University Industry Collaboration: A Promising Trilateral Co-Innovation Approach

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ABSTRACT Research and Development becomes one of the main pillars to build knowledge based economy nowadays. In highly competitive market, there is a real need for efficient mechanisms to have a successful technology development model. Open Innovation through University Industry Collaboration (UIC) is one of promising mechanisms to develop new technologies that can seed national knowledge economy. UIC model brings valuable benefits to both academia and industry in order to have efficient technology development processes. In addition, UIC offers university researchers an opportunity to have an exposure to industry and creates training and internship opportunities for university students. Trilateral collaboration model, which adds end-user to UIC arrangement, could bring an additional advantage to align the product development with actual customer needs making introduction of new product more successful. This paper gives an overview about the main aspects of trilateral collaboration and shows a real trilateral collaboration case between academia, technology provider and end-user to develop an actual product that serves end-user needs showing advantages and challenges of proposed model.

INDEX TERMS University Industry Collaboration (UIC), technology development, trilateral model.

I. INTRODUCTION

In highly competitive global market, organizations are looking for effective mechanisms to strengthen research and innovation processes reaching ultimately to actual products development. Traditional closed innovation approach becomes more difficult to implement due to complexity of new multidisciplinary technologies and rapid technology development [1]. It is shown that open innovation is a promising mechanism to generate valuable ideas through knowledge exchange between different organizations which usually do not have all competencies and know how to house to develop new technologies [2]. Open innovation allows organizations to share resources and complement each parties’ expertise. University Industry Collaboration (UIC) is one of the common open innovation models used to accelerate technology development nowadays [3]. University and industry can have various forms of collaboration including joint research facilities, contract research, collaborative research, IP licensing, shared publications, consultancy services and training or industry secondments for students. University Industry Collaboration (UIC) is a win to win strategy that bring valuable benefits for both parties.

From a university perspective, governments always encourage universities to perform research and allocate funds in order to facilitate innovation and keep up with technological development that could contribute to local economy [4]. However, universities recently are facing a decrease in the public fund and high competition from other research centers for this limited governmental fund. As a result, Universities start to look for alternative fund sources and they found partnership with industry one of potential fund sources to execute their research projects. Also, UIC allows universities to extract the value of their technologies quickly and efficiently. Industrial partner can play a significant role to transform university intellectual properties into actual products and introduce them into the market which helps the growth of the country’s economy [5]. In fact, university is willing to collaborate with industry to get their support to commercialize new technology through licensing or making new products [5], [6]. Moreover, UIC offers university researchers with a valuable opportunity to interact with industry helping to direct
their research toward actual market needs [7]. In addition, collaboration with industry will help the faculties to tune their academic programs to meet industry expectations [5]–[7].

Furthermore, there is a role for the universities to contribute to the community showing greater social accountability. University should develop entrepreneurship environment that could have a significant economical impact on the society and facilitate building relationship with industry to exchange the knowledge and experiences. Universities tend recently to generate new firms such as startups and spinoff through entrepreneurship environment to stimulate the regional innovation capabilities and the create new local jobs [8]. Moreover, university engagement with industry could create new training and internship opportunities for students helping them to build their industrial experience.

From Industrial perspective, F. Giones [3] presented a thorough analysis of the UIC. In many countries, governments encourage industrial firms to have partnership with universities in order to turn their technologies and intellectual properties into actual products that support national economy [9], [10]. Governments offer several incentives for industrial firms involved in R&D such as grants and tax credits [4]. In addition, industrial firms usually looking to acquire innovative university technologies and have exclusive rights for commercialization in order to get a competitive advantage in the market and maximize their revenue [6]. UIC could be an effective tool for industrial firms to compensate for the lack of in house expertise needed to develop novel technologies. In addition, UIC provides industrial firm with opportunities to access university resources such as high tech research facilities which could help to shorten distance to the market and recover development cost faster [5].

