RAPID PROTOTYPING of ROBOTIC PLATFORMS

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ABSTRACT

Building a robotic platform from raw materials can take anything from a few weeks to a few years to complete, depending on the complexity and size of the platform. This paper aims to introduce a novel approach of using abrasive waterjet machining for manufacturing a fairly complex robotic platform within a few days.

Two robotic platforms built using this approach will be discussed. These platforms are all-terrain vehicles, used as a mine inspection robot (Shongololo) and as agricultural inspection robot (Dassie), respectively. The advantage of using abrasive waterjet machining is the speed and precision at which the final product can be produced, with little to no additional finishing required.

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INTRODUCTION
The need for robotic platforms is increasing as many industries are moving towards automation. Being able to rapidly manufacture prototypes and demoing them to clients can give a company a big edge over its competitors. Abrasive waterjet machining is proposed as a method to manufacture robotic platforms rapidly. The waterjet enables one to rapidly manufacture large panels straight out of CAD with minimal setup time, experience and training required to achieve great results.

Almost any material in the range of thickness up to 200mm can be cut to create prototype chassis/ bodies or even the final product. One of the few limitations is the cutting of certain laminated materials, as this tends to produce delaminated cutting edges or even fractures in the case of laminated glass. Therefore materials which are both light weight and strong such as aluminium can be used, but also different engineering plastics and composites. This enables one to design and built platforms which are quite ruggedized and can be used in varying environments for different applications.
The first platform manufactured using this approach is an all-terrain inspection vehicle to be used in vineyards (Dassie) and the second platform that could have been manufactured using this method is a mine inspection robot (Shongololo).

Shongololo's frame is made from engineering plastics while the chassis of Dassie was made from aluminium and cut using abrasive waterjet machining. The advantage of using abrasive waterjet machining is the speed at which the final product can be achieved. Whereas solutions such as LASER cutting requires additional finishing such as deburring and for deeper cuts to straighten the cut, the waterjet gives a clean result requiring hardly any additional finishing. The chassis are made up of different sheets with internal shapes cut out to reduce the weight of the robot. Most mounting and screw holes can also be cut into the sheets.

1. WORKINGS OF ABRASIVE WATERJET MACHINING

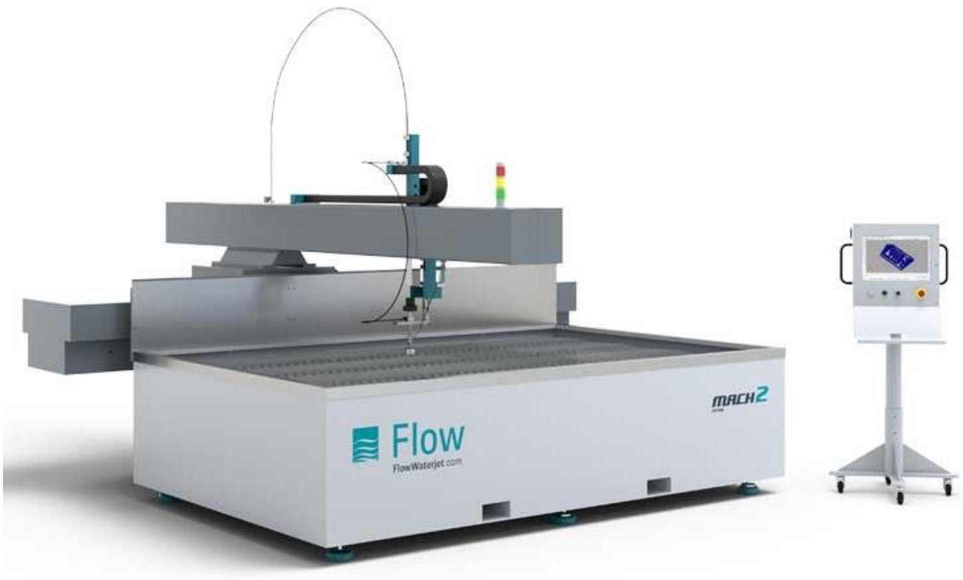

Figure 1: Picture of an abrasive waterjet machine [1]

