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Reinforcement Learning based Autonomous Mobile Mechanical Manipulator based Mechanical Engraving System

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ABSTRACT- This technical paper, outlines and discusses the design and testing of the Autonomous Mobile Mechanical Manipulator based Mechanical Engraving System . The manipulator utilizes Hindsight Experience Replay in combination with DDPG off-policy Reinforcement Learning Algorithm in order to learn and perform tasks like engraving a square on a surface. This paper acts as a highlight to the recent developments in the field of Industry 4.0 and finds an application of latest state of the art research in the field of Reinforcement Learning in the field of Manufacturing. The current Proof of Concept to the authors ultimate goal of creating a Mobile Laser Cutting System along with Human Avoidance capabilities which is comprehensively discussed in future prospects of this paper.

I. INTRODUCTION

Industry 4.0, is a new concept in which industry utilizes technological developments in fields of robotics, automation, and artificial intelligence, among other things to enhance productivity of its operations. Robotics is gaining popularity in a variety of businesses throughout the world. Both humans and robots have benefits and drawbacks. Working together in a safe manner will yield a higher-quality, more precise output in less time. The main goals of robotics and Industry 4.0 are to boost productivity, produce high-quality products at a low cost, and meet customer expectations.

Role of Robotics and Automation in Industry 4.0

Robotics is part of Industry 4.0. According to Technavio Research's new study 116, 'Robotics' is on the rise every day, owing in large part to Industry 4.0's ascent. The fundamental goal of Robotics Industry 4.0 is to build a smart industry where things can navigate their own way through production and establish backup plans in the case of a disruption.

Robots are used for a variety of tasks, including production, shipping, and office management.

Predictive Maintenance can also be done with robots.

Mobile robots are collaborative in nature, and the purpose of design is for them to work safely with humans. Mobile robots employ sensors, software, and some hardware to locate their environment.

Collaboration between humans and robots is critical in Industry 4.0. The robot supports the human operator in human-robot collaboration. It frees humans from boring duties such as moving large loads from one location to another. Collaboration aims to bring together the skills of humans and machines in order to produce more precise and accurate results.

The following are a few examples of robotics applications in Industry 4.0:
In the manufacturing industry:
There are several challenges that come with labor. Operating costs and a lack of competence are the two most major problems. One solution to this challenge is automation. Experts predict that machines will take over tasks that are too

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physically demanding or dangerous for humans to perform, such as installing hybrid batteries weighing more than 100 kg. Industrial robots are used in conjunction with current technological advances to improve the industry. Robot-based inspection systems are used in vision systems to detect faults in various parts and ensure proper part assembly.

Automobiles: As the world's population expands, so does the number of traffic accidents. The question is how to cut down on the amount of traffic collisions. Autonomous vehicles are used in a variety of industries, including manufacturing, mining, agriculture, logistics, and transportation. Material is transported to a warehouse using automated guided vehicles 637 (AGVs).

In the past few years reinforcement learning has gained many accomplishments in the field of sequential decision making issues such as the problem statement of this research paper using a mixture of reinforcement learning network and Deep Learning. This ranges from playing Atari games in a simulated environment to controlling a helicopter in a physical environment. We are going to discuss it in this paper. In this research, we utilize a state of the art RL algorithm of Hindsight Experience Replay (HER) with an off policy algorithm, in order to make our mechanical arm learn to perform tasks like sliding the engraver over machining surface. This algorithm which is precisely made for obtaining each condition of the network as a different objective improves efficiency in our situation. The core concept of HER is to reiterate all events with a distinct target from the one that the deputy was attempting to arrive at, and improve upon it until the desired goal is achieved..

A. Why we chose this Project

Robotics, in our perspective, is rapidly evolving and is infiltrating every aspect of our life, ranging from simple toy bots like the buzzing bee bot to advanced bots like the 'Eagle 2.0,' which is being utilized as a teaching aid in schools to help students understand concepts more clearly. Robots are also being used to assist or execute surgery, such as the 'Da Vinci Xi,' a manually operated robot that assists surgeons in doing accurate, minimally invasive surgeries.

Existing laser cutters and engravers are controlled by gantry frames housed in bulky box structures, ensuring the safety of human operators and preventing any unexpected accidents. As a result, larger frames are required for cutting and engraving larger structures, and the cutter is immobile due to the larger frames and high weight.

