IGUS Chain and its Applications
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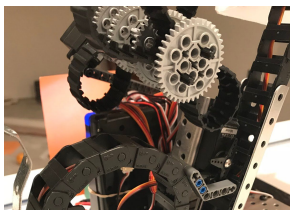
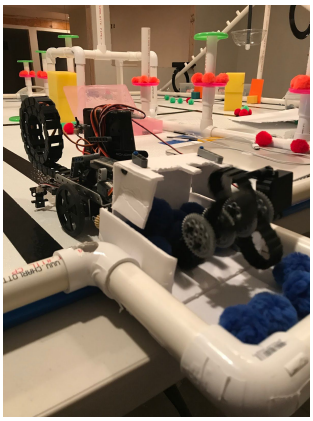
1. **Strategy**
    a. Our team's main strategy revolves around getting game pieces into the tram. The first challenge was creating an arm that would be able to hold an apparatus capable of grabbing pieces without bending or snapping. It also needed to be long enough to get these pieces up to the tram, even if this arm was fully extended. The IGUS Chain proved to be the best way to accomplish all of these goals in the most effective manner. Instead of requiring a complex arm made of metal that would need to fold to fit into the starting box, the IGUS Chain can solve this issue by coiling. This allows us to keep the sturdiness that a regular arm would provide, such as one made with metal parts or LEGOs, all while greatly reducing the space required to house such an arm.

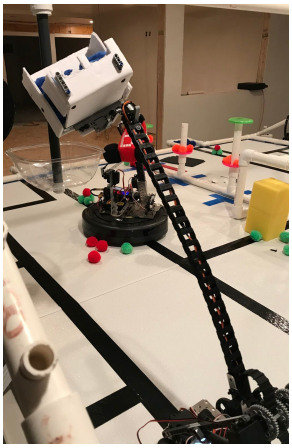
2. **Development**
    a. At Pembroke High School (PHS), we created 2 robots to compete in the 2018 Regional Botball competition. These robots have gone through two entirely different processes to get to where they are now, so we will describe them and the importance of the IGUS Chain in each design.
    b. Small robot (Named *AGUS*)
        i. We decided that AGUS (Always Gets Us Scoring) would be best suited to lift poms collected on the board (Whether those poms be from the aquifer or the black tape) and dump them into the tram.
        ii. The team immediately decided to experiment with building an arm out of the IGUS Chain, since the chassis of the small robot is typically very limiting in terms of what teams are able to add to it. This was accomplished by mounting the IGUS Chain to a small metal sleeve, which would be able to change its angle to the ground thanks to a servo that was attached to it.
        iii. This arm was surprisingly successful. We were able to extend the IGUS Chain with a motor with a servo horn attachment; the motor would spin, and the servo horn would act as a gear, which would be able to extend or retract the IGUS Chain. The chain would coil up every time because we



attached the loose end of the chain to the motor bracket, which prevented the chain from extending too far behind the robot.

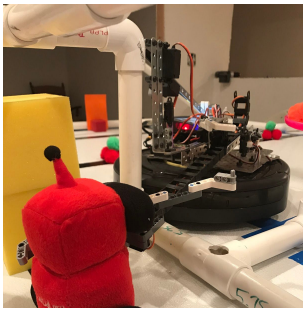
iv. Despite finding an arm that worked, we still had to figure out a way to get an appendage on the end of the chain that would be able to capture poms and dump them into the tram. This appendage would need to be light (since the IGUS Chain can't support a large amount of weight) and small enough to fit into the aquifer. The design of the appendage varied throughout the season. We began with a simple claw, which would clamp onto poms and squeeze them to hold them. This was a design that we kept for a while; the claw would successfully get 6-8 poms into the tram every run, which was a number we were happy with. As the competition neared, however, the number of poms we were getting per run decreased. Thus, we decided to completely scrap the claw in favor of a different design. This design ended up being so successful that we are still using it. It's simply a bucket that's attached to a servo, which allows it to dump collected poms into the tram. The bucket pushes underneath the Poms in the tram and scoops them up, allowing us to keep the design limited to using only one servo. This scooping method is also much more effective at retrieving Poms than our previous claw design, now averaging us 10-12 Poms per grab versus the claw's 6-8. Apart from a few refinements as well as the recent addition of a sweeper arm, which simply spins to funnel poms into the bucket, nothing drastic has happened to AGUS.