Although UIC could add a value to the technology development processes at both sides, there are barriers that could hinder such collaboration because companies and universities have different objectives. University usually has an objective to create knowledge that can add a value to society. They usually tend to get reputation by sharing their research to public through publications. On other hand, industrial partners tend to develop products and solutions that generate revenue in order to run their business operations. They usually prefer to protect their knowledge with IPs such as patents, copyrights and trade secrets. So, adequate methods should be introduced to establish successful industry-academia collaboration relationships.

Barriers that might deter the generation of UICs could be classified in two overarching categories: orientation and transaction barriers [11]. Orientation barriers is caused by the different vision both academics and industry have. Orientation barriers also include aspects such as gap between pure and applied scientific research, the conflicts between businesses’ short-term development compared to the long-term academic research and the distinct working practices and expectations of each organization [3]. On the other hand, ‘transactions barriers include the unrealistic or unclear impact of universities’ research versus the need for specific deliverables in the industry context, IP conflict or confidentiality, arrangements, the incompatible rules and regulation, and the limited capabilities of universities such as industry liaison offices to engage in business with firms [11].’

Fortunately, there are also enablers that can help overcome such barriers both at individual and institutional levels. At the individual level, trust between involved institutions facilitates the exchange of sensitive and confidential information which could help to identify needs and capabilities of each side. [13]. Also, UICs’ prior experience help both sides to establish new collaborative research themes and allow to have a better estimate of cost and resources needed to execute the project. [12]. At an institutional level, it is recommended to utilize variety of channels to establish collaboration that could help to diminish mentioned barriers while broader scope of collaborations could help involved parties to identify new collaboration opportunities and the convergence between the involved parties [11]. Finally, Geographical proximity between the parties and university’s research quality enhance the likelihood of interaction which could lead to innovative outcomes [14], [17] even when there is institutional distance between partners [15]. Even if there is a distance between the university and industrial partner, there are options to introduce intermediary organizations such as Technology Transfer Offices (TTOs) or joint research centers that increase proximity, accumulate knowledge and generate trust between industrial and academic organizations [16]–[18]. Regardless of the barriers and enablers, industrial and academic partners should have a minimum willingness to engage in joint projects because it is unlikely to see fruitful results without a minimal relational trust or pre-existent ties [5]. Due to significant value UICs can add to innovation and country growth, there is a great interest to identify potential policy interventions that could stimulate more interactions [23]. Such policy initiatives should be considered as part of the public entrepreneurship process to create organizations and mechanisms with aim to better serve public interests [20]. Nevertheless, there is no good systematic public policy evaluation approach for technology transfer or UICs which makes it difficult to determine appropriate intervention for each policy challenge [21]. In addition, the absence of a comparable evaluation leaves decision to policy makers to estimate the impact of selected policies and determine the appropriate mechanisms to mitigate existing concerns on the effectiveness and efficiency of academic innovation and entrepreneurship promotion policies [22]. The problem becomes more prevalent when the policy and desired outcomes are not well defined. So, it is recommended to utilize prior research experience for UIC policy interventions to manage the orientation and transaction barriers more efficiently. The selection of potential interventions should take into account the factors that could cause failure either from the supply or demand side. In the context of UIC, factors could be resources, capabilities and perceptions towards the behavior [23]. There are some interventions that could be utilized to overcome this situation such as grants to reduce resource limitations, vouchers to
facilitate access to capabilities and training to modify perceptions and motivations [21].

So, it is clear that collaboration between academia and industry could bring great advantages to foster research activities, improve research outcomes if project plan, roles, expectations, needs and risks are well defined. It is necessary to involve all parties related to technology development process starting from research phase up to market introduction. In some cases, it requires to have more than two parties to direct development process toward actual market requirements. A promising technology development arrangement namely Trilateral collaboration between academic research institution, technology provider and end-user could help to define project scope and requirement more precisely to serve actual market needs and facilitate commercialization of research outcomes. In this paper, we shed the light on key aspects of Trilateral collaboration approach and recommend best practices based on our experience. Although there are many papers in the literature discussing collaboration between industry and academia but few of them as per our knowledge discuss the trilateral collaboration model between academia and industry differentiating industrial partners as technology provider, who can formulate the technology in a product shape, and an end-user, who use the new technology in the manufacturing facility.

