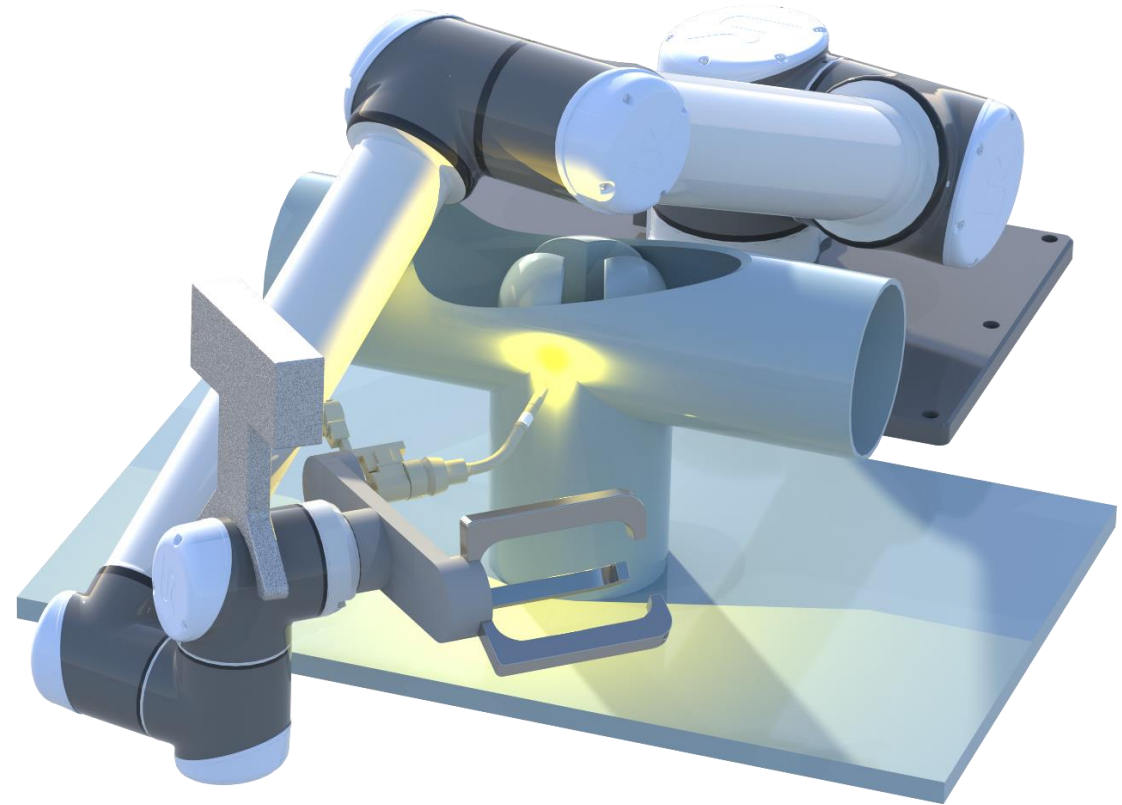


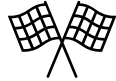
# AUTOMATED LASER PRODUCTION OF THREE WELDED PIPES

Archie Buxton (*B913210*) & Iola Ryland (*B823076*)  
23WSC600 - Advanced Manufacturing Processes and Technology



# CONTENTS

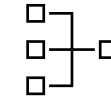
01



## INTRODUCTION

Project objectives and constraints, and final part dimensions

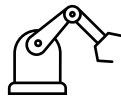
02



## SYSTEM OVERVIEW

Systems diagram and flow chart, overview of the equipment used

03



## SYSTEM DESIGN

Detailed explanation of conceptual design, automation and laser technologies used

04



## CRITICAL EVALUATION

Proposal evaluation based on specification points, including final justifications and viability



# 1.1 OBJECTIVES & CONSTRAINTS

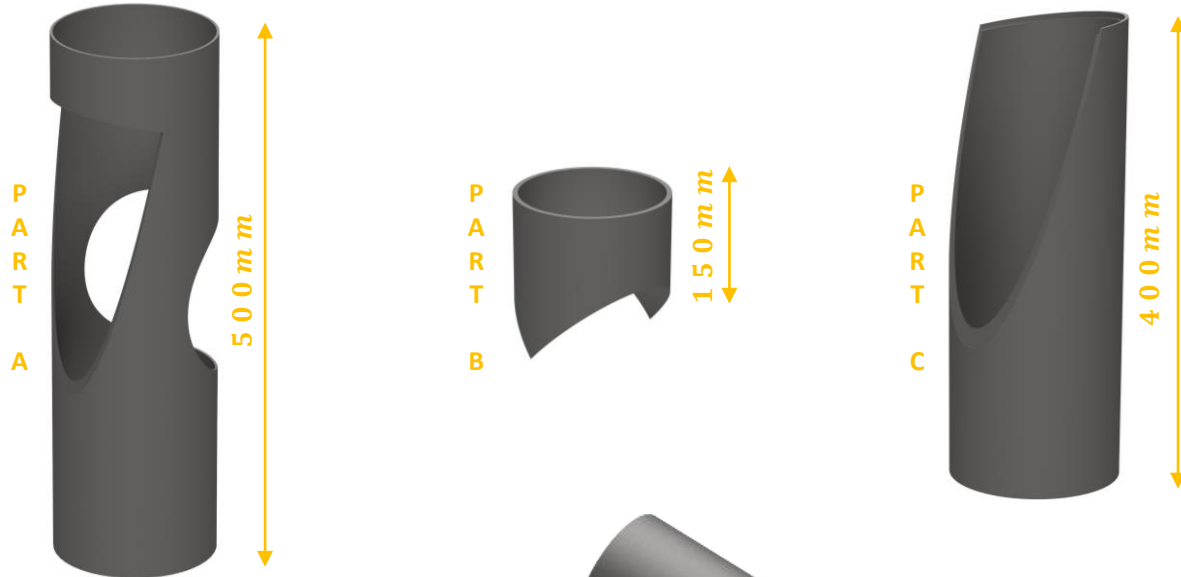
## OBJECTIVE

'Design an automated laser operation to weld the three pipes within a standard working shift.'

## CONSTRAINTS

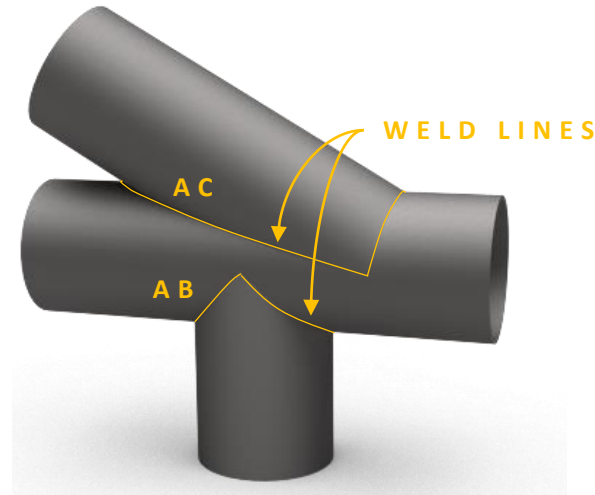
- Standard shift: 8 hours + 30-minute lunch break.
- 250 completed parts per day.
  - 250 of parts A, B, and C required
  - 4 parts manufactured over 432 seconds (7.68 minutes)
- Safety precautions (e.g., a PMMA cage) implemented to separate humans from robots.
  - Manual override should human intervention be required, e.g. maintenance.
- Air-tight welds.
- Initial parts are pre-cut.

## INITIAL PARTS



## FINAL PART

ALL  $\varnothing 150\text{ mm}$  &  
5 mm THICK &  
 $\pm 0.2\text{ mm}$  TOLERANCE



## MEASUREMENTS

Weld Lengths:

Part A&C: 817mm

Part A&B: 573mm

Total:

1390mm

## VOLUMES

Assumptions:  $7.8e^{-6}\text{ kg/mm}^3$

Thickness: 5mm

Part A: 854497mm<sup>3</sup>

Part B: 418659mm<sup>3</sup>

Part C: 722247mm<sup>3</sup>

Total:

1995403mm<sup>3</sup>

## WEIGHTS

Part A: 6.67kg

Part B: 3.27kg

Part C: 5.63kg

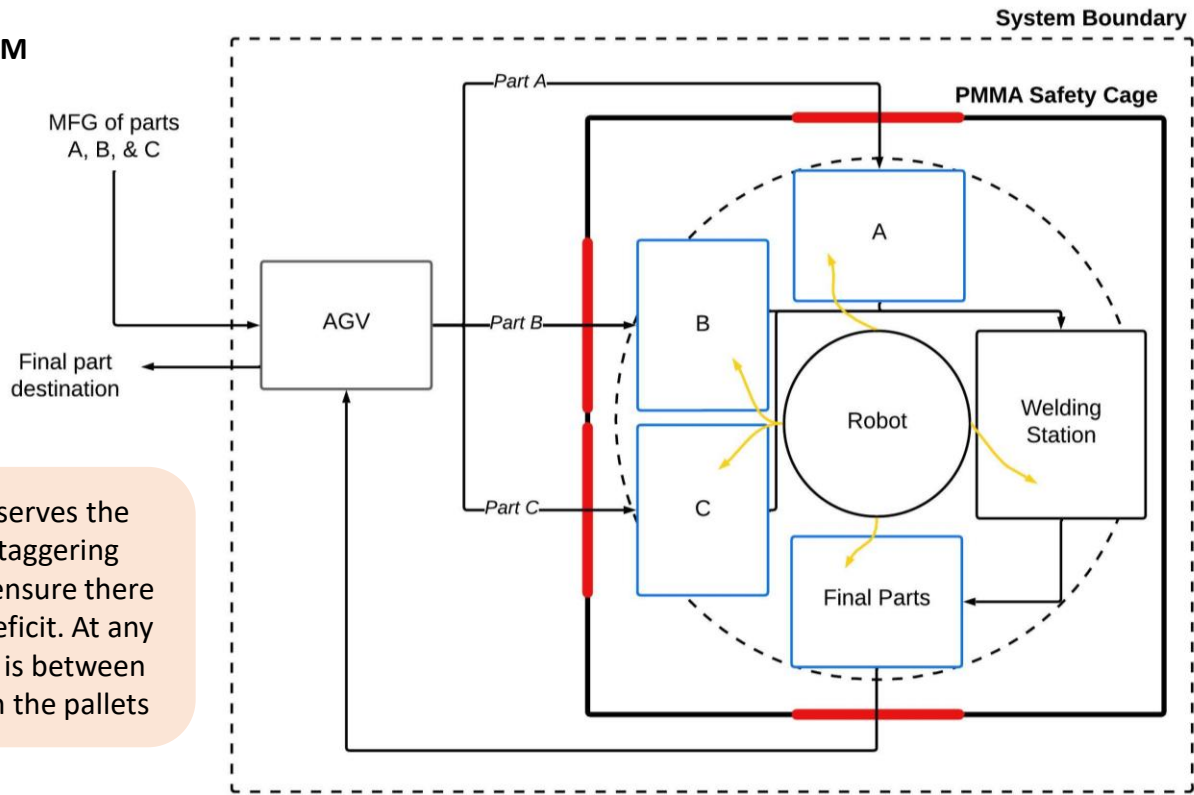
Total:

15.6kg

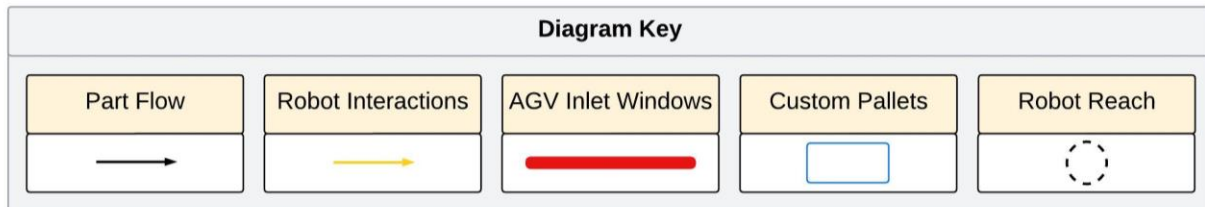


# 2.1 SYSTEM DIAGRAM & FLOW CHART

## SYSTEM DIAGRAM

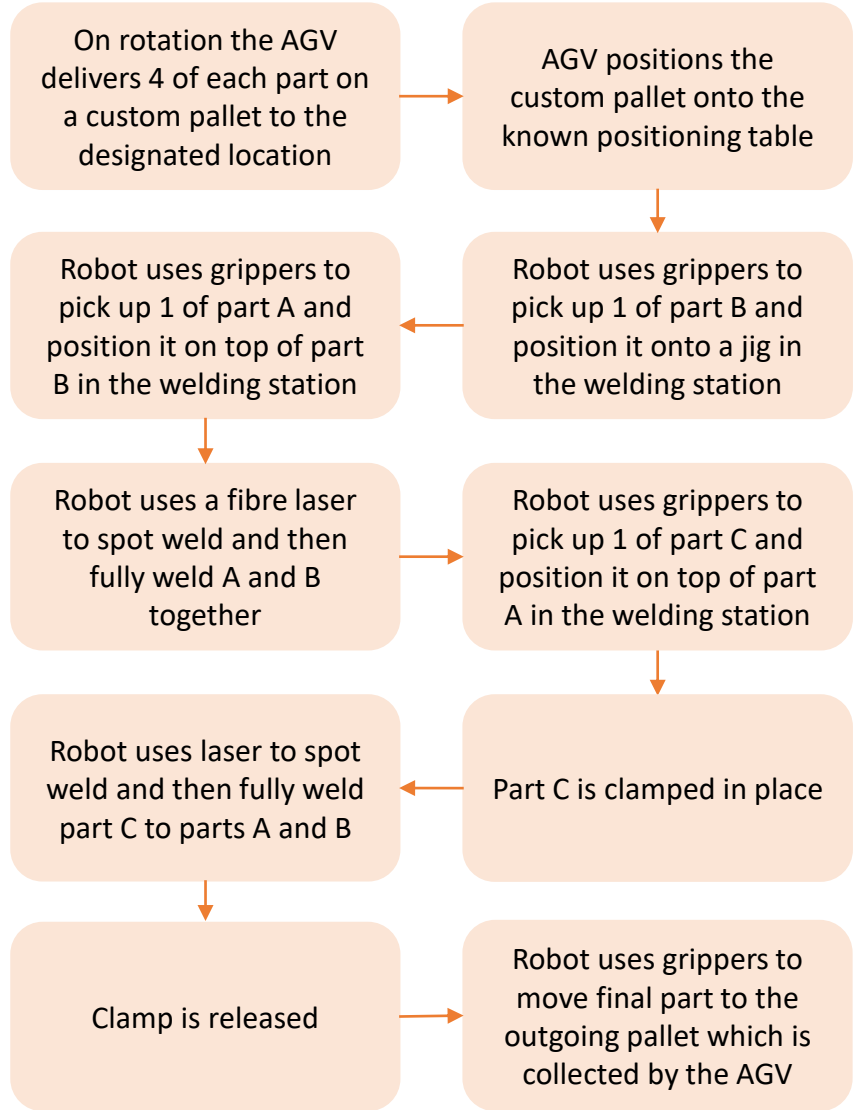


One AGV serves the system, staggering delivery to ensure there is never a deficit. At any time, there is between 4-0 parts on the pallets

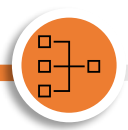


## FLOW CHART (one product cycle)

START

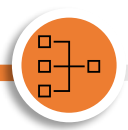
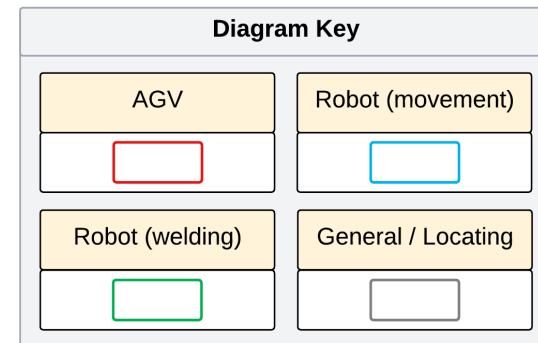
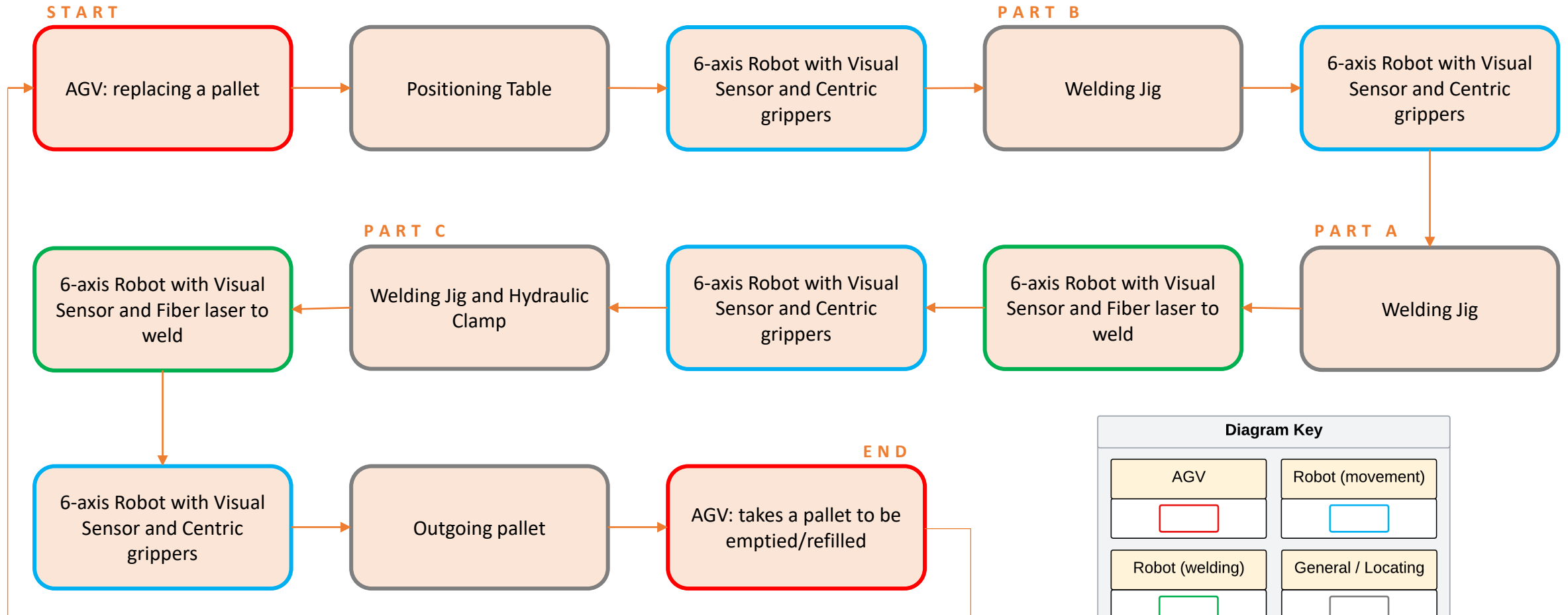


END



# 2.2 EQUIPMENT OVERVIEW

EQUIPMENT FLOW CHART  
(one product cycle)



# 2.2 EQUIPMENT OVERVIEW

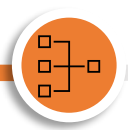
## EXAMPLE EQUIPMENT

**A** AGV, custom pallets, and positioning table



**B** 6 Axis Robot – for movement and welding

**C** Welding Jig and workpiece clamp





# 3.1.A POSITIONING TABLE

STEP 1



STEP 2

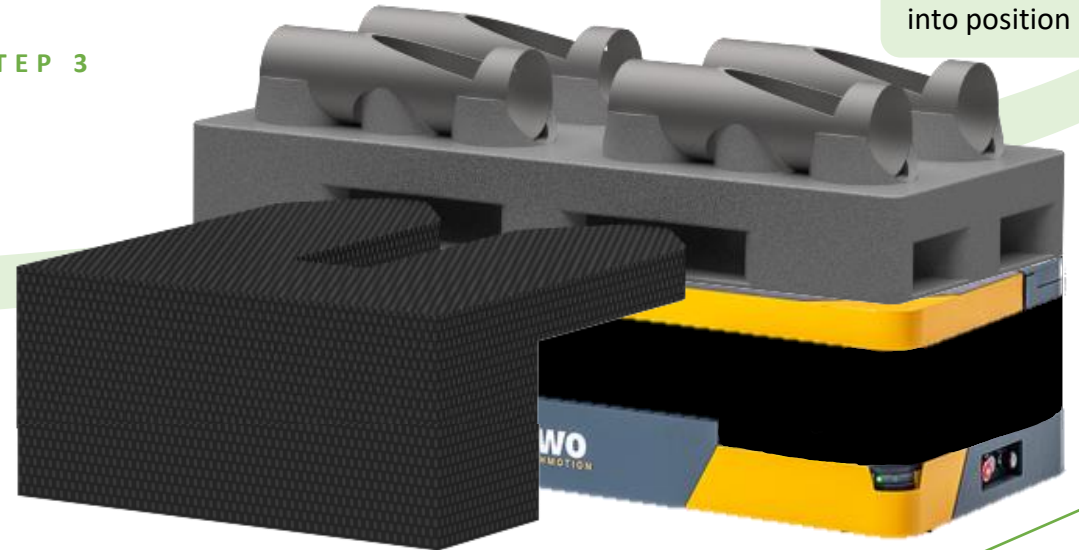
AGV extends



50 mm

AGV moves into position

STEP 3

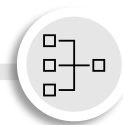


STEP 4

AGV descends, free to move to the next task



Parts ready to be collected by robot



# 3.1.A POSITIONING TABLE

## STEP 5

AGV moved to next task, parts ready for robot to collect



## FUTURE PROOFING

Shape of the pallets designed to be compatible with forklifts, encase the parts are changed and future and become much heavier.