One of the most important factors affecting precision in such structures is workbench accuracy, which means that the workpiece on the workbench must be positioned extremely precisely for laser beam/Engraver cut locations to be accurate; additionally, the workbench must be absolutely flat and accurate, with no vibration; however, achieving such a level of positioning accuracy is difficult and a prominent task for large workpieces that require a high level of detail both in their extrinsic and intrinsic details (i.e car chassis).

To reduce errors caused by misalignment of the workpiece and laser cutter/Engraver, we use a mechanical manipulator setup that provides the cutter with a high level of mobility and degrees of freedom, allowing the light weight cutter to approach intrinsic and extrinsic parts of heavy and large workpieces at desired orientation and position, thereby improving the ease with which precision can be obtained during the laser cutting process or Engraving process..

B. Goals for the Project

The following are the goals for this project:

1. Develop a Sensory system that can detect proximity or presence of human being in the range of the Laser Cutter Bot
2. Design the Robotic Manipulator based Engraving system to maximize the reach and increase mobility

The Desired output of the project is to design a mobile and light bot that can be safely utilized to cut and engrave in a workpiece.

II. METHODOLOGY

A. Reinforcement Learning

Policy and Q-Learning

The aim is to find an optimal policy for our setup which tells our setup how to act in a particular state.

Q-learning is a trial and error based reinforcement learning algorithm, hence called environment model free, hence does not use reward function associated with MDP and associated difficulties with it for adjustments.

Q-learning method follows the following steps:

1. Sample an action.
2. Keep an eye on the following state and the reward..
3. Take the action that has the best Q..

If an optimal policy is given by $\pi *$ such that$Q\pi$ (s, a)$Q\pi *$ (s, a) for any policy and each $s \in S$, $a \in A$..

Optimal policies are recognized by optimal Q-function, which is denoted as Q∗ and satisfies the following Bellman equation:

.Q ∗ (s, a) = Es 0∼p(·|s,a) r(s, a) + γ max a0∈A Q ∗ (s 0 , a0)

Deep Q-network (DQN)

DQN is a trial and error based reinforcement learning algorithm, hence called environment model free, but unlike normal Q-Learning its for discrete action spaces. DQN utilizes a deep neural network which is denoted by Q and maintains it in order approximate a state value function Q∗. It is a greedy policy with respect to Q that is it takes an action randomly from action space and takes action πQ(s) with probability 1 - probability with which it takes action. The greedy policy is defined as:

πQ(s) = argmax∈AQ(s, a).

While training this policy will generate episodes and transition tuples are stored in a replay buffer with Deep neural network training happening between pages on mini batch gradient descent such that policy satisfies Bellman Equation.

Hindsight Experience Replay: HER

Hindsight Experience Replay is a state of the art reinforcement learning method that allows users to learn from their mistakes and effective policies based on a small number of rewards.

Hindsight Experience Replay (HER)

Initial Data Provided:

• an off-policy RL algorithm A, . e.g. DQN, DDPG, NAF, SDQN

• a strategy S for sampling goals for replay, . e.g. S(s0, . . . , sT) = m(sT)

• a reward function r : S × A × G → R. . e.g. r(s, a, g) = −[fg (s) = 0]

Initializing DQN

Initializing replay buffer R

for episode in range(1, M) :

Get a sample of a initial state s0. and goal g

for t in range(0 , T-1):

An action is sampled using the behavioral policy from DQN:

at ← πb(st||g) refers to concatenation

Action at is executed and new state st+1 is observed

exit for loop

for t in range(0 , T-1):

rt := r(st, at, g)

Transition (st||g, at, rt, st+1||g) is being stored in R .standard experience replay

A set of additional goals for replay G := S(current episode) is sampled

for g′ belonging to G

r′ := r(st, at, g′)

Transition (st||g′, at, r′, st+1||g′) is stored in R . HER

exit for loop

exit for loop

for t in range (1, N) :

Minibatch B from the replay buffer R is sampled

Perform one step of optimization using DQN and minibatch B

HER performs what humans do instinctively: we pretend to have reached the goal where the puck is even when we didn't get it. Because it has fulfilled a goal, the algorithm receives any form of signal for learning how to set the next goal in order to reach the final goal as a result of this experience with hindsight experience is replayed .