This paper is organized as follow: section I introduces the trilateral research and development collaboration model, Section II explains the collaboration process, Section III discuss scenarios of trilateral collaboration model and Section IV presents a real trilateral collaboration case study.

II. TRILATERAL RESEARCH AND DEVELOPMENT COLLABORATION MODEL

There are several options to establish partnership between industry and academia aiming to develop technologies that serve market needs. One option is to establish a collaboration with end-users who operate industrial facilities. Although university is able to develop new novel technologies but research team usually is able to provide only a prototype used for demonstration and initial testing. In other words, university is not able to shape the product in a commercial form. If the new technology fall outside end-user manufacturing scope, then end-user will not be able to turn university outcome into a product due to lack of adequate in house competencies. Even if an end-user has the capability to produce the technology, it is not cost effective to have large scale in house production. Another option is engage with a technology provider in order to develop new solution for potential end-users. With help of technology provider, university is able to shape the technology in a commercial form which can be introduced to end-user with more confidence. Technology provider can get the advantage of university know how to keep pace with market in a cost effective manner. However, there is a risk that a product does not satisfy end-user expectations in terms of requirements, performance and cost leading to a significant investment loss for both university and technology provider. Trilateral collaboration model could be formed between three partners with different business domains and characteristics in order perform R&D activities that could end up with outcomes that satisfy end-user requirements. Trilateral collaboration could be formed between academia, government and private industry, industrial and academic partners or industrial partners. Our focus in this paper is on the collaboration between two industrial partners namely an end-user and a technology provider and an academic partner showing the benefits and impacts of having such arrangement on technology commercialization.

Trilateral research arrangement is one of promising collaboration model because it includes academic researchers having theoretical know how, technology provider having product development expertise and end-user having actual market needs which are valuable to guide research team to right direction and shorten the path toward commercialization.

Cluster, business incubators, technology parks etc. could help researchers to initiate their startups, but they may not have enough fund, expertise, and tools to complete the journey until product is introduced into the market. For this reason, adopting proposed trilateral model could help in filling these gaps and accelerate product development. In fact, these institutions can play a major role in establishing the proposed trilateral model, function as a hub to connect three parties and facilitate research and commercialization agreement processing. In the case study shown in this paper, the presence of Yokogawa in Dhahran Techno Valley and KFUPM Technology Transfer, Innovation and Entrepreneurship (TTIE) center played a major role to establish the communication between three parties and facilitates the development process.

Although trilateral arrangement has a clear impact on the research outcomes, it could add complexity to the process in terms of information confidentiality, collaborative research agreements, Intellectual Properties (IP) and commercialization activities. For this reason, institutions either academia or industry avoid trilateral arrangement at least in the early stages. Looking to the value added by end-user raises the need to find efficient mechanisms to manage trilateral arrangement that satisfy three parties’ expectations and overcome mentioned obstacles. In the following sections, we will explain how to manage process and how to handle various scenario of the trilateral collaboration model.

A. TRILATERAL COLLABORATION PROCESS

Trilateral collaboration usually follows similar process as the ordinary bilateral collaboration shown in Figure 1. The difference lies on the additional complexity of agreement preparation and negotiations. Usually, trilateral collaboration starts as a bilateral collaboration, then it is extended to include a third partner. There are several factors that shape the form of trilateral collaboration mainly technology readiness level (TRL) which plays a critical role in determining how to process collaboration process. Based on TRL, collaboration process can fall under one of the following cases:
• Case 1: TRL > 7
In this case, the technology reaches to a maturity level that needs only field data and field test for validation and evaluation. So, only Non-Disclosure Agreement (NDA) is required to involve the end-user. For this case, end-user cannot claim IP rights but it is highly recommended to provide some incentives such as free license for a limited period in order to encourage the end-user to involve in the project.