Positioning table made of steel to support the weight of the parts on the pallets.

In the same place each time because of the AGV's sensors (therefore a known location for the robot).



# 3.1.A AGV DELIVERY SEQUENCING

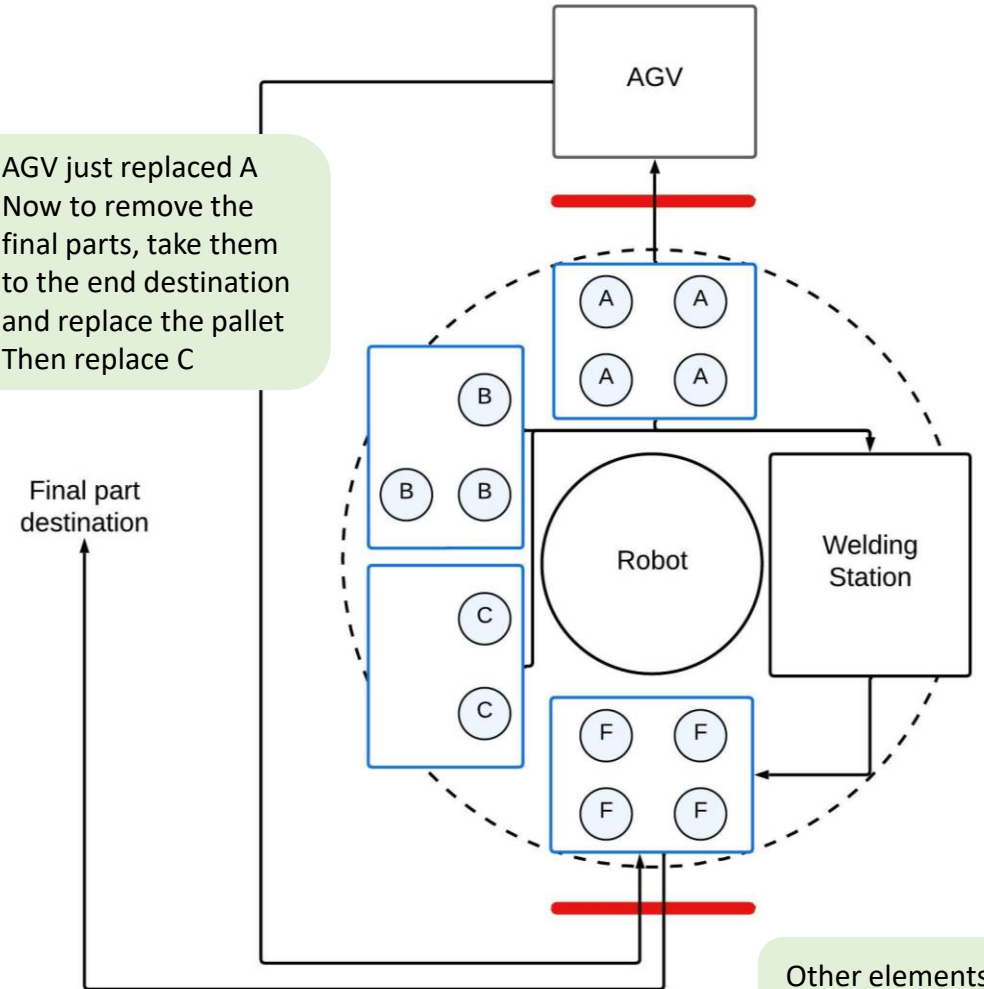
## SEQUENCING

A single AGV services the welding system, refilling / emptying 1 pallet per product cycle so it is **never left ideal or redundant**.

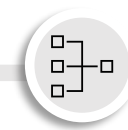
- Continuous manufacturing cycle assumed.
- At the start of each shift the system continues from where it left off the day before.

Pallet	Number of Parts on the pallet				
A	4	3	2	1 → AGV Action	4
B	3	2	1 → AGV Action	4	3
C	2	1 → AGV Action	4	3	2
Final Parts	4 → AGV Action	1	2	3	4 → AGV Action

- AGV just replaced A
- Now to remove the final parts, take them to the end destination and replace the pallet
- Then replace C



Other elements of the system diagram removed for simplicity



# 3.1.A AGV PROXIMITY SENSORS

## CAPACITIVE PROXIMITY SENSORS

Proximity sensors on the AGV used for non-contact detection of metallic and non-metallic objects, e.g., the PMMA safety cage and metallic positioning table, to prevent collisions.

## REASON FOR USE

Prevent the AGV from colliding with the safety cage which could damage the PMMA, or cause part misalignment on the pallets and/or positioning table.

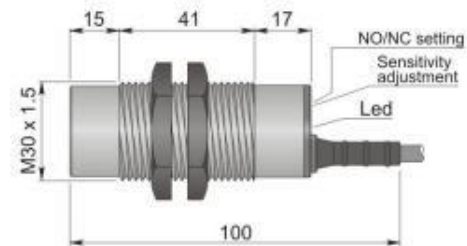
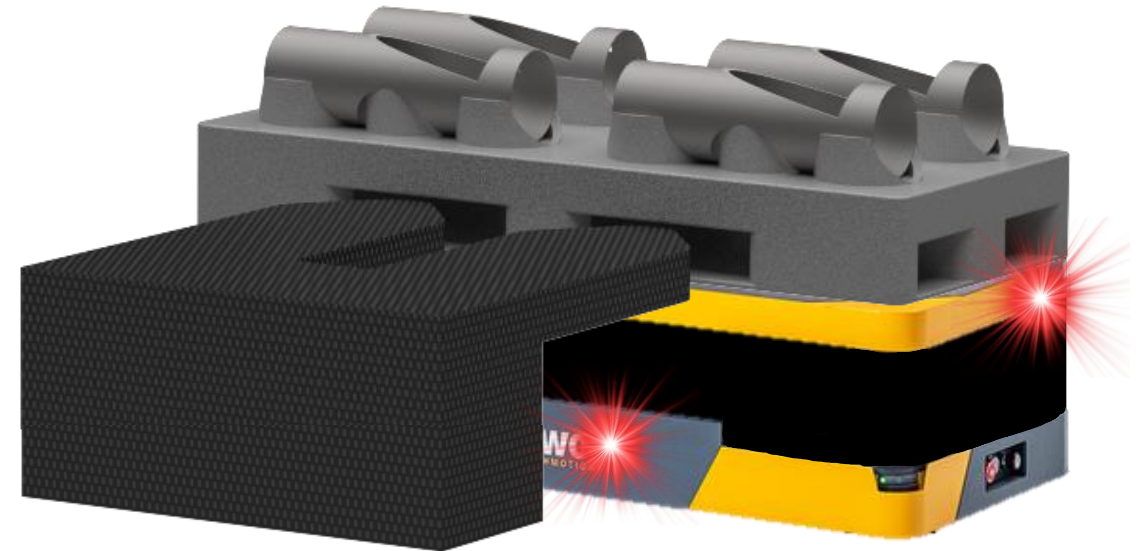
## EXAMPLE SENSORS

### Fargo Controls 30 mm Diameter AC/DC NO/NC Select [3]:

- 0-25mm operating distance
- IP65 rated
- LED function indicator
- -20 to +70°C operating temperature
- Suitable for metals and plastics

## JUSTIFICATION VS. OTHER SENSOR TYPES

- Metallic and non-metallic sensing
- Insensitive to colour or surface properties
- Sealed in housing so can operate in dirty/dusty environments such as factories without incurring damage



# 3.1.A CUSTOM PALLETS MATERIAL & COST

## MATERIAL

Polypropylene (PP) or High-Density Polyethylene (HDPE):

- Impact resistant and durable
- Easy to produce
- Recyclable; encase of future shape changes
- Custom colours; differentiating between pallets A, B, C
- HDPE cheaper than PP and low absorption, easy to clean/store
- Suitable in extreme temperatures

## EXAMPLE PALLET

**IPS 1208 M3R Closed [4]:**

- 1200 × 800 × 150mm
- Weight: 14kg
- 100% recycled PP or HDPE
- Maximum dynamic load: 1500kg
- Maximum static load, e.g., within the welding area: 3000kg
- £45.50+VAT (no customisations)

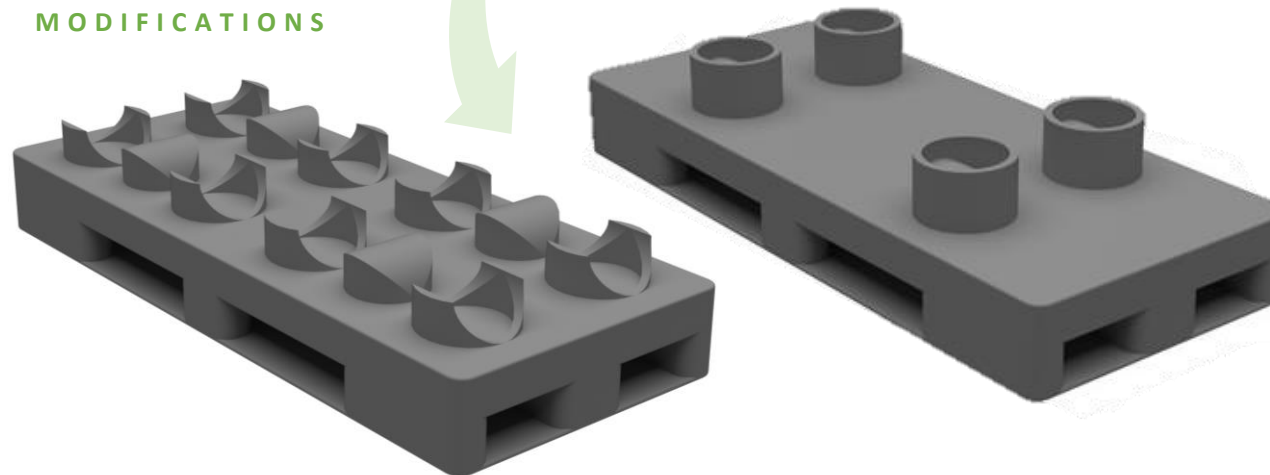
## SIZE, WEIGHT & CAPACITY

- Example pallet of similar size to that needed, justifying that ability to support the maximum load (62.4kg) without surpassing the AGV's maximum (800kg).
- Closed top design allows for part specific customisations



IPS 1208 M3R CLOSED BEFORE MODIFICATIONS

IPS 1208 M3R CLOSED WITH EXAMPLE MODIFICATIONS



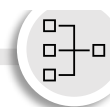
## JUSTIFICATION [5,6]

### Compared to wooden pallets:

- Plastic pallets are ~30% lighter, reducing transport challenges and load/wear on the AGV.
- Plastic pallets are a consistent weight and size, suiting them to an automated environment.
- Easier to clean and disinfect, preventing mould or bacterial damage during storage.
- Custom shapes would be more easily achievable with moulded plastic than wood.

