On the Selection of 2D Objects Using External Labeling

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ABSTRACT

We present an external labeling laid over small and/or overlapping 2D objects as an efficient representation for their selection. The approximation of objects with points allows us to transform the labeling problem to graph layout problem, which we solve by means of force-based algorithm. The input parameters allow us to influence the resulting layout of label boxes (e.g. to adapt their distance for imprecise input devices). In a study with 15 participants two implementations of our algorithm were compared against labeling method, where all label boxes share the same offset from corresponding objects. The results of the study show that implementation using a special functionality (temporary freezing of the label box position recalculation) was 14% faster with a comparable accuracy. The subjective evaluation revealed that the implementation with temporary freezing is perceived as most comfortable, fastest and most accurate. The implementation without temporary freezing showed much higher error rate and cannot be recommended.

Author Keywords

Object selection; external labeling; visualization; user study.

ACM Classification Keywords

H.5.2. [Information Interfaces and Presentation]: User Interfaces – Graphical user interfaces; Interaction styles

INTRODUCTION

In this paper we deal with the problem of selection of moving 2D objects in the screen space with given resolution. In general, when displaying objects on the screen, the size of objects' selection areas should follow guidelines [10] to ensure that the objects can be easily pointed with a pointing device (e.g. mouse cursor, touch input). The more imprecise the pointing device is, the bigger the size of selection area needs to be. However, in situations where the guidelines for the size of selection areas cannot be met it might be hard to point the desired object with a pointing device. This holds especially when many small objects are close to each other and/or certain objects are overlapping. The overlapping of objects makes visual identification of the desired object even harder.

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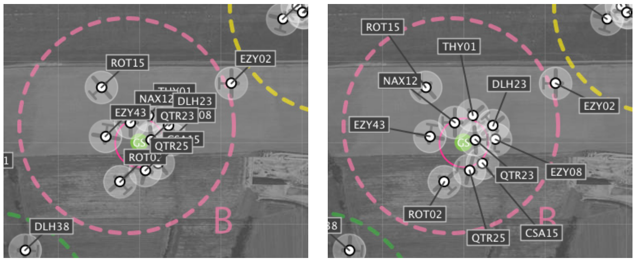
We have identified this problem during the work on the graphical user interface (GUI) for operation of Unmanned Aerial Vehicles (UAV). UAV is a small robotic plane or helicopter without human pilot that autonomously fulfills high level commands of the operator [12]. The primary task of the operator is to control many UAVs from the ground using our GUI of UAV control center prototype. The execution of such missions is often time critical and the low level of cognitive load is fundamental for fast and precise selection and assignment of the mission tasks to the particular UAV(s). In fact, the operator solves two complex tasks: visual search of the desired UAV, and pointing of the UAV with a pointing device as fast and accurate as possible. According to our pre-study the visual search task is the dominant one (84% of total time on average). The UAVs are displayed as small 2D objects overlaid over the map. The selection of UAVs becomes complicated due to their movement, proximity and/or overlapping. Other scenarios can be a real-time control of larger group of agents in multi-agent systems (transport of people in city, simulation of ecosystem) and tracking objects on the map.

In this paper, we separate the selection from the presented 2D objects. We introduce a selection space into which we put a handler for each object and deform the space to meet the guidelines for the size of selection areas of the handlers. We overlay the presented 2D objects with the deformed selection space. To establish the connection between the handlers and the 2D objects we join each handler with a corresponding object with a straight line. In this way we create an external labeling of the objects.

The external labeling should exhibit a number of criteria [7], which deal with the positions of label boxes (handlers), anchors (points approximating the objects), and leader lines (lines connecting anchors with label boxes). In our implementation we consider the following criteria: Leader lines do not cross. Anchors are not too near to each other. Leader lines are as short as possible so label boxes are near to the corresponding objects. Label boxes are not too near to each other. Label boxes do not overlap anchors. Movement of label boxes is temporally coherent.

We propose a hypothesis that an external labeling which exhibits these criteria (see Figure 1(b)) is an effective representation for selection of small and/or overlapping 2D objects. We test the hypothesis on a scenario where the operator selects UAVs, small moving and often overlapping objects. As the visual search and pointing are inseparable we test both tasks. Note that the visual search is the dominant task.



(a) (b)

Figure 1. *Fixed* mode (a) and *Dynamic/LabelFreeze* mode (b).

RELATED WORK

The problem we are solving is to find such positions of label boxes (for given anchors) that do not occlude the objects (approximated by anchors) or the remaining label boxes. An approach to this problem where the user specifies a circular focus containing the anchors and the label boxes are placed outside of this focus was introduced by Fekete and Plaisant [2]. Bertini et al. [1] improved the approach for areas with high and/or uneven density of anchors and Fink et al. [3] improved the approach by preventing leader lines from crossing, allowing curved leader lines, and clustering the anchors in areas with high density and providing a detailed view of the clusters on demand. All approaches above are designed for selection of static targets and their extension to the selection of moving targets is nontrivial.