In order to improve accuracy, Hindsight Experience Replay can be paired with any off-policy RL algorithm. We're utilizing HER + DQN in our configuration of setup.

III. SETUP

The experimental setup of the Mobile Mechanical engraver can be discussed in two following subparts:

A. Mechanical Arm

The Mechanical arm setup consists of a 3D Printed 5 DOF Mechanical arm built up using PLA material as base.It is actuated using one MG996R standard servo, ttwo standard Futaba S3004 Servos and 2 SG90 micro servo with gripper holding the 100g Mechanical engraver. The servos are controlled using an Arduino mega which tends to receive data from an Xbee Communication module acting as telemetry between the Setup and Ground Control Station. The ground station utilizes prebuilt Reinforcement Learning Environment which computes positional data as per methodology and converts it into angular format using a python module and transmits it over to setup using 2.4 GHz Xbee communication channel.

B. Rover

Considering high machining accuracy, strength and reliability requirements, a chassis was developed for the UGV consisting of an aluminum base and a 3D printed structure, designed to be compact to house the battery and electronicss. This setup is powered by a LiPo 3S battery and localizes itself using an onboard GPS. This chassis is supplemented by a caterpillar track based drive

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mechanism that rests on two wheels on each side and is propelled by two 12V DC Motors controlled by a Cytron MDD10A Dual Channel Motor Driver and a Pixhawk Cube Autopilot. The caterpillar track system simplifies turning and is highly durable, fit for a drive in any terrain.

IV. FUTURE PROSPECTS

The main goal of the paper was to use reinforcement based learning's strong points to teach robots manufacturing operations. As a result, we don't want to limit it to engraving operations and instead want to expand and develop the application to the field of laser cutting and welding for efficient chassis and pipeline welding.

The Laser Cutting and Welding System

Laser cutting is a method of slicing materials by the use of a laser. The most common way of laser cutting is to direct the output of a high-power laser through optics. Laser optics and CNC are used to direct the material or laser beam generated (computer numerical control). A focused laser beam is used to target the material, which melts, burns, vaporizes, or is blown away by a jet of gas, leaving a sharp edge and a high-quality surface finish.

Laser cutting uses three different types of lasers. Cutting, drilling, and engraving are all possible with the CO2 Laser. The neodymium (Nd) and neodymium-yttrium-aluminum-garnet .The only difference between Nd:YAG lasers and other lasers is their application. Nd is utilized for boring and when a lot of energy but not a lot of repetition is needed. The Nd:YAG laser is utilized when very high power is required, as well as for drilling and engraving. Welding can be done with both CO2 and Nd/Nd:YAG lasers. Fiber lasers are a type of solid-state laser that, unlike CO2, utilizes a gain medium that is solid rather than a gas or liquid. The "seed laser" generates the laser beam, which is subsequently amplified within a glass fiber. Fiber has a number of advantages over CO in this regard.The following are some of the advantages of using a fiber laser cutter:-

- Quick processing times.
- Energy usage and expenses are reduced as a result of increased efficiency.
- There are no optics to tune or align, and no bulbs to replace, thus the system is more reliable and performs better.
- Minimal upkeep is required.
- Lower operational expenses equate to higher productivity and a higher return on investment.
- When compared to a CO2 laser beam, it allows for easier beam distribution over fiber-optic cables without the need for mirror alignment
- Metals, especially good conductors, absorb more of it, while plasma vapors generated above the weld pool absorb less.
- Fiber lasers have a higher power intensity because they can be focused to smaller sizes.
- Because light is already present in a flexible fiber, it may be simply transmitted to a mobile system. This is particularly beneficial for laser cutting with a mechanical manipulator.

Points of Casualties in Laser Cutting

- The high-energy laser beam is invisible and can inflict serious eye damage, including blindness and severe skin burns.. The laser beam is disabled when the doors are opened since they are linked. Under typical circumstances, this will totally enclose the laser beam.
- Improper use of the controls, as well as tampering with the safety measures, can result in significant eye injuries and burns.
- As the substrate material is burned away during cutting, the high-intensity laser beam can produce extremely high temperatures and massive amounts of heat.

