Cyber Planner Code Report v0.1.0 (C++ Version)

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***Abstract*—The code report is abstract enough that no additional abstract is needed**

I. Introduction

WHAT can I say man? What can I say man? What can I say man? What can I say man?

Fujun Ruan
January 30, 2025

II. Path Planning

The conclusion goes here.

III. Trajectory Planning

Team 6328 proposed a Kairos solver in 2023. In their 23 season machine and code, they used an intake active avoidance strategy to avoid anti-collision. This allowed their solver to complete planning in a simpler way. They use linear interpolation as the initial position of waypoints, and then adjusts the position of waypoints to make the speed, acceleration, and torque meet the constraints based on the assumption that the time interval between each waypoint remains unchanged[**?**].

Our approach is very different from that of Team 6328. Instead of globally adjusting the time scale by assuming that the time intervals between points are consistent, we express the function of time with respect to arc length in a discretized form and parameter.

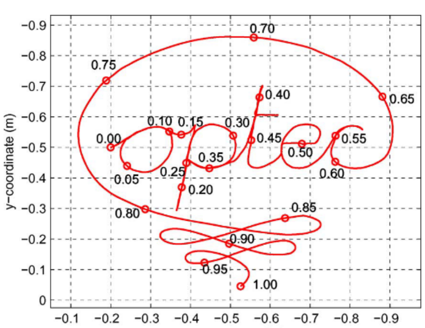

Fig. 1: The curve is uniquely determined by the arc length[**?**].

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See Z. Zhang from https://github.com/zhangzrjerry
See Y. Chen from https://github.com/mirrorcy
See R. Xu from https://github.com/rockyxrq

A. Time Optimal Path Parameterization

The total time of the trajectory is given by the integration of the whole path.

$$T = \int_0^T 1 \mathrm{d}t = \int_0^L \frac{1}{\frac{\mathrm{d}s}{\mathrm{d}t}} \mathrm{d}s \tag{1}$$

Velocity and acceleration constraints at elevator position x and arm radian θ are

$$\begin{aligned} -v_{x,\max} &\le v_x \le v_{x,\max} \\ -a_{x,\max} &\le a_x \le a_{x,\max} \\ -v_{\theta,\max} &\le v_\theta \le v_{\theta,\max} \\ -a_{\theta,\max} &\le a_\theta \le a_{\theta,\max} \end{aligned} \tag{2}$$

Given by chain rules, we have

$$\begin{aligned} \frac{\mathrm{d}x}{\mathrm{d}t} &= \frac{\mathrm{d}x}{\mathrm{d}s} \cdot \frac{\mathrm{d}s}{\mathrm{d}t} \\ \frac{\mathrm{d}^2x}{\mathrm{d}t^2} &= \frac{\mathrm{d}^2x}{\mathrm{d}s^2} \cdot \frac{\mathrm{d}s}{\mathrm{d}t} + \frac{\mathrm{d}x}{\mathrm{d}s} \cdot \frac{\mathrm{d}^2s}{\mathrm{d}t^2} \\ \frac{\mathrm{d}\theta}{\mathrm{d}t} &= \frac{\mathrm{d}\theta}{\mathrm{d}s} \cdot \frac{\mathrm{d}s}{\mathrm{d}t} \\ \frac{\mathrm{d}^2\theta}{\mathrm{d}t^2} &= \frac{\mathrm{d}^2\theta}{\mathrm{d}s^2} \cdot \frac{\mathrm{d}s}{\mathrm{d}t} + \frac{\mathrm{d}\theta}{\mathrm{d}s} \cdot \frac{\mathrm{d}^2s}{\mathrm{d}t^2} \end{aligned} \tag{3}$$