• Case 2: 3 < TRL < 7
This is the most difficult trilateral case to form because it needs negotiation of all aspects of collaboration research mainly IP rights. The main negotiating factor is the contribution of each partner both financial and technical ones. It should be formulated to be a win to win situation for all partners. Although involvement of an end-user at this stage could be beneficial to tune the product into actual market needs, a care should be taken not to over tune the product to a specific end-user needs. Another important point is involvement of an end-user should not limit technology provider and university to sell the solution to other end-users. So, research agreement and commercialization/IP agreement should clearly define the scope of each partner, outcomes and most importantly commercialization terms.

• Case 3: TRL < 3
It is rarely to start a trilateral collaboration at this stage and it is not recommended until the basic research and proof of concept are completed. This scenario may happen when an end-user initiates a request to develop a new cutting edge technology, requiring the involvement of both end-user and technology provider, which can add a high value to end-user processes.

B. TRILATERAL COLLABORATION SCENARIOS
A key aspect in trilateral collaboration is who the right partner and what is the right time to start the collaboration. The answer for this question depends mainly on technology maturity level as shown in Figure 2. Another important factor that should be considered and it could play a critical role in collaboration formation is the partner who initiate research and development activities. There are three main scenarios for trilateral collaboration formation which is explained as follow:

• Scenario 1: University Initiative
In this scenario, University usually performs basic/applied research with intention and plan for commercialization. During this phase, university attempts to protect their technologies by a form of IP mainly patent. Then, university works to publicize their research in order to get academic credits and attract the attention of industry. In some cases, researchers build a prototype to demonstrate their technologies to interested users. Although it is not easy for researchers to build their own prototypes, this step is highly recommended to facilitate commercialization negotiation with industrial partners who could be either a technology provider or an end-user. So, university researchers should not approach industry before their technology reaches at least TRL 3. Then, university research has the following cases:
  − IF 3 < TRL < 7
  Once the technology reaches TRL3, researchers can approach technology provider with more confidence to develop prototype/product. Once the solution’s TRL is more than 7, then the following actions are recommended to complete product development:
  1) Approach end-user to perform evaluation/validation of the prototype or minimal viable product and collect feedback from end-user.
  2) Develop final product/solution based on his requirements.
  − IF 7 < TRL < 9
  If the research team could advance their technology and raise it to TRL 7 or more, then they can collaborate with end-user to develop final product or license the technology. A common practice is to create Startup/Spinoff in order to commercialize the technology either through productization or licensing. However, there is a challenges that startup founders should overcome in order to penetrate into market and have a successful commercialization.
The first challenge is how to grant funds required to run the operation of new startup. Seed fund provided by the governmental institutions could be a good option to start startup’s operation but the amount usually is limited and difficult to acquire. Looking for investors who can invest in new business is another option but it requires a great effort to identify right investors and reach to an agreement. Licensing technology to an end-user or a technology provider for a specified royalty either lump sum amount or running type could be a fast and easy option but a care should be taken in agreement negotiation to get the maximum benefits especially for exclusive license case. A recent trend for startup and small companies is to have a partnership with technology provider who usually is looking to complement his products/solution portfolio in order to expand his business while startup and small companies could be able to penetrate market and get the reputation for their solutions. Technology provider and startup can go hand with hand to an end-user or even cooperate with him for technology validation, evaluation and ultimately implementation. So, we can see that trilateral collaboration could have a clear advantage through life cycle of product.

There are important advices for research team in order to start successful collaboration:

1) Do not approach industry with theoretical ideas only.
2) Show clearly the added value of your solution to the industry.
3) Make comprehensive market survey before approaching Industry.
4) Use simple words in your proposal, clear objective and plan.
5) Do not approach industry asking for their problems. It is better to ask for challenges and needs.

- Scenario 2: Technology Provider Initiative
Technology providers usually invest in research and development activities in order to maintain its competitive advantage in the market. Research done by technology providers can be divided into two main categories: incremental research which could be either product development or applied research. In the second category, the focus is on radical innovation which aims to develop cutting edge technologies that add competitive power in the market. Figure 6 shows an example of Yokogawa approach to perform research and development activities. Under this approach, there are three main cases which are as follows:

  - Case 1: Core Products Development
    In this case, technology provider prefers in-house development (closed Innovation) R&D in order to maintain quality of core business.