The power of water is known to most of us if you have ever seen water cannons being used to disperse protesters, cars swept away in floods or the water spewing from sluices of a dam. The process of abrasive water jet machining uses this power by adding an abrasive material and focusing the jet on a small area of the material that needs to be cut. The pressure energy of the water is transferred into kinetic energy of the water and abrasive material. This is done by exhausting the high-pressure water and the abrasive material through a small nozzle (0.1-0.4mm). The water is pumped to pressures between 150 – 400 MPa [2] before it is transferred to the nozzle. The abrasive material is mixed into the water just before exhausting through the nozzle. Many different kinds of abrasive material can be used; some common abrasive materials are granite, sand, and titanium. The fine jet of water travels at a high velocity, which results in a high kinetic energy. The impact of the abrasive water jet colliding with the surface of the object that needs to be cut corrodes the material away and makes a fine cut [3]. A picture of an abrasive waterjet machine can be seen in Figure 1.

The heart of abrasive waterjet machining is the abrasive nozzle that transfers the potential energy of the high-pressure water into kinetic energy of the abrasive that does most of the cutting of the material. A schematic of a nozzle can be seen in Figure 2. The key element is the jewel orifice that transfers the water from a high-pressure state to a high-velocity state, enabling it to carry a high amount of kinetic energy. This high-velocity water is then mixed with an abrasive material such as granite in the mixing tube. The combination of the high-velocity water and the high kinetic energy enables the waterjet to cut through almost any material.

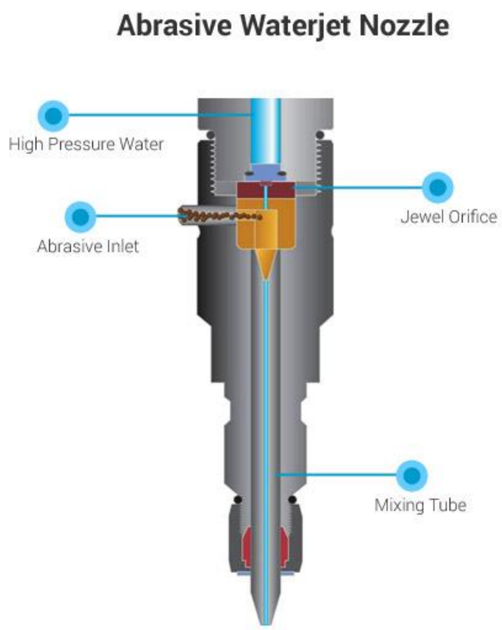

Figure 2: Picture of a waterjet Nozzle [4]

Compared to traditional machining methods like milling, abrasive water jet machining might be a bit slower, however, this is counteracted by the amount of time saved during the setup of the material. There is also less clean-up needed of the machine as waste material is washed into the water bed, which does not have to be cleaned after each job. Multiple parts can also be cut from one sheet on a single run of the water jet, saving time and reducing material waste. The water jet also saves time because all cuts are made with a single nozzle and no tool changes are needed as with most traditional methods [3]. A wider variety of materials (metal, composites, stone & tile, glass, stacked material, etc.) can be cut with a water jet when compared to most traditional machining processes. This is because abrasive water jet machining is not as affected by the properties of the material being machined [5].

Some of the key advantages of abrasive waterjet machining are listed below:

1. The nozzle focuses the water jet so that narrow cuts are possible, thus saving material
2. There are no heat-affected zones after cutting as experienced with other methods like plasma and laser cutting. This means no melting of materials (such as plastic), and metals do not harden at the cut edge.
3. Cutting plastics does not release toxic gas as is the case with cutting PVC with a laser cutter
4. Material that would clog blades during mechanical cutting can be cut with ease
5. Abrasive waterjet machining can be used in the explosive environment as the chance for a spark or large heat generation is small.
6. Abrasive waterjet machining is ideal for cutting re-enforced composites, as there is no cutting tip that dulls and the fibre dust is also kept out of the air by the water [6].

2. DESIGN METHODOLOGY FOR A WATERJET

In order for one to take full advantage of the capabilities of a waterjet, one needs to adapt the design methodology one takes in designing a product.

