Safety Considerations for Ceiling-Mounted Camera Systems

Published July 2020

Figure 1: image of Furio SkyDolly, which rides on top of rails that are supported from underneath. This eliminates the critical reliance on fasteners to support the weight of the system.

Introduction
Safety is an important consideration when it comes to any robotic system, whether it is in a manufacturing plant, on our roads, or in a television studio. These systems are getting larger, more complex, more intelligent, and more common, and while robot-related workplace accidents are relatively rare, a quick search of the United States Department of Labor's Occupational Safety and Health Administration database reveals that serious injuries, including fatalities, continue to occur on occasion. Therefore, Health & Safety issues need to be at the forefront of installers' and users' minds. And yet, for some reason, safety is often overlooked to some degree when it comes to ceiling-mounted robotic camera systems. This is somewhat surprising when you consider some of the larger systems, which can carry a broadcast camera and lens, perhaps even a full prompter, at relatively high speeds around the studio.

Fall Prevention – Provide Proper Support
Let's start with the obvious concern, which would apply even if this wasn't a robotic system: ensuring that nothing can fall down, whether that be parts of the camera rig, dolly, or tracks. It might be expensive but in general, a fall is not something you need to worry about with a floor mounted system, as there is little risk of injury if a wheel comes loose or a camera works itself free, or even if the dolly derails. However, it's a very different story for a suspended system, where if anything of significance comes loose, there's a high potential for injury. We need to take the same approach that we do with lighting fixtures, speaker arrays and monitors – or anything else that we suspend from the ceiling: everything must have a secondary attachment point so that if the primary mechanism fails, there is a secondary support element to keep parts from falling to the ground.

For example, if the rails come free from the trusses, then the dolly and the payload are likely to follow shortly afterwards. Or if the dolly comes free of the rails, the same thing is going to happen. One simple way to reduce the risk of things falling is to mount the rails such that they are supported from underneath, so that even if the fasteners fail, they don't instantly fall. Likewise, the dolly itself should ride on top of the rails, as illustrated in the figure below. In both cases, whether a fastener securing the rail to the frame support or the nut securing the wheel assembly to the dolly fails, the system is still supported and will not fall to the ground. Designs where the rails are clamped underneath the trusses, and the dolly hangs from the rails, are critically reliant on those fasteners not failing, as there is nothing else holding them up.

With this in mind, hanging the dolly from the rails is probably the least secure method of mounting the dolly. All of the weight of the system is below the rails, and there is no simple way to implement a backup attachment in case the wheels come off the rails or disconnect from the dolly, which can and does happen with fast moves, as an example. If one wheel comes off, in some cases that leaves just two wheel mounts to support all of the weight, with the system swaying perilously below. Mounting the dolly on top of the rails makes it far more difficult for the dolly to come off the rails, even if a wheel assembly comes free. Difficult, but not impossible. To be completely sure that the dolly cannot derail requires some additional features to ensure that it cannot be bumped off the tracks. For example, a second set of rails is added above the dolly to essentially trap it between the upper and lower rails, as shown in the image below. Additional brackets/features on the dolly and wheel assemblies ensure that the dolly will stay in place, no matter how it is bumped or jostled or how fast it is going.

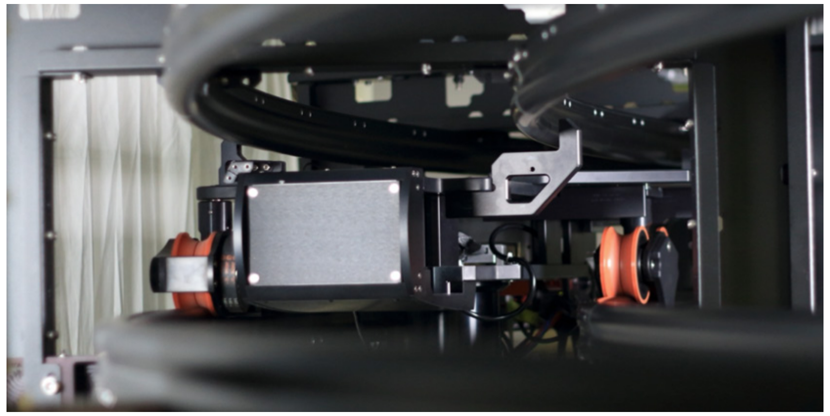

Figure 2: image shows secondary safety rails and brackets that prevent the dolly from working its way free from the lower rails that support the dolly. Additional brackets on the wheel assemblies further ensure that the dolly cannot derail.