### Compared to metal pallets:

- Metal pallets would be an unjustified expenditure and over engineered solution because the load is not great enough to demand this.
- Metal pallets are significantly heavier and may exceed the maximum load of the AGV.

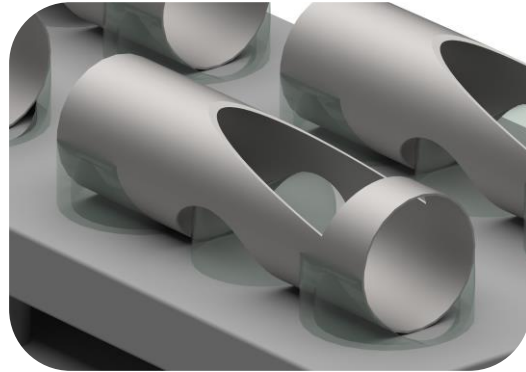
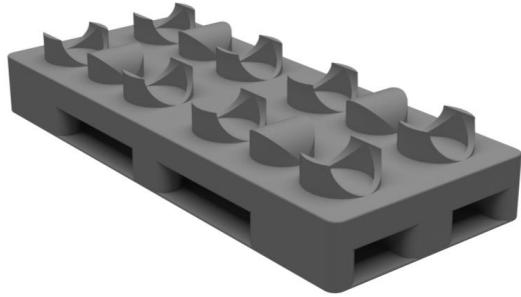


# 3.1.A CUSTOM PALLET DESIGNS

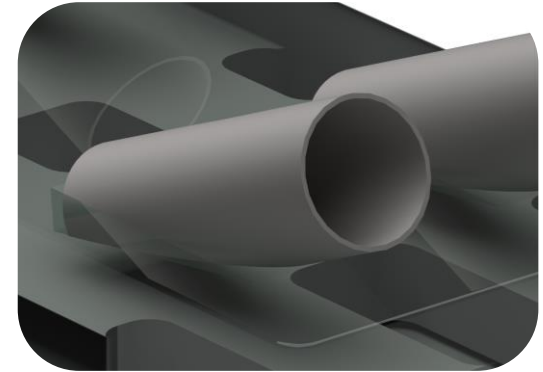
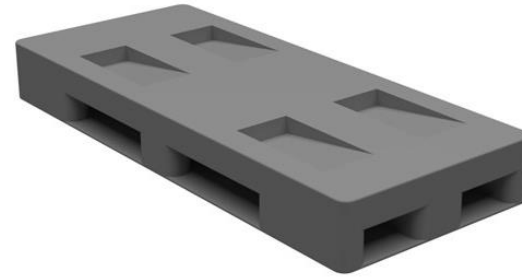
## SIZE JUSTIFICATION

Initially, the pallets would match the size of the AGV (1400 × 600). In future, entirely custom AGVs could be ordered for the minimum pallet size required (1000 × 300) if desired, but the cost would significantly increase. Currently, this expenditure is not justified.

P  
A  
R  
T  
A



P  
A  
R  
T  
C

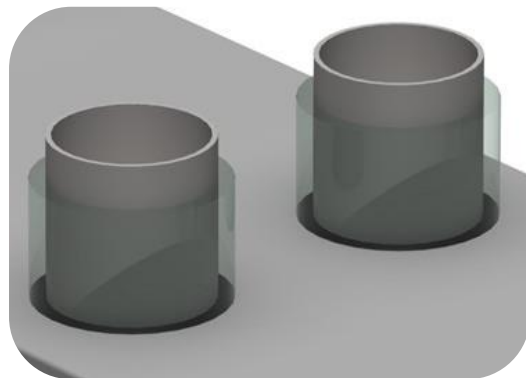
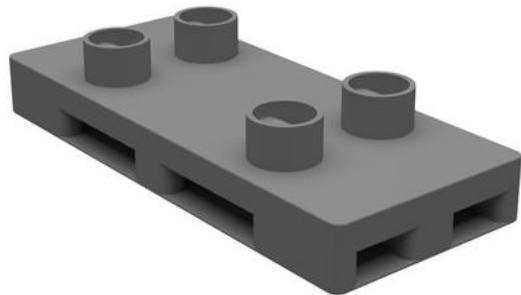


Three custom pallets have been designed so the part locations and orientations are always known.

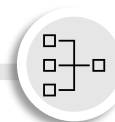
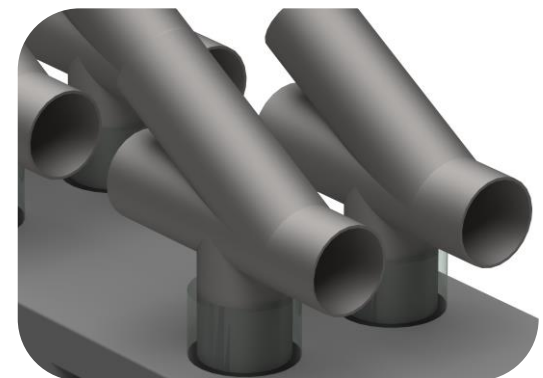
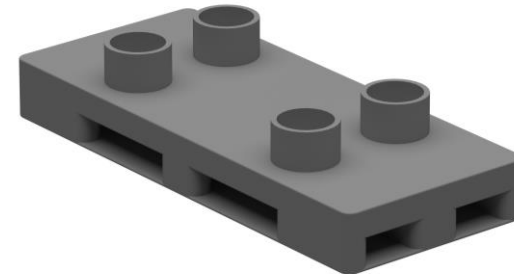
Pallet customisations made transparent to show how the parts fit in and are supported.

Pallets contain a gyroscope and GPS to help with tracking and positioning.

P  
A  
R  
T  
B



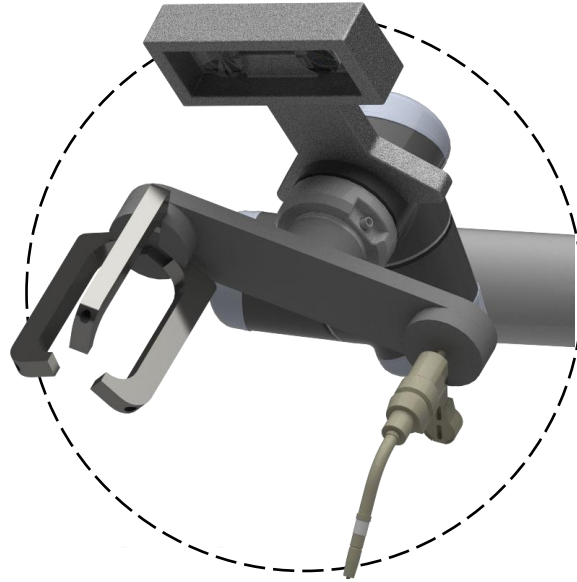
F  
I  
N  
A  
L  
P  
A  
R  
T  
S



# 3.1.B 6-AXIS ROBOT & GRIPPERS

## CENTRIC GRIPPERS

- Ensures parts remain central to the gripper and not lost within the system.
- Internal gripper to expand within the parts, easier to pick parts up and reduce the risk of movement during transit.



## FORCE TORQUE UNIT

- Measures the forces and torque in 6 axis, feeding back to the control unit to continuously adjust location data until accurately in the final position.
- Fixed centrally on the positioning tables
- Large enough to reach all components
- All parts and positioning tables are within the  $\varnothing 1904mm$  robot's reach
- IR proximity sensors on the robot's forearm to detect & prevent collisions.

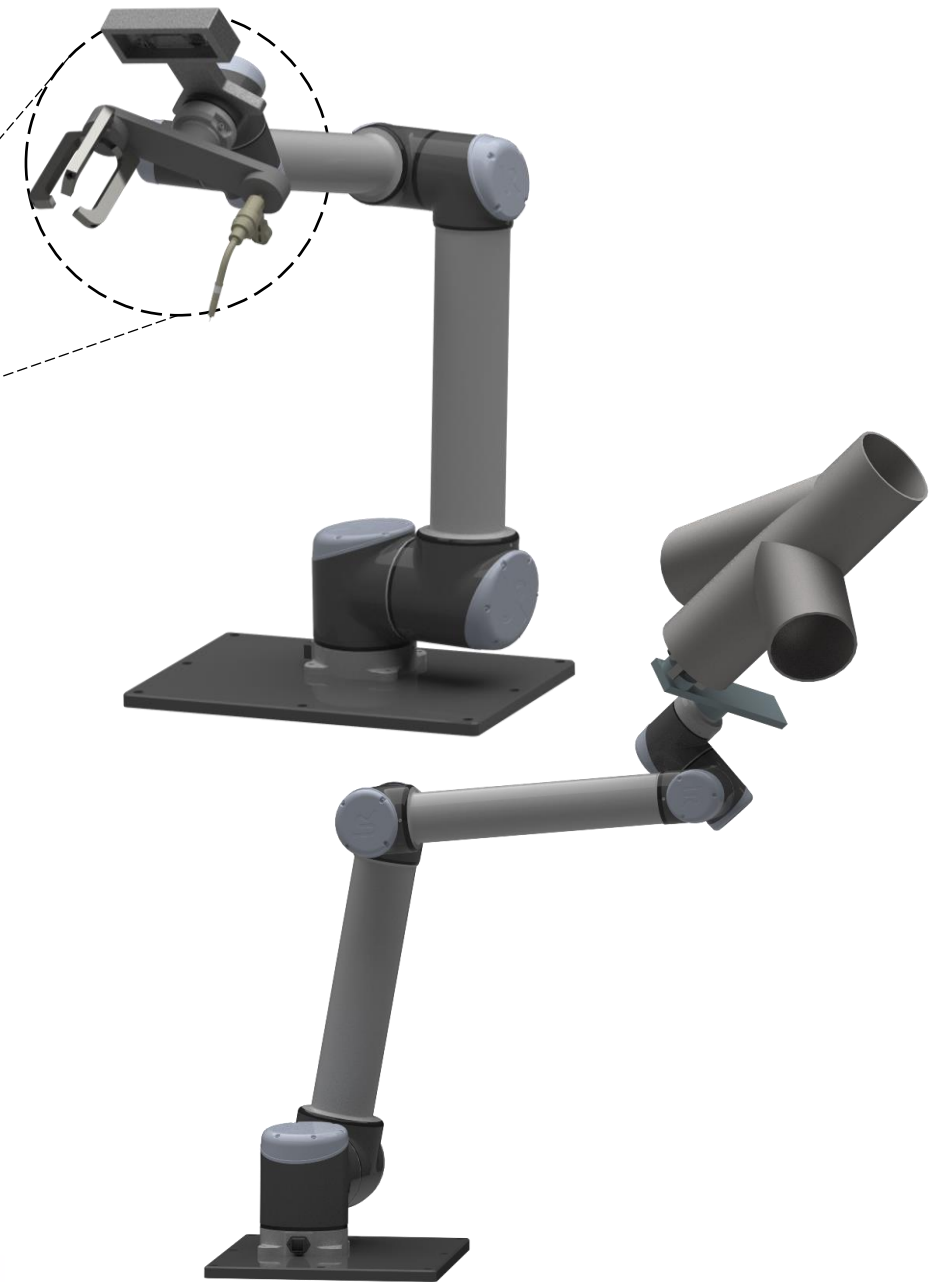
## DUAL TOOL MOUNT

Robot quickly able to switch between welding and manoeuvring parts.