As Stein and Décoret [11] we utilize the whole free screen area to place the label boxes. Inspired by work of Götzelmann et al. [5] we transform the labeling problem to the graph layout problem and use the force-based algorithms [4, 9] to solve it. In the area of moving targets selection our work is related to time freezing [6] and static proxies of moving targets [8].

EXTERNAL LABELING ALGORITHM

In our GUI the UAVs are small objects and therefore it is possible to approximate each UAV with a 2D point, anchor $\vec{a}_i$, in the center of its bounding box. Each label box is also approximated with a 2D point, endpoint $\vec{e}_i$, in the center of each label box. In our case all label boxes have similar size. Our algorithm operates with the anchors and endpoints. The labeling problem is solved in each frame as the position of anchors (UAVs) changes in time. The algorithm is as follows:

1) For each endpoint calculate the applied force $\vec{F}$.
2) Move each endpoint according to the applied force $\vec{F}$.
3) If there is the movement of endpoints or maximum number of iterations is not reached go to Step 1.

Our preliminary study showed that temporal coherence is crucial for efficiency of visual search and pointing. The limited number of iterations provides better temporal coherence and limits distracting fast movements of endpoints (label boxes), but at the price of leader lines crossing.

To calculate forces applied on the endpoints we construct graph $G(V, E)$. The set of nodes V contains the anchors and endpoints of the leader lines. The set of edges E contains two types of edges. The first type represents the attractive force between the nodes (representing 2D points) and the other one represents the repulsive force between the nodes. We model the attractive force $\vec{F}_a$ between points $\vec{p}_i$ and $\vec{p}_j$ as a spring according to Hooke's law

$$\vec{F}_a(w_a, \vec{p}_i, \vec{p}_j) = w_a(\vec{p}_j - \vec{p}_i) \tag{1}$$

We consider the spring relaxed when $\vec{p}_i = \vec{p}_j$. Thus, $\vec{p}_j - \vec{p}_i$ is a dilatation of the spring and w_a is the spring constant which we use as weight to influence the attractive force. We model the repulsive force $\vec{F}_r$ between points $\vec{p}_i$ and $\vec{p}_j$ as an interaction of charged particles according to Coulomb's law

$$\vec{F}_r(w_r, \vec{p}_i, \vec{p}_j) = \overbrace{k_e \cdot q_i \cdot q_j}^{w_r} \frac{\hat{v}_{ji}}{|\vec{v}_{ji}|^2} \tag{2}$$

where $\vec{v}_{ji} = \vec{p}_i - \vec{p}_j$,$|\vec{v}_{ji}|$ is a length of $\vec{v}_{ji}$, $\hat{v}_{ji}$ is a unit vector in direction of $\vec{v}_{ji}$, and w_r is a positive weight used to influence the repulsive force. In the equation, the weight w_r substitute the positive Coulomb's constant k_e multiplied by the negative charges q_i and q_j of the endpoints.

The edges in the graph are constructed according to the criteria for anchors and label boxes:

Anchor distance. As we cannot move the positions of anchors (UAVs), we omit this criterion.

Leader line length. We create an attractive edge between each anchor a_i and its associated endpoint e_i. Thus, the leader lines will be as short as possible and the label boxes will be near to the associated objects. The force used is $\vec{F}_1 = \vec{F}_a(w_1, \vec{e}_i, \vec{a}_i)$ and is influenced by the weight w_1.

Endpoint distance. We create a repulsive edge between each endpoint and all other endpoints to ensure that the endpoints are not too near to each other. The repulsive force applied on the endpoint $\vec{e}_i$ is $\vec{F}_2 = \sum_{j=1, j\neq i}^{n} \vec{F}_r(w_2, \vec{e}_i, \vec{e}_j)$ where n is the number of endpoints. The force is influenced by the weight w_2.

Anchor label box distance. We create a repulsive edge between each endpoint and all anchors to ensure that the label boxes do not overlap UAVs. The repulsive force applied on the endpoint $\vec{e}_i$ is $\vec{F}_3 = \sum_{j=1}^{n} \vec{F}_r(w_3, \vec{e}_i, \vec{a}_j)$ where n is the number of anchors. The force is influenced by the weight w_3.

Temporal coherence. We apply three additional attractive forces to improve the temporal coherence of endpoints. The first force, influenced by the weight w_4, is attracting an endpoint to its projection in the direction of its associated UAV. The second force, influenced by the weight w_5, is attracting the endpoint to its previous position. The last force, influenced by the weight w_6, is attracting all endpoints.

