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You-Are-Here Maps for International Space Station: Approach and Guidelines

J. J. Marquez, C. M. Oman, A. M. Liu
Massachusetts Institute of Technology, Dept. of Aeronautics and Astronautics

ABSTRACT

Guidelines for designing you-are-here (YAH) maps aboard International Space Station (ISS) are proposed, based on results from previous 3D spatial navigation studies conducted by our research group and colleagues. This paper reviews terrestrial YAH maps, the common errors associated with them, and how to appropriately implement what is known from terrestrial to micro-gravity YAH maps. We conclude with a creative example of an ISS YAH map that utilizes given guidelines and information visualization techniques.

INTRODUCTION

Space motion sickness, visual orientation, and spatial memory problems have been documented for both the U.S. and Russian spaceflight programs (e.g. Gazenko, 1964, Matsnev et al., 1983, Oman et al. 1986, 2000). Disorientation problems continue after several months, as evidenced by astronauts on Mir (Burrough, 1998; Linenger, 2000; Richards et al., 2002). Richards et al. summarize the wayfinding and spatial orientation issues that were reported on Mir:

- difficulty navigating through space station modules, especially the node,
- difficulty inter-relating the coordinate frames of adjacent modules,
- difficulty relating an exterior coordinate frame with interior, local reference frame (e.g., an inability to visually locate incoming Progress supply ship),
- incomplete mental survey map, even after 3 months in some cases.

Furthermore, wayfinding problems on Mir extended to visiting Shuttle crews who sometimes had difficulty finding their way back to the orbiter; Mir crewmembers fashioned arrows for route guidance (Richards et al., 2002; Smart et al. 2001).

The greatest concern resulting from these spatial disorientation problems is not in relation to everyday navigation, but rather emergency response times. Crewmembers of the International Space Station (ISS), regardless if they are visitors, first time or experienced astronauts, must be able to quickly identify escape route or emergency equipment. Upon assembly completion, ISS will have several nodes, about a dozen modules, and multiple egress routes. If the wayfinding problems seen on Mir also appear on the growing ISS, we suggest complementing current pre-flight training with adequate signs on ISS to better ensure safety. In this paper, we consider how you-are-here (YAH) maps, a commonly used aid for terrestrial wayfinding, might be implemented in future complex spacecraft.

Countermeasures already in place to aid wayfinding and to reduce spatial disorientation are:

- dual visual verticals consistent across modules,
- use of coloring on hatches to indicate direction,
- use of labels on end cones to identify surfaces,
- consistent use of lighting (from 'above'),
- pre-flight training on ISS mock-ups,
- emergency egress signage (Smart et al. 2001).

We propose to complement these established countermeasures with an in-flight YAH map. Maps are useful because they quickly provide spatial information about the environment beyond what can be seen and depicted in a physically small space (e.g. a sheet of paper). The most common reasons to utilize maps are to find your way or to learn a new environment. On many occasions, maps are most helpful when lost or disoriented. YAH maps can be distinguished from regular maps because they show users their location within the environment and also the surrounding areas. Hence, they are used for wayfinding in most buildings, e.g. museums, hospitals, schools, and malls.

YAH maps have been considered for ISS (Blume, 2001; personal communication). Aside from the obvious reasons for using these maps on ISS, namely for everyday wayfinding and reorienting when lost, there is a more subtle reason for considering implementing YAH maps on ISS. The maps could improve the crew's mental models of the spacecraft, which in turn would improve safety by decreasing confusion and aid in decision-making during emergencies.

The nature of mental models developed from learning through maps remains an active focus of research. Coined by Siegel and White (1975), three types of spatial knowledge are widely discussed in the literature: landmark, route, and survey or configurational knowledge. Landmark knowledge reflects mental representations based solely on the recognition of landmarks, while route knowledge implies an understanding of the ordered sequence of legs and turns required to get from one landmark to another. Finally, people with survey knowledge recognize the relative positions of landmarks (both in distance and orientation) and can identify the environment from different points of view.

