

Digital Twins in the Industry 4.0 vision: Virtualisation process of a sheet metal punching machine

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Short Abstract: This paper presents the process to virtualise a NC sheet metal punching machine. The results show that the Digital Twin manages to simulate the basic behaviour of the actual sheet metal machine: movements, machining operations and connectivity with robotic arms. The paper concludes with the necessity of going deeper in the virtualisation of the sheet metal machining process, by adding more realistic physical behaviour (heat transfer, accelerations, ...) and connecting the Digital Twin with real mechanical parts under new simulation tools.

Key words: Industry 4.0, Digital Twin, simulation, visualisation.

1- Introduction

It is a fact that the manufacturing landscape is changing by the introduction and adoption of the novel concepts presented under the Industry 4.0 tag. The technologies behind the Industry 4.0 concept will allow manufacturers to create new market opportunities regarding the products and services around the factories of the future.

The concepts addressed by the Industry 4.0 comprise several disciplines: from robotics, computer vision and simulation to knowledge management and big data analysis. Heng [H1] stated that all those technologies behind the Industry 4.0 conceptualisation are lacking of cohesion.

Visual Computing is a conceptualisation of different isolated technologies working together to solve real industry problems. It can be considered as one of the key enabling technologies for the realisation of the Industry 4.0 vision [PT1] and it shows how this mixture of different and complementary technologies, such as Computer Graphics, Computer Vision, Human Machine Interaction and Multimodal and Multimedia Technologies, can emerge from the heterogeneous landscape of technologies [SG1][BR1][IN1].

Simulation techniques can be integrated perfectly with Visual Computing [PT1]. For example, it is quite common in the

gaming industry the utilisation of real-time physical simulation engines to simulate the Newtonian physics: gravity, collisions, forces and friction.

But the industrial processes require harder requirements of what the simulations have to do [DH1], being one of the most important the accuracy of the simulation results. In the manufacturing scenarios, the simulation of the machining processes provides measurable benefits for the manufacturing industries, as lot of resources and energy can be saved and the workers' safety can be increased if the machining processes are optimised.

The design and programming of the machining processes can be simulated virtually. Once this stage fulfils the design objectives and tolerances, the produced NC program is transferred to the actual machine, expecting that the simulation results will match the actual results of the machine. If this happens, the virtual simulated machine is said to be a Digital Twin of the actual machine [A1], and it could receive the feedback from the actual machine and coexists during the manufacturing process.

This paper addresses the creation process of the Digital Twin of a material removal machine so that it can be used within a simulator to obtain valuable information for the designers and programmers without wasting resources.

The next section will describe the simulation case study, including a brief description of the actual machine and the machining processes targeted. Section 3 presents the results obtained after the virtualisation process. Section 4 presents some conclusions and some future work to address the further reduction of the distance between the virtual and real aspects of the Digital Twins.

2- Case Study Description

This section presents the process carried out to create the Digital Twin of a sheet metal punching machine. The Digital Twin of the actual punching machine is composed of *i)* the

3D virtual models, *ii*) the mechanical behaviour (axis movements) and *iii*) the sheet metal machining operations. Also, the interoperation capabilities of the machine with other systems are required. In our case study, we use a robotic lift arm which is used to extract the produced parts during or after the machining process.

2.1 – Sheet metal punching machine description

The case study uses the electric punching machine CHROMA from the DANOBOAT group [CH1], which can have attached a robotic arm to load and unload the sheet metals and produced parts (see Figure 1). This model has a circular turret which can store up to 43 stations and 20 auto-index stations.



Figure 1: Punching machine CHROMA, subject of the case study

2.2 – 3D Modelling of the machines

The 3D models provide the most visual impact regarding the exactness of the virtualisation. The closer to the actual machine, the more realistic immersion will be obtained.

Taking into account that the virtual model will be used in interactive simulations, the 3D models have to be light enough to be used with out-of-the-shelves computers and mobile devices in native applications or through HTML5 web interfaces.

In order to produce the appropriate 3D models, the CAD models of the machine were segmented in separated 3D parts. A polygon simplification and texturing process were carried out to adapt the number of polygons of the models to the interactive capabilities of the simulator and to provide a good looking appearance of the machine.

Each modelled part was assembled into scene graph, where the root node represents the whole machine and each internal node represents moving groups or axis of the punching machine. Therefore, moving an internal node would translate all the elements below it.

