Problem	Possible Solution
1.1 Stability of partially assembled (PA) structure	If deviations are unavoidable, temporary scaffolding can be used to support the PA structure.
1.2 Robotic Manipulation in different orientations	This problem has been solved in some precedent research by using robotic motion planning software. *(cite: ???)* Similar techniques can be used.
2.1 Robotic manipulation of long timber beams in a congested environment	This problem can possibly be solved by tuning the motion planning software. For example, by swelling the collision geometry to account for uncertainty.
2.2 Alignment of Joints	If deviations are unavoidable, active or passive alignment correction mechanisms can be used. Their correction range should accommodate possible deviation during assembly.
2.3 Fastening Joints	If fasteners are included, an extra robot is needed to manipulate the fasteners. This is possible but can cause other problems, such as a congested planning scene. However, if I start the research with integral timber joints without fasteners, we can avoid this problem.
2.4 Accumulation of Assembly Error	Multi-story timber structures have been built successfully with timber beams made from automatic joinery machines. Effect of error accumulation may not be significant enough to cause problems.
3.1 Unpredictable joint tightness	New mechatronics development is needed to create a high-force assembly actuator. As a starting point, the manually operated tools are studied.
3.2 Simultaneous assembly of joints	Multiple high-force actuator tools are needed at every joint to operate synchronously. However, it is difficult to mount them on a single tool and still accommodate different joint locations on the beam. Perhaps it is possible to have multiple separate actuators, each attending to one joint.
3.3 Timber joints located in many different locations along beams	
3.4 Many different types of timber joints and assembly direction	If the joint assembly actuators are separated and modular, they can be selected on-demand based on the joint type. For example, a screwdriver actuator can be designed specifically to address the challenge in 2.3 Fastening Joints.

Task Description	Shortened Name
1. <u>Place all necessary clamps onto the PA structure (repeat for all clamps)</u>	
Robot picks up a clamp from where the clamps are stored.	PickClampFromStorage
Robot brings the clamp to the PA structure.	ClampTransfer
Robot places the clamp onto the PA structure and releases it.	PlaceClampToStructure
2. <u>Bring the next beam to be assembled</u>	
Robot picks up a gripper from where the gripper is stored.	PickGripperFromStorage
Robot picks up the next beam to be assembled.	PickBeamFromStorage
Robot moves the beam to the work area, ready to approach the clamps.	BeamTransfer
Robot slides the beam into the clamp jaw and releases it.	PlaceBeamInClamp
Clamps operate together to assemble the beam.	ClampSyncAssembly
Robot moves the gripper back to its storage location.	GripperTransit
Robot places the gripper back to its storage location.	PlaceGripperToStorage
3. <u>Retrieve all clamps from the PA structure (repeat for all clamps)</u>	
Robot picks up a used clamp from the PA structure.	PickClampFromStructure
Robot brings the clamp to the PA structure.	ClampTransit
Robot places the clamp back in its storage location.	PlaceClampToStorage

* The terms 'transfer' and 'transit' are terminology borrowed from the AI planning community. They are often used to describe a robot transferring a workpiece to a different location (transfer), and a robot going to a new position empty-handed (transit).

Property	Value
Minimum cell voltage	3.2V
Maximum cell voltage	4.2V
Nominal cell voltage	3.7V
Typical discharge rate	30C to 70C continuous
Common package cell count	1S, 2S, 3S, 4S, 6S

Property	**Value**
Supply Voltage	7.0V - 24V
Control Signal Voltage	Compatible 3.3 V CMOS and 5V TTL Logic Levels
Output channel	2
Maximum continuous operating current	7A continuous, 50A peak
PWM Speed Control	0~10KHz.

Input from microcontroller			**Output to DC motor (OUT1 OUT2)**
IN1	**IN2**	**ENA**	**Effect on motor**
L	L	(Does not matter)	Dynamic Braking
H	H	(Does not matter)	Isolate motor terminals (Cruising)
H	L	PWM (0 to 100% duty cycle)	Motor rotate CW (OUT1 > OUT2)
L	H	PWM (0 to 100% duty cycle)	Motor rotate CCW (OUT1 <OUT2)

Brand Name	**Capacity**	**Discharge**	**Dimensions**	**Weight**	**Price (CHF)**
Turnigy Nano-Tech Plus	1000mAh	70C / 150C	72.5x35x26mm	124g	15.9
Turnigy Graphene Panther	1000mAh	75C / 150C	75x35x30mm	148g	22.4
Turnigy Nano-Tech	1300mAh	45C / 90C	73x31x35mm	155g	18.8
Turnigy Graphene Panther	1600mAh	75C / 150C	67x49x36mm	212g	23.3
ZIPPY Compact	2200mAh	60C / 70C	105x35x37mm	263g	26.85

Main control loop subroutines	Description
Read and Process Serial Command	Process command received from USB serial interface. This is used only for debugging. (see 4.3.3.1 Control Commands for details)
Motor Motion Control	Runs motion control loop for motion control. Only active when there is an active motion target. A separate timer is used to fix the motion control frequency. (see 4.3.3.2 Bang Bang Motion Control for details)
Battery Monitor	Check battery level using integrated ADC in microcontroller. (see 4.3.2.4 Microcontroller for details)

Command	Meaning	Example
h	Home device, towards extension direction. Begin immediately.	h\n
e	Synchronise the two arms, then extend (e) or retract (r) by 0.5 mm. Begin immediately. This functions like a small incremental jogging mode. It is considered a Motion Command.	e\n
r		r\n
0 to 9	Motion Command - Both motors go to position 0 (fully clamped) , or to other positions till 90mm. Begin immediately.	3\n (goes to 30mm position)
+	Motion Command - Both motors go to position 105mm (fully extended). Begin immediately.	+\n (goes to 105mm position)
s	Stop immediately.	s\n
$0	Set Axis Speed.	$010.0\n (set to 10mm/s)
$1	Set Motor 1 Default zero position relative to home switch.	$0888\n (set to step 888)
$2	Set Motor 2 Default home position.	Same as above
(	Begin Comment, ignore subsequent characters until the end-of-comment character or '\n' is received.	(this comment text will be ignored)
)	End of Comment character.	
?	Request a state report	?\n

Motion Control Parameter	Value
No movement over-heat protection duration	100 ms
Encoder-step per linear-travel (measured empirically)	82.285 step mm^{-1}
The allowable encoder error	15 step
Typical linear speed	2 mm s^{-1}