Thorndyke and Hayes-Roth (1982) found that map learners did better in judgments of relative location and straight-distance estimation, indications of survey knowledge, than direct navigation learners, who were better at estimating route distances. If we extrapolate these findings to the ISS microgravity environment, we should expect astronauts who use YAH maps to develop survey knowledge of the space station. This would be very beneficial because it is this type of knowledge that appears to be difficult to acquire in complex environments (Moeser 1988), in particular, Mir Space Station (Richards et al. 2002).

Our design guidelines for YAH maps for ISS are based on previous 3D spatial navigation studies, avoiding terrestrial mistakes and taking advantage of techniques used in maps and information visualization. The rest of this paper describes these guidelines, which relate to map and user orientation alignment, context and interiors.

APPROACH AND GUIDELINES

One common trait among successfully designed maps is that the mapmaker has wisely selected what information is necessary and what to exclude. By minimizing the amount of information, they avoid too much detail that could confuse the user. Along with simplicity, a map should not apply a large workload on the user, but rather minimize mental visualization as well as facilitate comprehension of spatial relationships. (Adapted from characteristics set forth by Southworth and Southworth 1982, Talbot et al. 1993) Other common characteristics of useful maps are: accuracy, a good fit between map and environment, clarity, and legibility. Finally, Southworth and Southworth point out that maps should permit interactivity, allowing users to change, update, and personalize the map.

Figure 1: Example of a terrestrial YAH map. This mall map has an 'x' that marks the reader's location.

Figure 1 is a YAH map that could be found in any mall. Many have experienced the frustration of using these maps, unable to find the information one needs and thus, preventing one from making quick and accurate decisions about which direction to go. In assessing this YAH map, we should ask:

- Is the map legible? Is the end destination identifiable?
- Is the YAH marker identifiable? Does it show the viewer's orientation?
- Is the YAH map oriented properly, e.g. is the right side of the map on the viewer's right?

A YAH map for ISS must not only deal with these questions but also the added complexity of navigation in 0-G and of the space station's architecture.

ORIENTATION AND REPRESENTATION OF MAP

Levine (1982) defines an orientation principle for terrestrial YAH maps: "The orientation of a vertical map is psychologically equivalent to that of a horizontal map produced by a simple laydown (90° forward rotation) transformation." In essence, the user has to do only one simple mental rotation to align the map to their orientation. He observed that maps that are contra-aligned (180° out of alignment) result in the highest number of mistakes and longest response times for direction tasks (Levine et al. 1982, Levine et al. 1984). This principle is not always followed in typical YAH maps due to lack of awareness of this simple, helpful rule. Usually only one map, labeled in one orientation, is made for all locations; hence, it is impossible to adhere to the principle.

Unfortunately, applying Levine's orientation principle for YAH maps is impractical for ISS. On Earth, users of YAH maps typically only have to figure out one rotation, in yaw (translations are fixed to one plane by gravity). In microgravity, astronauts can rotate in yaw, roll and pitch. There are modules that will be perpendicular to the 'floor' (e.g. docking modules, Node 3) and modules that are 'above' and 'below' the main section of ISS (e.g. Centrifuge Accommodation Module and Habitation Module). Thus, the YAH map cannot be "flattened" and simply laid-down, as suggested by Levine. Alternatively, another common orientation principle is to align the map with the terrain (Harris, 1967; Winterbothem, 1936). This principle can not be achieved either because it assumes the map would have to be manipulated by the user in order to align it to the environment.

For YAH maps on ISS, we suggest adhering to the "spirit" of Levine's orientation principle: minimize mental rotations when viewing the map. To accomplish this, the viewer's orientation needs to be fixed with respect to the map and the viewer must be able to align their current visual environment with the map in order to confirm their orientation within the module. An astronaut's orientation is highly unconstrained since they freely rotate with three degrees-of-freedom. Their orientation with respect to the map will be largely determined by the orientation of the text labels. This is naturally enforced since the map's readability will be worse if astronaut views it while floating upside down.

