Development of real-time monitoring and control system for Geothermal drilling by using digital twin technology

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Abstract

Currently, Kenya supplies its energy demand predominantly through hydroelectric power which fluctuates due to poor and unpredictable rainfall in particular years. Geothermal energy is proposed as a clean and reliable energy source in meeting Kenya's increasing energy demand. During geothermal drilling operations, disruptions due to tool wear and breakages increases the cost of operation significantly. Some of these causes can be mitigated by real-time monitoring of the tool head during operations. This paper presents the design and implementation of a digital twin model of a drilling tool head; represented as a section of a mechatronic assembly system. The system was modelled in Siemens NX and programmed via Total Integrated automation (TIA) portal using a Programmable Logic Controller, S7-1200 PLC. The digital model was programmed to exactly match the operations of the physical system using OPC (open platform communications) protocol. These operations were verified through motion study by simultaneous running of the assembly system and digital twin model. The study results substantiated that a digital twin model of a geothermal drilling operation can closely mimic the physical operation.

Keywords: Geothermal drilling; Digital twin; Open platform communication (OPC); Real-time monitoring and control; Siemens NX.

1 Introduction

The fourth industrial revolution also referred to as industrie 4.0 is the current trend in automation technology. It encompasses digitalization, networking technologies, internet of things, cloud computing and cyber physical systems. Digital twin is a key component in the realization of industrie 4.0. It involves the creation of a virtual representation of an existing physical system in cyber space. As discussed by Fei et al. (2019) such a representation acts as an effective test-bed for implementing data fusion, machine learning and artificial intelligence to achieve real time control, monitoring and optimization. Digital twins are gaining popularity in research and industry as they can accurately represent the status, position or working conditions of their physical counterparts.

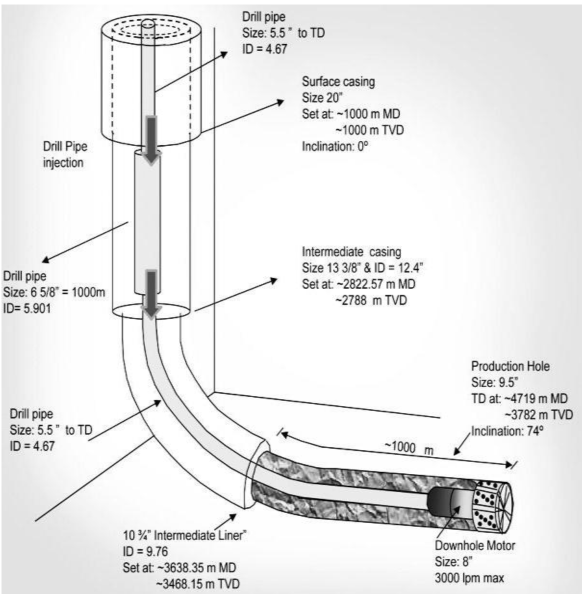

Figure 1: Drill pipe injection profile

This study was geared at solving current geothermal drilling challenges through the implementation of a drilling process digital twin. The underground section of geothermal drilling involves a rotating tool head with water vents to allow the circulation of slurry used to clear debris from the drill tip as shown in figure 1. By attaching a torque sensor to the drill shaft and relaying such information to the digital twin, an accurate picture of the drill tip status can be obtained. Monitoring of drill torque fluctuations is an effective method of early fault detection and diagnosis. This is expected to reduce the need to withdraw the drill tip from the borehole and subsequently save on cost and time losses due to drill halting. The initial step in the realization of a digital twin was the creation of a CAD model which was adequately programmed so as to closely synchronize with its physical counterpart. This study demonstrated the successful achievement of this concept.

