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A Comparison of Medical Article Transport Approaches

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Our senior design project is to develop a product named the Smartbox - a container capable of safely carrying and monitoring medical articles and accommodate a UAV drone carrying the container. These medical articles include sensitive medicines and human organs for transplantation. Speed, safety, and reliability are a must in this field, as the stakes if a payload is lost or improperly maintained can be life threatening. This project aims to improve on the existing medical transport logistics chains in use today. Time is the most important factor in transportation: many organs simply cannot survive outside of the human body for longer than a few hours. Current approaches to transporting an organ include ambulance, helicopter, and airplane transportation. In this report, our approach to organ transportation will be detailed, with our needs and anticipated benefits discussed. Current transportation networks will also be reviewed and compared to our proposed drone carrier network.

Typical Medical Transport Requirements

There are three must-have factors in any transportation network: speed, specimen control, and accountability. Regarding speed, most organs simply cannot last a long time outside of the human body, even with environmental control. Organs like the heart and lungs will only last 4-6 hours outside of a host body, while “longer-lasting” organs such as the liver and pancreas still last less than 24 hours [1]. This time decay is the greatest challenge in organ transportation, as the clock starts ticking before the transported organ even leaves the medical facility it originated from.

The environment these medical articles are transported in must be closely monitored and controlled, with temperature typically being the most important factor. For human organs, the ideal temperature range for transportation is 4ºC - 8ºC. Lower temperatures will cause the proteins of these organs to degrade while higher temperatures lead to hypoxic damage as the organs demand more and more oxygen [2]. Additionally, high humidity levels are also a concern for organs in transit. Brief variations in temperature can worsen the organ, and increase the likelihood that the organ must be discarded once it arrives at a medical facility and is re-examined.

Finally, with sensitive cargo such as human organs, there must be a robust monitoring system to ensure the carrier and status of the organ is known at all times. Many forms of transportation for organs involve multiple handoffs: for example, plane flights will involve handing off the package at the medical facility of origin, the departing airport, the arriving airport, and end at the destination medical facility. Records of these transactions must be maintained for accountability purposes. In the United Kingdom's NHS Blood and Transplant system, for instance, healthcare professionals must record dates and times of organ handoffs and maintain these records for thirty years [3].

Smartbox: Drone Transport Logistics

Our project consists of the creation of a container for carrying via a drone. The container holds a sensor network designed to provide the most data to consumers and medical partners of any medical transport system. Alongside GPS tracking integrated with Google Maps, the box also monitors external forces acting on the box to indicate collisions or break-in attempts. Inside the container, the sensor network monitors the internal humidity and temperature, as well as a visual feed of the payload via a webcam. This data is all received by the core of our network - a Raspberry Pi - which communicates with end-users via a 4G LTE receiver.

For environmental control, our system uses the temperature readings to control our cooling system: a Peltier device with two additional fans, one for circulation and another to cool the Peltier device's heat sink. The Peltier cooler is a current-controlled device with no moving parts, which makes it very easy to control its behavior and avoid overshoot and causing damage to the organ due to temperatures below the 4ºC - 8ºC range. The Peltier device is also a very light option for cooling, which makes it suitable for the weight requirements to ensure the container can travel via a drone carrier. The downside of this approach to cooling is the high current and power consumption of the Peltier device, which takes up to six amps of current at up to fifteen volts. Selecting an appropriate battery to power this cooler alongside the rest of the system involved balancing the weight of the container and the flight time of the system limited by battery capacity.

Our system utilizes a 118.4Wh lithium-ion polymer (LiPo) battery, which allows about one and a half hours to two hours of flight time on a full charge, depending on the cooling needs due to weather. The carrier drones fly at about 60MPH, indicating a maximum travel distance of our system of approximately **100 miles** on one container charge. Future improvements on insulation, efficiency, or larger drones to carry systems with larger batteries may improve the range of this solution to a few hundred miles. This would enable controlled transport between medical facilities across state lines to neighboring major transplant units. Transcontinental transportation across the U.S., of course, would still not be a feasible option.