In order to allow astronauts to easily align their visual environment with the map, we suggest depicting the station from a perspective view or "bird's eye view" of the ISS. Furthermore, the user should be able to see the interior features of the space station. This type of visualization was successfully implemented for Spacecraft-in-Miniature, or SIM (Marquez, 2001, Marquez et al. 2003). Even though SIM was an interactive visualization (i.e. the user could change its position and orientation), the user could always see inside the modules to identify key landmarks, which astronauts use to reorient (Richards et al., 2002). Information about the interiors in the YAH map permits the astronaut to align their current visual environment with the map in order to confirm their orientation within the module. In this manner, Levine's orientation principle is essentially followed – to align the map with the user. In addition, showing the interior of adjacent modules allows the user to understand their orientation relative to those modules.

Figure 2 illustrates an example of a YAH map for ISS implementing both a "bird's eye view" of station and visible interiors. The orientation of the labels is aligned with each of the module's individual vertical. Some symbols are used for escape vehicles. Unfortunately, an inside view of ISS in its entirety makes the map somewhat cluttered. Finding the YAH marker, in yellow, is rather difficult. Adhering to the orientation principle while showing interior views of the ISS compels the design of a YAH map to rely on more abstractions (e.g., symbols) in order to encapsulate important information about the environment.

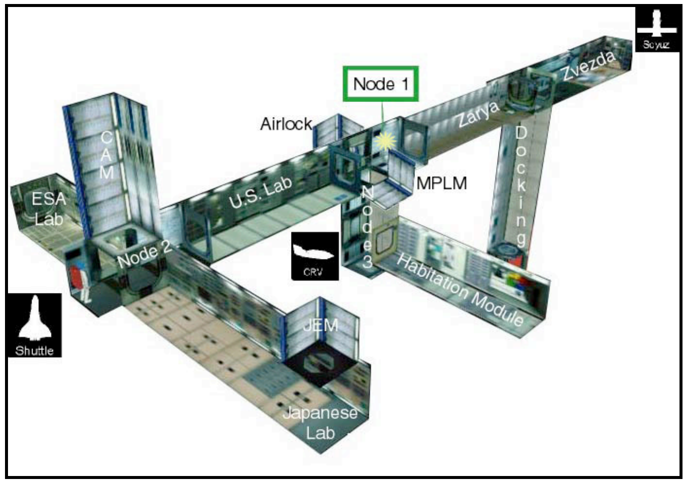

Figure 2: YAH map with "bird's eye view" of International Space Station and visible interiors.

IDENTIFYING KEY LANDMARKS

The goal of creating an ISS YAH map should be to minimize mental processing (e.g. mental rotations <u>and</u> visualizations) while retaining relevant information. However, the key landmarks are not clearly marked nor are apparent in Figure 2. Before creating an ISS YAH map, we will have to identify and verify which landmarks astronauts use most when reorienting and navigating in order to include them in the map. Based on the engineering design of modules, the following are likely key landmarks:

- hatches and their color
- light fixtures
- large fixed equipment (e.g. treadmill, monitors, windows, glove box)
- orientation of labels (words).

To denote landmarks, we could use graphical variables, such as symbols, shapes, and color. Symbols are quick and easy to interpret if they elicit the correct abstraction (e.g. Figure 3). For example, the international symbol for bathroom is a cartoon of a woman in a dress and a man; it is a good symbol because its abstraction is well known and understood. An example of salient landmark depiction is shown in Figure 4. Buildings and rivers are drawn, colored differently than the rest of the environment, which is left blank.