2.3 – Punching machine's behaviour model

The punching machine has two main movements: *i*) the sheet movement and *ii*) the circular turret movement. The sheet is moved by clamps attached to the X and Y axis of the machine. The punching action is produced by a tool located in a fixed angle of the turret. The turret rotation allows the machine to

change the current punching tool.

The machine can also modify the clamps' position over the sheet and therefore, the machine can reach further areas of large sheet metals.

The movements of the punching machine are only one half of its behaviour. The other half corresponds with the effect of the punching action in the sheet metal. This behaviour encloses a variety of effects, such as forming, embossing, threading, rolling or stamping, but the material removal is the most used in the sheet metal machining.

2.4 – Relationships with other systems

The CHROMA punching machine can be used independently, but also it can be attached to other modules and cooperate. For example, the CHROMA can be used in combination with a shear module or a laser cutting module. Additionally, a robotic lift arm can be attached to the CHROMA machine to support the loading and unloading of the sheet metals and the produced parts during the machining process.

3- Results

An interactive simulator of the punching process has been developed as a combination of Computer Graphics techniques, simulation techniques and knowledge representation.

3.1 – XML representation

The behaviour of the punching machine and all of its functioning parameters have been modelled and represented as a set of XML files. The simulator loads these files and produces a 3D virtual environment with the specified punching parameters.

The set of instructions of the NC program are converted to a XML file, acting as an abstraction of the different G-code dialects. Using this XML representation of the NC instructions, the simulator becomes independent of the actual G-code instructions which are specific to individual machines.

3.2 – Virtual scene

The virtual scene is created by loading the punching machine and the rest of the virtual elements (see Figure 2). The machine representation is given as another XML file and it basically arranges the 3D models in a graph representation. This XML file allows multiple configuration of the punching machine, including the definition of the circular turret and its available stations.

The rest of the elements may be just decoration 3D models (floor, building structure...) but also the robotic lift arm can be added to the scene and attached to the punching machine. Both elements have to cooperate and therefore, they exchange relevant information for both of them. For example, the robotic arm lift has to know where the zero

point or origin of the punching machine is, as it will be the reference to pick elements from the sheet metal, i.e. it defines the machine reference system.

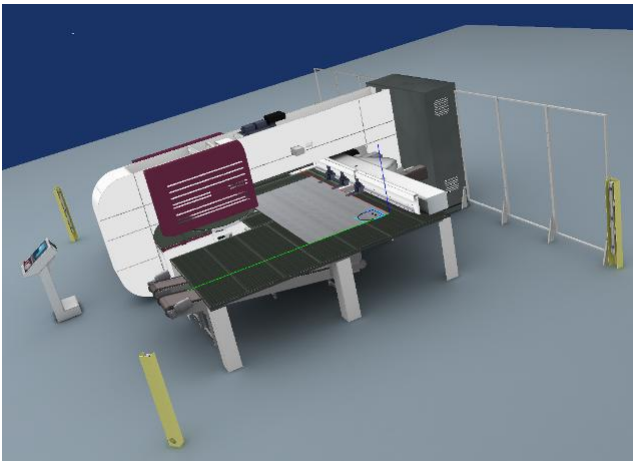


Figure 2: Digital Twin of the CHROMA punching machine

3.3 – Machining operations

Once the virtual scene is generated and the set of instruction is loaded, the simulation can begin. Each instruction defines precisely the targeted point of the sheet metal, its path (linear or arc), and its speed (linear speed or angular speed). Any other instruction is also timed. For example, the tool change instructions specify the amount of time that the simulator has to wait to complete the action. The simulator manages internally the punching machine state, which includes the current punching tool and the sheet position. Therefore, the punching machine can operate on the sheet metal appropriately when a punching instruction is executed.

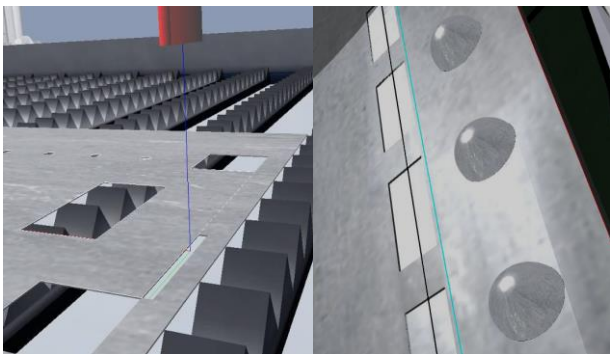


Figure 3: Punching operations

The punching machine main action is to punch the sheet with a loaded tool in the punching position. At the exact punching time, the tool is projected very fast towards the sheet metal and then, it returns to the resting position. While the tool is on the sheet metal, a geometric Boolean operation is performed between the tool and the sheet metal's geometry (see Figure 3). Although normally Boolean operation between 3D solids is computationally expensive, we simplify it by assuming that the Boolean operation can be performed between the 2D contour of the tool and the 2D representation of the sheet metal. Even with this optimisation, the geometry of the virtual sheet metal can become very complex and therefore, even the 2D Boolean

operations are slow. We have introduced a spatial subdivision to address this issue successfully [MS1].