During cutting operations, some materials can catch fire, resulting in gasses and smoke inside the instrument.

A fire, as well as a poor cut quality or mechanical component failure, can be caused by dirt and debris.

Users must stay with the laser during operation to ensure that any flare-ups or flames are properly contained and extinguished.

These gasses or pollutants in the air may have an impact on both the machine and your health. Stop using the laser cutter immediately if the air filter or exhaust system fails, and contact your supervisor.

B. Humans Avoidance System

In order to ensure human safety in the setup a HUman Avoidance system is designed which acts as a kill switch to power on the condition that a human approaches the setup in a particular range. Various methodologies and sensors that might be used to recognise the proximity of any object or person in the room or in the direction of the laser were studied. The four major approaches listed below were studied out of which RGB Camera based avoidance system was adopted:

1. Infrared Infrared
2. Ultrasonic Sensor

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3. Radar doppler
4. RGB Camera based Human Detection and Avoidance

Deep Learning (AI) based Visual (RGB) Human Detection and Avoidance System

We design a Deep Learning architecture for Human Detection and Avoidance, so that the laser manipulator system shuts down as soon as a human enters the RGB Camera's field of view. In computer vision, the challenge of human detection is classified as an object detection problem. After analyzing the entire video or employing a classifier for each frame, the majority of object detection algorithms provide a single action label to it. We want to train YOLO v3 classifiers for Human detection by using frames from a stream of video data to mimic how humans identify, localize, and classify actions of interest in real-time. Tiny Yolo Classifier is a yolo classifier deep learning model.

The YOLO Family of Object Detectors is known for its incredibly low processing requirements.

Figure 1:YOLO CLASSIFIER

It's a more advanced object detection method focused at real-time processing, with the benefit of being faster and more accurate than previous classification systems. YOLO separates it into many grids using a single Convolutional Neural Network. For each grid the bounding box prediction and confidence score are calculated. Based on the expected confidence score these bounding boxes are examined. YOLO includes 24 convolutional layers and 2 completely connected layers. To avoid any mistakes or accidents, the sensor must be accurate and quick in recognising the presence of any human in theoperating laser's path.

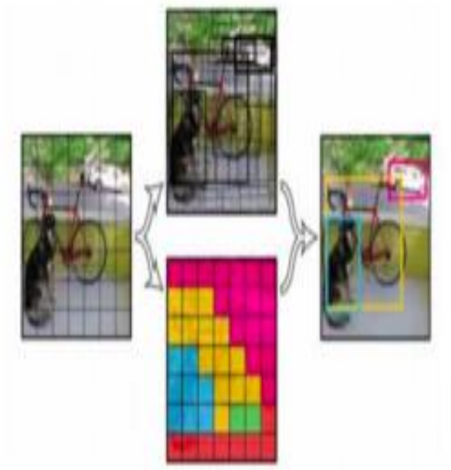

Figure 2: YOLO model regression

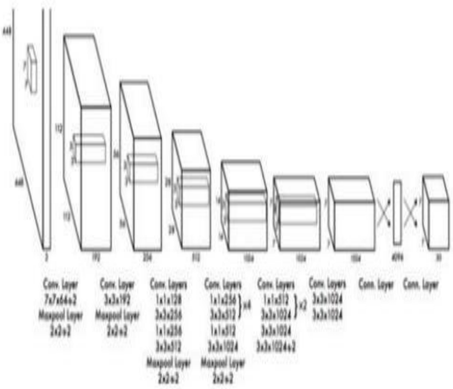

Figure 3: YOLO ARCHITECTURE

V. CONCLUSION

Smart machines and goods can connect and learn from one another thanks to sensors, and this all adds up to Intelligent factories. In the future, robotics and human collaboration in industry will aid in making complicated decisions in advance by allowing for a better knowledge of risk. Another distinguishing trait is their ability to govern one another collaboratively. The main question right now is whether robotics will eventually replace humans or eliminate all of their occupations. Humans have a lot of information, can handle things precisely, and have a good sense of touch. Robots are capable of doing repeated activities with consistency, efficiency, and speed. Industry 4.0 and robotic technology are the wave of the future, and when combined, they improve customer satisfaction, product efficiency, and product reliability.

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