- The waterjet has a uniform tolerance that does not fluctuate much between materials. This enables one to take this into consideration at key areas in one's design.
- The speed of the waterjet is fully unutilized when more than one component is cut in a single job as shown in Figure 3.
- By standardizing on one thickness of material, a single sheet can be loaded and all parts can be cut in one job, dramatically accelerating the manufacturing time.
- Manual or automated nesting of multiple parts into a single sheet can also dramatically reduce the amount of wasted material.
- All holes and pre-drill for tapped holes can be cut at acceptable tolerance on the waterjet which again dramatically reduces the amount of finishing work needed before assembly can start.

- If high accuracy holes or shapes are needed, a slightly smaller cut-out can be made on the water jet and a finishing cut can be made by a mill or other traditional machining tool.
- Complex shapes can be realized by using flat interlinked sheets. Combining this with technologies such as high strength epoxy metal bonding can eliminate long assembly times or skills required to realize a product.
- Bending lines can be scribed in on the material by the water jet which at that stage uses water without abrasive to mark the material. Thereby saving significant measuring time when bending the parts.
- Radii can be designed in on external corners to make handling of parts safer by removing sharp points

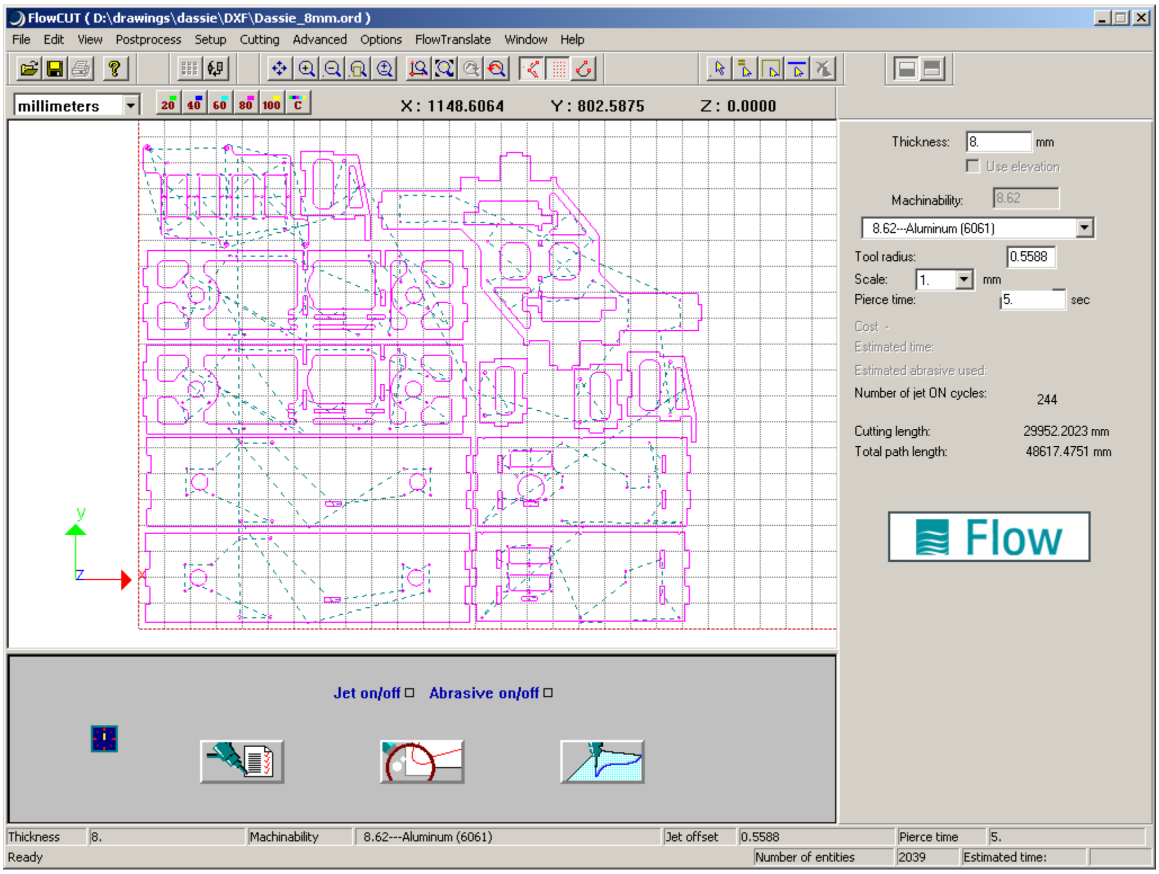

Figure 3: Nested Path for Dassie Parts

3. ROBOT DESIGN EXAMPLES

3.1 Shongololo

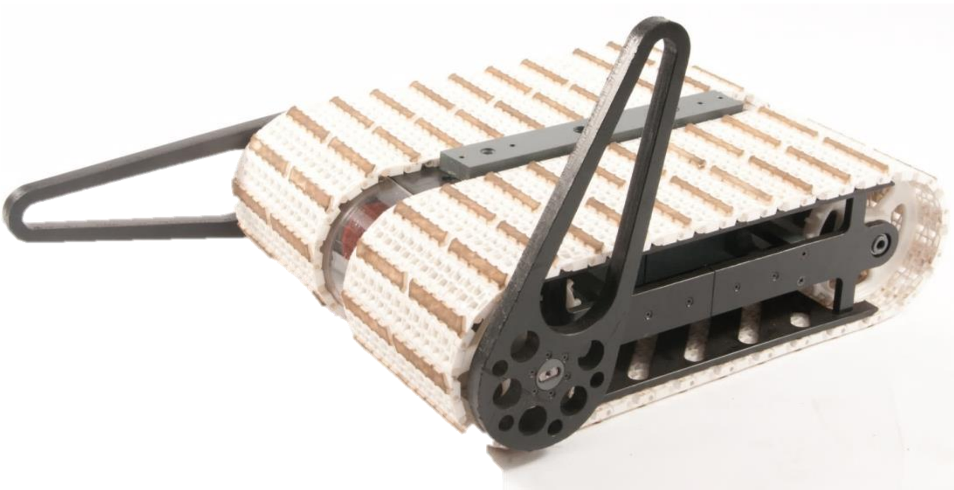

Figure 4: Picture of Shongololo

The aim of this project was to design a robotic platform that can operate in the underground gold mines of South Africa. After each blast in the mine, a waiting period of between 3 to 6 hours is enforced to allow the blasting fumes to be ventilated away and for the seismic activity to settle. During this waiting time no personnel is allowed to enter the area. This time can, however, be utilised by robots as they are less sensitive to blasting fumes. Robots that can do an inspection of the surrounding rocks and supporting pillars after the blast, will improve the safety for the human crew and save the mine time and money [7]. A picture of the complete robot platform can be seen in Figure 4.

