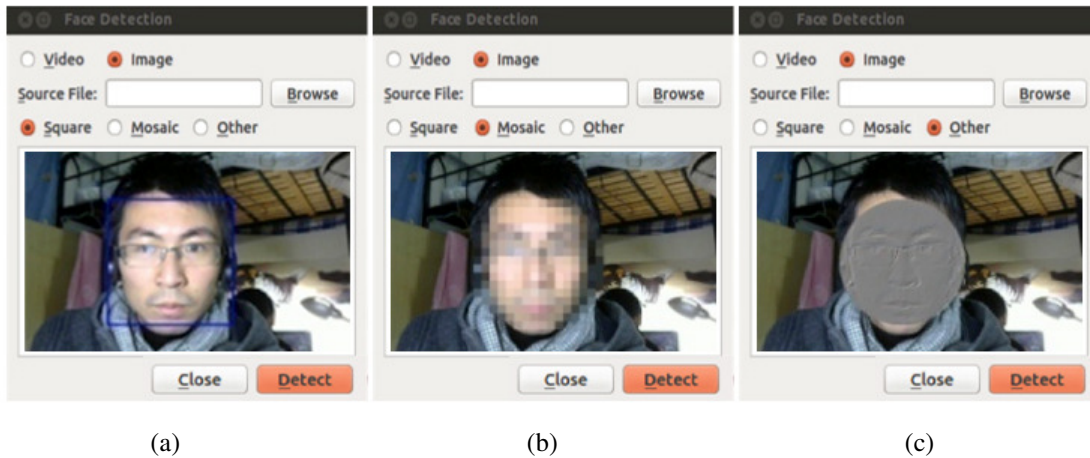
| (a) | (b) | (c) |

Figure 5. User Interface and special effects of the accelerated face detection system in Phase II: (a) Rectangle (b) Mosaic (c) Comic relief(Courtesy of Ref. [24], Taoxi Li, and Jiesheng Zhang).

With the foundation from Phase I, so the team made an excellent progress on user interface and creative application design. In its final version, the system supports two types of inputs, including video streams and still images. As shown in Figure 5, users can click the "Video" button or "Image" button to choose different forms of input. When choosing video as an input, a user needs to first connecther computer to a web camera. Then the system performs the real-time face detection on the camera-captured videos. When choosing image as input, a user needs to click the "Browse" button to locate an input document.Furthermore, the team developed special effects of the accelerated face detection system,which offers three optionsfor face displaying, includingrectangle, mosaic and comic relief, as shown in Figure 5.

3.3 Phase III: OpenCL-Based Face Detection and Recognition Algorithms Tuning (Summer, 2014)

To meet commercial requirements, the company challenged the teamto realize tilted face detection and detect multi-view faces.As shown in Table 2, the specifications for Phase III include an accuracy of 90%-95% with a multi-view, an efficiency of over 30fps for 480p videos, and an interesting innovative application[26].

Figure 6 shows three image pre-processing steps including skin segmentation, bounding boxes finding, and bounding boxes merging:

1) Skin segmentation:This segmentation is to identifyskin areas. First, RGB images are converted to YCrCb images which disregard illumination. Then a skin model is applied to extract segmented binary image. In addition, various topological methods, such as
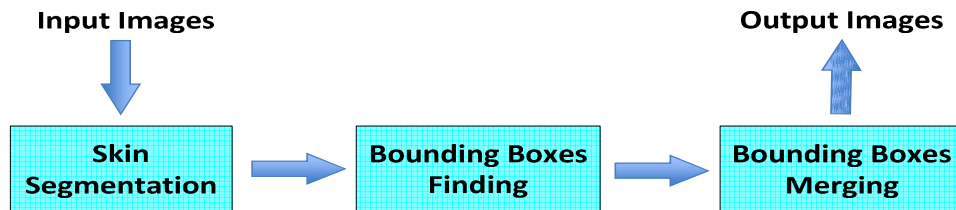