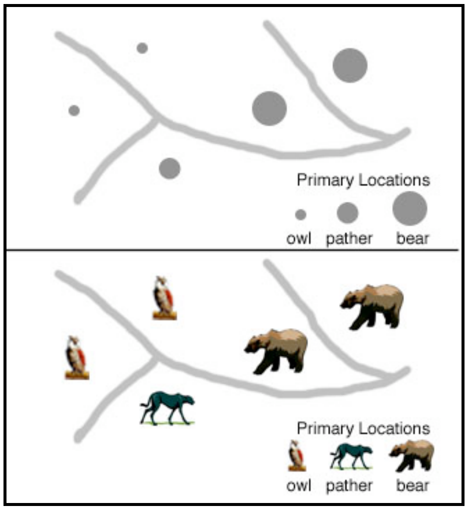

Figure 3: Example of symbol abstractions, adapted from MacEachren, 1994. Interpretation of map may be easier because of depictions of animals versus the circles of different sizes.

Figure 4: Highlighted landmarks, Cologne tourist map (By Herbert Lemkes for Verkehrsamt der Stadt Köln, Germany. From Southworth & Southworth, 1982).

Future ISS YAH maps could benefit from carefully selected symbols that represent landmarks. An important aspect to consider is that objects, as normally encountered in 1-g, are either intrinsically or extrinsically polarized (Howard 1982). Intrinsically polarized objects are those with consistent specific orientations with respect to gravity (e.g. a table). On the other hand, the orientation of extrinsically polarized objects is defined by its physical relationship with another object and to gravity (e.g. a pen on a table). Signs that are strongly polarized in a particular direction might be difficult to understand in microgravity if the crewmember is not aligned with the sign. Even a simple arrow may be ambiguous (Figure 5); does the arrow in the figure below indicate a pitch upwards or forward?

Intrinsically polarized symbols on the YAH map could represent both the location of a landmark and the orientation of the module in which the landmark is situated. Text labeling will also reinforce the local verticals of each module since text is strongly polarized. However, text that is rotated more than 90° takes longer to read (Koriat & Norman, 1985).

It is important to point out though all landmarks that astronaut use may not be intrinsically polarized, nor that intrinsically polarized landmarks make better visual cues in microgravity. This remains to be tested with the actual landmarks in use on ISS. However, using text and landmarks to reinforce relative orientations of modules exploits the existing framework of ISS established by visual verticals in the modules and training protocols.

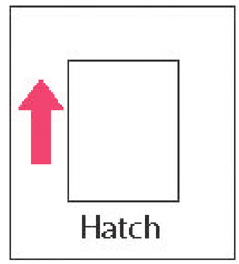

Figure 5: Ambiguity of arrow on a surface of hatch. In a microgravity environment, is the arrow pointing forward or up?

MAINTAINING CONTEXT

Even with the "bird's eye view" of ISS, capturing the large and complex space station in a physically small area remains a challenge. We believe that maintaining context of the entire environment, i.e., ISS, is crucial for understanding the spatial relationships of modules. Some information visualization techniques that could be applied to help keep context of the whole station. One particular technique, location probing, emphasizes important landmarks while still depicting the entire area of interest, as seen in Figure 6. This map shows the entire island of Manhattan while still zooming into Yeshiva University buildings, maintaining focus as well as context. Other information visualization techniques that allow focus and context are fish-eye lens (zoom in certain areas only) or perspective walls (see Figure 7, detailed central area with sides in perspective, 3D walls, for context). Considering these techniques when designing the YAH map will hopefully help find a creative solution to keep the entire context of the space station within a small area.

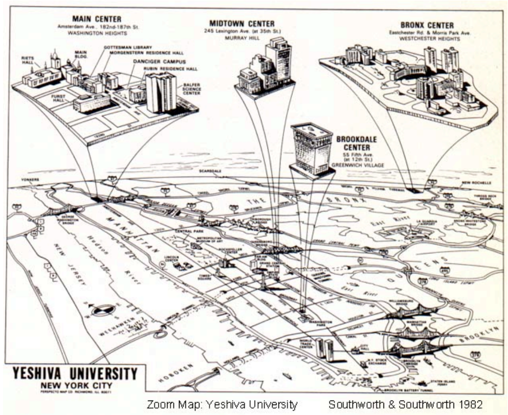

Figure 6: Location probing landmark map of Yeshiva University. Zooming on key buildings while maintaining geographic context of Manhattan. (Copyright © Perspecto Map Co., Inc., Richmond, IL 60071. Map artist, Eugene Derdeyn. From Southworth and Southworth, 1982)

