How OFFWorld's Swarm Robotic Mining Architecture is opening up the way for autonomous Mineral Extraction – on the Earth and beyond

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ABSTRACT:

Mining is one of the oldest activities of humanity, as the extraction of stones, ceramics and metals proved to be essential to develop tools and weapons and to drive forward human civilisation. Possibly the oldest mine – the "Lion Cave" – dates back to 41 000 BC. Located in Swaziland, its pre-historic operators mined haematite to make red-pigment ochre. The mine was likely in operation until 23 000 BC and at least 1200 tons of soft haematite had been removed in this timespan.[i] As time progressed, mining diversified and production methods improved. The ancient Egyptians, Greeks and Romans mined different minerals, such as malachite, copper and gold. Philipp II, the father of Alexander the Great, is believed of having conquered gold mines in Thrace, which provided him with 1000 talents (26 tons) of gold per year. Needless to say that Alexander's conquests would have not been possible without these extensive mining operations.[ii]

Over the ages, mining activities continued to intensify. Today, a tier-one open-pit copper mine like Chuquicamata in Chuquicamata, Chile, with a depth of 900 m, provides for a production of 443,000 tons of copper and 20,000 tons of molybdenum p.a.[iii] Naturally such levels of production come with a price tag. Thousands of workers, numerous heavy machines and investments that go into the millions and billions are required to set up a mine and to maintain its operation. At the same time large amounts of waste – the so-called tailings – are generated, often posing a significant environmental risk. The fact that ore yields have dramatically decreased over time has worsened the situation; today, the extraction of 1 ton of metal ore requires vast amounts of energy and can easily generate hundreds of tons of waste.[iv] Were it not for a significant technological progress in the extraction, transport and processing of the ores, today's mining operations could not be sustained.

Despite all these technological advances, the mining industry is at a decision point. The conventional trend of the last hundred years of counteracting shrinking ore yields by making the mining machinery faster and bigger is at its limits. Today's ore haulers weigh as much as 600 tons and require a net engine power of 2722 kW [v] to sustain operation. At the same time waste heaps have grown larger and larger – operations are clearly at their physical limits. Time is running out for enhancements and improvements, if mining is to

continue, a drastic paradigm shift seems to be the only solution. This paradigm shift will require humanity to mine more efficiently and intelligently, by aiming to extract only these rocks that contain the ore and doing so in a manner, which results in the smallest possible ecological footprint. This is where OffWorld's Swarm Robotic Mining Architecture comes into play.

The overarching purpose of OffWorld is to enable the human settlement of space by developing a new generation of small, smart, learning industrial robots. This robotic workforce has numerous things to do: build landing pads, excavate underground habitats, extract water ice and materials, make drinkable water, breathable air and rocket propellant, manufacture basic structures and solar cells, produce electricity, etc. OffWorld's overall vision is to operate thousands of robots that can mine, manufacture and build on the Moon, the asteroids and Mars. These robots need to be small and robust, extremely adaptable, modular and reconfigurable, autonomous and fast learning – they are lightyears ahead of the 2 million industrial robots that currently work in factories and warehouses.

Space is a tough place. The environment is harsh, resources are limited and the room for errors is close to zero. If a robot can succeed in space than it can surely excel in the terrestrial industry as well. This and the fact that OffWorld builds a swarm approach that relies on a small form factor, intelligence and surgical precision, has the potential to reduce the total cost of operations, can shorten the life of mine or industrial operation and can be easily scaled up and down in size. With all these benefits in mind, OffWorld is looking into a reduction in the total cost of operations of at least an order of magnitude within any industrial sector. This paper will introduce the design philosophy behind OffWorld's robotic workforce and will present the masterplan for developing space-bound systems by first maturing them in large scale deployments in terrestrial industries.

REFERENCES

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[iv] "500 years ago, copper was extracted from ores containing 8-10% of metal; today this ratio has fallen 0.35% - to produce 1 ton of Cu, 285 tons of ore need tob e digged.", stated in Consequences of over Exploitation of Mineral Resources, Debjani, http://www.preservearticles.com/2012021323185/consequences-of-over-exploitation-of-mineral-resources.html, accessed in April 2017

[v] Such as the Liebherr T 282B mining truck