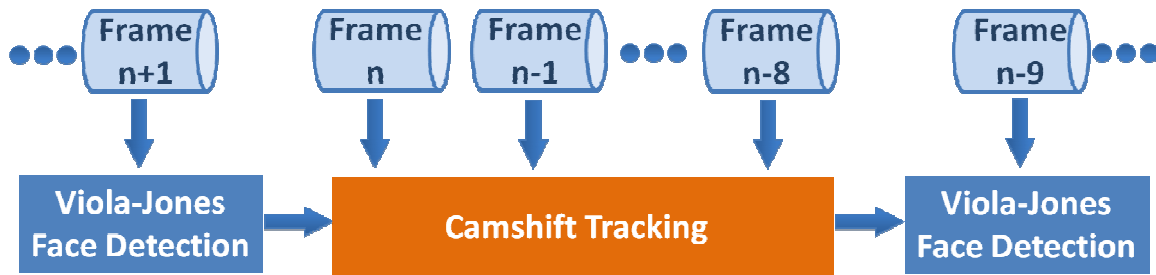Figure 6. Flow chart for image pre-processing in Phase III.

Figure 7. New pipeline combining Viola-Jones Face Detection with Camshift Tracking (Courtesy of Ref. [26]).

dilation,erosion and Gaussian smooth, are used to de-noise and smooth those binary images[27].

2)   Bounding boxes finding: The connected white components in the binary image are labeled first and each component's contours are found. Then rectangle windows are drawn to bounding each contour.

3)   Bounding boxes merging: The function of this step is to merge numerous overlapped boxes into a single larger joint box. The idea is to reduce the execution time.
Through those pre-processing techniques, detection area is significantly reduced and the speed is boosted.

On the other end, the team focused on increasing accuracy, finding tilted-face detection solution and meeting the video multi-view face detection requirement.The team adopted theContinuously Adaptive Mean-shift (Camshift) technique in order to detect tilted face in a large angle[28]. The final design solution builds a novel pipeline whichcombines the advantages with Viola-Jones and Camshift algorithm, as shown in Figure 7. The operation of Figure 7 is explained as follows. AViola-Jones algorithm is first used to detect faces for every 10 frame.Then the Camshift algorithm is employed to track those faces for 9 continuous frames. Finally, the previous two steps are iterated.

Figure 8. An innovative application in Phase III: A face-detection game controller (FDGC) (Courtesy of Ref. [26]).

Through this novel pipeline, the speed reached 32 fps for multi-view face detection and the accuracy achieved over 95%. Furthermore, an interesting application called Face-Detection Game Controller (FDGC) was developed. However, four more steps are required to developthis extended application:

1)   *Detect & track faces:* The purpose of this step is to detect and track faces.
2)   *Get the tilted angle*: The angle of the tilted face is calculated through geometrical principle.
3)   *Communicate the socketbetween Windows & Unix:* Signals (i.e. Left/Right, Up/Down) are controlled through usingsocket communication.
4)   *Simulate keyboard signal:*The Windows'library is used to simulate the hardware signal.
As shown in Figure 8, the accelerated face detection technique enables a user to play a video car racing game without a keyboard or a joystick.

4.STAKEHOLDERS' BENEFITSAND EDUCATION OUTCOME

The benefits of creating MNC-sponsored industrial-strength CDPs are specific to these three aspects, corporation, university, and student. Understanding the benefits of each aspect helps stakeholders create a sustainable win-win partnership.

4.1 Benefits of Industry

There are four areas that interest a corporation to make a CDPs investment and collaborate with a university, research and development, talent management, entrepreneurial innovation, and corporate branding.

First, it is about research and development. For most of engineers and scientists who works in MNCs, where innovation is a central core value, they are creative enough to regularly come up with great idea. Yet with other priorities and deadlines to meet, there is little time for them to execute an idea, validate a concept, and deliver a prototype. On the contrary, CDP provides a platform where their idea could be executed. During an interview with Shanghai TV in August 2011, Kenny He, Director of Intel Asia-Pacific R&D, noted, "From the corporate's vintage point, Intel can tap into talents' fresh new idea. From the students' point of view, it's a great opportunity to do something practical." Bob Liang, former General Manager of the same company, believes that "Intel, by nature, is an innovative corporation. The core of innovation is talent."