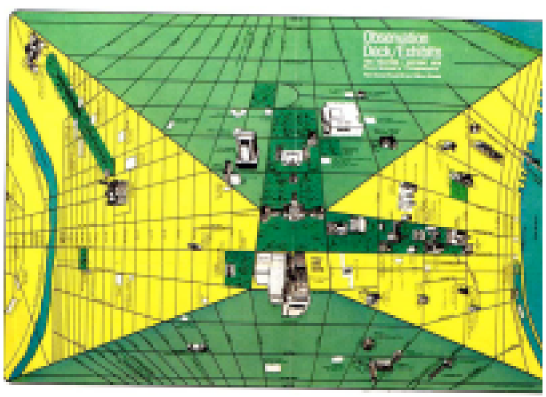

Figure 7: Perspective wall example of Penn Mutual's Philadelphia. Area of interest is zoomed while the surroundings are distorted in order to maintain geographic context. (Courtesy of and copyrighted © by The Penn Mutual Life Insurance Company, 1976. From Southworth and Southworth, 1982).

YOU-ARE-HERE SYMBOL & MAP LOCATION

The most important symbol on ISS's map is the "you-are-here" marker. Simply indicating position is not sufficient; depicting orientation is essential for wayfinding on International Space Station. Levine (1982) suggests using bipart YAH symbols, which is a marker that shows orientation of map within the terrain and also the user's orientation relative to the map. For example, the 'x' seen in Figure 1 is not bipart because it does not show which way the user is viewing the map; an arrow would have been an appropriate bipart symbol. Adding the orientation marking to position will minimize mental rotations. Graphically, position can easily be drawn; we suggest using a title for each map indicating the name of the current module. For orientation, we use an astronaut avatar (a model figurine); the orientation of the avatar is the one the crewmember should adopt to properly read the YAH map.

Other cues to indicate the astronaut orientation should reinforce both location and orientation, as well as take advantage of existing structural elements of the space station, such as hatch coloring and placement of lights. In 3D-task experiments (e.g. 3D spatial memory tasks), subjects could effectively determine their orientation within a cube if two surfaces were shown – the forward and the bottom surface (Oman et al. 2000, Richards et al. 2002/2003, Houdou, 2002). Hence, we suggest depicting at least two interior surfaces of the module where the map is located.

The placement of the YAH map in the module may also influence the mental workload needed to read the images. Aside from orienting and aligning the map correctly, Levine (1982) suggests using the principle of structure matching, or relating the map with the terrain. The minimum information required to do this task is the identification of two points on the terrain and their corresponding points on the map, referred to as the two-point theorem. There are ways to facilitate the matching of structures between map and environment, including: adding labels on terrain structures, using asymmetrical structures, and indicating direction in the 'you' symbol (Levine, 1982). Currently, many labels on ISS equipment exist, and these need to be absorbed into the map. We also propose that the likelihood of a particular direction of navigation should be considered. Identifying common routes and verifying them during spaceflight should provide insights as to where to place the YAH map. The astronaut ideally should be able to look at the map, determine their orientation, identify the final destination, and determine the path. If the first leg of the path is to turn right, the first movement the astronaut makes *should be* a right turn. It is important to note that this may imply that the maps in various locations on the station may look different from each other, i.e. have different points of view, depending on their location within the ISS.

A CREATIVE EXAMPLE

We developed a creative example of an ISS YAH map using the principles and guidelines delineated in this paper (Figure 8). There are two competing requirements: (1) creating a map that maintains all the context of the space station and (2) creating a representation that is clutter-free and intuitive. We turned the ISS map into a 'stick figure' pictorial of the layout, maintaining a spatial framework of the layout of ISS. The bird's eye point of view captures the entire context of the station. The map provides an overall sense of various places (modules) and their relationship to each other. A module's local orientation, or visual vertical, is depicted by the orientation of their labels. Emergency exit locations are labeled in red text and have symbols attached to them.