Another concern with hanging the dolly below the tracks is that the wheel attachments must bear all the stresses that result from the dolly moving along the rails at high speeds, especially along a curved track. Take the example of a dolly with an inverted column where the payload is hanging a couple meters below the dolly. As the dolly travels around a curve, the resulting centrifugal force (the apparent force that seems to be pushing the payload outward, away from the centre of the curve) will cause the dolly to try to tip away from the center. This will generate a torque on the dolly that is proportional to the distance between the rails and the center of mass: the lower the center of mass, the larger the torque. This is illustrated in the diagram below. If the dolly is hanging below the rails, as shown in (a), all of the weight of the system is below the rails, and the center of mass is lower. Having the dolly riding on top of the rails, as in (b), brings the center of mass up closer to the rails, and hence the torque on the dolly is reduced. In (a), these torques create additional forces on the inside (R) wheel assemblies, as if someone is trying to rip them free of the tracks. In (b), those forces are instead pushing the dolly down onto the rails, so there is no additional stress on the wheel attachment. In both cases, there is an upward force component on the outside (L) wheels that increases as the center of mass moves lower, away from the tracks. This is countered by the downward force of gravity acting on the mass of the system and its payload, and can be further mitigated by increasing the width of the dolly. In those rare cases where the velocity (and therefore the centrifugal acceleration) is so large that the outside wheels do lift off, the secondary rails and brackets described above would prevent the dolly from actually falling.

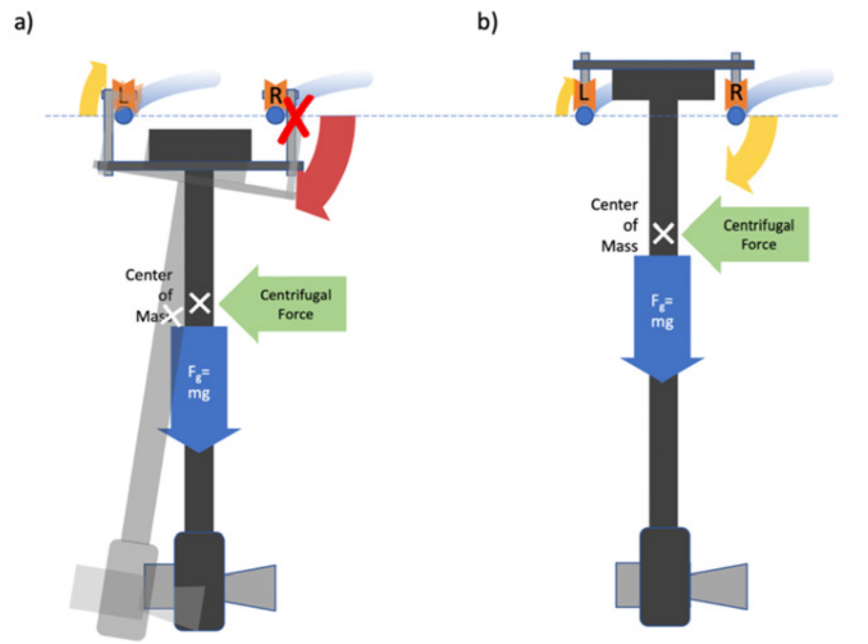

Figure 3: illustration of the forces acting on the inverted dolly when going around a curve. in (a) the dolly hangs below the rails, and the torque on the right side of the dolly is illustrated by the red arrow, which stresses the wheel attachment trying to keep the wheel on the track. If that attachment fails, the dolly is left dangling from the rails, and will likely fall off completely. In (b), where the dolly sits on top of the rails, the torque on the dolly is reduced since the center of mass is higher, and in any case there is minimal stress on the wheel attachment since the force is pushing the dolly onto the tracks, not trying to pull it away.

Fall Prevention – Tether the Unsupported

Consider next the head and payload, i.e. the camera, lens, prompter, and other accessories that are mounted on the cradle. Although the payload is supported from underneath, that cradle is rarely level, so once the bolts securing the payload to the cradle come free, it is unlikely to stay in place for long. Similarly, if the coupler that secures the head to the lift fails, both the head and payload are going to fall.

It is worth noting that in most cases, more than one fastener would have to come loose or fail before anything falls off, perhaps providing a false sense of security. However, the problem is that with the system up in the ceiling, it is difficult to notice without doing regular, rigorous checks of all the fasteners, none of which are in easy reach. Quite often, it is impossible to tell from below that only one fastener remains in place. As a result, the first time it is noticed is when the item falls off.

This is why it is standard practice to use tethers on ceiling mounted equipment. With a tether, the article can still come free from its attachment point, but doesn't fall to the ground. This way it is perfectly clear that the primary attachment has failed, but injury and damage to the equipment have been avoided. The same principle can be applied to the head and payload of a ceiling mounted camera system. The payload can be tethered to the head, while the head can be tethered to the dolly. Keep in mind, however, that tethering to the dolly only makes sense if the dolly itself cannot easily come free of the rails.