## EXAMPLE ROBOT

### Mitsubishi RV-20FRM-D [7]:

- 6 axis of freedom
- Maximum payload 20kg (finished part is 15.6kg)
- Repeatability 0.05mm
- Speed up to 4200mm/s.



# 3.1.B VISION SYSTEM

## VISION SYSTEM

The vision system provides image based automatic inspection and position analysis. Relaying live feedback for dynamic adjustment during welding.

## DATUM LOCATION

Attached to the robot's forearm to a known location. It is mounted out of the way of the 'wrist' to ensure use is possible for the gripper and welding tools.

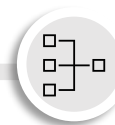
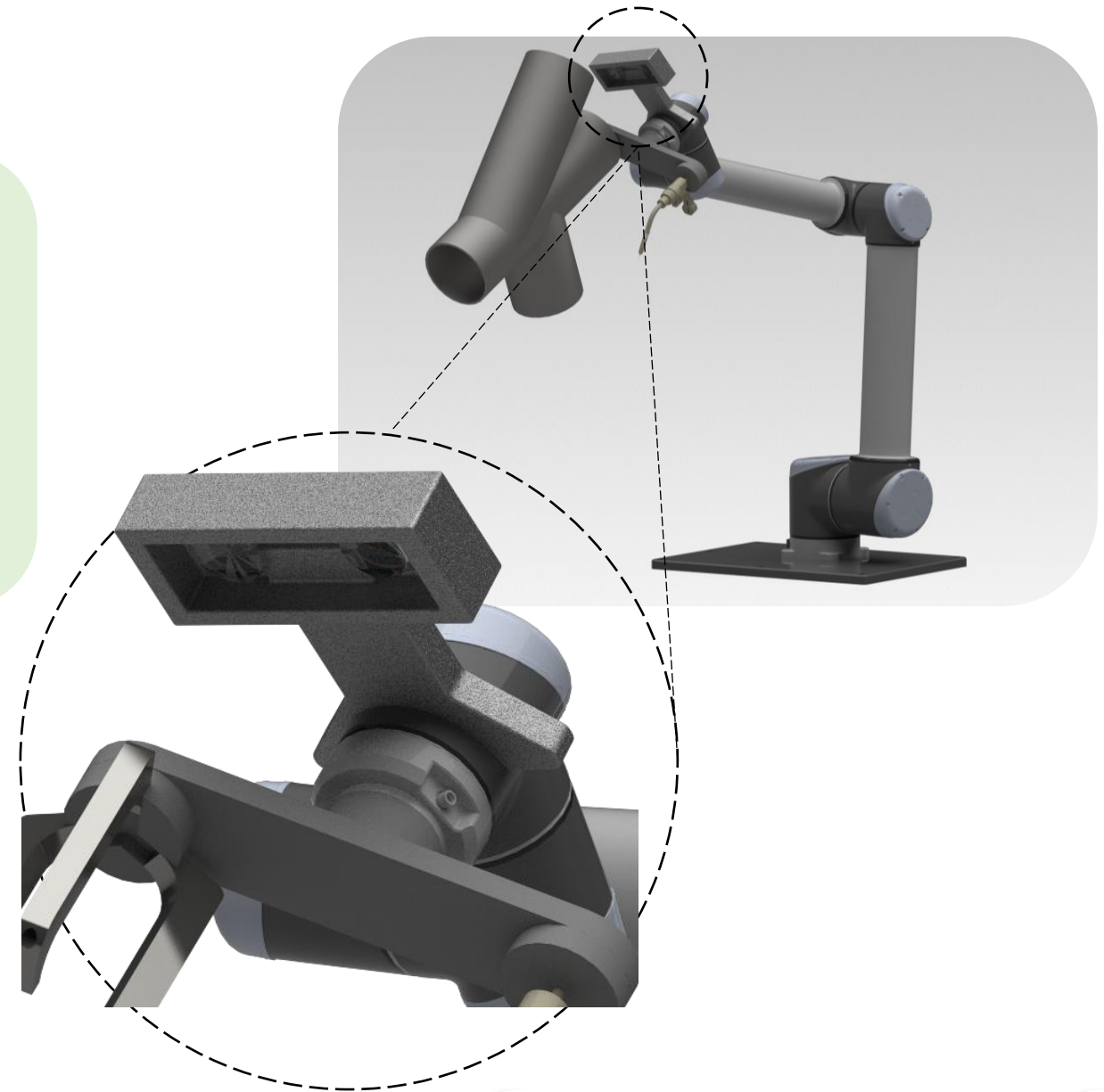
## EXAMPLE SYSTEM

### Keyence 2D Vision-Guided Robotics [8]:

- Up to a Monochrome 21-megapixel camera with IP64 for high accuracy
- 21.9ms processing speeds, suitable for the fast speed of welding.
- 60mm field of view with 1micro meter repeatability.
- Lighting attachment, to ensure image quality remains consistent.

## JUSTIFICATION

- Provides accurate position identification of the parts by taking pictures from multiple angles.
- Provides live feedback during welding to ensure central welds.
- Adapts to all parts regardless of shape/size/orientation.
- Long-term cost efficiency due to reduce error rate, material wastage, and increased productivity over manual welding



# 3.1.C LASER WELDING STATION

## STEP 1

Gripper initially closed until part B is located on top by the robot.

## STEP 2

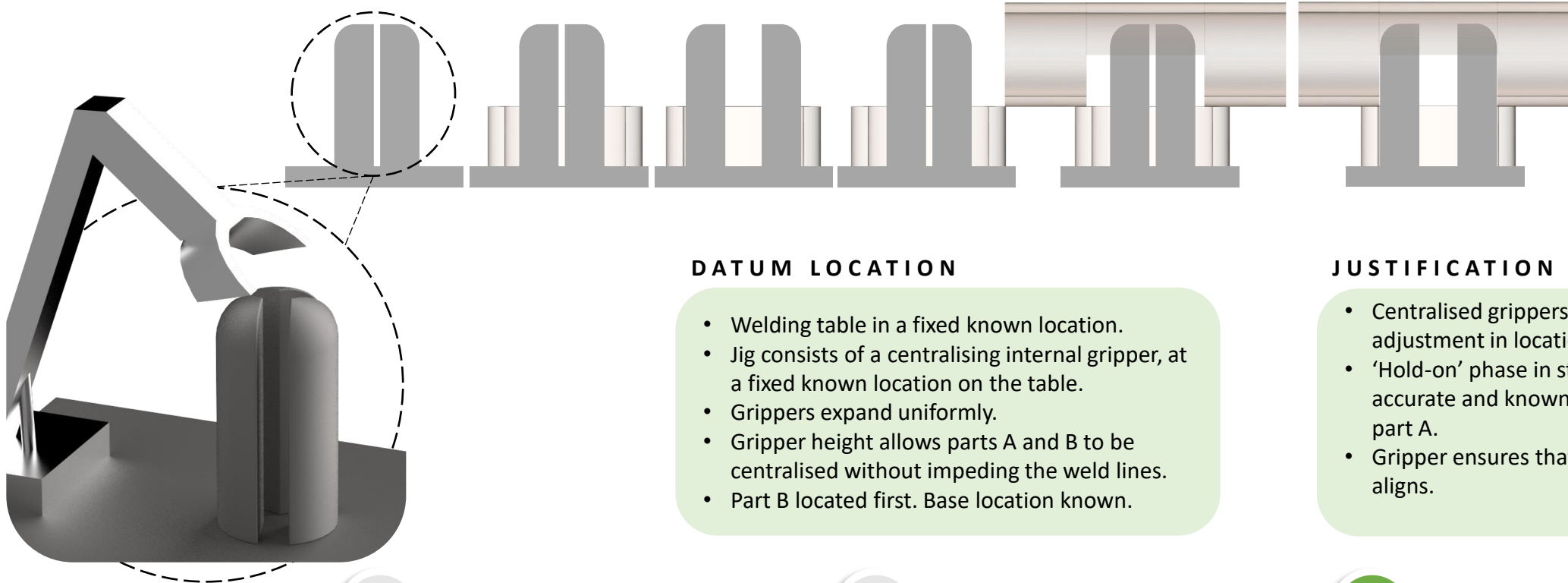
Gripper expands, centralising the part, and then closes.

## STEP 3

Robot places part A on top and maintains its hold as the gripper expands to centralise the part, allowing for adjustments where needed

## STEP 4

Gripper remains expanded until the part has been welded and part ready to be removed by the robot

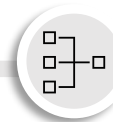


### DATUM LOCATION

- Welding table in a fixed known location.
- Jig consists of a centralising internal gripper, at a fixed known location on the table.
- Grippers expand uniformly.
- Gripper height allows parts A and B to be centralised without impeding the weld lines.
- Part B located first. Base location known.

### JUSTIFICATION

- Centralised grippers allow for slight adjustment in locations to prevent inaccuracy.
- 'Hold-on' phase in step 3 ensures and records accurate and known locational adjustment of part A.
- Gripper ensures that both parts are perfectly aligns.