The conditions in the mine are very harsh and due to the nature of the South African gold mines, the stopes in the mines can be very challenging for a robot. Multiple prototypes were created within short time spans to test different methods to solve the traction problem. Shongololo was one such solution; a tracked robot with articulating arms to improve manoeuvrability [7].

The chassis was manufactured from an engineering plastic called ABS. The platform needed to be low weight to ensure it could transverse the steep slopes. This was in part achieved by cutting material from internal plastic sheets to reduce the weight. The chassis was manufactured by means of a router table as this was available at the time of construction, but the same design and process could have been manufactured by means of abrasive waterjet machining and would have given better results.

If the project had to be redone on a water jet some small design alterations could be done to speed up the manufacturing, such as the use of a single thickness for all of the ABS parts, allowing for a single cutting session of a sheet of material. The sprockets to drive the tracks could also be cut on a water jet. Using this process would have saved a lot of material and time.
The strength of Shongololo’s resulting chassis is shown in Figure 5.

Figure 5: Shongololo supporting the weight of a male subject

3.2 Dassie

Figure 6: Photo of Dassie

The goal of the Dassie robotic platform was to develop a rugged robotic vehicle for the purposes of security patrols and inspection applications. The aim was to create a platform that was modular, all terrain, maintenance friendly, and low cost. The developed prototype was applied in the vineyards at the University of Stellenbosch's viticulture division. A photo of the completed platform can be seen in Figure 6.

The platform carries sensors that inspect different aspects of the vineyard. The payload included a SICK laser and a high definition camera. The data gathered by these sensors, in combination with an IMU and encoder data, can create a 3D map of the scanned vineyards. The map can be used to estimate crop yield, inspect the health of the vines and calculate leaf coverage.