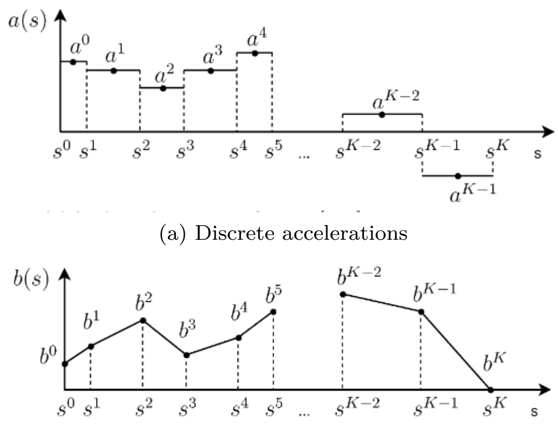
Denote

$$a(s) = \frac{\mathrm{d}^2s}{\mathrm{d}t^2}, b(s) = \left(\frac{\mathrm{d}s}{\mathrm{d}t}\right)^2 \tag{4}$$

The problem is described by

$$\begin{aligned} \min_{a(s),b(s)} \quad & \int_0^L \frac{1}{\sqrt{b(s)}} \mathrm{d}s \\ \text{s.t.} \quad & b'(s) = 2a(s) \\ & x'(0)\sqrt{b(0)} = 0 \\ & x'(L)\sqrt{b(L)} = 0 \\ & \theta'(0)\sqrt{b(0)} = 0 \\ & \theta'(L)\sqrt{b(L)} = 0 \\ & -b(s) \le 0 \\ & [x'(s)]^2 b(s) \le v_{x,\max}^2 \\ & [\theta'(s)]^2 b(s) \le v_{\theta,\max}^2 \\ & x''(s)b(s) + x'(s)a(s) \le a_{x,\max} \\ & -x''(s)b(s) + x'(s)a(s) \le a_{x,\max} \\ & \theta''(s)b(s) + \theta'(s)a(s) \le a_{\theta,\max} \\ & -\theta''(s)b(s) + \theta'(s)a(s) \le a_{\theta,\max} \end{aligned} \tag{5}$$

1) Discrete Case: Considering the problem in discrete case, we have



(a) Discrete accelerations

(b) Discrete velocities

Fig. 2: Discrete function of time with respect to arc length[?].

We obtain the discretized object function

$$
\begin{aligned}
\min_{a,b} \quad & \sum_{k=1}^{K} \frac{2(s^{k+1}-s^k)}{\sqrt{b^{k+1}}+\sqrt{b^k}} \\
\text{s.t.} \quad & \frac{b^{k+1}-b^k}{s^{k+1}-s^k} = 2a^k && \forall k \in [0, K-1] \\
& x'(s^0)\sqrt{b^0} = 0 \\
& x'(s^K)\sqrt{b^K} = 0 \\
& \theta'(s^0)\sqrt{b^0} = 0 \\
& \theta'(s^K)\sqrt{b^L} = 0 \\
& -b^k \le 0 && \forall k \in [0, K] \\
& [x'(s^k)]^2 b^k \le v_{x,\max}^2 && \forall k \in [0, K] \\
& [\theta'(s^k)]^2 b^k \le v_{\theta,\max}^2 && \forall k \in [0, K] \\
& x''(s^k)b^k + x'(s^k)a^k \le a_{x,\max} && \forall k \in [0, K-1] \\
& -x''(s^k)b^k + x'(s^k)a^k \le a_{x,\max} && \forall k \in [0, K-1] \\
& \theta''(s^k)b^k + \theta'(s^k)a^k \le a_{\theta,\max} && \forall k \in [0, K-1] \\
& -\theta''(s^k)b^k + \theta'(s^k)a^k \le a_{\theta,\max} && \forall k \in [0, K-1]
\end{aligned}
\tag{6}
$$

2) Second-Order Cone: To rewrite the problem to a second-order conic programming form, we first try to bound nonlinear term $\sqrt{b^k}$ with c^k, such that $\sqrt{b^k} \ge c^k, k \in [0, K]$. Going a step further, we introduce one more slack variable d^k, which satisfies $\frac{1}{c^{k+1}+c^k} \le d^k, k \in [0, K-1]$.