2 Literature review

According to studies by Capuano L. (2016), drill bit replacement and repair contribute to the overall cost of geothermal drilling. Efforts in making geothermal drilling more economical have been researched, with scientists focusing on material selection and bit design in making stronger and more wear resistant tool heads and better methods of project planning and management. From research conducted by Miyazaki et al. (2019) materials such as diamond bits and polycrystalline diamond (PDC) have been widely adopted in oil and gas drilling and research is ongoing on their suitability for geothermal application with promising preliminary research results. Drill bit designs also vary and include the conventional tri-cone roller and other innovations such as impregnated and dual-diameter bits as shown in figure 2. These new bit designs last longer and reduce drilling thus lowering the overall cost of well installation.

Figure 2 a.) Tricone roller drilling bit, b.) Impregnated drilling bit, c.) Dual diameter bit [Capuano L. (2016)]

As observed by Cai Y. et al. (2017), real time monitoring and data acquisition through the use of embedded sensors can aid in establishing the status of the down-hole motor and drill tip. Such knowledge can enable site engineers to mitigate drilling disruptions and tool extraction for inspection or repair. By looking at key parameters such as motor torque and spindle speeds, irregularities can be identified early and scheduled maintenance can be more informed and well planned. Such measures may lead to faster well installation and reduced drilling cost.

The concept of digital twin facilitates the above mentioned real time monitoring and control strategy. As highlighted, a digital twin is a virtual duplicate of a physical system. With regards to well drilling, the use of digital twin in operations has not been widely adopted; Haag S. et al. (2018). This research aimed to simulate a geothermal drilling operation where the virtual model was linked to its physical counterpart and real-time data obtained for drilling optimization. Access to actual geothermal drilling equipment suitable for experimentation was found to be difficult and hence the torquing station of a mechatronic assembly system was used as a representation of a typical drilling process.

3 Design of the digital twin for the torquing station in mechatronic assembly system

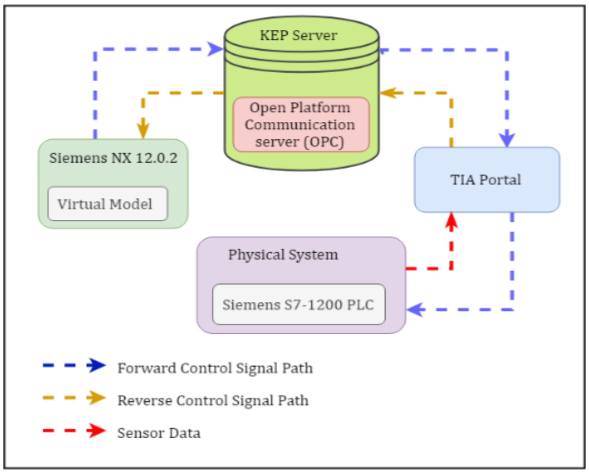

Figure 3: Block diagram of the digital twin implementation

Generally, the implementation of a digital twin for a physical system involves the following components: Virtual Model, Communication Platform, PLC Programming Software and the Physical system as shown in figure 3.

A virtual model refers to a digital representation of a physical system. The digital twin should mimic its physical counter-part in geometry and functionality. The design of the virtual model was done in Siemens NX 12.0.2. Siemens NX is a powerful CAD design software and is integrated with an application known as the Mechatronic Concept Designer (MCD). The MCD helps in assigning physical properties and motions to the CAD models which are similar to those of the actual physical system. The first step in the CAD implementation was acquiring accurate dimensions of the system and creating CAD models of the station components. The entire system was divided into several sub-assemblies. These included: the work piece, slide mechanism, torquing motor and tool, clamp assembly and control panel. Each of these sub-assembly was drawn in Siemens NX and later these sub-assemblies were put together to form the final assembly as shown in figure 4. To enable motion simulation, the physics, material and position control properties were configured into the CAD models and relevant joints assigned to connect the various components of the sub-assemblies.