Second, CDP is about talent management. Most corporate technical contacts involved with CDP focuses most of their attention on R&D aspects and evaluates how the students could help the company's R&D projects. However, the value of investing in CDPs is not only R&D bus also talent management. The traditional industry practice of hiring a college graduate is based on campus tour, résumé, multiple interviews, reference check, and every so often, a gut decision. Jack Welch, former Chairman of GE, once said that it normally takes about a year or two to know if a company has hired a right person[29].

Third, CDPs can be also related to entrepreneurial innovation, which is one of the benefits that stakeholders seldom pay attention to. The concept is that a CDP serves a platform for a corporate to learn with very-low risk before taking an idea from a concept to a successful business.Last, CDP is a venue for branding. Throughout the CDP process, a sponsor's brand is promoted through different venues within a university, such as classrooms, Design Reviews, Oral Defense,

and Design Expo. The brand is also propagated in different media, such as press release, website and brochure.

4.2 Benefits of University

There are three aspects that attract university stakeholders: industrial-strength education and research, higher engineering education improvement/influence, and finance.

First, it is about industrial-strength education and research. It is almost indisputable for any universities to show an interest in working with MNCs. The first and foremost advantage of getting a CDP sponsorship from a MNC is to directly engage in multidisciplinary real-world problems, dynamically blend the industry issues into course curricula, and vigorously build industrial-strength research and educational activities within the institution. "JI students are expected to work on a state-of-the-art engineering project in the real world. The MNC-sponsored CDP content demands each team member to possess quick learning skills, since most of the knowledge and skills we need do not come from classrooms," commented Jingyuan Sun who has been working on "Adaptive Video Encoding Based on OpenCL Face Detection" with Intel in 2014.

Second, multidisciplinary MNC-sponsor CDP fulfills one of JI's ambitions—to improve and influence higher engineering education in China. During a press conference of JI's winning Andrew Heirskell Award in March 2014 (IIE, 2014), Vincent Chang, JI's Teaching Professor and Faculty Director of Corporate Relations, shared his view on how JI's education was innovative and distinctive in three dimensions, Intro to Engineering for freshmen, Entrepreneurship/Leadership for all levels, and MNC-sponsored industrial-strength CDPs for seniors.

Third, MNC-sponsor CDPs support institution's finance. At JI, MNC-sponsored CDPs funding is sufficient to cover all the project costs, including material, machining, manufacturing, literature survey, transportation, miscellaneous, and management. In an early development stage, it is challenging for a university to convince a corporate decision maker to invest in CDPs. However, once trust is established between two sides, the momentum of getting corporate sponsorship picks up and does its own work. In 2014, JI's MNC-sponsored percentage in terms of the CDP funding reaches 96%. This funding scale can not only well support CDPs but also prop up other educational activities.

4.3 Benefits of Students

There are two main benefits through MNC-sponsored CDP training: internship/job opportunity and industry experience with certain skills. One of primary purposes to create MNC-sponsored industrial-strength CDPs is to develop students' career. In addition, the real-world multidisciplinary training throughout the CDP process can directly connect students to job markets. In 2013, two seniorswith the Phase II project interned at Intel immediatelyafter they finished CDPs. Both seniorsjoined the Intel Beignet team to contribute to the OpenCL specification and implementation of Intel's GPUs.

Second, three skills can be cultivated through the three-month CDP training: Basic skills, technical and creative skills, and leadership skills. Figure 9 shows learning curves associated with two different CDP models, Intel-sponsored CDP vs. conventional CDP. The level of skills evolves