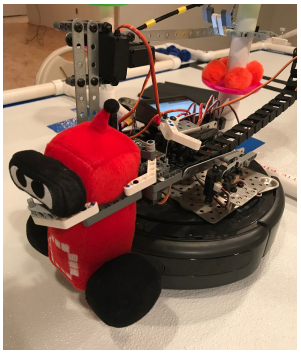


c. Large robot (Named Scorp)

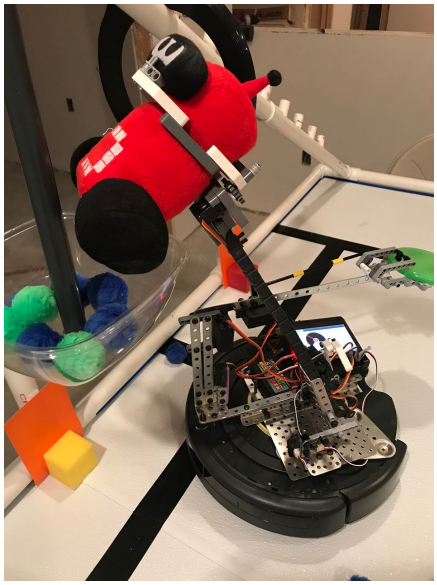
i. Our large robot, unlike our small robot, has had a drastically different developmental journey throughout the season. We knew immediately at the release of the game scoring sheets and the game board reveal that our team would be going for Botguy because he is a very powerful scoring component of most scoring scenarios. In the tram is where he has the most potential; he has a base value of 250 points, and he can, of course, score a lot more if the tram is slid over or if a Frisbee is placed in it. Because we needed to get Botguy into the tram while also fitting our robot in the starting box, we needed to design an arm that would not only be able to reach the tram, but also be able to fit inside the starting box. As such, we figured we needed to construct an arm using metal.

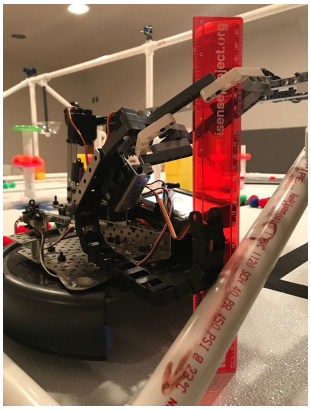


ii. We easily made an arm using metal strips and servos. This arm didn't exactly work as we had hoped. The metal parts along with the servos were simply too heavy for the servos, and our servo ports would short out due to this extreme weight. We attempted to switch out some metal with LEGO rods, but the weight issue was still existent. Our team even tried removing one of the servo connections in an attempt to reduce weight, but even this wasn't even enough to create an efficient arm. This design was finally scrapped in favor of the IGUS Chain design that we had used on AGUS.



iii. We were worried that the IGUS Chain would not be able to hold the weight of Botguy, especially while fully extended and held in the air, but our tests proved the chain to be much stronger than we had first thought. Once we duplicated the mechanism that was on AGUS, we built a simple claw that was specially designed to enclose around Botguy's neck, which is the best location to grab him from due to the indentation in his neck; it allows the claw to have a firmer grip on Botguy. This claw is extremely light, which is incredible because Botguy is the heaviest singular piece in the game, and a light claw is extremely helpful in minimizing the weight on the end of the IGUS Chain. Overall, the IGUS Chain apparatus on our large bot is surprisingly useful in grabbing Botguy and putting him in the tram. It uses very little materials and is extremely light and compact, which is less stressful for our servos and motors.

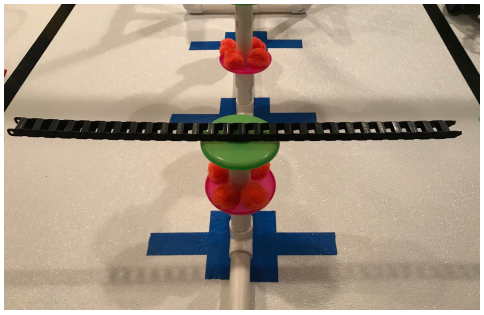




3. Mechanics

a. Effectiveness proportional to materials

i. After the initial designs failed to capture the effectiveness we needed, we created an-all new design using the IGUS Chain. It is able to coil up around itself, which can be extremely handy due to how little space it takes up, allowing it to fit within a limited area. With a traditional folding arm, we would have to use a servo for each part of the arm to fold out to keep it within the starting limits. However, with an



IGUS Chain arm, we can have one motor to extend and retract it as much as we need. The higher we need to go, the more efficient it is. This is also important because our robots have a lot of moving parts, and sparing materials where we can is extremely beneficial for our robots.

b. Strength
    i. The IGUS Chain is very strong and can be run many times without ever bending or weakening. With metal, this is not the case. With long metal arms, the metal shafts of the arm could easily bend just from the torque caused by gravity, as well as with the forces from the weight of constantly picking up materials. Metal arms are also very flimsy. Points, where the metal attaches to the servos, are very weak and can be damaged easily. If a run fails, metal arms could be severely damaged; if the arm malfunctions and hits a pipe, the metal could bend, or, worse, servos could short out and destroy the ports on the wallaby. The same can't be said for the IGUS Chain. Even when the chain is extended a significant amount, it stays relatively straight when turning and driving, making it much easier to grab payloads and not drop them during transport.