  - Case 2: Non-Core Products Development

  - Case 3: Non-Core Products Development
In this case, technology provider has more freedom to collaborate with external partners to develop new products that support and extend his business in near future. External partners could be universities or researcher centers but sometime they could be non-competing industrial partner, in which partners complement the expertise of each other, or an end-user. Trilateral formation is a possible option in this case which could include a university/research center, technology provider and a non-competing technology partner or an end-user.

- Scenario 3: End-user Initiative
In this scenario, end-user is usually looking for new solutions that can improve his operation, efficiency, safety, profitability, cost reduction etc. End-user could have in house R&D option but it is usually limited mainly to his core business and only large organizations can afford such type of R&D. Another option is to collaborate with a technology provider or university / research center to develop new solutions in a bilateral form. However, trilateral model could be required because either university does not have technical expertise to convert their technology into a robust functioning product or technology provider lacks enough technical knowledge to complete product development. This scenario has a high likelihood for commercialization as the market is already available. However, this formation could limit commercialization to other end-users because such projects are usually funded by the end-user who has more influence and control on commercialization of the research outcomes.

C. TRILATERAL TECHNOLOGY DEVELOPMENT CASE STUDY
We will show a real trilateral collaboration research case between an academia institution, a technology provider and an end-user to develop a solution that can improve the control loop performance that suffers from a common process issue namely control valve stiction. The outcome of this research is an advisory solution that guide plant operator to best controller parameters that can compensate for stiction in order to maintain product quality and keep the process online until next planned maintenance. This solution can save cost of

FIGURE 3. Yokogawa R&D approach.
unplanned maintenance and financial loss due to unplanned shutdown and higher rejection rate.

1) PHASE I: ACADEMIC RESEARCH
In the first stage, research team from King Fahd University of Petroleum and Minerals (KFUPM) was exploring potential areas that require further improvement to satisfy end users requirements. At this stage, research team identified one important area namely control performance monitoring and improvement that can have a significant impact on process efficiency, quality and profitability. Academic researchers, who had control engineering background, started to investigate root causes of control performance degradation such as controller tuning, incorrect sizing and control valve problems. Team selected one of the common and long standing control valve issues namely stiction. They found that physical maintenance is the only method to remove the stiction but it is not feasible at all times because it requires process shutdown which is not possible if there no bypass line. Keeping the process running with a sticky valve could lead to a loss in product quality, introduce oscillation into control loop and shorten control valve life. So, team thought about an intermediate solution that can improve control performance in order to maintain the quality while keeping the process online. The proposed solution was to add a soft control signal which acts as a compensation signal to mitigate the effect of stiction until next planned maintenance. To realize the idea, advance control techniques were used to determine the optimal parameters of the compensation signal. In order to evaluate the proposed approach, simulation program was built by MATLAB and Simulink. Initial Simulation results were promising which motivated team to continue the development of the compensation solution. Research team took one step further to validate simulation results by a quadruple tank process system shown in (Figure 4). As we mentioned, this is a useful step to demonstrate the technology to potential users on a real system. The setup has potential to allow wide range of control applications such as level control (1st order, 2nd order, systems with delays and decoupling) and flow control applications in a single loop configuration or Multi-Input-Multi-Ouput (MIMO) configuration. The setup was initially developed with the following instruments

- 4 × 110VAC solenoid valves. (S1,S2,S3,S4)
- 4 × 12VDC solenoid valves. (S-A1,S-A2, S-B1,S-B2)
- 2 × memorized control valve (CV-1,CV-2)
- 2 × 12VDC pumps (Pump A, Pump B)
- on each of the tanks, 2 wires that act like a level switch whenever the water short them.

The control valve used is the Omega PV12-SS pneumatic control valve (Figure 5). However, an additional pneumatic valve was cut to uncover the stem and the loading spring so the movement and the impact of stiction can be visible to the operator (Figure 6).