through three stages: basic-skill stage, technical/creative-skill stage, and leadership-skill stage. Aspointed out in Section 1, the CDP curriculum structure and practices in most major universities in
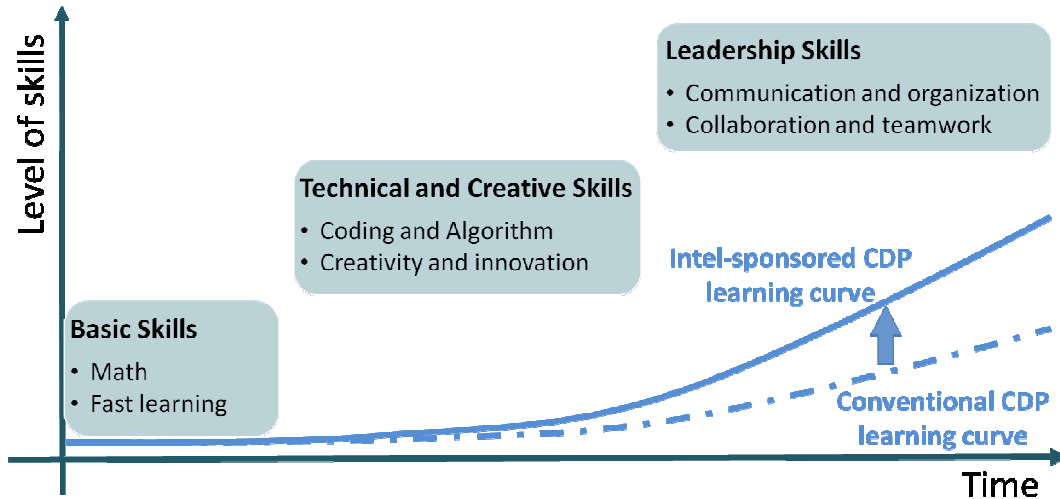

Figure9.Two types of learning curves associated with three different types of skills at three stages: Intel-sponsored CDP vs. conventional CDP.

China is conventional. Through the university-industry CDP collaboration model shown in Figure 1, students apply their knowledge to solve real world engineering problems and work efficiently with other team members.Therefore, their level of skills is elevated.

The first stage is associated with basic skills, which usually involve math and fast learning. Most students don't have a solid industry experience when they first enroll in a CDP. Therefore they need to learn quickly by reading books and asking questions in the first stage. The second stage is related to technical and creative skills, which covers coding and algorithm. For example, students need to figure out what a Viola-Jones algorithm is. This stage also involves creativity and innovation. Students are required to go through engineering design processes, such as benchmarking, customer requirements, engineering specification, brainstorming, concept selection and validation. The third stage pertains to technology leadership skills, which encompasses communication and organization. The primary venue to measure the progress of these skills is by four Design Reviews [6]. This stage also covers learning in collaboration and teamwork. Several indisputable leadership principles are learned along the way, such as the power of sharing thinking, innovation through collaboration, the law of weak-link, and the law of countability.

The two learning curves in Figure9 are presented conceptually instead of quantitatively. That is, there is no statistical data to support the diagram. The purpose of introducing this diagram is to illustrate students' learning experience for three vital skills required by the industry. The diagram does not answer questions such as how far these two curves are separated or to what degree the level of skills is improved.In addition, there is no comparison group of another 15 seniors going through a conventional CDP program. Although the authors cannot prove the rigor of this diagram, they believe the Intel-sponsored CDP approach gives students an edgeby offering a substantial improvement on learning experience. To support this argument, students' educational outcomes are addressed next.

4.4.Educational Outcomes

Table 3shows the post-graduation profile of 15 students who completed Intel-sponsored real-time multi-view face detection CDPs during 2013 and 2014. During the CDP course in the fall of 2013,

Table3. The post-graduation profile of the 15 students who completed Intel-sponsored real-time multi-view face detection CDPs.

