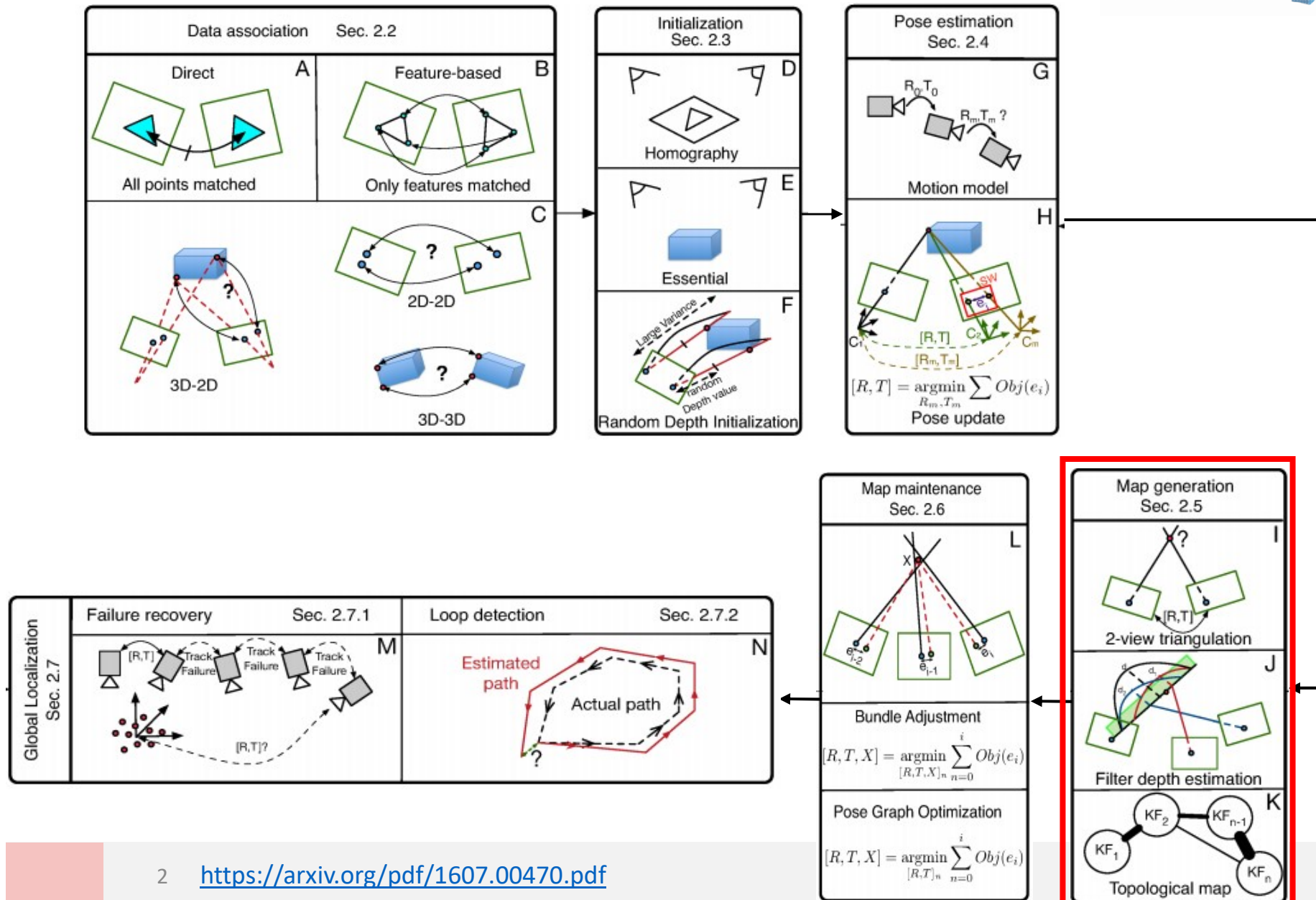
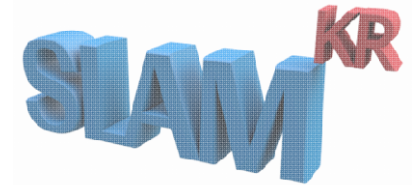