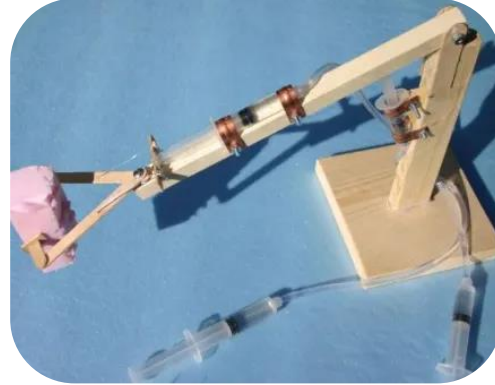


# 3.1.C HYDRAULIC CLAMP

## CLAMP SETUP

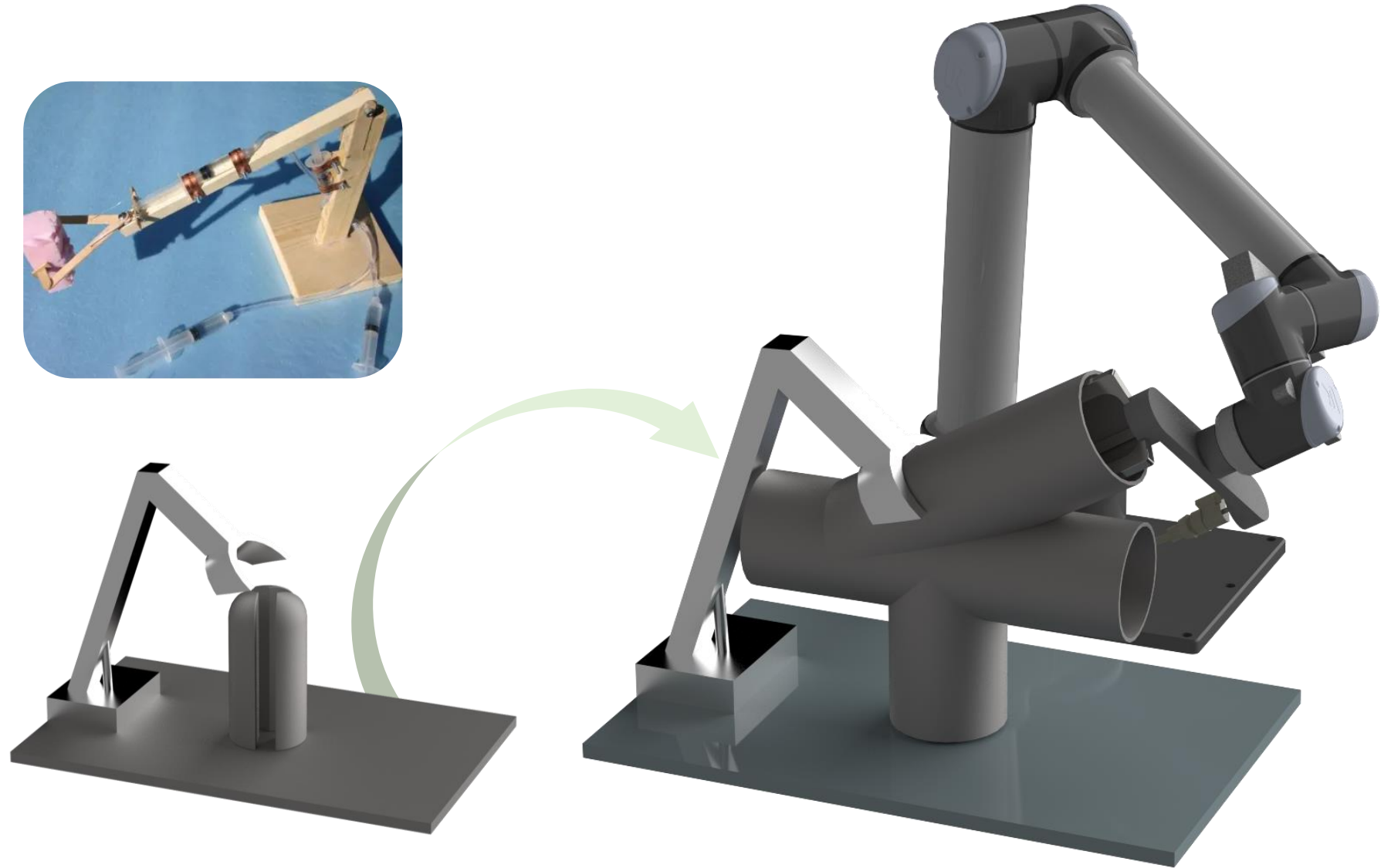
A hydraulic clamp will be used when welding part C to A:

- Used to ensure part C is fixed in place during the welding stage.
- Robot secures part C in place on-top of part A; the hydraulic clamp then comes down to secure the part and the robots sensors ensure the part doesn't move.



## JUSTIFICATION

- Hydraulic fluid is incompressible, ensuring a more secure hold.
- Clamp is needed to ensure the part doesn't move during welding.
- Clamp is a relatively cheap and fast way of fixing a part.
- This is not needed when welding A to B because gravity will keep the part in place, along with the spot welds before final welding.



# 3.1.C LASER WELDING

## FIBRE LASER SETUP

- **Conduction welding**
- **Inert assist gas**, e.g., Argon
  - Prevents oxidation of the mild steel which could weaken the weld.
- **Fiberoptic cable** attached to the robot with 0.5mm diameter to transport the beam from the laser to the hand of the robot.
  - Convenient and flexible for movement around the parts.
- **Beam focussing system** would be needed to focus the beam into the fibre optic.
  - Nozzle assembly with a **beam expander** to increase the diameter up to the desired beam width of 5mm.
  - Nozzle would also have a fixed optic which is common in manufacturing.

## ASSUMPTIONS

- 80% absorption of the beam [9]
- Negligible vaporisation of the material.
- $L_f = \sim 280 \text{kJ/kg}$
- Density of mild steel:  $7850 \text{kg/m}^3$
- Specific Heat Capacity =  $510.79 \text{J}/(\text{kg} \cdot \text{K})$  [10]
- Change in Temperature =  $1330 \text{ }^\circ\text{C}$  [11]
- Wavelength 1070nm.

## EXAMPLE ROBOT

**Raycus 3000W ABP Welding Fiber Laser** [12]:  
Chosen so it can be run at 80% power thus, can be used if production is increased.



## DATUM LOCATION

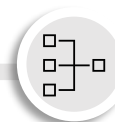
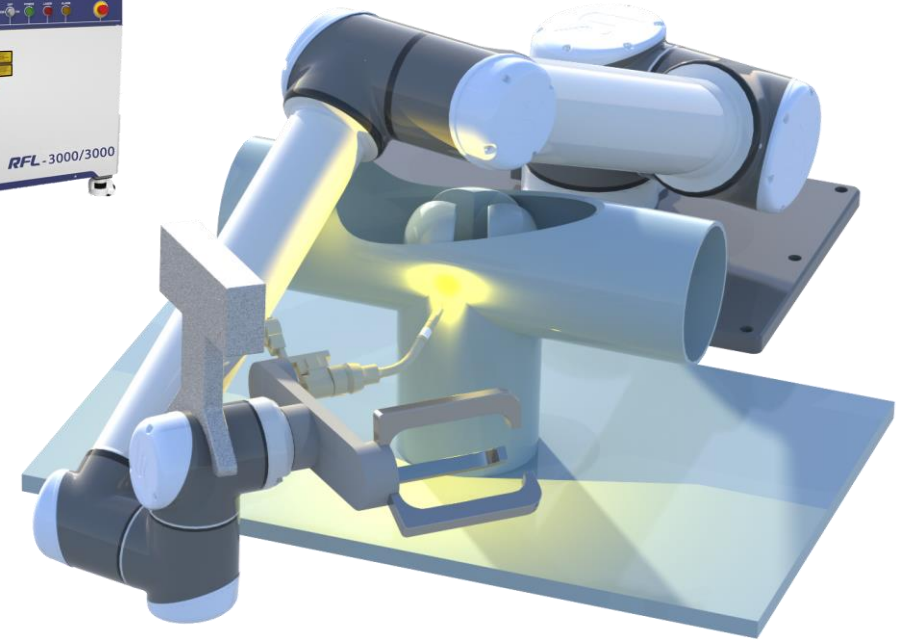
Vision system provides live feedback to the computer allowing for minor adjustments to the welding path, exact joint location always known.

## RESULTS

This will result in a  $2 \text{mm}$  penetration depth with the calculated power density of  $23.7 \text{kW/cm}^2$  [13].  
The results in a required Laser power =  $2370 \text{W}$ .

## TIME ESTIMATION

With assumptions, requirements, and known dimensions the welding time can be calculated for a speed of  $30.8 \text{mm/s}$  (within robot capabilities):  
 $45.2 \text{s} + 2 \text{s}$  (4 spot welds at  $0.5 \text{s}$  each on each weld) +  $8 \text{s}$  (moving to weld site) =  
Part A weld  $\sim 22 \text{s}$ , Part B weld  $\sim 23 \text{s}$   
**Total:  $\sim 55 \text{s}$  welding**



# 3.1.C LASER WELDING JUSTIFICATIONS

## LASER WELDING VS. MANUAL WELDING

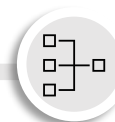
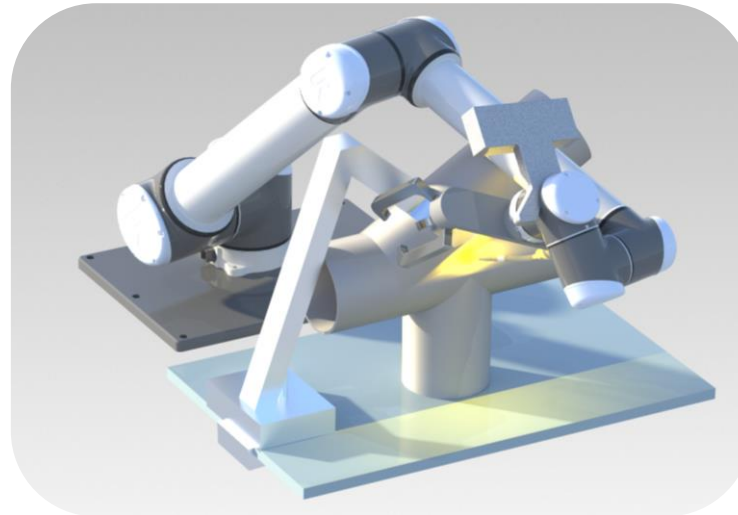
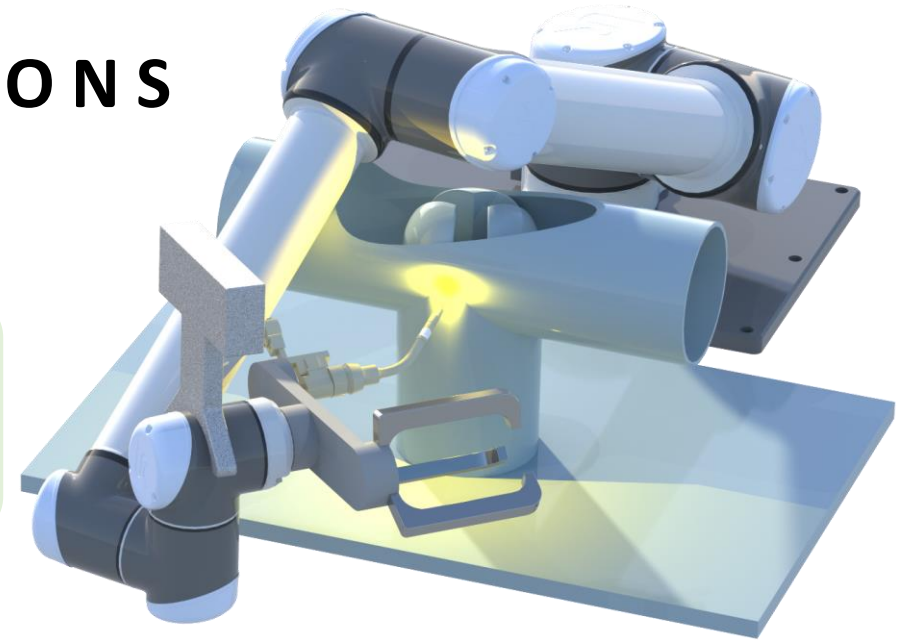
- Reduced time and skill needed due to process automation
- Higher accuracy and repeatability.
- Increased safety, as humans would be removed from the welding process.