The total force $\vec{F}$ applied on the endpoint $\vec{e}_i$ is $\vec{F} = \sum_{i=1}^{6} \vec{F}_i$. The weights $w_i, i = 1 \ldots 6$ are used to fine tune the behavior of the algorithm. We use $w_1 = 0.27$, $w_2 = 1200$, $w_3 = 395$, $w_4 = 0.86$, $w_5 = 0.83$, and $w_6 = 0.27$. An example of labeling produced with these weights is in Figure 1(b). To see

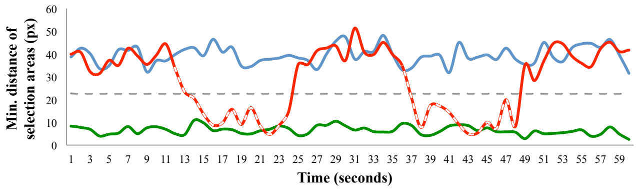


Figure 2. The minimum distance of selection areas of label boxes for *Dynamic* labeling mode (blue), *LabelFreeze* mode (red) with Ctrl key pressed (dashed red), and *Fixed* mode (green). The recommended distance of the selection areas for mouse is depicted as gray dashed line.

the interaction with the UAVs please look at the accompanied video. The external labeling algorithm using these weights ensures that the minimum distance of selection areas is always bigger than the recommended distance for mouse, see Figure 2. We define the minimum distance as a shortest distance between all pairs of endpoints and the recommended distance as a diameter of circle circumscribed to the selection area of recommended size [10].

The external labeling algorithm was implemented in *Dynamic* and *LabelFreeze* labeling modes. Unlike *Dynamic* mode, *LabelFreeze* mode gives an operator the ability to temporarily turn off the calculation of label box positions by pressing and holding Ctrl key. Then the mutual position of label boxes and anchors gets frozen and label boxes move with their associated anchors, until the Ctrl key is released. This should result in more predictable movements of label boxes while Ctrl key is pressed, but at the price of not fulfilling the recommended distance of selection areas (see Figure 2).

For evaluation purposes we implemented an external labeling method where all label boxes share the same static offset from the anchors, called *Fixed* mode (see Figure 1(a)). Due to the similar size of label boxes and UAVs the overlapping of the label boxes will be comparable. The *Fixed* mode does not fulfill the recommended minimum distance, see Figure 2. Our assumption is that this will make the selection of UAVs more difficult.

Our aim was to research if the measured speed of selection of UAVs (in UAVs per minute) is higher for our labeling method (*Dynamic, LabelFreeze* modes) than for *Fixed* mode.

EVALUATION

Participants. Fifteen participants (7 females) were recruited from our university. All were daily users of computers. They ranged from 26 to 67 years ($mean = 40.1, SD = 13.8$).

Apparatus. The hardware consisted of a standard PC computer with a 22 inches LCD display (resolution 1680×1050 pixels), a PC keyboard and optical mouse with 2 buttons. There were 30 UAVs whose movement was simulated based on a real UAV behavior to ensure the same conditions for all participants. The prototype of the UAV control center used in the experiment was developed in Java. We added name into each label box to be able to formulate selection tasks during the evaluation. The UAVs are selected by clicking either on the UAV or on the label box. The software recorded timestamps for each mouse click and distinguished between the click on the UAV itself, on the label box, and on the background. Usage of Ctrl key was also recorded. Two buttons were created in the GUI for starting and ending each experiment task.

Procedure. The experiment was performed in a usability lab dedicated for execution of user tests. Before the experiment was started the participants adjusted the position of the display and the mouse to feel comfortable. The experimenter explained the GUI, three labeling modes and the tasks. The experiment began with a training session. The participants were asked to accomplish two tasks for each labeling mode two times. The first task was to select 10 UAVs with a particular name in given order. The other one, more complex task consisted of three subtasks: 1) the selection of all UAVs with names starting with a specific prefix and moving on routes passing through a given area; 2) the selection of all UAVs with names ending with a specific suffix and moving on rounded routes; 3) the selection all UAVs with names starting with another specific prefix and moving on routes passing through another area. The intention was to simulate use-cases where the operator is asked to select the UAVs not only by their names, but also by other attributes. Each participant performed this training two times (105 UAVs selected, duration 30-40 minutes). The goal was to let the participants get familiar with the operation of the UAV control center, get used to the experiment procedure and to minimize any learning effects. The training session was followed by the test with the same two tasks for each labeling mode but with different UAVs to select. For each task there was prepared one set of UAVs for all three labeling modes (but with different names, to avoid the possibility to remember position of UAVs) to ensure the same conditions.

The participants were asked to proceed as quickly and accurately as possible. Between each task they were allowed to take short breaks. Each participant selected 72 UAVs and the test lasted 15-20 minutes. The participants were interacting with the mouse by means of moving cursor and performing left mouse button single click. For *LabelFreeze* mode participants could use Ctrl key on the PC keyboard to activate the freeze functionality.