Stereo Matching

Apr. 7, 2019

Kwang Hee Lee

Visual SLAM Workflow

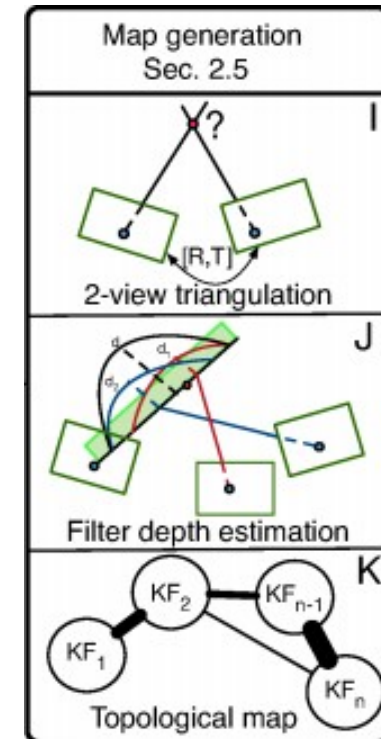


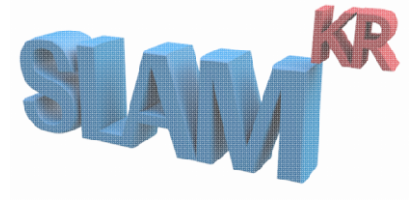
Mapping

• SLAM에서 Map의 유용성

- **Map저장**- 다음 부팅 시 맵에 로봇을 배치하기 위해 맵을 저장
- **탐색**- 로봇이 목표지점을 찾아 이동하는 것을 제어
- **장애물 회피**- 특징점만으로 부족, Dense map 필요
- **3차원 복원**- visualization, 주변환경의 재구성, 비디오게임
- **상호작용**- 사람과 지도간의 상호작용 (ex. AR, 로봇 명령 수행)

➡ Dense Map생성의 필요성

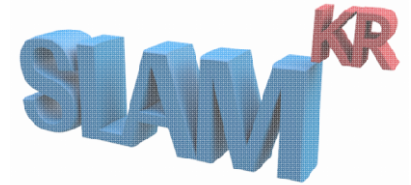




Dense Map

- 단안 카메라를 사용하여 카메라 이동 후 triangulation
- 양안 카메라를 사용하여 왼쪽과 오른쪽의 대사시차를 사용하여 픽셀거리 계산
- RGB-D카메라 사용

Stereo Vision



- Epipolar line상에서 block matching을 통해 corresponding point 결정

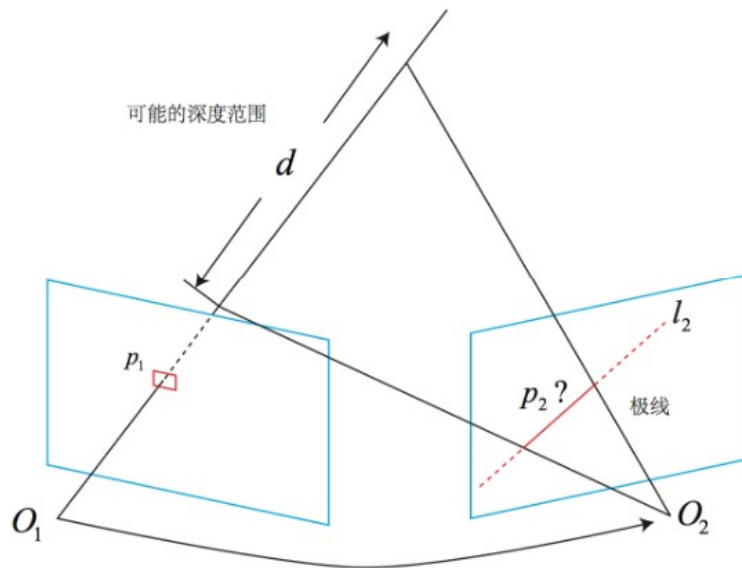


그림 13-2 epipolar line search의 개략도

MATCH METRIC	DEFINITION
Normalized Cross-Correlation (NCC)	$\frac{\sum_{u,v} (I_1(u,v) - \bar{I}_1) \cdot (I_2(u+d,v) - \bar{I}_2)}{\sqrt{\sum_{u,v} (I_1(u,v) - \bar{I}_1)^2 \cdot \sum_{u,v} (I_2(u+d,v) - \bar{I}_2)^2}}$
Sum of Squared Differences (SSD)	$\sum_{u,v} (I_1(u,v) - I_2(u+d,v))^2$
Normalized SSD	$\sum_{u,v} \left(\frac{I_1(u,v) - \bar{I}_1}{\sqrt{\sum_{u,v} (I_1(u,v) - \bar{I}_1)^2}} - \frac{I_2(u+d,v) - \bar{I}_2}{\sqrt{\sum_{u,v} (I_2(u+d,v) - \bar{I}_2)^2}} \right)^2$
Sum of Absolute Differences (SAD)	$\sum_{u,v} I_1(u,v) - I_2(u+d,v) $
Rank	$\sum_{u,v} (I_1'(u,v) - I_2'(u+d,v))$ $I_k'(u,v) = \sum_{m,n} I_k(m,n) < I_k(u,v)$
Census	$\sum_{u,v} \text{HAMMING}(I_1'(u,v), I_2'(u+d,v))$ $I_k'(u,v) = \text{BITSTRING}_{m,n}(I_k(m,n) < I_k(u,v))$