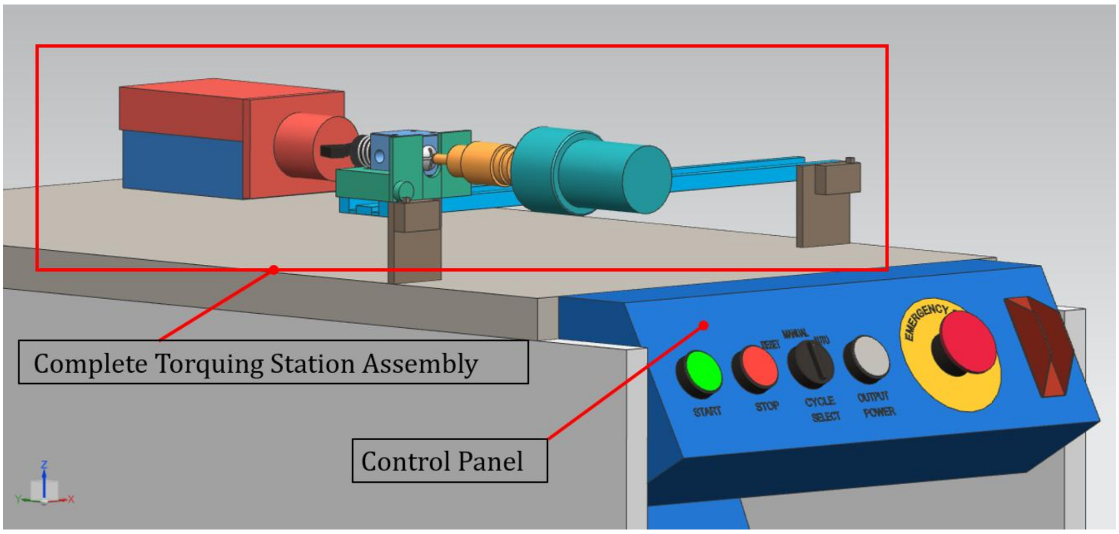

Figure 4: Final assembly of the torquing station

To ensure flow of data and control signals between the physical system and the virtual model, a suitable means of communication was required. An interoperability standard for secure and reliable exchange of data in industrial automation is the Open Platform Communication (OPC). These standards were facilitated via KEP server which provides client server communication. Through the KEP server, information was sent and stored from the digital twin to the physical system and vice versa. TIA refers to Total Integrated Automation portal. It is a Siemens specific platform for programming PLC hardware and enabling online communication, real time monitoring and integration with other features i.e. Cloud computing, Artificial Intelligence control etc. The functionality/various process steps of the physical system were defined and sequenced in code through the use of ladder diagrams. These were then downloaded to the PLC.

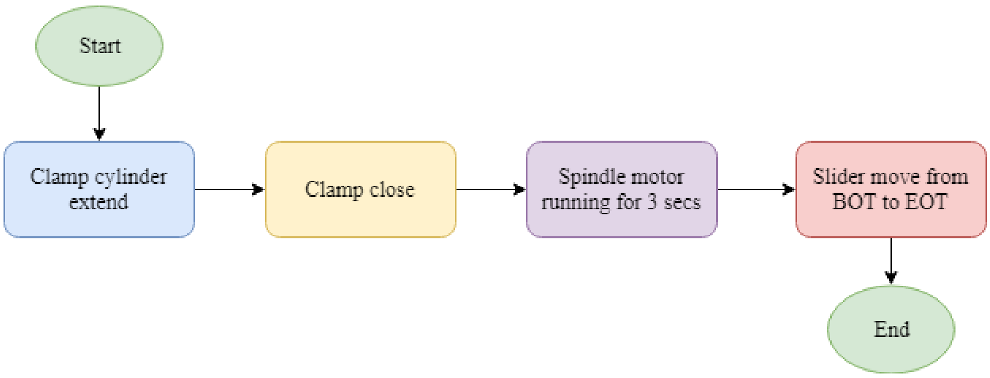

Figure 5: Process block diagram

The torquing station is part of a valve assembly system where, a torquing tool was used to tighten the spool on the work-piece and ensures it was held in place. This torquing action operates in a similar manner to the drilling of a geothermal well. The tooling that torques the valve screw represented the geothermal drill tip while the actual torquing operation represented the actual drilling process. Figure 5 shows a block diagram that highlights the step sequence of the torquing station. Once an assembled valve was placed on the torquing station, it was clamped and held in place by the pneumatic cylinder. After securing the work-piece, the spool screw was tightened by the tooling for a period of 3 seconds. With the torquing complete, the valve was un-clamped and transported to the end of travel of the station. This torquing process can be run under 3 distinct operation modes:

- Automatic Mode: This is the normal autonomous system operation mode, were the machine runs without interference by the user
- Manual Mode: In the event, calibration, repair or debugging is required, the process sequence steps are controlled directly by the user who manually drives the process from one step to the next.
- Reset Mode: During Automatic or Manual mode operation, the reset button can be pressed. This returns the system to its initial position.

As a safety feature of the system, an emergency stop button was incorporated. When pressed, all system operations cease until the system is reset.

4 Discussion

4.1 **Virtual model – CAD design**

Creating the virtual model involved designing the various sub systems and assembling them so that they replicate the actual physical system. This was done in Siemens NX where the various sub-systems; work-piece, slide mechanism, torquing motor, clamp assembly and panel were implemented as shown in figure 6 and figure 7. All these sub-assemblies were then combined into a final assembly previously referred to in figure 4. After adequate configuration each sub-assembly was tested to verify that it operated as intended.

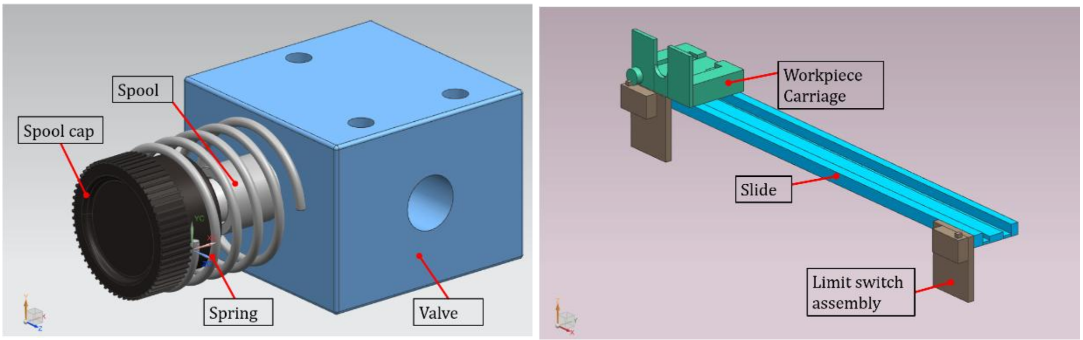

Figure 6: (a) Work piece - Valve assembly, (b) Slide mechanism.

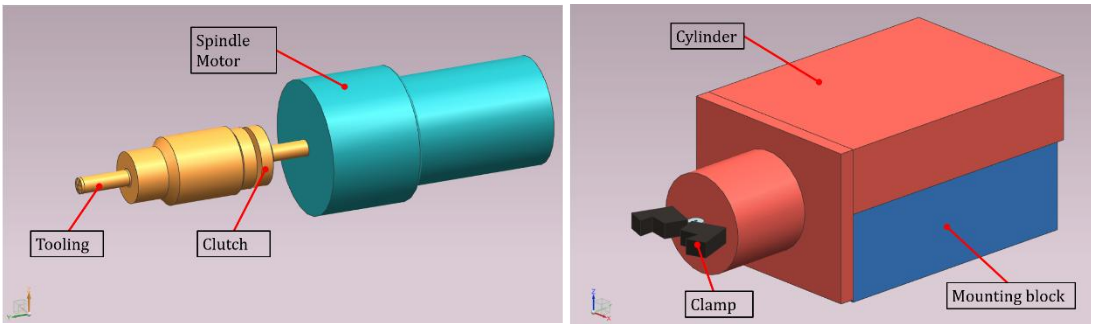

Figure 7: (a) Torquing motor and tool, (b) Clamp assembly.