After the data collection, the participants were asked on demographic data and completed a questionnaire investigating their subjective judgment about the level of comfort, speed and support for minimizing misclicks of each labeling mode (Likert scale 1-5 was used).

Design. The experiment was one factor (with three levels) within-subject design. The independent variable was the labeling mode. The order of labeling modes was counterbalanced using a Latin square. The total amount of UAVs to select (excluding training) was 15 participants $\times$ 3 labeling modes $\times$ 24 UAVs/mode = 1080 UAVs. The main measures were speed, calculated as a number of UAVs selected per minute, and error rate, calculated as a portion of misclicks in proportion to all clicks performed by the participant. Misclicks were defined as either clicking the background or a wrong UAV. For statistical analysis repeated measures ANOVA was used.

RESULTS AND DISCUSSION

Speed. There was a significant difference in speed between the labeling modes ($F_{2,24} = 7.38, p < .005$). The average speed for *Fixed* mode was 7.4 UAV/minute, for *Dynamic* 8.8 UAV/minute and for *LabelFreeze* 8.4 UAV/minute. A post hoc Scheffé test revealed significant differences between the *Fixed-Dynamic* and *Fixed-LabelFreeze* pairings ($p < .05$). There was no significant difference between *Dynamic* and *LabelFreeze* modes. The group effect was not detected.

Error Rate. The effect of labeling mode on error rate was significant ($F_{2,24} = 5.93, p < .01$). The average error rate for *Fixed* mode was 4.2%, for *Dynamic* 11.4% and for *LabelFreeze* 5.6%. A post hoc Scheffé test revealed significant differences between the *Fixed-Dynamic* and *Dynamic-LabelFreeze* pairings ($p < .05$). There was no significant difference between *Fixed* and *LabelFreeze* modes. The group effect was not detected.

Subjective Evaluation. We also asked the participants about the level of comfort, speed and error rate of each labeling mode. The average subjective rating of the error rate for each mode is as follows: 3.53 for *Fixed* mode, 3.07 for *Dynamic* mode, and 1.93 for *LabelFreeze* mode. The average subjective rating of comfort was: 3.93 for *Fixed* mode, 2.2 for *Dynamic* mode, and 1.67 for *LabelFreeze* mode. The average subjective rating of speed was: 3.87 for *Fixed* mode, 2.4 for *Dynamic* mode, and 1.93 for *LabelFreeze* mode.

There were significant differences between the labeling modes in all three measures (comfort: $F_{2,24} = 43.59, p < .0001$; speed: $F_{2,24} = 23.09, p < .0001$; error rate: $F_{2,24} = 9.72, p < .001$). A post hoc Scheffé test revealed significant differences between *Fixed-Dynamic* and *Fixed-LabelFreeze* pairings in comfort ($p < .0001$) and speed ($p < .0005$), but not between *Dynamic-LabelFreeze* pairing. *Dynamic* and *LabelFreeze* modes were perceived as more comfortable than *Fixed* mode. There were significant differences between *Fixed-LabelFreeze* and *Dynamic-LabelFreeze* pairings in error rate ($p < .05$), but not between *Fixed-Dynamic* pairing. *LabelFreeze* mode was perceived as producing fewer errors than *Dynamic* or *Fixed*. The group effect was not detected.

These results indicate that our labeling methods (*Dynamic* and *LabelFreeze* mode) are faster than *Fixed* mode in visual search and pointing tasks. However, *Dynamic* mode leads to much higher error rate ($2.7\times$ higher) than *Fixed* mode, what is caused by the unpredictable movement of label boxes. *LabelFreeze* mode, which makes the label boxes movement more predictable, reduces the error rate significantly ($2\times$ lower than *Dynamic* mode) to the same level as *Fixed* mode, while preserving the same speed as *Dynamic* mode. The reason why *LabelFreeze* mode is not significantly faster than *Dynamic* mode can be that the time of the pointing task is very small in comparison to the time of visual search. From subjective perspective *LabelFreeze* and *Dynamic* modes were perceived as more comfortable and faster than *Fixed* mode. *LabelFreeze* mode was moreover perceived as producing minimum errors in comparison to other two modes. According to high error rate *Dynamic* mode cannot be recommended as a promising solution.

CONCLUSION

We presented two external labeling methods with fixed anchors and floating label boxes called *Dynamic* and *LabelFreeze*. *LabelFreeze* mode showed up as an effective representation for selection of small and/or overlapping 2D objects. It is 14% faster than *Fixed* mode, it has similar error rate (objective measures) as *Fixed* mode, and is subjectively perceived as more comfortable and faster than *Fixed* mode. The study showed that *Dynamic* mode suffers from more than $2\times$ higher error rate than *LabelFreeze* or *Fixed* mode.

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