$$
\begin{aligned}
\left\| \begin{matrix} b^k - 1 \\ 2c^k \end{matrix} \right\|_2 \le b^k + 1 &\Leftrightarrow \begin{bmatrix} b^k+1 \\ b^k-1 \\ 2c^k \end{bmatrix} \in \mathcal{Q}^3 \\
\left\| \begin{matrix} c^k + c^{k+1} - d^k \\ 2 \end{matrix} \right\|_2 \le c^k + c^{k+1} + d^k & \\
&\Leftrightarrow \begin{bmatrix} c^k + c^{k+1} + d^k \\ c^k + c^{k+1} - d^k \\ 2 \end{bmatrix} \in \mathcal{Q}^3
\end{aligned}
\tag{7}
$$

$$
\begin{aligned}
&\min_{a,b} \sum_{k=1}^{K} \frac{2(s^{k+1}-s^k)}{\sqrt{b^{k+1}}+\sqrt{b^k}} \Leftrightarrow \\
&\min_{a,b,c,d} \sum_{k=1}^{K} 2d^k(s^{k+1}-s^k) \\
&\text{s.t.} \quad \left\| \begin{matrix} c^k + c^{k+1} - d^k \\ 2 \end{matrix} \right\|_2 \le c^k + c^{k+1} + d^k \\
&\qquad \left\| \begin{matrix} b^k - 1 \\ 2c^k \end{matrix} \right\|_2 \le b^k + 1
\end{aligned}
\tag{8}
$$

Rewriting the constraints of the optimization problem, especially the nonlinear terms $\sqrt{b_k}$, we get the final objective function [?].

$$
\min_{a,b,c,d} \sum_{k=1}^{K} 2(s^{k+1}-s^k)d^k
$$

Subject to

$$
\begin{aligned}
\begin{bmatrix} c^k + c^{k+1} + d^k \\ c^k + c^{k+1} - d^k \\ 2 \end{bmatrix} &\in \mathcal{Q}^3 && \forall k \in [0, K-1] \\
\begin{bmatrix} b^k+1 \\ b^k-1 \\ 2c^k \end{bmatrix} &\in \mathcal{Q}^3 && \forall k \in [0, K] \\
2(s^{k+1}-s^k)a^k + b^k - b^{k+1} &= 0 && \forall k \in [0, K-1] \\
[x'(s^0)]^2 b^0 &= 0 \\
[x'(s^K)]^2 b^K &= 0 \\
[\theta'(s^0)]^2 b^0 &= 0 \\
[\theta'(s^K)]^2 b^L &= 0 \\
-b^k &\le 0, && \forall k \in [0, K] \\
[x'(s^k)]^2 b^k &\le v_{x,\max}^2 && \forall k \in [0, K] \\
[\theta'(s^k)]^2 b^k &\le v_{\theta,\max}^2 && \forall k \in [0, K] \\
x''(s^k)b^k + x'(s^k)a^k &\le a_{x,\max} && \forall k \in [0, K-1] \\
-x''(s^k)b^k + x'(s^k)a^k &\le a_{x,\max} && \forall k \in [0, K-1] \\
\theta''(s^k)b^k + \theta'(s^k)a^k &\le a_{\theta,\max} && \forall k \in [0, K-1] \\
-\theta''(s^k)b^k + \theta'(s^k)a^k &\le a_{\theta,\max} && \forall k \in [0, K-1]
\end{aligned}
\tag{9}
$$

All constraints are divided into second-order cone constraints, equality constraints and inequality constraints [?].

$$
\begin{aligned}
\min_{x} \ & c^T x \\
\text{s.t.} \ & A_i x + b_i \in \mathcal{K}_i \\
& Gx = h \\
& Px \le q
\end{aligned}
\tag{10}
$$

3) Augmented Lagrangian Method: Therefore, we can reformulate the problem using the Augmented Lagrangian method for Symmetric Cones.