Phase (Time of Bachelor Graduation)	Undergraduate Student	Graduate School	Graduate Major	Company	Industry
I (August, 2013)	A1	Carnegie Mellon University	Information Technology	Google	Information Technology
	A2	Columbia University	Computer Science	Amazon	Information Technology
	A3	Stanford University	Computer Science	Facebook	Information Technology
	A4	University of Michigan	Computer Science	Epic	Information Technology
	A5	University of California, Berkeley	Mechanical Engineering	Deloitte	Consulting
II (August, 2014)	B1	■	■	The Yangtze River hydrographic center	Hydro
	B2	■	■	Synopsys	Semiconductor
	B3	■	■	Chinese Academy of Sciences	Research Institute
	B4	University of Texas at Dallas	Computer Science	◇	◇
	B5	■	■	IBM (intern)	Information Technology
III (August, 2014)	C1	University of Michigan	Computer Science	◇	◇
	C2	University of California, Los Angeles	Computer Science	◇	◇
	C3	University of Michigan	Computer Science	◇	◇
	C4	University of Michigan	Computer Science	◇	◇
	C5	■	■	Jefferies	Investment Banking

■indicate the students straightly work right after bachelor degree
◇indicate the students still do not finish the post-graduate degree

two students joined Intel Beignet team to implement the OpenCL specification for the Intel GPUs.Right after their graduation, one third (5) of these students went to marketplace. The student B1 worked for the Yangtze River hydrographic center, a state-owned enterprise, whereas B3 forChinese Academy of Sciences, a domestic research institution. The rest of the three entered the multinational corporations, including IBM, Jefferies and Synopsis, respectively.

On the other hand, two thirds (10) of these students went to graduate schools in the US, including Carnegie-Mellon University, Columbia University, Stanford University, University of California at Berkeley,University of California at Los Angeles, University of Michigan,and University of Texas at Dallas. During their graduate studies, nine students chose computer science or information technology and one mechanical engineering. At the time of this writing, five students in Phase I have already finished the master's degree and currently work for world leading companies, including Amazon, Deloitte, Epic, Facebook, and Google.

5.CONCLUSION

To strengthen its competitiveness in mobile market andimprove its GPU and RealSense, Intel has funded 21 projects for four consecutive years since 2011. The ultimate goal for Intel is to catch up with mobiles/wearablesand compete against predominant industry players.This paper is a longitudinal case study following three Intel-sponsored multi-view real-time face detection CDP teams with 15 undergraduate students in three different phases during 2013 and 2014. The execution of this 3-phase work consistently followsthe university—industry collaboration framework including the dual-track processes proposed in this paper.

The platform development and system design of this workis based on Intel HD 4000 graphics andOpenCL. Prior to this project, the speed of the original version was 3 fps for 480p videosfrontal view face detection. After the platform setup and system validation in Phase I, it reached 9 fps and an accuracy of 81%.With the techniques of image decomposition and 2D task allocation, the speed and accuracy increased to 30 fps and 94%,respectively, for frontal view detection in Phase II. Combiningthe Viola-Jones algorithm with theCamshift tracking method, the speed reached 32 fps and the accuracyachieved 95% for real-time multi-view face detection in Phase III. Furthermore, an innovative game-controller application called FDGC was developed. The technology has been implemented in wearable devices and mobile with Intel cores at the time of this writing.

On the other end, this research addresses benefits of stakeholders. Industry benefits cover research and development, talent management, entrepreneurial innovation, and corporate branding. University welfares include industrial-strength education, influence on higher engineering education, and funding.Student benefits consist of internship/job opportunities,industry experience with three skills: basic, technical and creative and leadership.

The educational outcomes are excellent from the university administration's perspective. During Phase II, two students joined the Intel Beignet team to implement the OpenCL specification for Intel's GPUs.After their graduation, one third (5) of these students went into the marketplace: two with domestic enterprise/institution and three with international companies, including IBM, Jefferies and Synopsis. The rest entered graduate schools in the US, including Carnegie-Mellon University, Columbia University, Stanford University, UC Berkeley, UCLA, and UM. During their graduate studies, nine students chose computer science or information technology and one

mechanical engineering. At the time of this writing, five students in Phase I have already finished the master's degree and currently work for world leading companies, including Amazon, Deloitte, Epic, Facebook, and Google.

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He always dream of making life better by making the techniques more easy to use and more ways to be used. And this idea makes me to join this project and want to make the face detection more easily to use and have a wild use in all areas.

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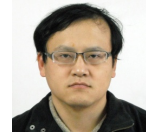
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