Probabilistic Depth Sensor

- 가우시안 분포 깊이 필터
 - 탐색범위가 길면 일반적으로 불룩한 함수를 얻지 못함.
 - 여러 peak들로부터 true depth를 찾기 위해 단일값을 사용하는 대신 확률 분포 사용

깊이에 따른 초기 확률 분포

새로 관측된 분포

갱신된 분포

$$P(d) = N(\mu, \sigma^2). \quad \Rightarrow \quad P(d_{\text{obs}}) = N(\mu_{\text{obs}}, \sigma_{\text{obs}}^2). \quad \Rightarrow \quad N(\mu_{\text{fuse}}, \sigma_{\text{fuse}}^2)$$

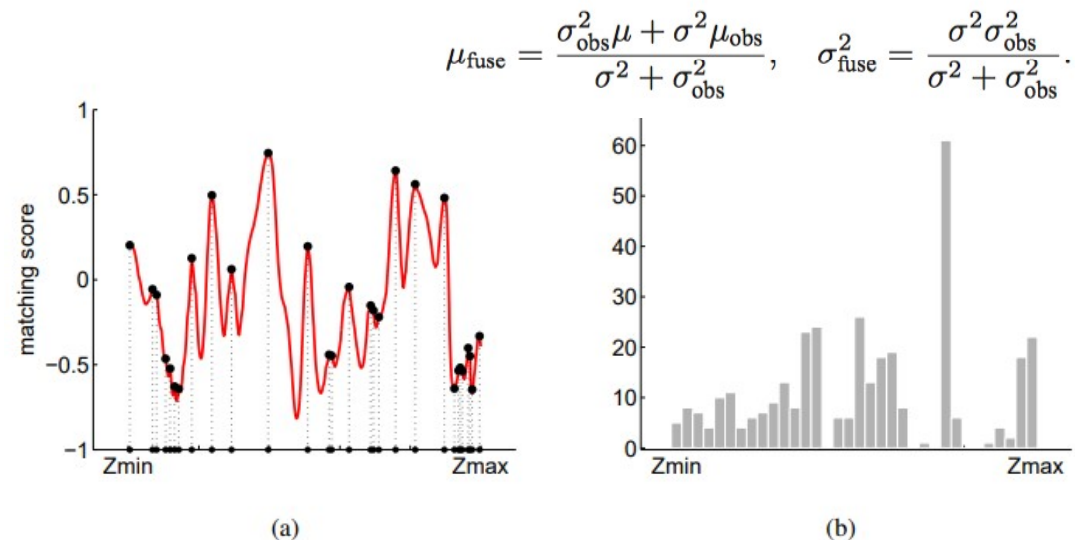
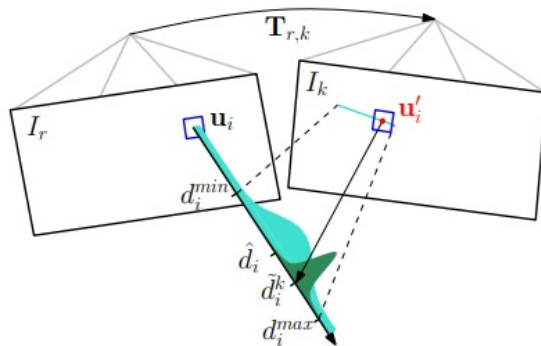
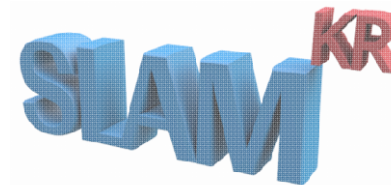


Figure 2: **Depth estimation with NCC maxima.** (a) NCC score across depth along optic ray. The black dots correspond to local maxima. (b) Histogram of local maxima for 60 neighboring images. Local maxima are either generated in the vicinity of the true depth or are uniformly generated across the depth range.