c. Weight & Torque
    i. The chain is a lighter material than most metal parts, which was very important for this design; our team found that if an arm was too heavy, the servo would blow the port in its Wallaby controller. When working with metal-based arms, we were forced to swap wallabies and have them sent in for repairs many times before discovering this problem. With the chain arm, we cut weight out by a large enough factor that this problem became irrelevant to us.
    ii. However, this wasn't exactly a straightforward task. One area where the IGUS Chain lacks is its ability to change angle when completely extended; the longer the chain is extended, the tougher it is to change its angle. This can be attributed to the forces of gravity and torque, which means that along IGUS Chain can't be moved as easily as a shorter one because gravity pulls on the longer chain with more force, requiring the servo to exert an astronomical amount of force in order to move it. And with the introduction of the new metal-geared servos without Wallaby optimization, this means that the servo will blow out the Wallaby if it's working against too much weight. Fortunately, there is a simple way around this issue. We found that if we set the angle of the sleeve before extending the chain, the arm was able to hold the angle of the arm even

while holding all that weight and working against a lot of torque. While it is disappointing that we can't adjust the angle of the arm while the chain is extended, our strategy doesn't require that method of adjustment. All we need from our arm is to extend to grab Botguy or poms, retract, and then drop them in the tram.

4. **Versatility**
    a. The end of the chain is easy to add onto, making it perfect for when we decided to duplicate this design onto our large robot. We were able to completely recreate the sleeve and attach a completely different claw onto it with ease. This creates a system of interchangeable parts; if we aren't satisfied with our current claw design or want to change its purpose, it's easy to change out the claw for something else. This means that our IGUS Chain arm can be utilized in a multitude of scenarios using an interchangeable parts subsystem while maintaining its simplistic design.
5. **Real-world applications**
    a. In Botball, the IGUS Chain serves as an extremely efficient form of easy cable management. Of course, in our robot designs, we take advantage of the chain's cable management as well as its sheer strength to create an arm capable of extending to great lengths, all while taking up minimal amount of space on our robot. However, the applications of the IGUS Chain can extend far beyond Botball.
    b. IGUS Chains can be found in many machines and mechanical products.
        i. Minivans/Vans
            1. An IGUS Chain manages the cables that run along a sliding door/ This helps the sliding door slide smoothly while keeping the cables that connect to it organized and safe from moving parts.
        ii. Printers/3D Printers
            1. The chain helps keep cables and wires organized and moving with the printer heads. These heads move horizontally in regular printers, and in all directions in 3D printers. This cable management is essential in these machines, as these heads require constant power and information, but also need to have room to move without the risk of damaging its cables.
        iii. Factory robotics
            1. Robots in factories have tons of moving parts, and these parts require data or power transfer. The IGUS Chain can help keep these necessary wires and cables out of the way and moving with the robots.
6. **Programming**

a. The design of this arm is much simpler than other arms our team has worked on in the past, making it easier to create functions and code for this arm.
b. The IGUS Chain and the angle of its sleeve are controlled by one motor and one servo, respectively. For easy use, we created a function for each to extend and retract the chain to its required lengths. The arm was simply programmed in main to be raised and lowered as necessary.
c. To keep ourselves straight we flatten against the pipe walls whenever we have the opportunity, this keeps us on the correct path so the robots don't run off their paths.

7. Results

a. Our final builds were successful, in that we are able to do everything we wanted to most of the time. Once the first successful test finished it we knew that everything we had been working towards was possible and now we have been working ever since to optimize and improve the success rate so that it works every time.

8. Conclusion

a. In past years, we were upset to always find our IGUS Chain unused and unopened. So, this year, we decided to give the IGUS Chain a shot in our robotic builds, and we found a massive amount of success using this unique part. We were excited to experiment with the IGUS Chain, as there were so many ways to use the material in different and revolutionary ways. It's a very underused and undervalued part that most teams simply brush to the side. However, in many ways, it can be the most advantageous and powerful addition to any robot. Not only can this chain provide flexible cable management, but it can also completely replace bulky arms or other large attachments that require way too much maintenance or attention. With the IGUS Chain, it's easy to create a simple arm that can extend and retract with just one motor. And with a servo, you can extend this arm in any direction and any angle you wish. It's such a successful design. So successful, in fact, that we put a similar apparatus on each one of our robots! And while each robot completes vastly different tasks, they both require a way to suspend game pieces into the air and dump them into a bucket. The IGUS Chain is a perfect replacement to any arm that is extremely bulky or large. It is compact, takes up very little space, and can complete almost every task that a normal arm can. With this, we hope to see this design used more often in the future of Botball. It's a design that has loads of potential and is extremely versatile. Our team was able to turn a simple cable management system into a fully functional arm that lifts many game pieces into the air. While this design took hours of testing and experimenting to get perfect angles and lengths, the end result was absolutely

worth the effort, and we are extremely proud of the arms that we have created using the IGUS Chain.