A graphical user interface (GUI) was developed using Labview in order to control the setup and monitor the response of the system. Using GUI, the following stiction analysis have been achieved:

- Characterized the nonlinear dynamic of the valve.
- Tune the original PID and assess the performance of the level loop
- Use inverse of the valve nonlinear model to compensate for stiction and improve the loop performance and therefore extend the valve life-cycle.

Figure 7 shows the nonlinear behavior of the valve. It is found that the dynamic has been fit to 3rd order polynomial using Microsoft Excel. An inverse model has been calculated and introduced in the control loop. Figure 8 show the inverse dynamic model of the valve and result of its implementation on the control valve response which becomes almost linear. In this phase, we can see that University research team was able to proof the concept both using simulation and experimental setup which is an essential step to gain the confidence of industrial partners.
2) PHASE II: BILATERAL COLLABORATION

a: PARTNERING WITH TECHNOLOGY PROVIDER

After KFUPM research team reached TRL3, they decided to reach a technology provider to commercialize the technology. Fortunately, KFUPM established a science park called Dhahran Techno Valley (DTV) which has several international companies that have R&D centers. In this park, KFUPM has a technology transfer office to coordinate the communication between DTV partners and KFUPM researchers. KFUPM research team introduced this work to Yokogawa Saudi Arabia R&D center which found proposed work very interesting in terms of result and potential. The company recognized that the concept of compensating for valve stiction and increasing the life cycle of the valve will have a definite use in the process control industry. KFUPM research team decided to develop a product through a collaborative research project with Yokogawa Saudi Arabia. KFUPM Technology Transfer office made several agreements such as Non-Disclosure Agreements (NDA), Collaborative Research Agreements (CRA) and Joint Invention Administrative Agreement (JIAA) that determine all legal related terms, management structure, intellectual properties rules and commercialization arrangement. Key Performance Indicators (KPI’s) were also put in place to evaluate the performance of joint collaboration. For example, number of undergraduate and graduate students involved in the research, number of publications generated, number of patents and ultimately prototyping and commercialization. The team had regular meetings to review the progress and ensure that plan and milestones are successfully reached. A continuous joint effort was made to reach to the local industry and publicize the project and potential outcomes through an international conferences and journal publications. In order to visualize and demonstrate the application to a potential end-user, the experimental setup had to be upgraded and equipped with industrial components. Yokogawa provided KFUPM with a common control valve used in industry equipped with Yokogawa valve positioner and help to configure and setup these components. Theses two new components are Baumann pneumatic control valve and Yokogawa valve positioner.

1) Baumann Pneumatic Control Valve:

Bauman\textsuperscript{TM} 24000 Little Scotty\textsuperscript{TM} bronze control valve with pneumatic actuator (Figure 9) was used in order to perform all the stiction compensation tests. The valve is brand new, which means that it does not suffer from any physical stiction. Hence, we are sure that only stiction affects the valve is a software simulated data-driven stiction which is introduced during our tests.

2) YOKOGAWA Valve Positioner:

YVP110 YOKOGAWA advanced valve positioner (Figure 10) was used in order to provide a feedback of the valve stem position. This feedback will improve the accuracy of stiction quantification as it provides an access to the input signal and output signal of control valves which, in turn, enhance the efficacy of stiction compensation methods. Valve positioner uses a common communication protocol namely Foundation Fieldbus protocol to communicate with the control station to send position feedback and receive control signal needed to correct valve opening and overcome stiction if it exist.

b: IMPLEMENTATION OF STICION COMPENSATION

Stiction is nonlinear element added to the control valve. In order to cancel this element, a nonlinear inverse model was used to remove the effect of stiction. Although the nonlinear inverse model is the best compensator, it is not easy to be implemented. As a result, research team proposed to use a linear compensator namely Finite-Impulse-Response (FIR) which is a common widely used model in both academic research and industry. The optimization of the filter parameters have been done using Differential Evolution (DE) technique offline but an online adjustment of FIR can be done to adapt to the stiction which varies with time. The adaptive DE-based technique gave very promising results in terms of performance Improvement. A MATLAB code is used to audit the loop performance, perform stiction analysis and optimize compensator parameters such as FIR gains. Graphical user interface was built using Labview as shown in 11 to allow...
the user to monitor and control the experimental setup and visualize the results.