Probabilistic Depth Sensor - Uncertainty



깊이에 따른 초기 확률 분포

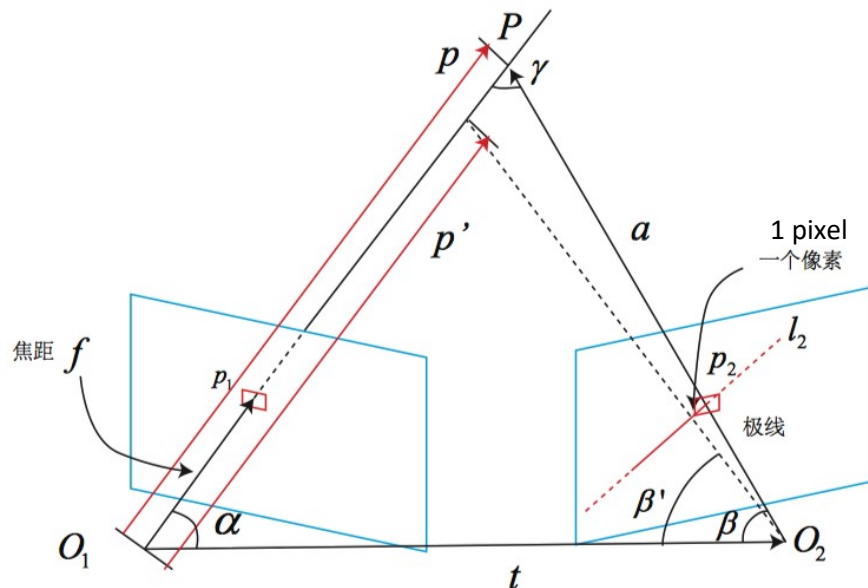
새로 관측된 분포

갱신된 분포

$$P(d) = N(\mu, \sigma^2). \quad \rightarrow \quad P(d_{\text{obs}}) = N(\mu_{\text{obs}}, \sigma_{\text{obs}}^2). \quad \rightarrow \quad N(\mu_{\text{fuse}}, \sigma_{\text{fuse}}^2)$$

관찰한 깊이 분포를
결정하는 방법?

$$\mu_{\text{fuse}} = \frac{\sigma_{\text{obs}}^2 \mu + \sigma^2 \mu_{\text{obs}}}{\sigma^2 + \sigma_{\text{obs}}^2}, \quad \sigma_{\text{fuse}}^2 = \frac{\sigma^2 \sigma_{\text{obs}}^2}{\sigma^2 + \sigma_{\text{obs}}^2}.$$



$$\mathbf{a} = \mathbf{p} - \mathbf{t}$$

$$\alpha = \arccos \langle \mathbf{p}, \mathbf{t} \rangle$$

$$\beta = \arccos \langle \mathbf{a}, -\mathbf{t} \rangle.$$

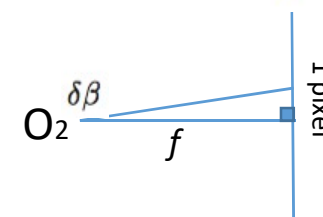
$$\beta' = \beta + \delta\beta$$

$$\gamma = \pi - \alpha - \beta'.$$

$$\|\mathbf{p}'\| = \|\mathbf{t}\| \frac{\sin \beta'}{\sin \gamma}.$$

$$\sigma_{\text{obs}} = \|\mathbf{p}\| - \|\mathbf{p}'\|.$$

$$\delta\beta = \arctan \frac{1}{f}.$$



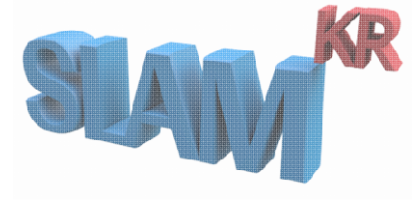
The Sine Rule

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$



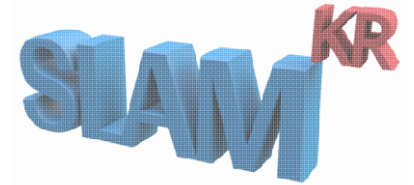
Probabilistic Depth Estimation

1. 모든 픽셀의 depth에 gaussian distribution을 각각 초기화
2. 새로운 frame으로부터 epipolar line 및 block matching 수행
3. 기하학적 관계를 기반으로 triangulation을 통해 depth와 uncertainty를 계산
4. 현재 관측치를 이전 추정치에 통합
5. 수렴하면 계산 중지하고 그렇지 않으면 2단계로 돌아감

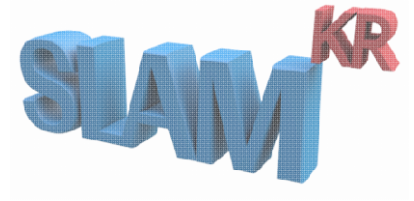


Q&A

Reference



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- M. Pizzoli, C. Forster, and D. Scaramuzza, "REMODE: Probabilistic, Monocular Dense Reconstruction in Real Time," in Proc. IEEE Int. Conf. on Robotics and Automation, 2014.
- C. Forster, M. Pizzoli, and D. Scaramuzza, "Svo: Fast semi-direct monocular visual odometry," in Robotics and Automation (ICRA), 2014 IEEE International Conference on (rs, ed.), pp. 15–22, IEEE, 2014.
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Thank you