$$
\begin{aligned}
\mathcal{L}_\rho(x,\mu,\lambda,\eta) =& c^T x + \\
& \frac{\rho}{2}\sum_{i=1}^{m} ||P_{\mathcal{K}_i}(\frac{\mu_i}{\rho} - A_i x - b_i)||^2 + \\
& \frac{\rho}{2}||Gx - h + \frac{\lambda}{\rho}||^2 + \\
& \frac{\rho}{2}||\max[Px - q + \frac{\eta}{\rho}, 0]||^2
\end{aligned} \tag{11}
$$

$P_{\mathcal{K}}$ is the projection of a vector on a symmetric cone

$$
P_{\mathcal{K}}(v) = \arg\min_{x\in\mathcal{K}} ||v - x||^2 \tag{12}
$$

In second order cone case,

$$
P_{\mathcal{K}=\mathcal{Q}^n}(v) = \begin{cases} 0, & v_0 \le -||v_1||_2 \\ \frac{v_0 + ||v_1||_2}{2||v_1||_2}(||v_1||_2, v_1)^T, & |v_0| < ||v_1||_2 \\ v, & v_0 \ge ||v_1||_2 \end{cases} \tag{13}
$$

And the gradient of the augmented Lagrangian function is given by

$$
\begin{aligned}
\nabla\mathcal{L}_\rho(x,\mu,\lambda,\eta) =& c - \rho\sum_{i=1}^{m} A_i^T P_{\mathcal{K}_i}(\frac{\mu_i}{\rho} - A_i x - b_i) + \\
& \rho G^T(Gx - h + \frac{\lambda}{\rho}) + \\
& \rho P^T\{\max[Px - q + \frac{\eta}{\rho}, 0]\}
\end{aligned} \tag{14}
$$

So we can use a L-BFGS method to solve this convex and unconstrained function [?], [?], [?].

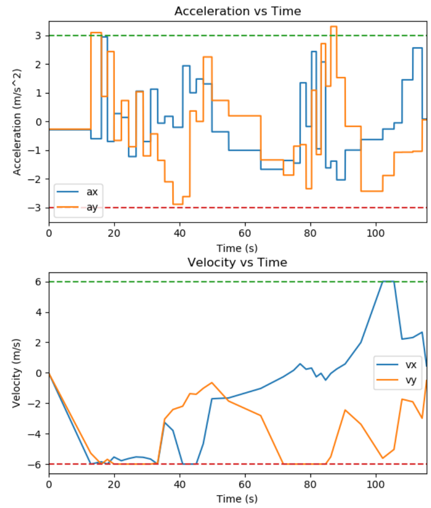
$$
\begin{aligned}
x &\leftarrow \arg\min_x \mathcal{L}_\rho(x,\mu,\lambda,\eta) \\
\mu_i &\leftarrow P_{\mathcal{K}_i}(\mu_i - \rho(A_i x + b_i)) \\
\lambda &\leftarrow \lambda + \rho(Gx - h) \\
\eta &\leftarrow \max[\eta + \rho(Px - q), 0] \\
\rho &\leftarrow \min[(1+\gamma)\rho, \beta]
\end{aligned} \tag{15}
$$

γ is the growth rate of ρ and β is the upper bound of ρ, which is typically 10^3.

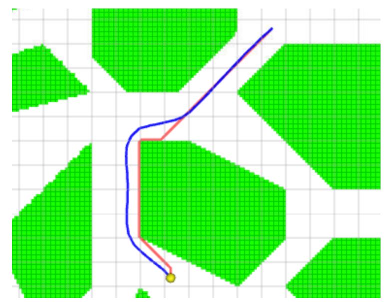
B. *Constraints on voltage and current*

Can we go one step further? Although we can set constraints for speed and acceleration in segments instead of setting a global maximum value, it is difficult to exhaust all possibilities and enumerate all the required constraints. A conservative constraint will waste control resources.

On the contrary, under the guidance of the feedforward model, speed and acceleration together constitute a feasible control domain. Under the guidance of the theory of control allocation, we redesign the speed and acceleration constraints into voltage and current constraints. Doing so enables the model to dynamically adjust the energy distribution on speed and acceleration, maximize the use of control resources on the field.