Existing Solutions

As mentioned in the introduction, three methods of organ transportation are currently in use today: ambulance transport, helicopters, and planes. Driving is the simplest and most straightforward option listed here, as the number of cargo handoffs are minimal and arrival at the destination is similar to other supplies being delivered to a hospital. Designated organ transplant vehicles are commonly considered to be emergency vehicles, which means they are authorized to deploy sirens as needed to make their trip as fast as possible. Environmental control is a much simpler approach - typically a transport container is filled with either wet or dry ice. Dry ice is used if the container has any ventilation to allow the carbon dioxide the ice forms when it sublimates to escape the container, otherwise wet ice is used to prevent a pressure buildup due to the CO_2. The downside of this approach is in the lack of controllability of the organ temperature. The inside of the transport box is cooled and built to maintain a cold temperature, but there’s no control over the lower temperature bound. Ice will remain below 0ºC, and as the organ spends time at that temperature, its proteins may degrade and increase the likelihood of being discarded.

Helicopter transportation is similar in strategy to ambulance transport, but for much longer distances. Helicopters typically fly through the air at about 160MPH, making the same trips as cars in less than half the time when considering the helicopter can travel in a straight line without regard for road conditions [4]. The helicopter approach has one main drawback - price. Medical flights via helicopter are very expensive. Pricing for current organ transportation-specific flights aren't publicly accessible, but the median cost of an air ambulance flight was $39,000 in 2016 [5]. The other potential concern is the need of a helipad at the destination for this form of transportation to be an option, but this is one of the reasons hospitals with trauma centers or transplant centers are required to have a helipad.

Plane transportation is another option, suitable only for very long distance transportation. Commercial passenger planes fly at about 500MPH, with smaller private jets flown specifically for organ transport capable of flying up to 711MPH [6]. While the issue of prohibitively high costs comes into play with this form of transportation like the helicopter, there are additional complications. More cargo handoffs take place with plane transport. On a commercial flight, the container containing an organ must be checked as special cargo at the origin airport and received at the destination airport. With both types of plane travel, though, the destination airport is not the final destination for the cargo, so additional travel must take place, either via a transplant ambulance or by helicopter transport. Commercial travel, though, is particularly problematic due to unexpected delays in transportation. In a study by Kaiser Health News between 2014 and 2019, almost 170 organs were discarded following "transportation issues", while another nearly 370 endured "near misses" following delays of two or more hours [7]. Due to the time lost in airport boarding, landing, and transferring to another transportation method, planes are only meant to be used for these very long distances.

Comparison

Where our drone carrier system and accompanying Smartbox container win out over legacy logistics networks is in the robust monitoring and accountability throughout the logistics chain. Currently, there are no federal agencies in the U.S. that mandate the monitoring of organs being transported [7]. Instead, there are independent organ procurement organizations that work with medical facilities to arrange transportation, and these groups establish their own standards on how they monitor ongoing transportations if at all. Rather than keeping written records of handoffs and making phone calls with progress updates, the Smartbox system is built to provide this information to medical partners in real-time. Additionally, while the drone carrier network is still in early planning stages, the expectation is to compete against helicopter transportation on price and ambulance transportation on speed. Medical plane or jet flights are the only feasible option for very long distance transportation at this time. Future improvements may come either through improvements in speed or carrying capacity of the drones carrying these containers. Speed increases would allow the drones to come closer to matching helicopter transportation's advantage of ~160MPH speeds, while carrying capacity improvements would allow the container to hold a larger battery or more insulation to increase the amount of flight time the container can sustain. So far, the only approach to organ transportation has been to consider how to get an organ to a transplant center. One task the drone delivery network cannot do that the legacy methods can do is the inverse of this approach - bringing transplant recipients to a hospital with an organ waiting for transplant on-site. This is an option that our system is incapable of performing due to tighter weight and size limitations.

Conclusion

Our approach to medical article transportation is a novel one which seeks to reach a middle ground between the point-to-point speeds of helicopter transport and ambulance transport without the high costs. The accompanying Smartbox container is the primary focus of our senior design work, and the monitoring and accessibility features of the container far exceed the majority of offerings available in the current space. Controlled cooling prevents cold shock damage, which the solutions that rely on dry ice run the risk of. The downside of our container is the significant power consumption required to maintain active cooling. The drone carriers, though, may be able to provide power-sharing solutions via a universal charging port to share power between the carrier and the container. The monitoring and accountability associated with our project exceeds the standards of most current procurement organizations, and integration of the Smartbox into drone delivery networks may encourage these standards to improve as the benefits of this level of monitoring become more apparent.

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