4.2 **Communication**

Relaying of control signal and data between the digital twin and the physical system was achieved through the use of OPC standards via KEP server. Firstly, Siemens NX was configured to communicate with KEP-Server via the External Signal Configuration (ESC) feature. The ESC feature facilitated the merger between control signals from the digital twin to an external source which in our case was the TIA portal. The TIA portal connected to the KEP-server using link tags that specify sensor and actuator control signals. These tags were then configured in the ESC feature, by assigning them similar names and addresses. This step completed the communication linkage between the digital twin and physical counterpart. The communication was then tested and the status of the links were deemed to be adequate.

4.3 Control Sequence

The process control sequence of the torquing station started by extending the clamp cylinder while checking if the magnetic reed switch was active. If the clamp cylinder reached its limit, the reed switch was activated and the clamp closed. Once completely closed, the inductive sensor became active and the torquing motor ran for 3 seconds. After 3 seconds the torquing motor stopped and the clamp released and retracted. The work-piece was then transported from the beginning to the end of travel via the slider mechanism. A sample of the sequence of operation is as shown in figure 8 which illustrates the last step of the control sequence where the valve body was in transit from the beginning of travel (BOT) to end of travel (EOT).

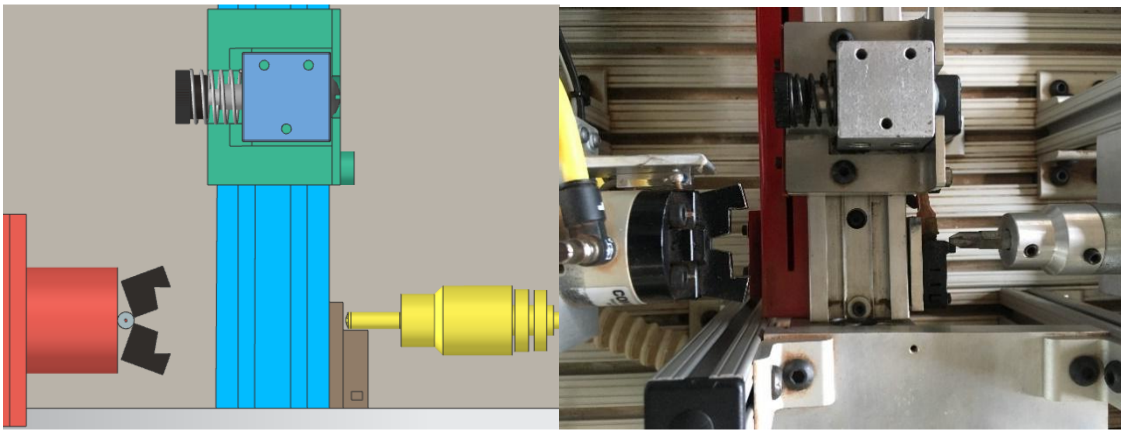

Figure 8: (a) Machine, body in transit to EOT, (b) Virtual model, body in transit to EOT.

5 Conclusion

In light of increasing local and global energy demands, geothermal energy is considered as one of the most promising options. However, high drilling cost limits the quick development and exploration of potential geothermal energy sources. In this paper, a real time monitoring and control method through the use of a digital twin was proposed for use in geothermal drilling. The concept was implemented on a torquing station of a mechatronic assembly system. The first step in achieving this was the creation of a virtual model, linking the model to its physical counterpart and verification to ensure that the functionality of both are synchronized. This goal was fully achieved and tested through the use of Siemens NX and TIA portal which were linked through a KEP-server running the OPC protocol. A future step in this research is the incorporation of sensor data acquisition through cloud computing and analysis of acquired data for optimized control of drilling operations.

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