(a) Velocity and acceleration under constraints



(b) The corresponding path

Fig. 3: Our previous work showing constraints on velocity and acceleration[?].

Elevator feedforward model, i_e means the ratio from motor radian to elevator position meter:

$$
V_E = K_g + K_S \cdot \operatorname{sign}(\dot{d}) + \frac{K_v}{i_e} \cdot \dot{d} + \frac{K_a}{i_e} \cdot \ddot{d} \tag{16}
$$

Arm feedforward model, i_a means the ratio from motor radian to arm radian:

$$
V_A = K_g \cdot \cos(\theta) + K_S \cdot \operatorname{sign}(\dot{\theta}) + \frac{K_v}{i_a} \cdot \dot{\theta} + \frac{K_a}{i_a} \cdot \ddot{\theta} \tag{17}
$$

The motor current at a given voltage and speed is:

$$
I = -\frac{K_v}{R} \cdot \omega + \frac{1}{R} \cdot V \tag{18}
$$

IV. Project Deployment

A. *Protocol Buffers*

B. *gRPC Service*

C. *ImGui Application*

D. *Node Selector*

In case we have $6*(8+1) = 54$ objects to select in field. It is impossible for driver to do so with a joystick. We need some autonomous method to handle it. Hence, the Node Selector Panel came.

The backend of the system runs on roboRIO, based on the native Network Table 4 of WPILib. By accessing port 5810 of roboRIO, the WebSockets will send the necessary resources to the driver station. Lightweight code makes this system plug-and-play. For the communication solution between the front-end and the middleware, we used nt4.js by 6328 [?].

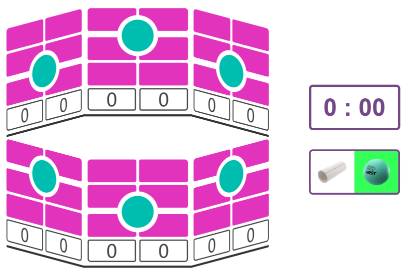


Fig. 4: Screenshot of the panel

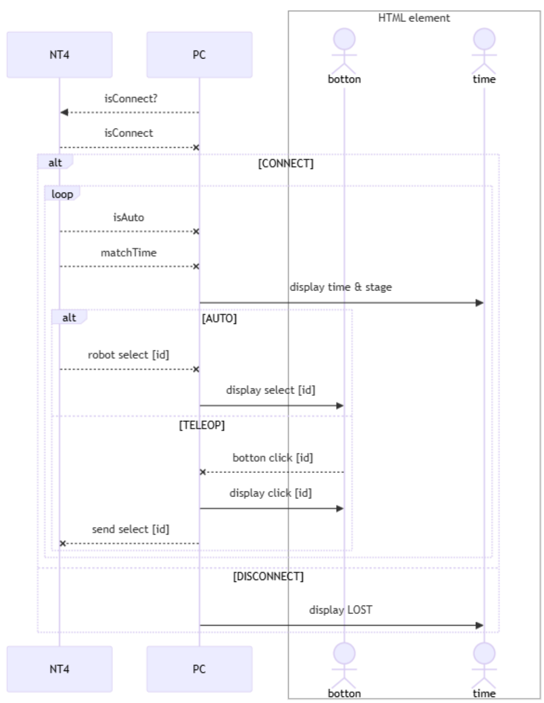
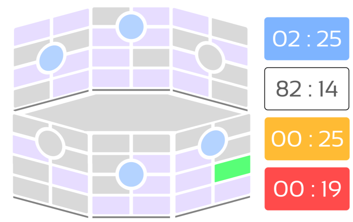
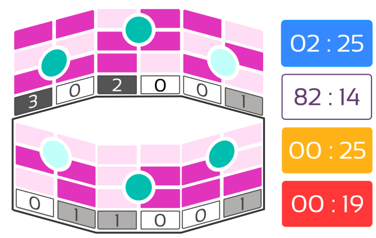


Fig. 5: Architecture of the panel



(a) Macaron Color



(b) High Contrast

Fig. 6: Alternative GUI Solutions

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