This YAH map implements the information visualization technique of a fish-eye lens projection. The module within which the astronaut is located is enlarged. The labels of modules farther away from this location are decreased in size proportional to the distance. This YAH map allows the astronaut to see inside the ISS station layout, but only around their immediate location, which is the title of the map. The location of the map itself is indicated with a green star. The orientation the astronaut should adopt to properly view the map is also depicted. Furthermore, the color of the three visible interior surfaces corresponds to their actual color and arrangement. One key physical landmark has been included, in this case, a computer station. However, the structure of this map prevents us from displaying landmarks in other modules, relative orientations of other landmarks are unknown.

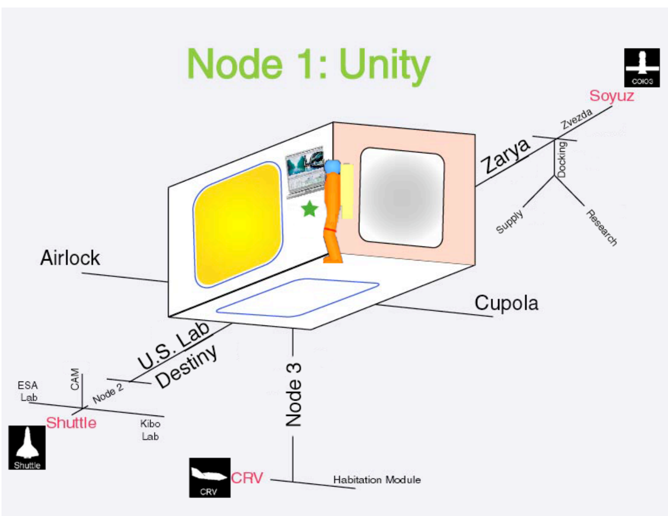

Figure 8: Fish-eye lens International Space Station you-are-here map.

CONCLUSION

Based on general map-making philosophy the *specific guidelines for ISS YAH maps* described in this paper can be summarized into seven design requirements:

1. Orient a YAH map with visual verticals to facilitate alignment of the viewer, environment, and map.
2. Keep the entire context of the space station; for example use a perspective or "bird's eye" view of ISS in the YAH map.
3. Show interiors and key landmarks, used for orientation and wayfinding; mark them with labels and/or symbols that are, if possible, intrinsically polarized.
4. Depict local verticals for every module so relative module orientation are distinguishable.
5. The YAH marker should be clearly visible, and identify location and orientation.
6. Carefully consider placement of YAH maps; keep in line with common and emergency egress routes.
7. Some creative techniques, such as zooming only certain areas, may help achieve competing requirements, like context vs. clutter.

While all these guidelines are necessary, the first is the most important because without it, the map could contribute to disorientation instead of being an effective countermeasure.

Further understanding of how spatial knowledge is encoded in a microgravity environment, by quantifying in-flight wayfinding, would help improve ISS YAH map designs. How much survey knowledge does an astronaut really acquire? Which landmarks are used for reorientation and wayfinding? Are there preferred routes, rotations, and maneuvers? This information could also be used to identify key map locations, e.g., high "traffic" areas like nodes.

To test the effectiveness of YAH maps as a wayfinding tool, we suggest testing users through a series of route and survey description tasks. For example, with map at hand, given an initial position and orientation, can the user point to the location of the CRV? Can they describe a route, with segments and turns, to the CRV? Additionally, measuring the effects of different information visualization techniques on route selection times could be part of a validation process before implementing the YAH map.

In conclusion, ISS you-are-here maps should be helpful to reinforce astronauts' survey knowledge. This survey knowledge will be beneficial to crewmembers during times of emergency. Their construction should adopt the map principles and characteristics that have defined successfully designed maps. The map design guidelines presented in this paper were created in an effort to accomplish these principles.

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CONTACT

Jessica Marquez

Man-Vehicle Laboratory

Massachusetts Institute of Technology

jjm@mit.edu