The platform needed to be low weight so as to not disturb the ground in the vineyards. Aluminium was chosen to create the chassis of the platform. The chassis was 8mm sheet aluminium and the cover 2mm aluminium, meaning only two sheets had to be cut on the water jet to get all the parts for the frame. The chassis is made from different plates that fit into each other. Holes for the shafts and mounting holes for different components were all cut by means of abrasive waterjet machining. Shapes were also cut from the plates to reduce the weight of the chassis. Finite Element Method (FEM) analysis on the Computer Aided Design (CAD) of the chassis can identify low-stress areas of the chassis that can be cut away.

A fast curing epoxy material was used to integrate the various internal and external plates, speeding up the manufacturing process considerably whilst giving a larger carrying capacity through the larger contact area of the bonds. An added benefit is the fact that the chassis is now sealed from the outside world, which was a design requirement, and is now achieved through a single manufacturing process.

The chassis design for Dassie can be seen in Figure 7. Relatively complex 2D shapes were cut from the plates. The different sheets have slots and tabs cut into them with the water jet, which fit into each other to ease assembly and improve rigidity. After the different sheets are fixed together, a complete chassis is formed. The only finishing needed on the plates was a light deburring of plate edges, countersinking and tapping mounting holes for mounting of internal components.

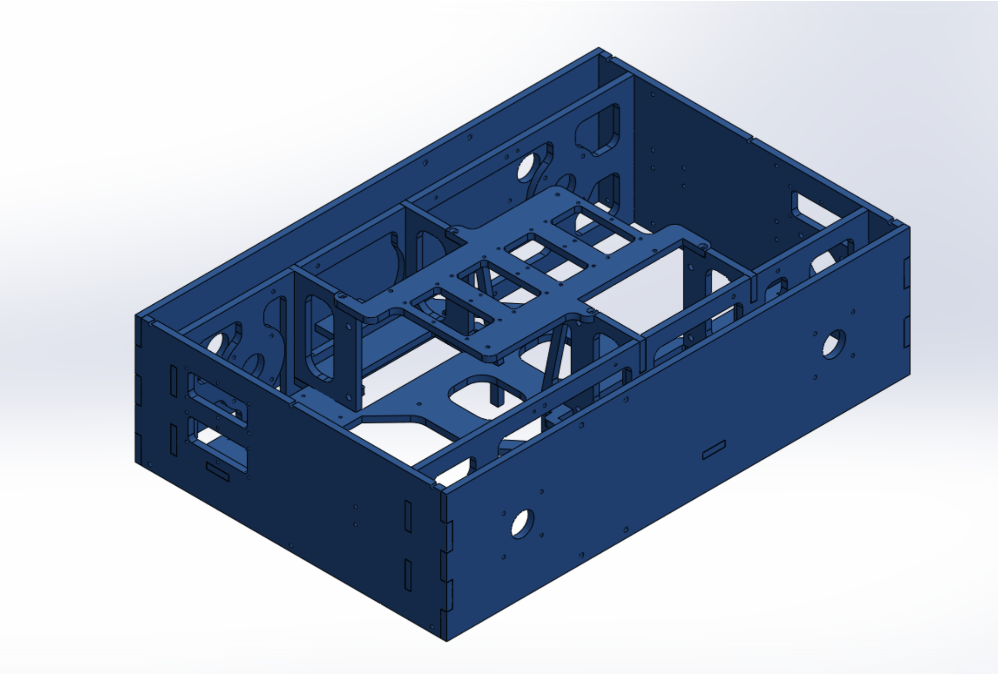

Figure 7: Computer Aided Design of the chassis for "Dassie"

The load carrying capacity of the platform was designed to be 40kg and this was demonstrated when Dassie carried a person whilst driving through the vineyard, proving the soundness of the epoxy bonding solution.

4. CONCLUSION

Using abrasive waterjet machining simplifies the manufacturing process for prototyping and small production runs of robotic platforms. This approach allows for the construction of medium size robotic platforms with varying complexity in a matter of days compared to weeks using the more traditional machining methods. Various machining and manufacturing steps are eliminated using the waterjet methodology whilst the amount of materials wasted can also be greatly reduced.

One must remember that the water jet is only a tool, and still a proper design process is needed to ensure the success of the resulting product.

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