The typical punching operations are oriented to cut the sheet metal (producing holes in it), but there are many other punching instructions which modify the sheet metal's geometry in different ways. The virtualisation process of such instructions improves the realism and capabilities of the simulator. The current implementation of such advanced punching instructions allows the deformation of the sheet metal's geometry to support several expected outputs: forming, embossing, threading, rolling and marking.

3.4 – Part extraction with a robotic arm

An optional robotic arm can be attached to the punching machine to automate the unloading of the machined parts during the simulation (see Figure 4). The lift is fully customizable. It can have any number of strips in X or Y directions. Each strip has a number of suction cups that will be the ultimate responsible for lifting the sheet metal parts. They can be activated individually or in predefined groups. The arrangement of the suction cups is also configured in separate XML files.

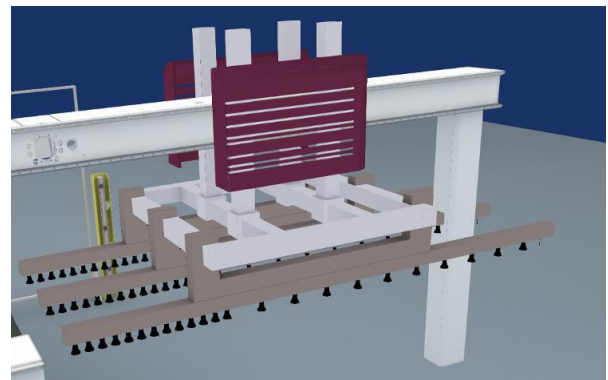


Figure 4: Robotic arm attached to the punching machine.

A specific NC instruction is used to activate the lift, passing the target point as parameter of this instruction. The lift will use this reference point and its own configuration (regarding axis orientation and strip configuration) to move the 3D models towards the specific point over the sheet metal. This movement is not a direct line from one point to another. It is decomposed in X, Y and Z movements, and the movements are sent in that specific order.

The behaviour model of the robotic arm is completed with the unloading action, i.e., when the arm returns to the resting position with the loaded parts. The deactivation instruction does not require additional parameters, but the movements of the axis have to be inverted: Z, Y and X. At the end of the movement sequence, the parts are unloaded.

From the sheet metal's point of view, a geometric operation has to be done to detect if there is loose parts under the active suction cups of the lift. The spatial subdivision breaks the sheet geometry into disjoint pieces, and therefore, any knowledge about the existing parts inside the sheet is lost. Using Computer Vision techniques like flood filling

algorithms, the loose parts can be reconstructed, segmented, detected and finally, removed from the rest of the sheet metal's geometric representation.

4- Conclusions and Future Work

This paper has shown how a Digital Twin of a commercial punching machine has been created. The process can be divided in several stages: *i)* model in 3D the individual parts of the machine, the parts of the robotic arm and any other 3D elements, *ii)* extract the behaviour of the machine and create a knowledge representation, *iii)* establish the relationship between the machine and the robotic arm and integrate it to the knowledge representation, *iv)* model the machining operations and the effects on the sheet metal and *v)* design and develop a functional simulator where all pieces cooperate to bring a virtual experience to the users of the actual machining operations.

Even if the results show a clear resemblance with the output of the actual machining processes, there is room for improvement. For example, the physical parameters of the process are not taking into account. The current implementation can punch sheet metals with any thickness with the same punching force. Also, deformations in the sheet metal's edges due to the punching force are not simulated. The implementation of all these physical behaviour in the simulator will bring the Digital Twin closer to the actual machine, closing the distance between reality and virtuality.

The connectivity and synchronisation of the Digital Twin with the real punching machine has to be explored. It is expected that the feedback coming from a working punching machine could be pass to its Digital Twin. Then, the simulator would replicate virtually the movements and reactions of the real punching machine.

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