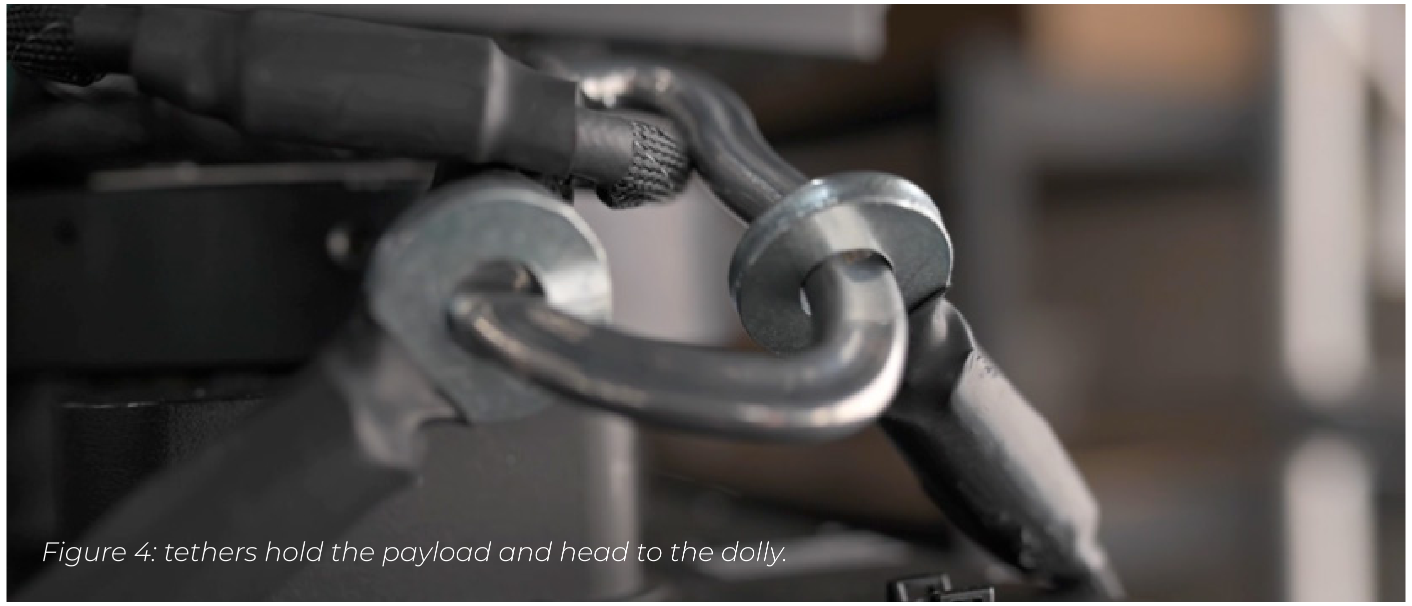

Figure 4: tethers hold the payload and head to the dolly.

Collision Avoidance

The other safety consideration when it comes to any robotic system is the possibility that the system will collide with personnel while it is in motion. With a dolly system that can move at speeds in excess of 2 m/s, this a serious consideration. It is therefore very important that anyone working with or around the robots receive proper safety training so that they know what to watch out for, and how to avoid collisions.

To help protect against personal injury, large robotic equipment is required to include at least one Emergency Stop (e-Stop) button that quickly and safely brings the system to a halt. While an e-Stop button mounted on the dolly is necessary and useful on a floor dolly, it is less convenient on a ceiling mounted system, where the dolly is not within reach. In this case the availability of a remote e-Stop that can be installed anywhere in the studio is critical to the safe operation of the robot.

Figure 5: Remote e-Stop brings the system to a rapid but controlled stop, avoiding injuries or property damage due to collisions.

In addition to e-Stops, it is recommended that, where possible, barriers or floor markings are used to keep personnel away from areas where the robots are operated. In some cases, advanced features such as light curtains, vision-based detection systems or other proximity sensors can be used to raise alarms or automatically stop the robots. The challenge here is in developing a detection system that does not generate false positives that result in the camera stopping in the middle of a programmed on-air movement, disrupting the broadcast. This is a consideration that is somewhat unique to broadcast robotics: in manufacturing, occasionally halting a robot because of a false alarm has a limited impact on the output of the factory. In broadcast, this may not be tolerable. So the industry is still working on developing effective collision avoidance solutions that can effectively detect and avoid collisions without unnecessarily disrupting broadcasts.

Conclusion

Safety is an important consideration when using any robotic system, but this is amplified when they are mounted overhead. This can be addressed in part through careful design, supporting elements from underneath wherever possible, not relying on fasteners to support the load. When this isn't possible, adding a backup attachment, such as a tether strap, is essential for preventing things like the head or payload from falling. Finally, preventing the moving robot from colliding with personnel in the studio is critical when transporting heavy equipment around at head height, and at high speeds. Safety training and clear indications of potentially hazardous areas are essential to maintaining a safe workplace when robots are present. Remote e-Stops allow the ceiling mounted system to be brought to a quick, safe stop, avoiding or limiting any damage or injury. In the future, effective collision avoidance technologies offer the promise of automated prevention should either of these approaches fall short.