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Roke Manor Research Ltd
a Siemens company

Visual Exploration of Buildings

The Visual Exploration of Buildings system allows a robot vehicle, equipped with only a single visual camera, to autonomously explore an indoor environment. Vision processing software (DROID) detects visual features in the camera output and calculates their three-dimensional positions using a structure-from-motion algorithm. Obstacles are identified and a map of the explored area is built up.

We have investigated the interpretation of the three-dimensional point cloud of visual features output by the DROID software, in order to present information about the explored region to a human user in an intuitive way or use this information for further mission planning.

Aim

To investigate methods of interpreting a 3D point cloud representing visual features on surfaces viewed by a camera mounted on a small autonomous robot.

Approach

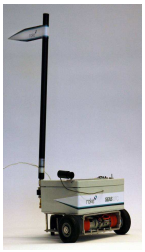
Existing algorithms have been adapted to the visual data output by the DROID software. We focused on measuring high-level properties of rooms (such as size, shape and interconnectivity) rather than attempting to identify specific items.

Outcomes

Methods of extracting more complex information are in general less reliable compared to results from laser scanner data, but some promising approaches towards presenting simple room features such as size and shape have been identified.

Autonomous Exploration and Mapping

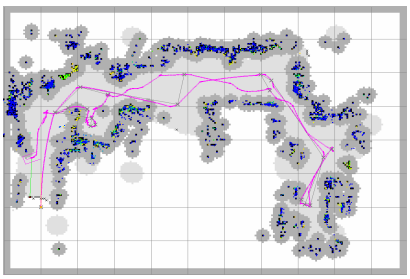
The VEB system consists of a small remote controlled "hobbyist" vehicle (right) equipped with a single video camera and a transmitter.



Images from the camera are transmitted to an off-board standard PC running the DROID 3D Vision software.

DROID extracts point features within the images, tracks them as the vehicle moves and uses a structure-from-motion algorithm to determine their 3D positions and the camera movement (the ego-motion).

As the vehicle moves, a 3D map of features detected in the explored region is built up (below). Obstacles are identified and a safe route around them is planned and transmitted to the vehicle. A frontier-based exploration algorithm is used to select the robot's next destination, enabling autonomous operation.



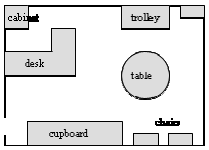
Requirements of contents analysis

Requirements of the analysis of a room and its contents depend on the purpose of the exploration. These could include:

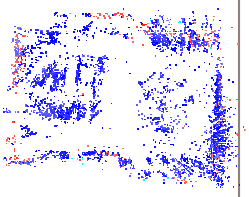
- Room size, dimension and shape
- Spatial distribution of bulky room contents
- Possible places of concealment
- Fields of fire and sight lines
- Access ways within rooms
- Interconnections between rooms
- Identification of enclosed volumes
- Thoroughness of exploration

Such high-level information is thought to be more important than detailed labelling of individual items within a room.

Example experimental data



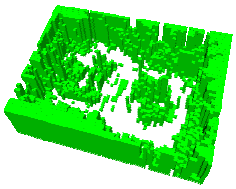
(left) Human-drawn layout of a room explored by the vehicle.



(right) 3D positions of features detected by the DROID software. Points are colour-coded by height (red high). The challenge is to extract information about this room from the point cloud.

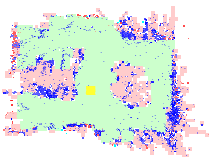
3D model

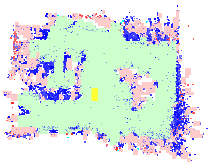
Block 3D model was built by:
- classifying 3D cells as floor, obstacle or ceiling
- using "sightlines" between the camera and the observed feature to deduce the presence of free space
- using rules and information about neighbours to fill in cells for which there is no other information.

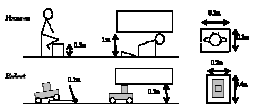


Access ways

The 3D model was used to build up maps of access ways within the room for a human (top right) and a robot (bottom right). Green areas show accessible regions. The smaller robot is able to access areas underneath a desk and table.







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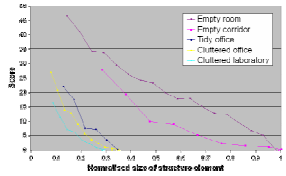
Distribution of contents

The 3D model was used to make a measurement of the level of "clutter" within the room, distinguishing between rooms which were clear and empty and those which contained many objects, by measuring the number of objects of a given size that would fit into the empty space within the room.



The results show a clear divide between empty rooms and office environments, which contain many pieces of furniture and other obstacles. This measure of how "cluttered" the room is could be useful for determining the time necessary to search a room, or estimate the number of possible hiding places.

Room segmentation

In order to analyse data from a series of rooms within a building, it is necessary to separate points originating from different rooms. A method used previously on data from a vehicle equipped with a laser scanner has been tested on our visual data, and a successful separation is shown below (left: true plan of explored area; right: segmented room is highlighted). However, due to the sparse nature of the visual features, accurate separations were much less reliable than for laser scanned data.

Recommendations

Analysis of the contents of rooms explored, in particular extracting layout features such as walls and doorways, has proved to be a difficult task and it is recommended that in the short term less complex objectives be addressed. New methods of extracting information from visual feature point clouds could be researched in the long term.

An example short-term objective would be the selection of a small number of still images from the large collection accumulated during exploration, which would quickly give a human user a good idea of the layout and contents of the room.

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