## CONDUCTION WELDING VS. OTHER WELDING

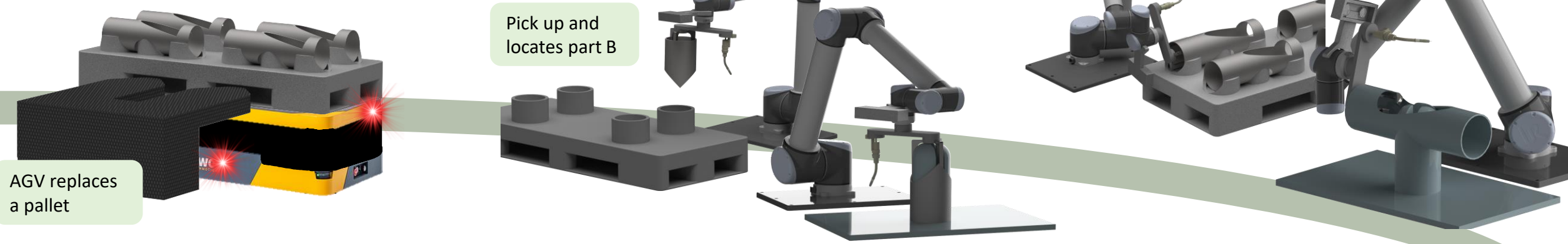
- Very tolerant for joint mismatch.
- Keyhole welding has issues with cracking
- No material loss or joint preparation
- Slower but welding is not the bottleneck in the system and 250 parts can still be achieved.
- Conduction is a simpler process due to no need for added material.
- Conduction welding will also produce a lower number of defects and higher quality welds.
- Lower power consumption over keyhole welding, therefore, reduces costs.

## FIBRE LASERS VS. OTHER LASERS

- Good absorption by mild steel.
- Low maintenance.
- Laser unit doesn't have to be mounted on the robot's arm, can be run along an optic fibre.



# 3.2 SYSTEM SUMMARY



## CONTINUOUS LOOP



# 3.3 SAFETY SYSTEM

## PMMA SAFETY CAGE

- Safety cage constructed from polymethyl methacrylate (PMMA).
- Dimensions:  $4 \times 3 \times 2m$  WLH, fully enclosing the positioning tables and robot at maximum reach in all directions.
- 4 small cut outs will allow the AGVs to enter and exit the safety system.
  - Finished Parts side:  $1500mm \times 900mm$
  - Part B&C side:  $2870mm \times 640mm$
  - Part A side:  $1500mm \times 640mm$

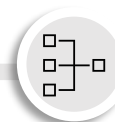
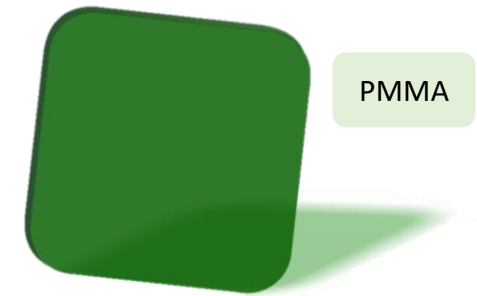
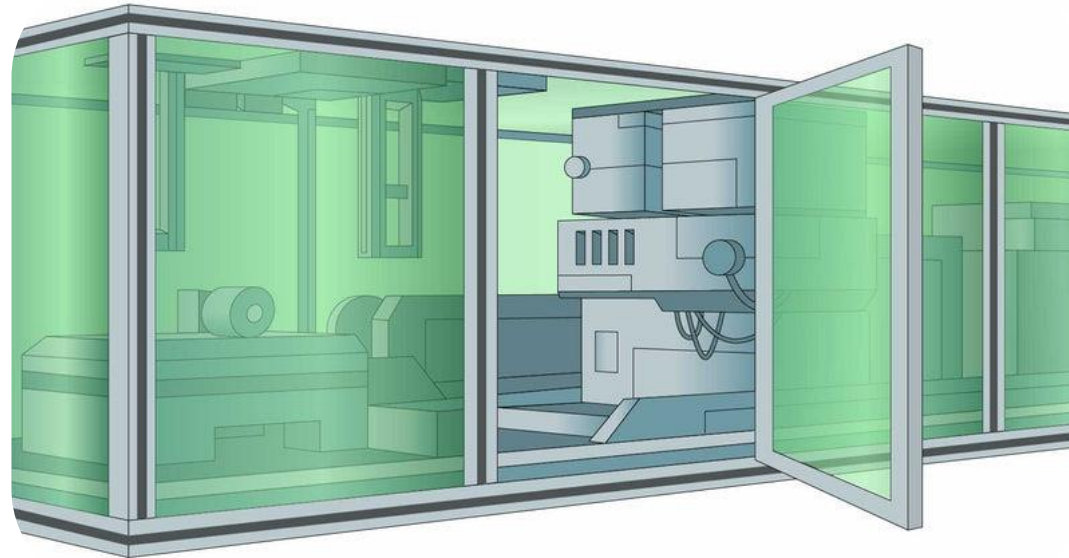
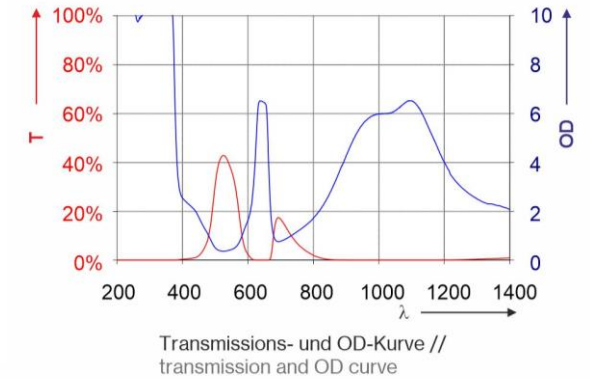
## FURTHER SAFETY CONDIERATIONS

- AGVs proximity sensors to prevent collisions.
- AGC walkways marked out on the floor to prevent people crossing into their path.
- Emergency stop button override the laser welding system in case a human needs to enter, e.g. for maintenance
- Cut outs for the AGVs to enter the safety cage around knee height on a human, preventing accidental entry into the welding area

## EXAMPLE SAFETY CAGE

**Laser safety window P1H09 [14]:** laser protection window suitable for fibre lasers.

- Certified according to DIN EN 60825-4 and CE marked.
- Protection of (OD6+) for the 1070nm wavelength of the fibre laser.



# 3.3 SAFETY SYSTEM JUSTIFICATION

## ROBOT JUSTIFICATION

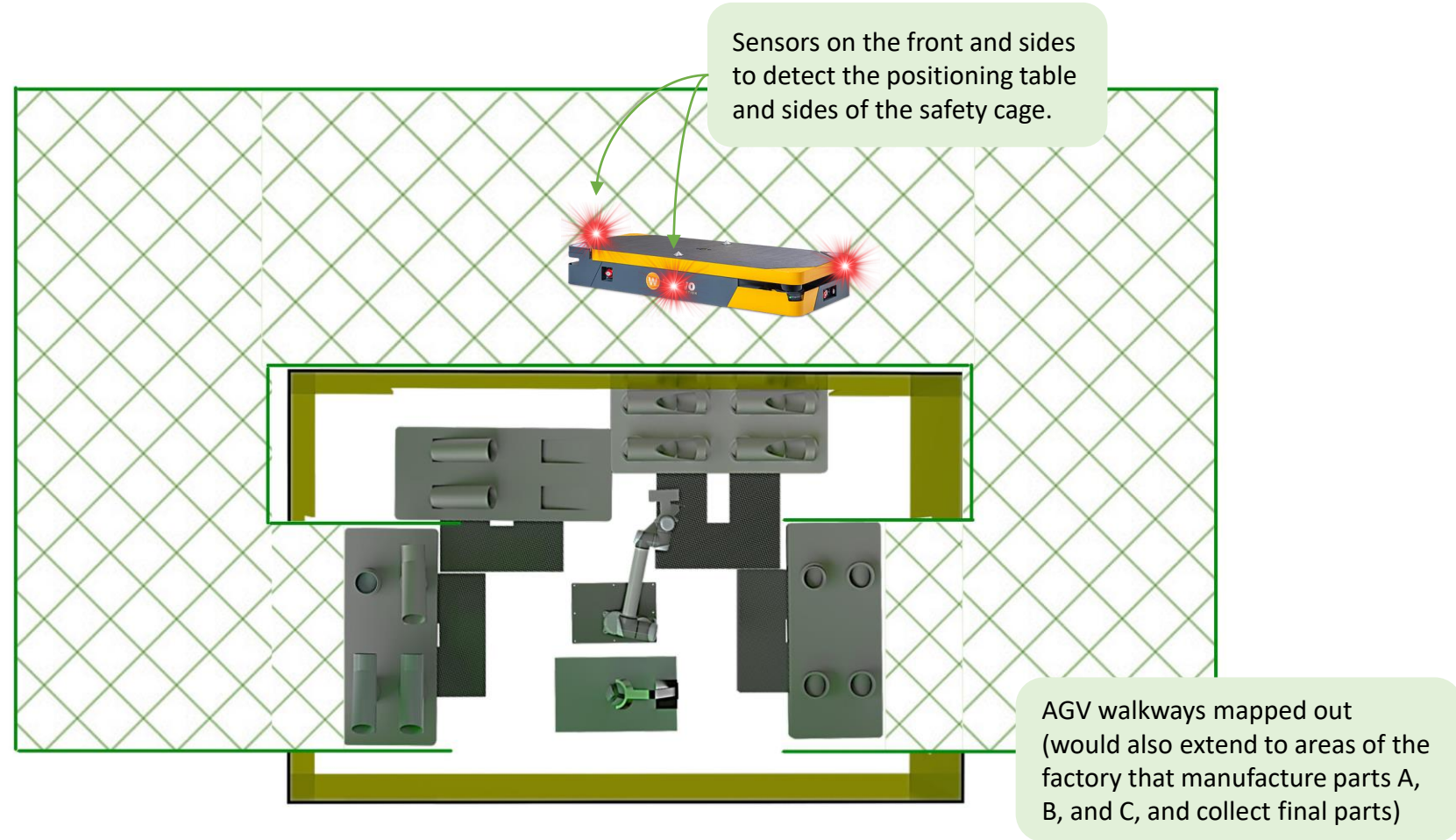
The size of the cage will be greater than the reach of the robot, and therefore doesn't need to be reinforced to prevent breaking upon collision.

## LASER JUSTIFICATION

The PMMA is certified to stop fibre laser wavelength and therefore anyone will be able to observe the process without the need for safety equipment.

## AGV JUSTIFICATION

The proximity sensor is a cheap method of ensuring the AGV will stop before impacting with anything. The painted floor lines will ensure humans are made aware that they are not allowed to cross the path of the robots at any time.



# 4.1 ESTIMATED TIMING PLAN

## PRODUCTION CAPACITY

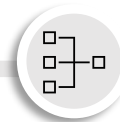
**250 parts** per standard working shift (8 hours) gives **460.8 seconds per 4** completed part.