D. PHASE III: TRILATERAL COLLABORATION

The Involvement of the End-User: After proof of concept is completed, research team approached an end-user in order to get their feedback and understand their actual requirements. This was useful to build the final product version as per end-user expectations which could increase the opportunity to have a successful market introduction. Several presentations have been made in different forums where the audience is mainly end-users. In our case, KFUPM TTO played an important role to establish the communication with one of the world-wide company showed interest in the technology and decided to get involved in order to develop the product that fits its needs and operation. KFUPM TTO spent a great effort to coordinate between three parties, prepare agreements and acquire field data. The involvement of end-user put a second thrust for this collaboration. Trilateral collaboration model allowed academic researchers and technology provider to interact with end-user’s subject matter experts in order to tune the solution based on the end-user’s requirements. In addition, trilateral collaboration model could give research and development team the opportunity to get the field data to validate new solutions and it could allow to test and evaluate new solution in the actual field. Although mentioned benefits could be achieved through a bilateral collaboration model, Trilateral collaboration model allowed academic research team and technology provider development team to tune computation engine and product development simultaneously taking into the account end-user’s requirements. This collaboration model allowed the involved parties to agree on the shape of the intended solution and required components that satisfy end-user requirements. For intended stiction solution demonstrated in this paper, parties agreed on the following functions:

- Read real-data logs.
- Allow the user to select from the recording the data set that is need for the audit
- Perform data clustering to detect if the operation is around one single operating point or multiple points and give a visual graph that may show the degree of linearity of the input-output.
- Confirm and quantify stiction.
- Help in validating the stiction detection.
- Allow the user to investigate several scenarios of control compensation.
- Compare the different strategies of compensation and estimate the improvement on the residual-life cycle of the device.

As the stiction compensation concept is relatively new to industry, end-user preferred to implement it as an offline advisory solution until it reaches to a confidence level that allows online implementation. As a results, a Control Performance Advisory solution (CPA) has been created which can performs stiction analysis and diagnosis and recommends best controller parameters to compact the stiction leaving the implementation decision to operation team. The development went through several iterations in order to converge to the final prototype shown below. The prototype was created using MATLAB standalone compiler as shown in Figure 12.

III. CONCLUSION

University-Industry collaboration is one of useful approaches to promote research ideas into fruitful outcomes for both academia and industry. UIC approach paves the road to build strategic partnerships that provide a cost and time effective approach to deliver new technologies into market adding a value to society. It is necessary to make the appropriate formation with right partner at the right time in order to be able to commercialize new technologies successfully. Trilateral collaboration between an academia, a technology provider and an end-user could be best approach to achieve this goal. We see a trilateral model as one of promising candidates for technology development as competition becomes high at all levels. At the academic research level, the number of academic institutes is increasing around the world while public fund allocated for research is limited. In addition, there is a pressure on academic and research institutions to transform into an entrepreneurial organizations that are able to generate
revenue to support their operations and contribute to the local economy. At technology manufacturing level, there is very high competition to deliver latest technologies fast with competitive price while in-house resources and expertise are limited in order to maintain a share in the market. At the end user level, there is a need to acquire latest technologies that improve the efficiency of the operations, maintain the reputation in the market, maximize profit margin and deliver competitive product to the market. Although Trilateral collaboration is a promising approach, partners should keep in mind that significant effort and care are required to make the right formation and determine the right time to engage the partners. In addition, agreement on legal terms and IP rights is one of the most challenging part in UIC especially for the trilateral form. Therefore, it is highly recommended to start negotiation as early as possible because this process usually takes long time and to avoid dispute on IP rights between parties later on. Moreover, trilateral collaboration is not always the best option. In some cases, bilateral collaboration could be the best option if the partners have required expertise and enough information about end-user needs. In this paper, we demonstrated a real trilateral collaboration case that ends up with several outcomes such as technical papers, patents, prototypes and product under development.

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