## ASSUMPTIONS

- Distance travelled by the AGV is completed within the 115s, including picking up the empty pallet, travelling to refill it, and unloading it back in the designated location again (or taking completed parts to the intended final destination) – assumed possible in the factory
- Timing plan only states longer than 15 seconds, others such as small adjustments of the gripper are absorbed into their parent steps
- This is a 460.8 second snapshot of the normal production time and would be repeated continuously over the 8-hour standard shift
- Standard working shift is only 8 hours due to humans being part of the process in other areas of the factory.

← 4 PARTS MANUFACTURED OVER 460.8 SECONDS (7.68 MINUTES) →

<b>AGV:</b> Deliver stack of 4 parts to the positioning tables (115s~)	Replaces pallet B	Replaces pallet A	Replaces pallet C	
<b>Robot:</b> Locates part B and positions onto welding table (15s)	█	█	█	█
<b>Robot:</b> Locates part A and positions onto welding table (15s)	█	█	█	█
<b>Robot:</b> Welds (spot and conduction) parts A&B together (27s)	█	█	█	█
<b>Robot:</b> locates part C onto the welding table (15s)	█	█	█	█
<b>Robot:</b> Welds (spot and conduction) parts A&C (28s)	█	█	█	█
<b>Robot:</b> Pick up finished part and places it on outgoing pallet (15s)	█	█	█	█
<b>AGV:</b> Removes outgoing pallet (115s)				Replaces Outgoing Pallet



# 4.2 RESOURCE UTILISATION ANALYSIS

## ASSUMPTIONS

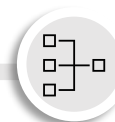
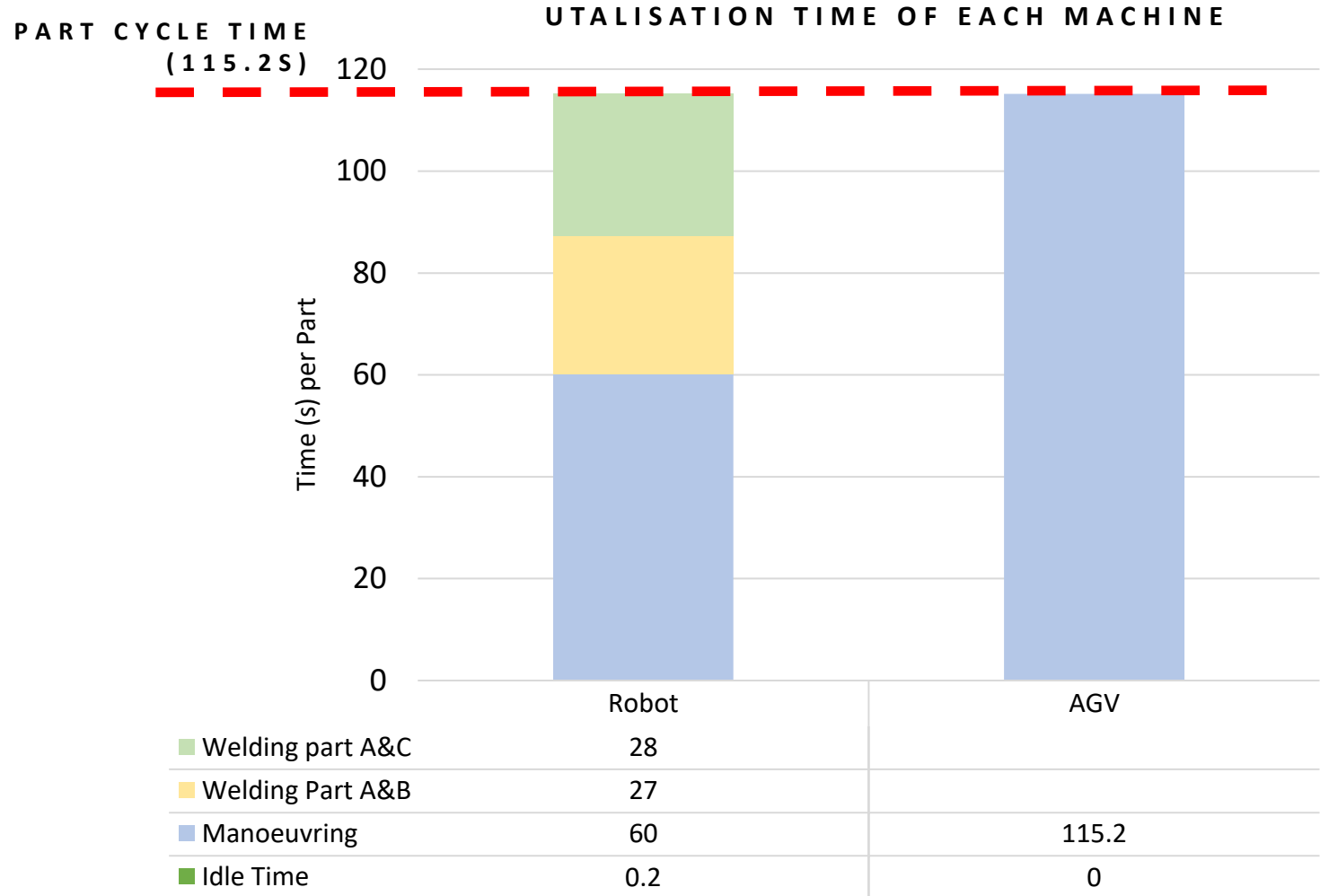
The AGV's speed and distance travelled is assumed to result in a 100% utilisation.

## ANALYSIS

Both the Robot and AGV currently have a utilisation of 100% and a balancing of 0%. They are both continuously in use and are therefore cost-effective.

## FUTURE PROOF

- Should demand increase, a second AGV could be added to distribute the workload.
- The robot's laser power, currently operating at 80%, could also be increased to reduce the welding time.
- The robot's speed could also be increased to reduce movement time between tasks.
- If needed, because the whole system is automated, it could also be left running longer than a standard shift.



# 4.3 COST ANALYSIS

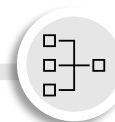
## ASSUMPTIONS

- They were already using the laser welder has a handheld laser welder, and therefore it doesn't need to be included in the cost analysis.
- Prices are just an estimation of the final cost.
- It would require 3 people to create 250 parts in one day.

## RESULTS FOR ANALYSIS

- Higher initial cost with both machine cost and automation.
- No labour costs apart from maintenance.
- The automated system will cost more than a manual system for the first 4 years, and then after will **save a company £18,166 a year.**

COST ANALYSIS	AUTOMATED SYSTEM	MANUAL SYSTEM
Labour per year	1 Skilled Labourer (£60,000)	3x Labour (£30,000 each)
Initial Cost [7, 8, 15, 16]	6 axis Robot: Mitsubishi RV-20FRM-D (£34,209) Vision System: Keyence 2D Vision-Guided Robotics (£1,642) Gripper: Pneumatic Gripper PZN100 (£681) Hydraulic Clamp (£159) PMMA Cage (~£1000) AGV with proximity sensors (~£30,000) <b>Total: ~£72,000</b>	
Bank Loan	3-year bank loan at 8% on £72,000 = £1920 per year, therefore total payback £24,640 per year.	
Added Electricity bill per year [17, 18]	21,915 kWh (based on working 8 hours working per day at an average power draw of 2.9 kW) and £0.27 per kW/h = £11,834 per year	
Cost per year for the first 3 years	£96,474	£90,000
Cost per year after 3 years	£71,834	£90,000



# 4.3 BENEFITS OF AUTOMATION

**INCREASED  
PRODUCTIVITY**



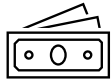
250 easily producible with multiple ways identified of increasing the daily output if required.

**INCREASED  
PRECISION &  
ACCURACY**



Vision system, locator jigs, and sensors ensuring repeatable and consistent performance of tasks.

**COST  
EFFICIENCY**



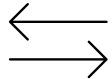
Estimated savings of £18,166 per year, after the first 4 years.

**ENHANCED  
SAFETY**



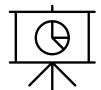
Humans removed and safety considerations included (safety cage with cut outs below human height, emergency stop, AGV walkways and sensors)

**INCREASED  
FLEXIBILITY**



System easily adapted in case of future part changes and does not require training as humans would.

**DATA  
COLLECTION  
POSSIBILITIES**



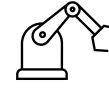
Sensors could be included in future to monitor performance: output, maintenance need, efficiency.

**IMPROVED  
QUALITY  
CONTROL**



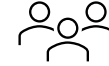
Real time monitoring to ensure accuracy and immediately detect faults.

**REDUCED  
TOOL WEAR**



Non-contact process, no effect on tooling, and automation ensures consistent processes reducing wear caused by error.

**ERGONOMIC**

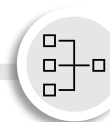
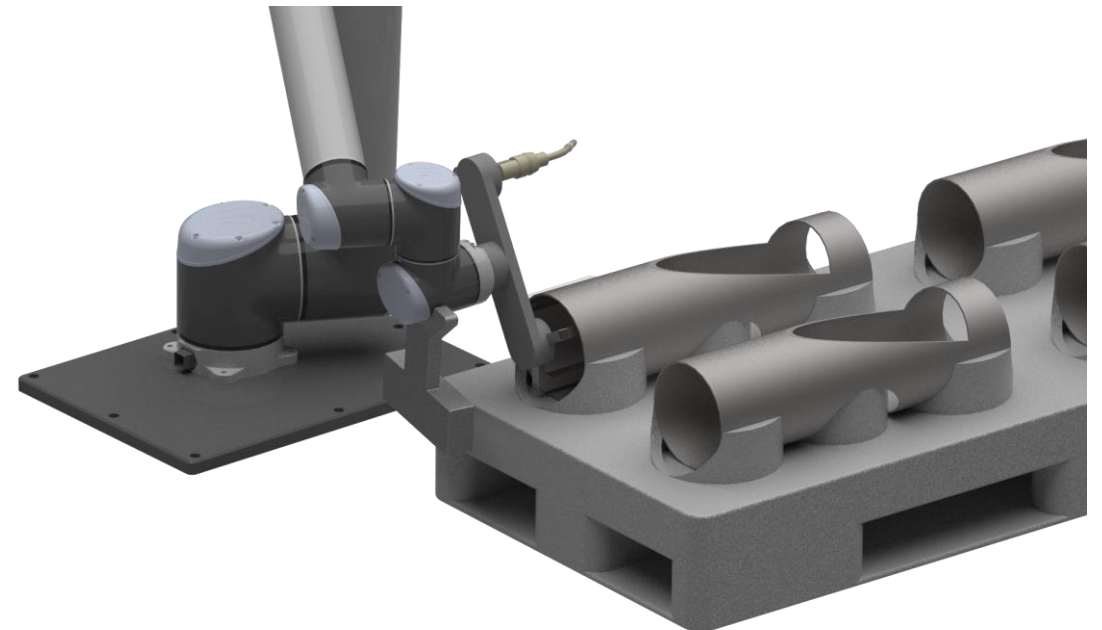


Removes people from dull, mundane, and potentially dangerous jobs due to robots and heavy parts.

**INCREASED  
SPEED**



Manual welding is highly skilled and takes time to perfect the skill and perform repeatably.



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